foundations

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Different Mass Definitions and Their Pluses and Minuses Related to Gravity

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Abstract: The discussion of what matter and mass are has been going on for more than 2500 years. Much has been discovered about mass in various areas, such as relativity theory and modern quantum mechanics. Still, quantum mechanics has not been unified with gravity. This indicates that there is perhaps something essential not understood about mass in relation to gravity. In relation to gravity, several new mass definitions have been suggested in recent years. We will provide here an overview of a series of potential mass definitions and how some of them appear likely preferable for a potential improved understanding of gravity at a quantum level. This also has implications for practical things such as getting gravity predictions with minimal uncertainty.

Keywords: mass; gravitational mass; inertial mass; kilogram mass; collision-time mass; Newton mass; gravity constant; gravitational force

1. Mass and Gravity: A Short Historical Perspective

The atomists Democritus and Leucippus, who lived around 500 B.C., assumed that all matter and energy ultimately consisted of indivisible particles with spatial dimensions; see [1,2]. Next, let us move forward to Isaac Newton, who had similar ideas as the ancient atomists about the ultimate building blocks of nature. In his book *Optick* [3], published in 1704, Newton wrote:

> *"All these things being consider'd it seems probable to me, that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, movable Particles, of such Sizes and Figures, and in such Proportion to Space, as most conduce to the End for which he form'd them; and that these primitive Particles being Solids, are incomparably harder than any porous Bodies compounded of them; even so very hard, as never to wear or break in pieces; no ordinary Power being able to divide what God himself made one in the first Creation. While the Particles continue entire, they may compose bodies of one and the same Nature and Texture in all Ages; But should they wear away, or break in pieces, the Nature of Things depending on them, would be changed. Those minute rondures, swimming in space, from the stuff of the world: the solid, coloured table I write on, no, less than the thin invisible air I breathe, is constructed out of small colourless corpuscles; the world at close quarters looks like the night sky–a few dots of stuff, scattered sporadically through and empty vastness. Such is modern corpuscularianism."*

In his more famous book *Principia* [4], first published in 1686, Newton also indicated that ultimate particles have spatial dimensions, or extension in space:

> *"The extension, hardness, impenetrability, mobility, and vis inertiae of the whole, result from the extension, hardness, impenetrability, mobility, and vires inertiae of the parts; and thence we conclude the least particles of all bodies to be also all extended and hard and impenetrable, and moveable, and endowed with their proper vires inertia. And this is the foundation of all philosophy. Moreover, that the divided but contiguous particles of bodies may be separated from."*

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Citation: Haug, E.G. Different Mass Definitions and Their Pluses and Minuses Related to Gravity. *Foundations* **2023**, *3*, 199–219. https://doi.org/10.3390/foundations3020017

Academic Editor: Eugene Oks

Received: 7 March 2023
Revised: 7 April 2023
Accepted: 13 April 2023
Published: 18 April 2023

This is in contrast to modern physics' hypothesis that elementary particles can even be point particles and, yes, that even all the mass and energy of the observable universe can fit inside a singularity, something that would be impossible in atomism and Newton theory. Newton, in *Principia*, also mentioned indivisible time, which is discussed in detail in [5]. Newton further defined mass as the quantity of matter, or in his own words:

> *"The quantity of matter is the measure of the same, arising from its density and bulk conjunctly. It is this quantity that I mean hereafter everywhere under the name of body or mass."*

What is often forgotten in modern physics is that Newton's gravity force formula, that he only stated by word in *Principia*, had no gravity constant and corresponds to:

$$F = \frac{M_n m_n}{R^2} \tag{1}$$

On purpose, we use a different notation of the mass than in today's modified Newton force formula. We use M_n and m_n for the mass rather than M and m to make it clear this is Newtonian mass, not the modern kilogram mass. The original Newton formula was used at least as late as 1873, which is also clear from Maxwell's [6] famous book *A Treatise on Electricity and Magnetism*, where he defined gravitational acceleration as simply $g = \frac{M_n}{R^2}$ rather than the modern $g = \frac{GM}{R^2}$ and also discussed the meaning of the Newtonian mass to some extent; something we soon will get back to. Actually, Maxwell used the notation $\frac{m}{R^2}$ for the gravitational acceleration, but here, we have used M_n, again to distinguish it from the kilogram mass and also to distinguish the large mass in the Newton formula from the small. The Newton gravitational formula was successfully used for 200 years without any gravitational constant.

The so-called Newton gravitational constant was actually first introduced in 1873 by Cornu and Baille [7]. They gave the formula $F = fMm/R^2$, where f was the gravity constant. Boys [8] in 1894 is likely the first to use notation G for the gravity constant. Einstein [9] used the notation k for the gravity constant at least as late as 1916, and Max Planck used the notation f to at least 1928. It is naturally only of cosmetic interest if one uses f, k, or G for the gravity constant. What is important here is that the gravity constant was introduced hundreds of years after Newton invented his gravitational force formula, and researchers had used it successfully for a long series of gravity predictions with no knowledge of any gravity constant. We think it is no coincidence the gravitational constant was introduced about the same time as the kilogram mass became the new mass standard in scientific circles, not only for smaller masses but now also for astronomical objects. The Newton gravity force formula is today known as:

$$F = G\frac{Mm}{R^2} \tag{2}$$

Thüring [10] has correctly pointed out that the gravity constant was inserted somewhat ad hoc and that it also cannot be associated with a unique property of nature. This will all become clearer in this paper. It is also often claimed that Cavendish [11] measured the gravitational constant. This is not true, as is pointed out in several papers [12–14]. Cavendish just measured the density of the Earth relative to a known uniform substance. What is true is that a Cavendish apparatus can also be used to measure the gravitational constant after one has defined the kilogram mass of the large balls in the Cavendish apparatus, but Cavendish never tried to do this.

The gravitational constant was invented to make one standardized system universal for all masses, including astronomical mass or what can better be described as gravitational mass, for astronomical predictions are almost always related to gravity, and one went for the kilogram in this standardization process. That it was the kilogram is not important here; it could just as well have been the pound. What is important is that one now wanted to use a humanly-defined, arbitrary clump of matter as mass standard rather than, for example, the somewhat mysterious mass that came directly out of Newton's formula, but that had been used successfully for several hundred years. It will become evident that this could be viewed as a misstep, potentially contributing to the limited advancements in quantum gravity research. In this paper, we will delve deeper into our understanding of the mass related to gravity, as well as the gravitational constant. Surprisingly, even the standard theory of gravity appears to contain quantum aspects when examined at a deeper level, which are connected to the Planck length and the reduced Compton frequency in the gravitational mass. We will soon explore these aspects further. Hence, we may be closer to a quantum theory of gravity than we previously assumed.

2. Different Mass Definitions in Gravity; Which One Is Preferable?

We will below briefly examine some of the mass definitions; we will compare them in terms of how complete the mass definition is and what are the plus and minus with the different definitions. Our focus in this article is mass in relation to gravity. In physics, gravity theory spans from Newton to Einstein, and that has been successful at predicting accurately many observations for large macroscopic and larger size objects such as moons, planets, and suns; see, for example, [15]. On the other hand, we have quantum mechanics that has been successful at describing the atomic and subatomic world; see, for example, [16]. In standard theory, it has not been possible to bridge these two theories together; that is, to unify gravity with quantum mechanics. A key to achieve this is, therefore, in our view, to understand mass more deeply in relation to gravity, which is the aim of this article.

2.1. Kilogram Mass

In 1799, the Kilogramme des Archives protype was designed as the weight of 1 dm^3 water at the temperature of its maximum density, about 4 Celsius. Later, a kilogram prototype stood in Paris. However, the kilogram was hardly used yet in the rest of Europe. The kilogram mass definition of mass was first accepted in scientific circles across Europe after 20 May 1875 when the meter convention was signed in Paris by 17 nations. The international prototype of the kilogram was the kilogram standard from 1889 to 2019.

The kilogram is related to weight, and mass is not weight, but already in *Principia*, Newton pointed out that weight is proportional to the amount of matter for a given gravitational field. That is, one object weighing twice as much as another when measured at a location with the same distance to the center of the gravitational object—in our case, the Earth—then also has twice the amount of mass.

When it comes to gravity theory, modern physics gives little insight into what mass is. The weak equivalence principle between inertial mass and gravitational mass is often discussed. Standard quantum mechanics, which describes the behavior of matter at the quantum level, has not yet been successfully integrated with the theory of gravity. Despite numerous attempts and some progress, there is a general consensus that a major breakthrough is still needed in this area, as evidenced by sources such as [17–20].

