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Testing quantized inertia on Proxima Centauri

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ABSTRACT

The Alpha Centauri system has two close stars Alpha and Beta (A & B) and one much further away: Proxima Centauri. All three stars are co-moving with similar chemistry, which implies they are bound, but the fast orbit of Proxima implies it is gravitationally unbound given the visible mass of A and B. This problem cannot be fixed with the addition of dark matter, which must be uniform on such scales, or adding mass to A and B (their mass is well constrained) or by Modified Newtonian Dynamics. A new model for inertia called Quantized Inertia (QI) has been proposed that solves the galaxy rotation problem by reducing the inertia of low-acceleration stars at the galaxies' edge in a new way, thus keeping them bound without the need for dark matter. It is shown here that if QI is applied to Proxima Centauri in the same way, it predicts the observed orbital velocity, within the bounds of observational uncertainty, and binds Proxima, without the need for extra mass.

Key words: celestial mechanics.

1 INTRODUCTION

General relativity has been in existence for over 100 yr and is certainly the dominant theory of gravity but it has several problems. For example, singularities plague it and it does not mesh well with quantum mechanics (Iorio 2015; Debono & Smoot 2016). Most damningly, it has not yet predicted a single galaxy rotation correctly, in the edge regime where the stars' accelerations are extremely low. It is therefore important to find simple systems where it can be tested in the regime it appears to fail: at low accelerations. The idea of testing models of gravity using widely dispersed and therefore, low acceleration systems has been tried by Iorio (2013) using the Alpha Centauri system, as here, using wide binaries by Pittordis and Sutherland (2018) and Hernandez et al. (2019, 2022) and using pulsars orbiting the galactic centre by Iorio (2018).

The three stars of Alpha, Beta, and Proxima Centauri are the closest stars to our Solar system (Henderson 1839; Voute 1917) only 1.30197 ± 0.00008 pc away (Gaia Collaboration 2016, 2023), so they have been relatively well observed. Alpha and Beta (A and B) Centauri orbit each other at a distance of between 10 and 30 AUs but the much smaller Proxima orbits much further away: 15 000 ± 700 AU from the other two. The three stars are thought to be a bound system, since they have the same age and chemical composition and are co-moving so that the chance of them being unbound has been estimated to be one in a million (Matthews and Gilmore 1993).

However, it has been shown that the orbital velocity of Proxima Centauri, which is 0.53 ± 0.14 km s^{-1}, should be enough to allow it to break free of the gravitational attraction of Alpha and Beta Centauri given the apparent mass determined from their luminosity assuming a normal mass to light ratio (Anosova et al. 1994). To solve this problem Matthews and Gilmore (1993) suggested a 3σ increase in the mass of the two central stars, but this is much larger than the uncertainty in their masses. Recently it has been shown it is possible for Proxima to be bound if it is near its apastron, but even in this case with extreme assumptions, Proxima was more likely to be unbound than bound (Wertheimer and Laughlin 2006).

This anomaly has a similarity to the galaxy rotation or galaxy cluster missing mass problem (Zwicky 1937; Rubin and Ford 1970) in which the outer stars of galaxies also show velocities too large to be bound by the gravitational pull of the galaxies' visible matter. In galaxies and galaxy clusters this has been typically corrected ad hoc by adding dark matter.

One alternative to dark matter is MoND (Modified Newtonian Dynamics; Milgrom 1983) in which either the gravitational force on, or the inertial mass of, orbiting stars is modified for very low accelerations. In this case though, MoND's predictions are very similar to the Newtonian, since its External Field Effect means that the acceleration of this system within the galaxy as a whole is important. MoND requires an adjustable parameter to be set by hand. Only if this is set to be artificially low at $a_0 = 1.2 \times 10^{-10}$ m/s^2 does MoND predict an orbital speed for Proxima which agrees with that observed, 0.424 ± 0.001 km s^{-1} (Beech 2009). MoND also has no physical model and relies on its adjustable parameter, a0, being fitted to astrophysical data by hand, which is unsatisfactory.

