# A Close Look at the Foundation of Quantized Inertia

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March 5, 2018

**Abstract**

In his recent work, physicist Mike McCulloch has derived what he has coined "Quantized Inertia" from Heisenberg's uncertainty principle. He has published a series of papers indicating that quantized inertia can predict everything from galaxy rotations (without relying on the concept of dark matter) to the EM drive, see [1, 2, 3, 4]. Clearly, it is an interesting theory that deserves some attention until proven or disproven. We think McCulloch has some excellent insights, but it is important to understand the fundamental principles from which he has derived his theory. We will comment on the derivation in his work and suggest that it possibly could be interpreted from a different perspective. Recent developments in mathematical atomism appear to have revealed new concepts concerning the Planck mass, the Plank length, and their link to special relativity, gravity, and even the Heisenberg principle. We are wondering if Quantized Inertia is compatible with the atomist view of the world and, if so, how should McCulloch's theory be interpreted in that light?

Key words: Heisenberg's uncertainty principle, Quantized Inertia, Planck length, Planck mass, Planck momentum.

## 1 McCulloch's Derivation of Quantized Inertia from Heisenberg's Uncertainty Principle

McCulloch has derived Newtonian gravity [5] from the Heisenberg uncertainty principle; see [6, 7]. In a recent note [8] we have commented on this and we strongly recommend reading that paper before this one. However, we will repeat some of the most important things from that paper that also apply here.

McCulloch [7] goes further and derives what he has coined "Quantized Inertia" from the Heisenberg uncertainty principle [9], which is given by

$$\Delta p \Delta x \geq \hbar \tag{1}$$

Next McCulloch goes on to say " Now $E = pc$ so" :

$$\Delta E \Delta x \quad \geq \quad \hbar c \tag{2}$$

He does not comment on the fact that a momentum of the form $p = mc$ only can relate to the momentum of a Planck mass particle. He also does not mention that $E = pc$ only can hold for the Planck mass momentum. Further, we claim that it only can hold for a Planck particle. While the Planck mass, Planck length, Planck time, and Planck energy was introduced in 1899 by Max Planck himself [10, 11], the Planck particle was likely first introduced by Lloyd Motz, when he was working at the Rutherford Laboratory in 1962; see [12, 13, 14].

The momentum formula that holds for any particle is the relativistic momentum formula put forward by Einstein

$$p = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{3}$$

Multiplying this by $c$ clearly does not gives us the kinetic energy formula or the rest-mass energy formula. So how do the Planck momentum fit in here? If it also follows relativistic principles, then we must have

$$p_p = \frac{m_p c}{\sqrt{1 - \frac{v^2}{c^2}}} = m_p c \tag{4}$$

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This is only possible if $v = 0$. That is to say, the Planck mass particle must always stand still, even as observed across different reference frames. This is exactly what Haug has claimed in a series of papers. In other words, this indicates that there is a breakdown of Lorentz symmetry at the Planck scale, something that several quantum gravity theories also claim, and something we will return to later. Our point is that the way McCulloch gets to his relation $\Delta E \Delta x \geq \hbar c$ likely only can be done with regard to Planck mass particles, or at least Planck masses. The Planck mass particle is, in our view, the building block of all other particles (an idea first suggested by Motz). Further, we will claim that the Planck particle only lasts for one Planck second. Within one Planck second it goes from mass to pure energy. We can also get a hint about this from the Planck acceleration, $a_p = \frac{c^2}{l_p} \approx 5.56092 \times 10^{51}\ m/s^2$. The velocity of a particle that undergoes Planck acceleration will actually reach the speed of light within one Planck second, $a_p t_p = \frac{c^2}{l_p}\frac{l_p}{c} = c$.