In 2019, the kilogram was redefined as being linked to the Planck constant in connection to the watt balance; see [21–23]. However, this redefinition has not significantly contributed to the understanding of how mass works at the quantum level in relation to gravity within standard physics.

2.2. Deeper Understanding of Kilogram Mass

Arthur Holy Compton [24] in 1923 expressed the Compton wavelength of an electron as the following function of the kilogram mass of the electron:

$$\lambda = \frac{h}{mc} \tag{3}$$

We [25,26] were possibly the first to simply think about solving this for mass m and claiming any kilogram masses can be expressed by the formula:

$$m = \frac{h}{\lambda}\frac{1}{c} = \frac{\hbar}{\bar{\lambda}}\frac{1}{c} \tag{4}$$

where $\bar{\lambda} = \frac{\lambda}{2\pi}$ is the reduced Compton wavelength and $\hbar = \frac{h}{2\pi}$ is the reduced Planck constant also known as the Dirac constant. Solving the Compton wavelength formula for m is trivial, yet it has not received much attention despite its potential significance, as will become apparent when we explore its implications for gravity. Some will perhaps think that one can only, at best, do this for an electron, as Compton came up with the Compton wavelength from scattering electrons with photons, and this gave a measure of the Compton wavelength for electrons. There has also been discussed the Compton wavelength of the proton; this was possibly first discussed by Levitt [27] in 1958, and has later been discussed by, for example, [28]. Likely only elementary particles such as the electron have a single Compton wavelength related to physical aspects of their structure. Moreover, composite particles have an aggregated Compton wavelength that is the sum of the Compton wavelengths of the elementary particles comprising their mass. However, calculating the aggregated Compton wavelength in a composite particle is not as simple as pure addition; it must be determined using the following formula:

$$\lambda = \frac{1}{\sum_i^n \frac{1}{\lambda_i}} = \frac{1}{\frac{1}{\lambda_1} + \frac{1}{\lambda_2} + \frac{1}{\lambda_3} \cdots \frac{1}{\lambda_n}} \tag{5}$$

This is discussed in detail in [29] and can even be used to find the Compton wavelength of the mass-energy equivalent in the whole observable universe, fully independent even of knowledge of G and $\hbar$, see [30]. There is an additional small adjustment for binding energy (see, for example, D'Auria [31]), but it is always less than 1% and typically considerably less than 1%, so even ignoring it, one will be quite accurate.

Next, we will look closer at the kilogram mass in relation to gravity, but at a deeper level than you will find in even advanced physics books and papers. Our approach will be simple, but this does not imply that it cannot give deep new insight into gravity. As gravity physics has stagnated, the approach has mainly been to add more and more complexity in math and in fancy terms on the "top" of existing theory, but such an approach has, in our view, led to little. The people involved in adding complexity to a fundament when they do not understand gravity at depth will naturally often claim something different; they have built their career on putting out papers with more and more complexity that fewer and fewer researchers can understand. However, one thing we have in common: complex theories in quantum gravity and our simple approach, that will come clearer in this paper, both assume the Planck scale plays an important role in quantum gravity theory.

The Planck units were published by Max Planck [32,33] in 1899 and 1906. He assumed there were three important universal constants: the speed of light, the Planck constant, and the gravitational constant. Furthermore, Planck utilized the Boltzmann constant (k_b), which, in essence, simply serves as a conversion factor between temperature and energy, specifically relating joules to temperature. Then, combining these with dimensional analysis, he derived a unique length: $l_p = \sqrt{\frac{G\hbar}{c^3}}$, time: $t_p = \sqrt{\frac{G\hbar}{c^5}}$, mass: $m_p = \sqrt{\frac{\hbar c}{G}}$, and temperature: $T_p = \frac{1}{k_b}\sqrt{\frac{\hbar c^5}{G}}$. These are today known as the Planck units.

Mathematically, we can easily solve the gravity constant from the Planck mass formula. This gives $G = \frac{\hbar c}{m_p^2}$. This was done in 1984 by Cahill [34,35], who suggested that the gravity constant was likely a composite constant and that the Planck mass was more fundamental. Cohen [36] derived the same formula for G but correctly pointed out that, as no one had been able to find a way to find the Planck mass or other Planck units without first knowing G, this would just lead to a circular problem that not seemed possible to solve. This has been repeated at least as late as 2016; see [37]. In other words, G seemed much more fundamental than the Planck units, as the Planck units could be derived from G and c and

$\hbar$, but G seemed like it could not be derived from any Planck unit as one had to know G to find these.

However, in 2017, we [38] showed for the first time how one could find the Planck length independent of any knowledge of G and showed that the Planck length can be found using a Cavendish appartus as given by

$$l_p = \sqrt{\frac{\hbar 2\pi^2 L R^2 \theta}{M T^2 c^3}} \tag{6}$$

In the equation above, $\hbar$ represents the reduced Planck constant, L denotes the distance between the two small balls in the apparatus, R is the distance between the center of the large ball and the small ball, T stands for the measured oscillation period, c indicates the speed of light, θ refers to the measured angle of deflection, and M is the mass in kilograms of one of the large balls in the Cavendish apparatus.

To determine the mass of the large ball in the Cavendish apparatus, one can use a standard weight balance to find its relative weight in comparison to the old (pre-2019 NIST standard) prototype of the kilogram. It is important to note that while knowledge of G is not required to find the kilogram mass of the large balls in the Cavendish apparatus, one does depend on the kilogram definition of mass, as well as on the calibration of the Planck constant to the chosen clump of matter known as the kilogram. The gravitational constant G in relation to the kilogram is actually only needed to find the kilogram mass of objects that are so large that we cannot find their weight by a balance weight. Astronomical objects such as the Earth and the Moon naturally fall into this category.

Recent research [39] has shown that the Planck length can also be determined in a Cavendish apparatus using the following equation:

$$l_p = \sqrt{\frac{\bar{\lambda}_M 2\pi^2 L R^2 \theta}{T^2 c^2}} = \frac{\pi R}{Tc}\sqrt{\bar{\lambda}_M L 2\theta} \tag{7}$$

In this equation, $\bar{\lambda}_M$ denotes the reduced Compton wavelength of the large mass in the Cavendish apparatus. Importantly, this approach does not require any information about the kilogram or the Planck constant but instead relies on the reduced Compton wavelength of the mass in question. The reduced Compton wavelength of any mass can be determined independently of knowledge of $\hbar$ or the kilogram mass of the mass in question, as discussed in [39,40].

Later, we have shown how the Planck length and Planck time can be found independent of G $\hbar$ and even without knowledge of c; see [29,40]. So, now that we know we can easily find the Planck length independent of G, then we can solve the Planck length formula for G; this gives:

$$G = \frac{l_p^2 c^3}{\hbar} \tag{8}$$

That is, we can now claim the gravity constant is a composite constant consisting of more important constants; see [41] like the Planck length. While this composite formula for G may offer limited insight on its own, our aforementioned paper demonstrates that all observable and verifiable gravity phenomena can be described in terms of the Planck length; see also Section 7. Furthermore, as we will demonstrate in this paper, the Planck constant embedded in the composite constant, we will soon see cancels out and is not necessary for any gravity predictions. Additionally, we will show (in Sections 2.3, 6 and 7) that we can achieve quantization in gravity without affecting the output predictions. It is when G in its composite form is multiplied by the mass in kilogram, as expressed in Equation (4) above, we see something interesting:

$$GM = \frac{l_p^2 c^3}{\hbar}\frac{\hbar}{\bar{\lambda}_M}\frac{1}{c} = c^3 \frac{l_p}{c}\frac{l_p}{\bar{\lambda}_M} = c^3 t_p \frac{l_p}{\bar{\lambda}_M} \tag{9}$$

where $\bar{\lambda}_M$ is the reduced Compton wavelength of the mass M. That is, the Planck constant embedded in the gravity constant cancels with the Planck constant embedded in the kilogram mass. Be aware that all gravity phenomena that are related to something that we can observe are predicted by GM in the formula for that phenomenon and not GMm. Two-body problems where we do not have $m \ll M$ have gravitational parameter $\mu = G(M+m) = GM + Gm$; in other words, one always has G multiplied by the kilogram mass when predicting something observable. Actually, $c^3 t_p \frac{l_p}{\bar{\lambda}_M}$ is equal to c^3 times what we have coined the collision-time mass—something we soon will get back to. The important point here is that the 1873 form of Newton gravity theory needs G to correct the kilogram mass into a mass that is related to gravity. It removes the Planck constant embedded in the kilogram mass and puts the Planck length in. This is naturally not something they had in mind when inventing the gravity constant, as the Planck constant and Planck units were not even invented yet in 1873. The gravity constant is what is missing in the kilogram mass that one finds by calibration, and at a deeper level, this is exactly what is happening when one gets the Planck constant out and the Planck length into the mass.