To solve the galaxy rotation, and other, problems, without the need for dark matter or adjustable parameters, but with a physical reason, McCulloch (2007, 2013) has proposed a new model for inertial mass. When an object accelerates, say, to the right, an information horizon forms to its left and Unruh radiation also appears (now observed by Lynch et al. 2021). If it is then assumed that the wavelengths of Unruh waves have to fit into the distance between the object and the horizon (with nodes at the horizon and object) then there will be fewer Unruh waves in the direction opposite to the acceleration

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vector, and the Unruh field will become anisotropic, pushing the object back against its acceleration. This models standard inertia (McCulloch 2013). Furthermore, this model predicts that some of the Unruh radiation will also be suppressed, this time in all directions equally, by the distant Hubble horizon which will make this inertial mechanism less efficient, reducing inertial mass in a new way for very low accelerations for which Unruh waves are very long (McCulloch 2007). This model, called quantized inertia (QI), modifies the standard inertial mass (m) as follows:

$$m_i = m\left(1 - \frac{2c^2}{|a|\Theta}\right), \tag{1}$$

where c is the speed of light, $\Theta = 8.8 \times 10^{26}$ m is the co-moving cosmic diameter, $|a|$ is the magnitude of the acceleration of the object relative to the matter with which we are calculating the interaction, in this case the barycentre of Alpha & Beta Centauri. That means there is no External Field Effect in QI because the inertial mass for each interaction is only determined by the mutual acceleration in that interaction. Equation 1 predicts that for terrestrial accelerations (eg: $9.8\,\mathrm{m/s^2}$) the second term in the bracket is tiny and standard inertia is recovered, but in environments where the mutual acceleration is of order $10^{-10}\,\mathrm{m/s^2}$, for example at the edges of galaxies, in dwarf galaxies or wide binaries the second term becomes larger and the inertial mass decreases in a new way. It is not possible for inertial mass to become negative, as equation 1 may imply, because for accelerations approaching the minimum of $2c^2/\Theta$ the inertial mass collapses and the acceleration then increases again. One can see this by rewriting equation 1 defining the acceleration $|a|$ gravitationally, $a = GM/r^2$, thus

$$m_i = m\left(1 - \frac{2c^2r^2}{GM\Theta}\right). \tag{2}$$

It is clear from this formula that as the acceleration of an orbiting body reduces as r increases and $GM/r^2 \rightarrow 2c^2/\Theta$ then m_i approaches zero, at which point, because of the collapse of the inertial mass $m_i \rightarrow m(1 - 1) = 0$ the resulting heliocentric acceleration will increase again and the system will reach equilibrium close to the point where $a = GM/r^2 = 2c^2/\Theta$. This implies that there is a cosmic acceleration minimum of $2c^2/\Theta \sim 2 \times 10^{-10}\,\mathrm{m/s^2}$. Proxima's observed orbital speed is $0.53 \pm 0.14\,\mathrm{km\,s^{-1}}$, which has a maximum possible value of $0.67\,\mathrm{km\,s^{-1}}$, which implies an acceleration of $a = v^2r = 2 \times 10^{-10}\,\mathrm{m/s^2} = 2c^2/\Theta$. Therefore it is consistent with the predicted minimum acceleration.

The inertial mass of A & B relative to Proxima would also be reduced but because P has so much less gravitational mass, the effect is much smaller. This modification of inertia does not affect equivalence principle tests using torsion balances since the predicted inertial change is independent of the mass.

QI correctly models galaxy rotation without the need for dark matter (McCulloch 2012, 2017) because it reduces the inertial mass of outlying stars and allows them to be bound even by the gravity from the smaller amount of visible matter. This result is encouraging, but not decisive, since more flexible theories like dark matter or MoND can be fitted to the data.

In the case of the Alpha Centauri system the solution of adding dark matter is not possible since, to work on galactic scales, dark matter must be smooth on these smaller scales and the alternative solution of adding baryonic matter to Alpha and Beta requires more mass than is plausible. So the Alpha Centauri system could be a decisive experiment and it makes sense to determine whether QI can make Proxima gravitationally bound, just as it makes larger galaxies bound.