We know nothing with rest-mass can travel at the speed of light, so no "normal" particle can undergo Planck acceleration if the shortest possible acceleration time interval is the Planck second. The solution is simple. The Planck acceleration is an internal acceleration inside the Planck particle that turns (dissolves) the Planck mass particle into pure energy within one Planck second. This also explains why the Planck momentum is so special, namely always $m_p c$, unlike for any other particles that can take a wide range of momentums.

The Planck mass can be described as

$$m_p = \frac{\hbar}{l_p}\frac{1}{c} \tag{5}$$

Naturally, we do not know the Planck mass exactly, just as we do not know the Planck length exactly. However, the more precisely we know the Planck length, the more precisely we will know the Planck momentum. From the Heisenberg principle point of view, the Planck mass momentum collapses into a certainty principle, as recently described by Haug [21]:

$$\begin{aligned} \Delta p \Delta x &\geq \hbar \\ m_p c l_p &= \hbar \end{aligned} \tag{6}$$

Before we go forward, it is also worth mentioning that there is no limit on what momentum a proton or electron, for example, can take in modern physics. From the relativistic mass formula we can see that the relativistic momentum can get as close to as infinity as one would want, because from special relativity theory the only limitation on $v$ is that $v < c$, so we can go as close to the speed as light as we want. However, with Haug's suggested maximum limit on anything with rest-mass $v_{max} = c\sqrt{1 - \frac{l_p^2}{\bar{\lambda}^2}}$, the maximum momentum for any non-Planck mass becomes

$$p_{max} \approx \hbar\sqrt{\frac{1}{l_p^2} - \frac{1}{\bar{\lambda}^2}} \tag{7}$$

For any observed elementary particle so far, the reduced Compton wavelength is considerably larger than the Planck length, that is $\bar{\lambda} >> l_p$ and in this case we have

$$p_{max} \approx \hbar\sqrt{\frac{1}{l_p^2} - \frac{1}{\bar{\lambda}^2}} \approx \frac{\hbar}{l_p} = m_p c \tag{8}$$

So only the Planck mass particle always has a momentum of $m_p c$ and other observed particles likely have a maximum momentum that is just below the Planck momentum. In practical measurable terms (even for measurement in the future), this is hardly distinguishable from the Planck momentum. Since McCulloch derives his quantized inertia from a momentum of the form $mc$, it should always be connected to a Planck mass particle, or the maximum velocity of particles somehow.

McCulloch also suggests that it is the mass-energy plus the energy uncertainty that is conserved, rather than just the energy, and based on this he gets

$$m_1 c^2 + \frac{\hbar c}{\Delta x_1} = m_2 c^2 + \frac{\hbar c}{\Delta x_2} \tag{9}$$

I wondered about this equation for a while, but in correspondence with McCulloch, he confirmed that he had made a small typo (as we all do sometimes), so this should actually be

$$\begin{aligned} m_1c^2 - \frac{\hbar c}{\Delta x_1} &= m_2c^2 - \frac{\hbar c}{\Delta x_2} \\ m_2c^2 - m_1c^2 &= \frac{\hbar c}{\Delta x_2} - \frac{\hbar c}{\Delta x_1} \\ m_2 - m_1 = dm &= \frac{\hbar}{c}\left(\frac{1}{\Delta x_2} - \frac{1}{\Delta x_1}\right) \end{aligned} \tag{10}$$

The last line correspond to what McCulloch himself has derived and based his theory on, so his typo do not affect the many calculations he has gone forward with. However based on this minor revision, we think it should no longer be interpreted as conservation of mass-energy plus the energy uncertainty, because it is now the rest-mass minus the uncertainty in mass. Here we will speculate on a different interpretation that possibly could lead to a greater understanding of the quantized inertia theory; additional work is needed. We note the following possible structural similarity with the formula McCulloch gets, as shown above, and some of our own derivations from atomism