The kilogram mass is, in our view, incomplete. The kilogram mass contains information that gravity does not care about and that therefore is not needed for gravitation. Anything about kilogram units cancels out when the Planck constant embedded in G and M cancels out against each other when they are multiplied with each other as they do when we are going to predict a gravity-related phenomenon. This means that any gravitational phenomenon that can be predicted and checked with observations can be done so without knowing the kilogram mass or the gravitational constant, as demonstrated in [42]. However, this does not mean that gravity is not dependent on mass, but rather that important components of gravitational mass are not contained in the kilogram mass, and also that the kilogram mass contains unnecessary information about gravity.

To work with kilogram mass in gravity therefore leads to unnecessary calibration steps to make gravity predictions. First, one must find G by, for example, using a Cavendish apparatus. Next, one must find the kilogram mass of, for example, the Earth, then multiply these two together to again get rid of the kilogram units that both G and M contain. Why this is not optimal will become clearer as we look at other mass definition alternatives to kilogram.

2.3. Collision-Time Mass

We have, in a series of papers [43–45], laid out the foundation and discussed what we call collision-time mass and collision-length energy. The collision-time mass for any mass is given by:

$$m_t = \frac{l_p}{c}\frac{l_p}{\bar{\lambda}} = t_p \frac{l_p}{\bar{\lambda}} \tag{10}$$

where $\bar{\lambda}$ represents the reduced Compton wavelength of the mass under consideration. Therefore, if you are working with a large mass in the Newton formula, the reduced Compton wavelength would be denoted as $\bar{\lambda}_M$.

That is, any mass is the Planck time multiplied by a factor $\frac{l_p}{\bar{\lambda}}$, where this factor is equal to the number of Planck mass events per Planck time, and the Planck mass in collision-time is simply the Planck time. That is correct; we have defined mass as a particular type of time. This is the time two indivisible particles are standing together in a collision. We have not just assumed that the duration of this is the Planck time; this is what we find when calibrating out gravity model to gravity phenomena; see the papers just mentioned above. The factor $\frac{l_p}{\bar{\lambda}}$ gives quantization. It is the reduced Compton frequency in the mass of interest per Planck time.

The collision-time mass is simply equal to the kilogram mass multiplied by $\frac{l_p^2}{\hbar}$ that again is equal to multiplying the kilogram mass with $\frac{G}{c^3}$. Based on this set up, the new gravity force formula is given by

$$F = c^3 \frac{M_t m_t}{R^2} \tag{11}$$

This gravity force formula has output units m·s^{-1} while the 1873 Newton gravity force formula has output units kg· m· s^{-2}. Be aware that the original Newton force formula also has different output units than these two gravity force formulae, something we soon will get back to. Still, despite different output units than the 1873 Newtonian modified gravity force formula, this new gravity force formula gives the same predictions both in numbers and output units as the one used today. This because the small mass cancels out in any derivation of something observable, and the gravity constant times the large mass is identical in our new formula and the 1873 Newton force formula both in value and in output units—that is, $c^3 M_t = GM$.

This means our gravity constant in the new formulation is c^3. This has a big advantage over standard 1873 Newton gravity theory as c has no uncertainty in it. Furthermore, even if we should just measure it, we need no knowledge of gravity to do so. One can even order amateur kits and measure the round-trip speed of light with relatively low measurement uncertainty. That the speed of light is entering the gravity force formula strongly indicates it is the speed of gravity. In that case, we should also be able to extract it from gravity phenomena, something that we can easily do, as we have demonstrated in [40]. That the speed of gravity is the same as the speed of light has been assumed for a long time; see, for example [46]. However, this has been confirmed first recently by measuring gravitational waves; see [47]. The approach that we have presented is, however, measuring the speed of gravity in a much easier way, as we claim to have discovered that the speed of gravity must unknowingly be embedded in even standard Newton theory.

We naturally also need to know the collision-time mass of the large mass in the gravity force formula to make any gravity predictions based on Equation (11). This mass we can find easily from most observable gravity phenomena. For example, we can measure the gravitational acceleration on Earth by dropping a ball from height H. The gravitational acceleration is then given by the well known formula:

$$g = \frac{2H}{T_d^2} \tag{12}$$

where T_d is the time it took from we adropped the ball until it hit the ground. In other words, there is no need to know G or the kilogram mass to measure this. The gravitational acceleration in standard 1873 Newton gravity is given by $g = \frac{GM}{R^2}$, but that is for prediction. Similarly, in our theory, it is given by $g = \frac{c^3 M_t}{R^2}$, so now we can set this equal to the measured g and solve with respect to M_t. We get:

$$\begin{aligned} \frac{c^3 M_t}{R^2} &= \frac{2H}{T_d^2} \\ M_t &= \frac{2HR^2}{T_d^2 c^3} \end{aligned} \tag{13}$$

Now that we know the collision-time of the Earth, we can use it to predict a series of other gravity phenomena. The formulae are the same as in standard Newton gravity theory, except M is replaced with M_t, and G is replaced with c^3 (see Section 7). On the other hand, if we should find the kilogram mass of the Earth from gravitational acceleration, we get:

$$\begin{aligned} \frac{GM}{R^2} &= \frac{2H}{T_d^2} \\ M &= \frac{2HR^2}{T_d^2 G} \end{aligned} \tag{14}$$

In this case, M is dependent on finding the gravitational constant first. That is, to find the kilogram mass of the Earth, we need to do additional gravitational observations of a small mass that we have already linked to the kilogram. This can be done in a Cavendish apparatus. So, finding the kilogram mass of an astronomical object is both more complicated than finding its collision-time mass, and it also leads to higher uncertainty, as we need a constant with considerable uncertainty, namely G, while in c there is no uncertainty. This is discussed at length in [48].

Alternatively, we can model gravity from collision-length energy [45,49] given by:

$$E_g = l_p \frac{l_p}{\bar{\lambda}} \tag{15}$$

This gives a gravity force formula of:

$$F = c\frac{E_g {\scriptstyle E}_g}{R^2} \tag{16}$$

This is quite similar to the Newton gravity force formula formula, except the large mass M and the small mass m is replaced with the collision-length energy of the large and the small mass, respectively E_g and ${\scriptstyle E}_g$, and the gravity constant G is simply replaced by c.

Again, the gravity constant is just linked to the speed of gravity that again is identical to the speed of light. Similar to the collision-time mass, the collision-length energy can be found more easily than the kilogram mass for astronomical objects, like the Earth, and with less uncertainty in the measurement than for the kilogram of astronomical objects.

2.4. Newton Gravitational Mass

Back to the original Newton gravity force formula as it was given in *Principa*, it was given as (but only in words by Newton):

$$F = \frac{M_n m_n}{R^2} \tag{17}$$

Then, the gravitational acceleration is given by:

$$g = \frac{M_n}{R^2} \tag{18}$$

Since gravitational acceleration has dimensions $[L \cdot T^{-2}]$, this means the mass in the Newton formula must have dimensions $[L^3 \cdot T^{-2}]$. See [50] for a detailed discussion. We are naturally not the first to find this out. If one reads the book *A Treatise on Electricity and Magnetism* by Maxwell [6] published in 1873, this is exactly what he said are the dimensions of mass, or what Maxwell called mass in the astronomical system, as it the dimension of mass derived from original Newton gravity. Maxwell also mentioned gravitational acceleration as the formula above without any gravitational constant, and this is how he derived the dimensions of the Newtonian mass that he called astronomical mass units. The gravitational constant was not yet invented. Actually it was invented in the same year Maxwell published his book *A Treatise on Electricity and Magnetism*; likely, it was invented some months later, as Maxwell's book was published in February. Maxwell also mentioned the standard unit of mass in the United Kingdom as *avoirdupois pound* preserved in the Exchequer Chambers. Furthermore, he mentioned *grain*, which he said is defined to be the 7000th part of this pound. Maxwell mentioned the gram based on the kilogram preserved in Paris. So, the gravity constant was invented to make these human arbitrary mass definitions, such as kilogram, also the mass standard in the astronomical system linked to gravity. This, we think, could have been a mistake as one could have got much faster to the bottom of what gravitational mass really is by digging deeper into the Newtonian original mass formulation instead.