2 METHOD & RESULTS

The Alpha Centauri system is made up of two stars Alpha and Beta (A and B) which orbit each other at a distance between 10 and 30 AUs and have a combined mass, determined from their mutual orbit, of $2.00 \pm 0.11\,\mathrm{M_\odot}$ (Anosova et al. 1994) so we can assume that they are one central star from the point of view of Proxima Centauri (P) which is much less massive at $0.123 \pm 0.006\,\mathrm{M_\odot}$ (Segransan et al. 2003) and orbits far out at 15 000+ /−700 AU. The orbital balance is written as

$$\frac{GMm}{r^2} = \frac{mv^2}{r}, \tag{3}$$

where G is the gravitational constant, M is the combined mass of A and B, m is the mass of Proxima, r is its orbital radius and v is its orbital velocity. This would normally produce the Newtonian result

$$v = \sqrt{\frac{GM}{r}}. \tag{4}$$

So that for the values and error bars discussed already the predicted orbital velocity for Proxima is $0.344 \pm 0.018\,\mathrm{km\,s^{-1}}$. The problem is that its observed orbital velocity is significantly larger: $0.53 \pm 0.14\,\mathrm{km\,s^{-1}}$, and in order to predict an orbital velocity in agreement with the observed velocity (taking account of the uncertainties in both values) requires an increase in the mass of A and B about three times larger than the uncertainty in that mass. This fast orbit then implies that Proxima is gravitationally unbound, but, as said before, this contradicts evidence from stellar chemistry and the three stars' co-movement through the sky that both imply that the three stars are bound.

The theory of QI predicts (McCulloch 2012) an orbital speed (v) for Proxima of:

$$v^4 = \frac{2GMc^2}{\Theta}. \tag{5}$$

So

$$v = \left(\frac{2GMc^2}{\Theta}\right)^{\frac{1}{4}} = 0.483 \pm 0.01\mathrm{km\,s^{-1}}. \tag{6}$$

Therefore QI predicts a velocity for Proxima Centauri that agrees within error bars with the observed orbital velocity of $0.53 \pm 0.14\,\mathrm{km\,s^{-1}}$ and also satisfies the chemical and co-moving data that suggests that Proxima is bound to A and B (the prediction of QI is closer than that of MoND which was $0.424 \pm 0.001\,\mathrm{km\,s^{-1}}$). The formula used here (equation 5) is identical to the one used by McCulloch (2012, 2017) to successfully predict the rotation of dwarf galaxies, galaxies, and galaxy clusters without dark matter.

3 DISCUSSION

The Alpha Centauri system is ideal for testing QI since it is close to us and well-observed. The mass of A and B has been well determined from their close mutual orbit so their masses cannot be altered to fix this problem and also dark matter cannot be used for this small scale system.

For this case of Proxima Centauri, QI predicts that because of its very low acceleration with respect to nearby matter (Alpha and Beta Centauri) it has lost some of its inertial mass in a new way, but its gravitational mass is unaffected (a subtle violation of the equivalence principle that by its nature cannot be detected in a torsion balance experiment). This means that Proxima can more easily be bent into a bound orbit even by the visible mass of A and B (assuming the standard mass to light ratio) and accounts for its fast but still bound orbit.

The prediction of QI differs significantly from the Newtonian and MoND predictions of the velocity so that when more constrained data on the orbit of Proxima becomes available from ESA's new *GAIA* satellite, it may be possible to compare these different approaches conclusively. This approach can also be applied to wide binary stars (McCulloch and Lucio 2019).

Some simplifications have been made in this study, for example nothing has been specified about the orbit of Proxima, save that whatever it is, it maintains itself somehow above QI's minimum acceleration of $2c^2/\Theta$. As stated above, if Proxima happened to be at its apastron, it would be possible for it to be bound, but even in that special case it has been shown in simulations to be more likely to be unbound (Wertheimer and Laughlin 2006). The solution from QI would not require any such special case.

It has been noted by Makarov, Zacharias and Hennesy (2008) that weakly bound gravitational systems like this are surprisingly common, and therefore stable, which suggests that new physics might be at play. Makarov (2012) suggested the use of very wide binary stars as tests of alternative dynamical models.

4 CONCLUSION

The Alpha Centauri system provides a good experiment, since chemical similarities and the co-movement of its three stars strongly imply the three stars are bound, whereas the orbital speed of Proxima Centauri, if Newtonian, implies that the gravity of the two central stars should be insufficient to bind it.

The solution of adding ad hoc dark matter is not possible in this small-scale case and the solution of increasing the mass of A and B, requires an increase of mass three times larger than the uncertainty in that observed mass. MoND also does not predict this system, due to its external field effect.

A new (unadjustable) model for inertial mass, QI, predicts the correct orbital speed for Proxima Centauri within the observational bounds of error, and also that it is bound, reconciling the chemical, co-moving, and orbital aspects of the system without the need for extra mass.

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DATA AVAILABILITY

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