$$\begin{aligned} \frac{m_2}{\sqrt{1-\frac{(\Delta v_2)^2}{c^2}}} - m_1 &= \frac{\hbar}{c}\left(\frac{1}{\Delta x_2} - \frac{1}{\Delta x_1}\right) \\ \frac{\frac{\hbar}{\bar{\lambda}}\frac{1}{c}}{\sqrt{1-\frac{(\Delta v_2)^2}{c^2}}} - \frac{\hbar}{\bar{\lambda}}\frac{1}{c} &= \frac{\hbar}{c}\left(\frac{1}{\Delta x_2} - \frac{1}{\Delta x_1}\right) \\ \frac{\hbar}{\bar{\lambda}\sqrt{1-\frac{(\Delta v_2)^2}{c^2}}}\frac{1}{c} - \frac{\hbar}{\bar{\lambda}}\frac{1}{c} &= \frac{\hbar}{c}\left(\frac{1}{\Delta x_2} - \frac{1}{\Delta x_1}\right) \\ \frac{\hbar}{c}\left(\frac{1}{\bar{\lambda}\sqrt{1-\frac{(\Delta v_2)^2}{c^2}}} - \frac{1}{\bar{\lambda}}\right) &= \frac{\hbar}{c}\left(\frac{1}{\Delta x_2} - \frac{1}{\Delta x_1}\right) \end{aligned} \tag{11}$$

Where we "must' have $\Delta x_1 = \bar{\lambda}$ here and where $\Delta x_2$ is directly linked to $\bar{\lambda}\sqrt{1-\frac{(\Delta v)^2}{c^2}}$, that is the uncertainty in the reduced Compton wavelength of a elementary particle. It is also linked to uncertainty in the velocity of the particle, and therefore must be much smaller in an accelerated particle than it is in a non-accelerated particle. Under Haug's atomism, the reduced Compton wavelength will undergo standard length contraction (when measured with Einstein-Poincarè synchronized clocks) as when $v > 0$, but cannot contract more when it reaches the Planck length.

This also means the maximum velocity a particle can take, as has been suggested by Haug in a series of papers [17, 16, 15, 20, 19], is

$$v_{max} = c\sqrt{1-\frac{l_p^2}{\bar{\lambda}^2}} \tag{12}$$

Further, we must have

$$\bar{\lambda}\sqrt{1-\frac{v_{max}^2}{c^2}} = \bar{\lambda}\sqrt{1-\frac{\left(c\sqrt{1-\frac{l_p^2}{\bar{\lambda}^2}}\right)^2}{c^2}} = l_p \tag{13}$$

If we input $v_{max}$ in formula 11 above for $\Delta v$, then we get Haug's maximum kinetic energy formula for non-Planck masses

$$\begin{aligned} K_{e,max} &= \hbar c\left(\frac{1}{l_p} - \frac{1}{\bar{\lambda}}\right) \\ \frac{K_{e,max}}{c^2} = d_{max}m &= \frac{\hbar}{c}\left(\frac{1}{l_p} - \frac{1}{\bar{\lambda}}\right) \end{aligned} \tag{14}$$

As the Planck length is linked to all observable gravity phenomena, we wonder if quantized inertia could have something to do with maximum kinetic energy? This is partly because McCulloch derives it from the Planck mass momentum, which only holds for a Planck mass particle and, in our view, is linked to both gravity and the maximum velocity of matter. Is McCulloch's quantized inertia connected to the newly-introduced maximum kinetic energy of non-Planck mass particles, which are actually linked to the Planck mass particle. As we consider these questions, we also reflect on recent work showing that the Planck mass and the Planck length can be found totally independent of the Newtonian gravitational constant, as recently explained by [19]. In addition, we have given evidence that the Planck length is likely the smallest $\Delta x$ possible.