The Newton formula in this form, without any knowledge of any gravity constant or other constants, can be used to predict all that the modern 1873 Newton version can do, except the kilogram mass of objects; this is well demonstrated in [50]. The Newton mass, or astronomical mass as Maxwell called it, is the gravitational mass, as the mass is derived from gravity. So, to understand gravity, we must understand this mass from a deeper level.

From a deeper quantum perspective, this mass can be interpreted in several ways. In the special case, one links length to time through the speed of light, and then we have $c = 1$. The formula is actually a special case of the collision-time gravity force formula given a bit further above, so it is also compatible with that mass is simply collision-time, but then again, we must set $c = 1$. Newton could theoretically have been able to do this even in his time period, as he mentioned about how fast the speed of light is based on how long it takes to travel from the sun to the Earth.

Alternatively, if we should allow different units for length and time, then the Newton gravitational mass must, at a deeper level, be:

$$M_n = c^2 \frac{l_p^2}{\bar{\lambda}_M} \tag{19}$$

There is nothing wrong about calling this mass, as this can also be written as:

$$M_n = c^2 l_p \frac{l_p}{\bar{\lambda}_M} = c^3 t_p \frac{l_p}{\bar{\lambda}_M} \tag{20}$$

The last term $\frac{l_p}{\bar{\lambda}}$ is the number of collisions between indivisibles per Planck time as discussed in [45]. The mass is therefore the quantity of matter, as indeed suggested by Newton, and it is even now linked to the idea of indivisible corpuscular particles, or indivisibles that Newton claimed was the behind all his philosophy in *Principia*. We can see that M_n alone are exactly the same as GM when broken down to the quantum level, by comparing Equations (9) and (20).

2.5. Time-Speed Mass

We [51] introduced what we called time-speed as a mass concept in 2014. Then, we simply assumed mass consisted of colliding indivisible particles, that we assumed have a minimum length. We did not know what this minimum length was but speculated it could be the same as the Planck length. Still, we did not, at that time, know how to ever find out what the minimum length of this particle was. Some years later, we figured out how to indirectly measure the diameter of this particle based on a gravity theory assuming there was a minimum spatial dimension particle. When this model was calibrated to gravity, it was clear its diameter was the Planck length. This mass is given by:

$$m_s = \frac{l_p}{\bar{\lambda}} \frac{1}{c} \tag{21}$$

This mass has incorporated the Planck length, the Compton wavelength, and the speed of light. So, in this sense, it contains, as we will see, all that is needed for gravity. The reduced Compton wavelength is the distance between particles as described in [51]. The speed of light is how fast these particles move when not colliding, as measured with Einstein synchronized clocks. Still, the mass definition was not too intuitive, and neither optimal nor complete for gravity modeling.

One of the drawbacks of this mass is that the gravitational constant must contain the Planck length in addition to the speed of light (speed of gravity). This mass definition is, we would say, more complete than the kilogram mass even if many will feel it is less intuitive, but that is likely because they are used to working with the kilogram mass.

Still, it is not a complete mass description for modeling gravity. Also, this mass must be fixed with a gravity constant that is unnecessarily complex, even if less complex than G when understood from a deeper perspective. We just include this mass to show that there is a series of ways to define mass that is at least just as good as the kilogram mass for gravity purpose. If the mass is not complete for gravitational modeling, one needs to fix the mass with what is lacking in the mass using a gravitational constant that has this in it from calibration or otherwise. We will soon see that any mass definitions that lead to a gravitational constant that contains more than the speed of light can be seen as incomplete.

The gravitational force, when using time-speed as mass, must be given by (see [52]):

$$F = G_s \frac{M_s m_s}{R^2} = l_p c^3 \frac{M_s m_s}{R^2} \tag{22}$$

That is, the gravitational constant is now given by $G_s = l_p c^3$. This gravitational constant contains less information than the standard gravity constant. It contains only l_p and c while G embedded contains $\hbar$, l_p, and c as understood from a deeper level, since we have $G = \frac{l_p^2 c^3}{\hbar}$. The reason the gravity constant needs to contain less information than G is that the mass is more complete. Still, this mass and its corresponding gravity constant is also not that intuitive and also not complete. This gravity force formula, despite different output units, also gives all the same predictions as standard Newton gravity theory when it comes to predictions for observable gravity phenomena. This is because we have:

$$l_p c^3 M_s = c^3 M_t = GM \tag{23}$$

Again, it is only the large mass multiplied with the gravity constant that is used in gravitational predictions where $m \ll M$, so if the gravity constant times the large mass is the same in different theories both in number outputs and units, then they will predict the same in numbers and output units. However, some choice of mass and gravity constant is much more intuitive than others. The time-speed mass formulation has one similar drawback as the kilogram mass: it needs us to find a constant with large uncertainty in it to find the mass of the astronomical object. Collision-time mass does not have this problem as it seems to be complete for gravity modeling.

A long series of other mass detentions can be made but, as we soon will see, only the Newtonian type of mass and the collision-time mass are complete masses for gravitational purposes.

3. Mass Definition Comparison

In Table 1, we show a series of masses we have discussed above and additional series of possible mass definitions. We claim that only the collision-time mass and collision-length energy of these are intuitive. These do not require any more fundamental aspects than time and space, but it is a particular type of time and space, indirectly observable in the form of collision-time and collision-length.

Only collision-time and collision-length, in addition to the Newtonian types of masses, are complete for modeling gravity. One of the Newton types of mass is identical to collision-time mass when setting $c = 1$. All other masses in the table require much more complicated gravitational constants. This is needed to fix these incomplete mass descriptions into what these complete masses already have, as is shown more clearly in Tables 2 and 3, that we will soon come to. Anything with kilogram related to it is almost the worst in term of completeness as it, from a deeper fundamental perspective, contains the Planck constant that is only needed in the gravitational constant to cancel it out from the mass that contains kilogram.

Table 1. The table shows different mass definitions, their dimensions or units, and our comments on the mass intuition, completeness in relative to model gravity, as well as how easy the mass is to measure for macroscopic object.

Mass or Energy Label	Mass	Dimensions or Energy	Intuition	Completness	Measure for Gravity
Collision-time	$m_t = \frac{l_p}{c}\frac{l_p}{\bar{\lambda}}$	$[T]$	High	High	Easy
Collision-length	$E_g = l_p\frac{l_p}{\bar{\lambda}}$	$[L]$	High	High	Easy
Kilogram modern physics	m	$kg\ [M]$	Low	Low	Medium
Kilogram deep understanding	$m = \frac{\hbar}{\bar{\lambda}}\frac{1}{c}$	$kg\ [M]$	Medium	Low	Medium
Joule (deep understanding)	$E = h\frac{c}{\lambda} = \hbar\frac{c}{\bar{\lambda}}$	$kg \cdot m^2 \cdot s^{-2}$ $[M \cdot L^2 \cdot T^{-2}]$	Medium	Low	Medium
“Newton” alternative-1	$m_n = c^2 l_p \frac{l_p}{\bar{\lambda}}$	$[L^3 \cdot T^{-2}]$	Medium	High	Easy
“Newton” alternative-2	$m_n = \frac{l_p}{c}\frac{l_p}{\bar{\lambda}}$ & $c = 1$	$[T]$	High	High	Easy
Time-speed	$m_s = \frac{l_p}{\bar{\lambda}}\frac{1}{c}$	$[T \cdot L^{-1}]$	Medium	Medium	Medium
Frequency per Planck time	$m_f = \frac{l_p}{\bar{\lambda}}$		High	Medium	Medium
Planck length times Frequency	$m_e = l_p\frac{c}{\bar{\lambda}}$	$[L \cdot T^{-1}]$	Medium	Medium	Medium
Frequency per second	$m_y = \frac{c}{\bar{\lambda}}$	$[T^{-1}]$	High	Low	Medium
c^2 times Planck time frequency	$m_x = c^2\frac{l_p}{\bar{\lambda}}$	$[L^2 \cdot T^{-2}]$	Medium	Medium	Medium
Joule per Planck time	$m_z = \hbar\frac{l_p}{\bar{\lambda}}$	$kg \cdot m^2 \cdot s^{-1}$	Medium	Low-medium	Medium
Kilogram per Planck time	$m_k = \frac{\hbar}{\bar{\lambda}}\frac{1}{c}\frac{l_p}{c}$	$kg \cdot s$	Low	Low-medium	Medium

Table 2. The table shows different mass definitions and gravity constants needed for each mass definition. All these mass definitions, when multiplied with their corresponding gravity constant, give the same results both in output units and value. The M subscript on the reduced Compton wavelength is just to make it clear that this is the reduced Compton wavelength of the large mass in the gravity force formula.

Mass or Energy Label	Mass or Energy	Gravity Constant	Gravity Contant Times Mass
Kilogram	M	G	$GM = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
Kilogram (deep)	$M = \frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}$	$G = \frac{l_p^2 c^3}{\hbar}$	$\frac{l_p c^3}{\hbar} M = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
Collision-time	$M_t = \frac{l_p}{c}\frac{l_p}{\bar{\lambda}_M}$	c^3	$c^3 M_g = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
“Newton” alternative-1	$M_n = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$	1	$M_N = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
“Newton” alternative-2	$M_n = \frac{l_p}{c}\frac{l_p}{\bar{\lambda}_M}$	$c^3 = 1$	$c^3 M_n = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
Time-speed	$M_s = \frac{l_p}{\bar{\lambda}_M}\frac{1}{c}$	$l_p c^3$	$\frac{l_p c^2}{\hbar} M_s = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
Frequency per Planck time	$M_f = \frac{l_p}{\bar{\lambda}_M}$	$l_p c^2$	$l_p c^2 M_f = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
Planck length times Frequency	$M_e = l_p \frac{c}{\bar{\lambda}_M}$	$l_p c$	$l_p c M_e = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$

Table 2. *Cont.*

Mass or Energy Label	Mass or Energy	Gravity Constant	Gravity Contant Times Mass
Frequency per second	$M_y = \frac{c}{\bar{\lambda}_M}$	$l_p^2 c$	$l_p c M_y = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
c^2 times Planck time frequency	$M_x = c^2 \frac{l_p}{\bar{\lambda}_M}$	l_p	$l_p M_x = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
Joule per Planck time	$M_z = \hbar \frac{l_p}{\bar{\lambda}_M}$	$\frac{l_p c^2}{\hbar}$	$\frac{l_p c^2}{\hbar} M_z = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$
Kilogram per Planck time	$M_k = \frac{\hbar}{\bar{\lambda}_M} \frac{1}{c} \frac{l_p}{c}$	$\frac{l_p c^4}{\hbar}$	$\frac{l_p c^4}{\hbar} M_k = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$

Table 3. The table shows different mass definitions and the corresponding gravity constant and gravity force formula. All these formulae, when divided by the small mass, give the same output units and predictions, except some of the formulae give higher uncertainty in the output. Some of the mass definitions are much more intuitive and so is the gravity constant for these.

Mass or Energy Label	Mass or Energy	Gravity Constant	Gravity Force	Dimensions	Accuracy	Intuition
Kilogram	M	G	$F = G\frac{Mm}{R^2}$	$kg \cdot m \cdot s^{-2}$	Less	Low
Kilogram (deep)	$M = \frac{\hbar}{\bar{\lambda}_M} \frac{1}{c}$	$G = \frac{l_p^2 c^3}{\hbar}$	$F = \frac{l_p^2 c^3}{\hbar} \frac{Mm}{R^2}$	$kg \cdot m \cdot s^{-2}$	Top	Less
Joule (deep)	$E = h\frac{c}{\lambda_M} = \hbar \frac{c}{\bar{\lambda}_M}$	$G_E = \frac{l_p^2}{\hbar c}$	$F = \frac{l_p^2}{\hbar c} \frac{E_E}{R^2}$	$kg \cdot m \cdot s^{-2}$	Less	Less
Collision-time	$M_t = \frac{l_p}{c} \frac{l_p}{\bar{\lambda}_M}$	c^3	$F = c^3 \frac{M_t m_t}{R^2}$	$L \cdot T^{-1}$	Top	Good
Collision-length	$E_g = l_p \frac{l_p}{\bar{\lambda}_M}$	c	$F = c\frac{E_g E_g}{R^2}$	$L \cdot T^{-1}$	Top	Good
"Newton" alternative-1	$M_n = c^2 l_p \frac{l_p}{\bar{\lambda}_M}$	1	$F = \frac{M_n M_n}{R^2}$	$L^4 \cdot T^{-4}$	Top	Less
"Newton" alternative-2	$M_n = \frac{l_p}{c} \frac{l_p}{\bar{\lambda}_M}$	$c^3 = 1$	$F = c^3 \frac{M_n M_n}{R^2} = \frac{M_n M_n}{R^2}$	$L^4 \cdot T^{-4}$	Top	Less
Time-speed	$M_s = \frac{l_p}{\bar{\lambda}_M} \frac{1}{c}$	$l_p c^3$	$F = l_p c^3 \frac{M_s m_s}{R^2}$	T^{-1}	Less	Less
Frequency per Planck time	$M_f = \frac{l_p}{\bar{\lambda}_M}$	$l_p c^2$	$F = l_p c^2 \frac{M_f m_f}{R^2}$	$L \cdot T^{-2}$	Less	Less
Planck length times Frequency	$M_e = l_p \frac{c}{\bar{\lambda}_M}$	$l_p c$	$F = l_p c \frac{M_e m_e}{R^2}$	$L^3 \cdot T^{-3}$	Less	Less
Frequency per second	$M_y = \frac{c}{\bar{\lambda}_M}$	$l_p^2 c$	$F = l_p^2 c \frac{M_y m_y}{R^2}$	$L \cdot T^{-3}$	Less	Less
c^2 times Planck time frequency	$M_x = c^2 \frac{l_p}{\bar{\lambda}_M}$	l_p	$F = l_p \frac{M_x m_x}{R^2}$	$L^3 \cdot T^{-4}$	Less	Less
Joule per Planck time	$M_z = \hbar \frac{l_p}{\bar{\lambda}_M}$	$\frac{l_p c^2}{\hbar}$	$F = \frac{l_p c^2}{\hbar} \frac{M_z m_z}{R^2}$	$kg \cdot m \cdot s^{-3}$	Less	Less
Kilogram per Planck time	$M_k = \frac{\hbar}{\bar{\lambda}_M} \frac{1}{c} \frac{l_p}{c}$	$\frac{l_p c^4}{\hbar}$	$F = \frac{l_p c^4}{\hbar} \frac{M_k m_k}{R^2}$	$kg \cdot m \cdot s^{-1}$	Less	Less

When it comes to how easy it is to measure the mass, we are thinking about mass used to predict gravitational phenomena, as is the purpose here. Only for the masses that are marked as *high* in relation to *Completeness for gravity* we have also marked as "*easy*" to measure. All these masses marked as *easy* can be extracted directly from one observable gravity phenomena without doing any other gravity calibration first to find the gravitational constant, or without defining a clump of matter and calling it kilogram or pound first. This is because these complete masses maximum need a gravity constant that is the speed of light. All the other masses need one to first calibrate a gravity constant, which can be quite complicated and lead to larger uncertainty in the measurement of the mass as discussed in detail in our recent paper [48]. There will, for this reason, be smaller uncertainty in the gravitational mass measures for the complete masses than for any of the other masses.

Table 2 demonstrates that all these different mass definitions, when multiplied by their corresponding gravity constant, give exactly the same output units and results, despite the different mass and different gravitational constant. All outputs from the gravity constant multiplied by the mass are, at the deeper level, equal to $c^2 l_p \frac{l_p}{\bar{\lambda}}$. The small mass in the gravity force formula will always cancel in derivations to get formulae that can predict anything observable, and, at the deeper level, all these, when used in their respective gravity force formulae, will predict the same. However, some of them are much easier to use as well as more intuitive and lead to lower uncertainty in gravity predictions. Please note that all mass definitions, when multiplied by their respective gravity constant, contain the term $\frac{l_p}{\bar{\lambda}}$. This term represents the quantization of gravity, as pointed out in Section 2.3. Specifically, it represents the reduced Compton frequency in the gravitational mass per Planck time, given that $\frac{c}{\bar{\lambda}} t_p = \frac{l_p}{\bar{\lambda}}$. This is actually an aggregate of frequency probabilities, a number $\frac{l_p}{\bar{\lambda}} = 3.5$, which is what one get for a mass equal to 3.5 Planck masses, meaning that in a Planck time observational window, there are for sure three Planck events, and there is a 50% probability of one more.