Returning to McCulloch's work, as Big Bang skeptics, we question his use of the radius of the observable universe. Although widely discussed and accepted into mainstream thinking, the Big Bang theory is rooted in a particular interpretation of cosmological red-shift that is not really proven yet. The Big Bang theory has lead us to an assumed observable universe radius, but is still just a hypothesis. True, that many observations are not inconsistent with it, but we must make note of some observations that do appear to be inconsistent with it. The series of challenges to the Big Bang theory, include the fact that it does not seem to be consistent with high Z quasar studies [18], for example. In my view, there seem to be too many holes in the Big Bang theory; however, some type of cosmic horizon could play a role due to other unknown effects.

In formula 14 above, $\Delta x_1$ should likely be much smaller than it is in the McCulloch formula, as it not is the cosmic radius in our maximum kinetic energy formula. However, even in our maximum kinetic energy formula, $\Delta x_1$ could actually be the distance between the gravity objects one is working with – the distance between the center of a galaxy and the stars for which one is calculating orbital velocity, as an example. Still, this is much smaller than the observable universe radius. In addition, $\Delta x_2$ is (for most applications) much smaller, as it is then the Planck length. Again, we do not know if there is a link between formula 14 and 10. But we see very strong structural similarities that we would like to explore further in the near future. We would like Mike to think about this as well (for some light years to come!).

McCulloch mention the Rindler horizon $d = \frac{c^2}{a}$, where he suggests putting $\Delta x_2 = d$. It is also worth mentioning that the maximum acceleration for any non-Planck particle from Haug's suggested maximum velocity of matter must be xt

$$a_{max} = \left( \frac{c^2}{l_p} - \frac{c^2}{\bar{\lambda}} \right) \sqrt{1 - \frac{l_p^2}{\bar{\lambda}^2}} \tag{15}$$

For the maximum acceleration possible this would mean that we have a Rindler horizon of

$$d = \frac{c^2}{\left( \frac{c^2}{l_p} - \frac{c^2}{\bar{\lambda}} \right) \sqrt{1 - \frac{l_p^2}{\bar{\lambda}^2}}} \tag{16}$$

For any known observable masses $\bar{\lambda} >> l_p$ and this can then be well-approximated as

$$d = \frac{c^2}{\left( \frac{c^2}{l_p} - \frac{c^2}{\bar{\lambda}} \right) \sqrt{1 - \frac{l_p^2}{\bar{\lambda}^2}}} \approx l_p \tag{17}$$

So it seems that our theory could "at least" lead to some boundary conditions on McCulloch's theory of quantized inertia, or alternatively, it might generate a new interpretation. Again, we are questioning if the cosmic radius is really a necessary input in McCulloch's model, or if there could be another combination of inputs to $\Delta x_1$ and $\Delta x_2$ that give a different and deeper understanding of quantized inertia?

# 2 Conclusion

This paper offers a preliminary study of McCulloch's theory of Quantized Inertia. We think there could be something great in this theory. However, it is important examine it deeply and we think his interpretation may not be optimal yet. McCulloch derives his theory from Planck momentum and therefore we think his theory must always be related to Planck mass particles in some way. Planck mass particles and the Planck length have recently been shown to play a very important role, even in cosmic gravity measurements. Further, the Planck mass seems to play a central role in a newly-suggested maximum kinetic energy, as well as maximum momentum for all subatomic particles. The structural form of McCulloch Quantized Inertia theory seems to be very similar to that of Haug's maximum kinetic energy formula. In a further area of common interest, the Heisenberg uncertainty principle has recently been shown by Haug to likely be broken at the Planck scale.

We wonder if what McCulloch has indirectly discovered is the same, but from a different and more practical perspective. It may be that his interpretation is non-optimal, but his use of the theory opens up the possibility to explain several anomalies in a simpler way than other theories, such as dark matter. We will not conclude one way or the other right now, but we strongly encourage people to study Quantized Inertia alongside the rapid developments in mathematical atomism advanced by Haug that 1) seem to be consistent with all well-known physics formulas, 2) that offer boundary conditions on special relativity theory where Lorentz symmetry breaks down, and 3) that examine how the Heisenberg uncertainty principle can become the certainty principle at the Planck scale.

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