Masses significantly smaller than the Planck mass are mainly influenced by probability related to Planck-mass events, while masses much larger than the Planck mass are wholly determined by determinism. This explains why the force of gravity on any observed macroscopic object is so predictable (see [43]). Again, the $\frac{l_p}{\bar{\lambda}}$ is the reduced Compton frequency per Planck time. The frequency for a mass smaller than the Planck mass is less than one, and since only integer frequencies can be observed in a given time window, a frequency below one can also be interpreted as a probability for an observable part of the frequency occurring within that time frame. For composite particle masses, the term $\frac{l_p}{\bar{\lambda}}$ is a probability aggregate where the integer part is typically large. For example, for the Earth, the integer part is approximately $\frac{l_p}{\bar{\lambda}_{Earth}} = \frac{l_p}{\hbar/(M_{Earth}c)} \approx 2.75^{32}$ per Planck time, indicating that gravity is dominated by determinism. For an electron, the Compton frequency per Planck time is $\frac{l_p}{\bar{\lambda}_e} \approx = 4.19 \times 10^{-23}$, which can be seen as a probability for the electron to be in a collision-state that again is related to gravity in a given Planck-time. Therefore, the gravitational behavior of the atomic and subatomic world is dominated by probability. Based on this deeper understanding, it is reasonable to think that standard gravity theory to a large degree explains why gravity behaves deterministically for astronomical objects while probabilities dominate the modeling of gravity for atomic and subatomic particles. This understanding is already embedded in our theories when viewed from a deeper perspective.

Table 3 summarizes the masses and their respective gravitational force formulae. The gravity force formulae and masses' definitions are different. Still, as the small mass cancels in all these gravity force formulae, they all give the same output. However, the gravity force formulae that rely on incomplete mass definitions to model gravity require unnecessarily complex gravity constants, needed to fix the incomplete mass definitions. We will again claim only the collision space-time mass and the collision-length energy, as well as the original Newton mass, can be seen as complete as they do not need to rely on complex gravity constants to fix the incomplete mass definition. The Newton alternative 1 has everything incorporated in the mass. This means no gravity constant at all is needed. However, in our view, this leads to a less intuitive mass than the collision-time, as it leads to that mass has dimensions $[L^3 \cdot T^{-2}]$, so this is less intuitive than having a mass that simply has dimensions $[T]$. It is not that it is just dimension $[T]$ but also that in previous work, we have been able to carefully describe how this is collision-time related to the duration of indivisible particles standing in collision state, which is the Planck mass at a deeper level.

The other mass, like kilogram, has a mysterious gravity constant G. At a deeper level, this gravity constant is simply $G = \frac{l_p^2 c^3}{\hbar}$. We naturally did not assume this is what Newton assumed, as he never invented a gravity constant, nor that Cornu and Baille the inventors of what today is known as Newton's gravity constant assumed this. The Newton gravity constant is simply related to what is missing in the kilogram mass to do gravitational modeling. It is a composite constant, not by assumption, but by calibration. When this is understood at a deeper level, one understands that the kilogram mass is incomplete for modelling gravity without first being fixed by this ad-hoc inserted constant. All the other mass definitions also lead to gravity force formulae, but any of these mass definitions that have a gravity constant that contain more than just c can be seen to contain a incomplete mass defintion. This is not just about aesthetic and intuition; it is also about the reduction of uncertainty in gravity predictions, as discussed in detail by Haug [48].

4. Kilogram Mass Versus Gravitational Mass

What happened in 1873 with the invention of the gravitational constant was basically that one wanted to make one mass standard between small masses and large astronomical masses. As Maxwell indirectly pointed out, the kilogram or pound was not used in the gravitational force formula before 1873. This is natural, as no gravitational constant was introduced before 1873. Any human arbitrarily-chosen clump of matter used as mass standard will require that any other mass will be relative to it. When we say the mass of an electron is about 9.11×10^{-31} kilogram, it means it is this fraction of mass relative to one kilogram. The pound and the kilogram mass are fractional masses. The mass of an electron divided by one kilogram is:

$$\frac{m_e}{m_{1kg}} = \frac{\frac{\hbar}{\bar{\lambda}_e}\frac{1}{c}}{\frac{\hbar}{\bar{\lambda}_{1kg}}\frac{1}{c}} = \frac{\frac{c}{\bar{\lambda}_e}}{\frac{c}{\bar{\lambda}_{1kg}}} = \frac{\bar{\lambda}_{1kg}}{\bar{\lambda}_e} \approx 9.11 \times 10^{-31} \tag{24}$$

That is, the kilogram mass of the electron can be seen as a Compton frequency ratio: that the Compton frequency in one electron divided by the Compton frequency in one kilogram.

The reduced Compton wavelength of one kilogram is given by: $\bar{\lambda}_{1kg} = \frac{\hbar}{1kgc} = \frac{\hbar}{c}$. Now we can replace that back into the formula above and we get that the mass of the electron in kilogram divided by the mass of one kilogram must be:

$$\frac{m_e}{1kg} = \frac{\bar{\lambda}_{1kg}}{\bar{\lambda}_e} = \frac{\frac{\hbar}{c}}{\bar{\lambda}_e} = \frac{\hbar}{\bar{\lambda}_e}\frac{1}{c} \tag{25}$$

This is the same as we get from solving the Compton wavelength formula for m. This means a kilogram mass (and the same is the case with any human arbitrarily-chosen clump of matter used as mass standard) gives a frequency ratio. Standard joule energy is also just frequency times the Planck constant. So, to work just with standard joule energy in relation to mass, the kilogram mass is sufficient.

Assume a frequency of only two per a given time unit. A frequency alone says nothing about what is turning it into a frequency of two. For something to be two, there must be an event that distinguishes it into two parts. We have argued in papers on collision space-time that this part is the collision between indivisible particles, and that this collision only has a duration of the Planck time. So, indivisible particles move back and forth at the speed of light over the reduced Compton wavelength of the particle in question and collide every reduced Compton time $t_c = \frac{\bar{\lambda}}{c}$. The collision itself lasts only the Planck time. These collisions are what, in our view, causes gravity through a likely shielding effect, so we have a gravity similar to La Sage gravity, see [53,54] and also the detailed description of our collision time-space theory. The Planck length or Planck time are not needed for relations between joule energy and kilogram mass, as they both only contain embedded a frequency but not what distinguishes the different frequency elements, which is these collisions. So standard gravity theory using kilogram mass must somehow get this aspect back into the mass being used for gravitational modeling. This is done in modern Newton gravity as well as in Einstein's [9] general relativity theory by multiplying the mass with G. So, modern Newton theory and general relativity also accomplish this, but they are not aware what G represents in the physical word or why it is needed in the form it has. It has more or less just become the standard, and very few question why one has a gravity constant G that is multiplied by M. For example In her recent book, “Existential Physics” [55], Hossenfelder makes the claim that “*Newton’s constant (G) quantifies the strength of gravity.*” However, this statement is only partially true, or perhaps even incorrect. While the original Newtonian gravity formula does not include a gravity constant, it is still capable of accurately predicting all of the same gravitational phenomena as the modified 1873 formula that does include G. This does not mean that the original formula was incorrect in its assessment of the strength of gravity. Instead, it is necessary to include the gravitational constant in order to properly incorporate the Planck Length into the kilogram mass and remove the Planck constant from the kilogram mass. By doing so, all the necessary information needed to accurately model gravity can be incorporated.

5. Weak Equivalence Principle

The weak equivalence principle consists of several different aspects related to gravity. Part of the weak equivalence principle goes all the way back to Galileo Galilei, who suggested, and to some degree of precision demonstrated, that bodies with different density all fall at the same rate in a gravitational field. This is naturally only fully true in a vacuum, and it has been tested and found to hold in extremely high precision experiments in recent years (see [56–58]). Thus this part of the weak equivalence principle clearly holds. Moreover, the Newtonians $1/R^2$ rule has in recent years been tested all the way down to submillimeter scale (see [59,60]), something that is consistent with all the gravity force formulae discussed here.

The weak equivalence principle also states that gravitational mass and inertial mass are equivalent masses (see for example: [61–63]). This has been well tested and is assumed to be true. We are not at all questioning the validity of these experiments, but we will actually question whether these experiments have been interpreted correctly in relation to the kilogram mass and the 1873 version of the Newton gravity force formula. Mathematically, the weak equivalence principle also holds for Newton theory and is often represented by the well-known relation:

$$m_i a = G\frac{Mm}{R^2} \tag{26}$$

The inertial mass m_i is on the left side multiplied by the acceleration a. The gravitational masses are assumed to be in the gravity force formula, so both M and m are assumed to be gravitational masses, as this formula with these masses can be used to successfully predict a series of gravitational phenomena. It is clear that the inertial mass is in kilograms (see for example Mana and Schlamminger [64]). It is claimed that the equivalence between $m_i = m$ is well tested. The problem here is that in the gravity force formula as given above, the small mass m always simply cancels out with m_i in derivations for any predictable phenomena. One then mistakenly thinks that M and m are of the same type of masses, even in the modified 1873 Newton formula. They are not, however, as the large mass is fixed by being multiplied by G. It is GM (or $c^3 M_t$ if one uses collision space-time theory, see Section 2) that is the gravitational mass. To turn m into a gravitational mass we also need to multiply it with G. This is done in two body problems where m is not $m \ll M$ and its gravitational effect can be ignored. As we have mentioned before, the gravity parameter is then $\mu = G(M+m) = GM + Gm$, so if the weak equivalence principle really should hold then we have to compare m_i with Gm. Actually, in collision space-time theory, we have weak equivalence here, as the masses are properly defined, also for gravity.

So, in our view the weak equivalence problem has likely been misinterpreted by thinking that kilogram mass is the same as gravitational mass. One uses two kilogram masses that contain no information about gravity, that is, for the inertial mass m_i and the small m in the gravitational force formula, but it does not matter, as they are merely used in derivations to cancel each other out in order to come up with formulae with which to predict observable gravity phenomena. In real observable gravitational phenomena, we end up with well-known formulae such as orbital velocity $v_o = \sqrt{\frac{GM}{R}}$ or gravitational acceleration $g = \frac{GM}{R^2}$, where again the gravitational mass is related to GM and not M or

m. Two errors do not make one right. That neither the inertial mass m_i nor the small assumed gravitational mass m contain any information needed in a mass to model gravity is not important, as m_i and m are merely used in derivations where they cancel each other out. We believe that not recognizing the difference between the kilogram mass and the gravitational mass has prevented the gravity community from examining the true nature of gravitational mass more closely. This lack of understanding has contributed to slow progress in unification theories and success in quantum gravity theory. We do not ask the reader to take this for granted but hope this can at least open up some space for more scientific discussions about the optimal mass definitions for gravitational mass.

6. Einstein's Field Equation

The main focus of this paper is on the mass linked to the Newtonian gravitational force formula, which is considered a good weak field approximation to the general theory of relativity. An interesting question is whether we can obtain a gravity field equation with a Planck constant simply by substituting $G = \frac{l_p^2 c^3}{\hbar}$ into the second part of Einstein's field equation [65]. This was actually suggested by Haug in 2016 [66], but without much discussion. By doing so, we obtain

$$R_{\mu v} - \frac{1}{2} g_{\mu v} R = \frac{8\pi l_p^2}{\hbar c} T_{\mu v} \tag{27}$$

Based on the rewritten field equation, it seems that the Planck constant might play a significant role in gravity. However, upon closer study, one will discover that the Planck constant present in the rewritten field equation will cancel out with the Planck constant embedded in the stress-energy tensor, making it unlikely to affect predictions about gravity or quantum gravity. Nonetheless, some experimental studies have suggested that gravitationally induced quantum interference using neutrons depends on both the Planck constant and gravitational acceleration, see Colella, Overhauser, and Werner [67] and Abele and Leeb [68]. We will suggest that this may be because one at that time did not fully understand the kilogram mass and its relation to gravity at a more fundamental level. In the formulae they used to compare their observed values with their predictions, they included a factor of $\frac{m_n^2}{h^2}$, where m_n is now the neutron kilogram mass (More precisely, in Equation (2) in [67], we have $h^{-2}M^2$, where M is the neutron mass. Similarly, in Equation (2) in [68] and the lines below it, we have $\frac{m_n^2}{h^2}$. The Planck constants are needed to cancel out the Planck constants that are embedded in the kilogram mass. Thus, we can claim that also these gravitational observations at a deeper level are not related to the Planck constant, but rather to the Planck length. In their formulae, the Planck length is embedded in the gravitational constant g, as well as in the reduced Compton wavelength of the gravitational mass.). However, if we rewrite the kilogram mass in terms of its fundamental components, $m_n = \frac{\hbar}{\bar{\lambda}_n}\frac{1}{c}$, we can see that the Planck constant that explicitly appears in their formula, is needed to cancel out with the Planck constant embedded in the kilogram mass. Consequently, their observations can be predicted completely without relying on knowledge of the Planck constant.

That the Planck constant does not play a role in gravity at what we think is the deepest quantum level can be observed more easily through the study of the Schwarzschild [69,70] solution of Einstein's field equation. When we express G in its composite form and the mass M in kilograms as $M = \frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}$, we can rewrite the Schwarzschild solution as follows:

$$
\begin{aligned}
c^2 d\tau^2 &= \left(1-\frac{R_s}{R}\right)c^2dt^2 - \left(1-\frac{R_s}{R}\right)^{-1} dR^2 - R^2(d\theta^2+\sin^2\theta d\phi^2) \\
c^2 d\tau^2 &= \left(1-\frac{2GM}{c^2R}\right)c^2dt^2 - \left(1-\frac{2GM}{c^2R}\right)^{-1} dR^2 - R^2(d\theta^2+\sin^2\theta d\phi^2) \\
c^2 d\tau^2 &= \left(1-\frac{2\frac{l_p^2c^3}{\hbar}\frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}}{c^2R}\right)c^2dt^2 - \left(1-\frac{2\frac{l_p^2c^3}{\hbar}\frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}}{c^2R}\right)^{-1} dR^2 - R^2(d\theta^2+\sin^2\theta d\phi^2) \\
c^2 d\tau^2 &= \left(1-\frac{2l_p}{R}\frac{l_p}{\bar{\lambda}_M}\right)c^2dt^2 - \left(1-\frac{2l_p}{R}\frac{l_p}{\bar{\lambda}_M}\right)^{-1} dR^2 - R^2(d\theta^2+\sin^2\theta d\phi^2) \qquad (28)
\end{aligned}
$$

Here, we can see that the Planck constant embedded in G cancels out with the Planck constant embedded in the kilogram mass. Therefore, the Schwarzschild solution, which is used to derive a series of predictions that actually have been tested against observations, has no relation to the Planck constant. Although one may mistakenly think that this approach does not lead to quantization since the Planck constant is typically linked to quanta of energy in standard quantum mechanics. This would be a mistake as we have reasons to think the quantization in gravity seems to be linked to the Planck length and reduced Compton wavelength, which is also consistent with all we have found in Newton theory (see Table 4, where there are no Planck constants in any of the formulae). Again, the term $\frac{l_p}{\bar{\lambda}}$ is the reduced Compton frequency in the gravitational mass per Planck time. The Schwarzschild radius is now given by:

$$
R_s = \frac{2GM}{c^2} = 2l_p\frac{l_p}{\bar{\lambda}_M} \qquad (29)
$$

In the standard interpretation of general relativity theory, it is assumed that no mass smaller than half the Planck mass can have a Schwarzschild radius. This is because the Planck length is believed to be the shortest possible length [71,72], and a proton or electron, for example, would have a Schwarzschild radius much shorter than the Planck length. For instance, the Schwarzschild radius of a proton is given by $\frac{2GM_{pr}}{c^2} \approx 2.49 \times 10^{-54}$ m, which is much smaller than the Planck length $l_p \approx 1.62 \times 10^{-35}$ m. However, a new interpretation was suggested earlier [43] that introduces probabilities into gravity without altering the general relativity theory or Newton's theory, except for replacing G with the composite form and the mass as done above. In this framework, the Schwarzschild radius of a proton or electron is related to twice the Planck length multiplied by the factor $\frac{l_p}{\bar{\lambda}_M}$. When the mass M is smaller than the Planck mass, the factor $\frac{l_p}{\bar{\lambda}_M}$ is less than one. As explained in Section 2.3 and discussed in more detail in Ref. [43], this factor should be interpreted as a frequency probability. This means that masses smaller than half the Planck mass also have a Schwarzschild radius of approximately the Planck length, but that this radius fluctuates in and out of existence at the reduced Compton frequency of the particle in question. See the aforementioned paper for a deeper discussion on this. Thus, from this new perspective, both general relativity and Newtonian gravity are probabilistic below the Planck mass. This should not be taken for granted, but we believe that this framework is worthy of further study.

7. Gravity Predictions

All the various gravitational masses and gravitational constants listed in Tables 1–3 yield identical gravitational predictions. This is especially evident when each mass and gravitational constant is expressed in terms of their respective components, such as the Planck length, the speed of light, and the reduced Compton wavelength, as shown in Table 4. In this table we only show four of the different mass or energy definitions, but we have tested it out on all the mass definitions and respective gravitational constants given in Tables 1 and 2.

Table 4. The table demonstrates that when different mass or energy definitions are used in conjunction with their corresponding gravitational constant, they all yield the same gravitational predictions and ultimately converge to the same formula. Although we have only displayed this phenomenon for four of the mass definitions provided in the table above, we have verified that it holds true for all of the definitions listed in Table 2. The variable H in the Newton's cradle formulae below represents the height of the ball drop. Additionally, the variable x represents the spring displacement.

Prediction	From Macroscopic Surface Level to Deepest Level
Gravity acceleration	$g = \frac{GM}{R^2} = \frac{M_n}{R^2} = \frac{c^3 M_t}{R^2} = \frac{c^2 E_g}{R^2} = \frac{c^2 l_p}{R^2} \frac{l_p}{\bar{\lambda}_M}$
Orbital velocity	$v_o = \sqrt{\frac{GM}{R}} = \sqrt{\frac{c^3 M_t}{R}} = \sqrt{\frac{c^2 E_g}{R}} = c\sqrt{\frac{l_p}{R} \frac{l_p}{\bar{\lambda}_M}}$
Orbital time	$T = \frac{2\pi R}{\sqrt{\frac{GM}{R}}} = \frac{2\pi R}{\sqrt{\frac{M_n}{R}}} = \frac{2\pi R}{\sqrt{\frac{c^3 M_t}{R}}} = \frac{2\pi R}{\sqrt{\frac{c^2 E_g}{R}}} = \frac{2\pi R}{c\sqrt{\frac{l_p}{R} \frac{l_p}{\bar{\lambda}_M}}}$
Velocity ball Newton cradle	$v_{out} = \sqrt{2\frac{GM}{R^2}H} = \sqrt{2\frac{M_n}{R^2}H} = \sqrt{2\frac{c^3 M_t}{R^2}H} = \sqrt{2\frac{c^2 E_g}{R^2}H} = \frac{c}{R}\sqrt{2Hl_p \frac{l_p}{\bar{\lambda}_M}}$
Frequency Newton spring	$f = \frac{1}{2\pi R}\sqrt{\frac{GM}{x}} = \frac{1}{2\pi R}\sqrt{\frac{M_n}{x}} = \frac{1}{2\pi R}\sqrt{\frac{c^3 M_t}{x}} = \frac{1}{2\pi R}\sqrt{\frac{c^2 E_g}{x}} = \frac{c}{2\pi R}\sqrt{\frac{l_p}{x} \frac{l_p}{\bar{\lambda}_M}}$
Gravitational red shift	$z = \frac{\sqrt{1-\frac{2GM}{R_1 c^2}}}{\sqrt{1-\frac{2GM}{R_2 c^2}}} - 1 = \frac{\sqrt{1-\frac{2M_n}{R_1 c^2}}}{\sqrt{1-\frac{2M_n}{R_2 c^2}}} - 1 = \frac{\sqrt{1-\frac{2cM_t}{R_1}}}{\sqrt{1-\frac{2cM_t}{R_2}}} - 1 = \frac{\sqrt{1-\frac{2E_g}{R_1}}}{\sqrt{1-\frac{2E_g}{R_2}}} - 1 = \frac{\sqrt{1-\frac{2l_p}{R_1}\frac{l_p}{\bar{\lambda}_M}}}{\sqrt{1-\frac{2l_p}{R_2}\frac{l_p}{\bar{\lambda}_M}}} - 1$
Time dilation	$T_R = T_f\sqrt{1-\frac{2GM}{Rc^2}} = T_f\sqrt{1-\frac{2M_n}{Rc^2}} = T_f\sqrt{1-\frac{2cM_g}{R}} = T_f\sqrt{1-\frac{2E_g}{R}} =$ $T_f\sqrt{1-\frac{2l_p}{R}\frac{l_p}{\bar{\lambda}_M}}$
Gravitational deflection (GR)	$\theta = \frac{4GM}{c^2 R} = \frac{4M_n}{c^2 R} = \frac{4cM_g}{R} = \frac{4E_g}{R} = 4\frac{l_p}{R}\frac{l_p}{\bar{\lambda}_M}$
Advance of perihelion	$\sigma = \frac{6\pi GM}{a(1-e^2)c^2} = \frac{6\pi M_n}{a(1-e^2)c^2} = \frac{6\pi c M_t}{a(1-e^2)} = \frac{6\pi E_g}{a(1-e^2)} = \frac{6\pi l_p}{a(1-e^2)}\frac{l_p}{\bar{\lambda}_M}$

The different methods when not going to the deepest level, however, necessitate distinct inputs. Some of these inputs, such as the gravitational constant G and the kilogram mass M, necessitate more calibration than the original Newton mass M_n and its gravitational constant, which is simply 1, or the collision time-mass where the gravitational constant is simply c^3. Regardless, all the definitions of mass and corresponding gravitational constants result in the same output, both in terms of output units and numerical values.

When broken down to the quantum level, all the formulae yield equations located on the far right of the table. It is essential to note that these formulae all contain the factor $\frac{l_p}{\bar{\lambda}_M}$, which we interpret as the quantization of gravity [43,73], as discussed in Section 2.3 of this paper. This quantization factor $\frac{l_p}{\bar{\lambda}_M}$ simply represents the reduced Compton frequency per Planck time, eliminating the need for the Planck constant in gravitational predictions despite quantization. In our view, there is an embedded quantum gravity theory even in standard Newtonian and general relativity theories, but this can only be understood when G is replaced with its composite form and the kilogram mass with its form $M = \frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}$. From a deeper perspective, all the gravitational predictions (at least the ones in the table below) are dependent on the Planck length and the reduced Compton wavelength of the gravitational mass, as well as naturally occurring variables such as the distance to the center of the gravitational object R.

8. Conclusions

We have discussed a series of different mass definitions in relation to gravity. The kilogram mass is clearly not the optimal mass, as it is incomplete, but fixed with an ad hoc inserted constant invented in 1873, there is the so-called Newtonian gravitational constant that Newton never invented, used, or needed. Few researchers seem aware of Newton's original view on matter and that his original gravity force formula was $F = M_n m_n / R^2$. The mass in his formula seems to be superior to the kilogram mass when working with gravity, and it is also compatible with a quantum gravity theory that has defined mass as collision-time linked to the Planck scale. Collision time-mass and Newtonian mass, which can also be seen as the same type of mass at the deeper level, are mass definitions that are complete with respect to containing information needed to model gravity. Therefore, this mass does not need to be fixed with any ad hoc inserted gravity constant, that again needs calibration to be found by, for example, a Cavendish apparatus.

When the mass definitions are complete then the gravitational constant is never more complicated than containing just c, or even this can be incorporated into the mass definition. When the mass is incomplete, as is the case for kilogram mass or in another newly suggested mass definition known as time-speed, then one needs more complex gravity constants than are necessary for complete mass definitions in relation to gravity. This leads to larger uncertainty in predictions as one needs to find the gravity constant in a way that increases the overall uncertainty in the gravity predictions. The optimal mass definition is not only more intuitive, but it also even has practical implications on gravity predictions as one gets lower uncertainty in the prediction.

This also means anyone using gravity theory with G, without understanding and discussing it as a composite constant, has not looked at their own theories from the deepest possible level. We strongly encourage the gravity research community to start paying attention to that G is a composite constant needed to fix an incomplete mass. We have good reasons to think part of the stagnation in quantum gravity research is simply linked to improper understanding of the gravity constant and the kilogram mass from a deeper perspective. Hopefully, this paper will be fruitful for further discussions and paths to gravity.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No data has been used for this study.

Acknowledgments: Thanks to three anonymous referees for useful comments.

Conflicts of Interest: The author declares no conflict of interest.

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