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A new 'more Natural' ToE model with Covariant Emergent Gravity as a solution to the dark sector

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Arguments have been raised against several of the central ideas in theoretical physics, such as M-Theory's (MT's) inability to provide for the falsification necessary to avoid relegating it to the scientific dustbin of an anthropic principle based rationalization, such as the Multiverse. Along similar lines, ideas of a uniquely falsifiable inflation era after the Big Bang (BB) have also lost some of their traction. Recent major experimental results too have sent shock waves, such as the confirmation of the low Higgs mass constraining notions of super symmetry, and the Planck satellite's detail mapping of the Cosmic Microwave Background (CMB) fixing the Hubble parameter at odds with other more traditional methods. Even the null results of major experimental apparatus are causing consternation, as in the search for particle based Dark Matter (DM). Thankfully, all this seems to be opening the door for a more serious investigation into alternative theories that attempt to answer the big questions related to the causal relationships between the Standard Model (SM), General Relativity (GR), and 95% of the known Universe, namely cosmology's dark sector (Dark Energy (DE) and DM). This paper attempts to connect the dots between some of these alternative ideas as they relate to MOdified Newtonian Gravity (MOND), covariant emergent gravity (CEG), and the fundamental parameters used to fix Natural or Planck units-of-measure. The result is intended to point the way toward a fresh discussion in the directions available for unification of GR with SM while resolving the now more open problems in theoretical physics today.

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I. INTRODUCTION

This paper will present connections between diverse topics related to MOND, Emergent Gravity, CEG, Newton's Gravitational constant (G_N), the Hubble parameter (H_0), along with a notable connection to the Higgs mass (m_H). It will do so in such a way as to point to an alternative theory for the unification of GR with the SM of quantum mechanics (QM).

This section gives a very brief overview of the CEG related theories that support a new look at a new 'more Natural' model of space-time. Please note that rather than attempting to paraphrase the authors, I offer citations and quoted excerpts.

A. MOND

In his 2014 review of "MOND Theory" initially promulgated in 1983, Milgrom[1] presents $a_0 \approx (1.2 \pm 0.2) \times 10^{-8}\text{cm s}^{-2}$. "It has been pointed out from the very advent of MOND[2–4] that this is a cosmologically significant acceleration. We have the near equalities

$$\tilde{a}_0 \equiv 2\pi a_0 \approx cH_0 \approx c^2(\Lambda/3)^{1/2} \tag{1}$$

where H_0 is the Hubble constant, and Λ the observed equivalent of a cosmological constant."

B. Emergent Gravity

In 2016 presenting a_0 as a part of his theory of emergent gravity from 2009, Verlinde suggests[5] "the most important aspect we have to deal with is that de Sitter space has a cosmological horizon. The first indication of the emergent nature of space-time and gravity comes from the laws of black hole thermodynamics [6]. A central role herein is played by the Bekenstein-Hawking entropy [7, 8] and Hawking temperature[9, 10] given by:

$$S = A/4G\hbar \qquad \text{and} \qquad T = \hbar\kappa/2\pi. \tag{2}$$

Hence, it carries a finite entropy and temperature given by (2), where the surface acceleration κ is given in terms of the Hubble parameter H_0 and Hubble scale L by [11]

$$\kappa = cH_0 = c^2/L = a_0 \tag{3}$$

The acceleration scale a_0 will play a particularly important role in this paper."

C. CEG

In several very recent papers[12, 13] Hossenfelder presents a covariant Lagrangian based on Verlinde's 2016 work[5] on emergent gravity.

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"The defining equation of MOND is:

$$\vec{\nabla}\cdot\Big(\mu(|\vec{\nabla}\phi_{\rm MOND}/a_0|)\vec{\nabla}\phi_{\rm MOND}\Big) = 4\pi G\rho\ , \qquad (4)$$

where G is Newton's constant, ρ is the energy density of baryonic matter and $\phi_{\rm MOND}$ is the modified Newtonian potential. The function μ is the interpolation function and a_0 quantifies an acceleration that is the theory's one free parameter."

"From comparison with data one finds that the following relation is approximately correct[14]:

$$2\pi a_0 \approx H_0 \approx \sqrt{\Lambda/3} \qquad (5)$$

where H_0 is the Hubble constant and Λ the cosmological constant. The numerical value is $a_0 \approx 10^{-10}$ m/s^2."

"The defining Lagrangian of CEG is that of matter coupled to gravity and an additional vector field u_μ. In the non-relativistic limit it gives rise to the equation:

$$\vec{\nabla}\cdot\left(\left|\vec{\nabla}\phi\right|\vec{\nabla}\phi\right) \ = \ \frac{2\pi G}{3L}\rho \qquad (6)$$

where L is a constant of dimension length (more about which later), and ϕ is proportional to the absolute value of the vector-field u_μ. "[13] Later, Hassenfelder explicitly relates this to the Hubble length scale (aka. Hubble radius $R_H = c/H_0 = L$) as done by Verlinde[5].

"The free constant L which enters $\tilde{a}_0$ fixes this constant by the following argument, hereafter referred to as 'Verlinde-matching.' The additional force acting on baryonic matter is caused by the change in entanglement entropy induced by the presence of the matter. This change comes about because inserting a baryonic mass into an asymptotic de-Sitter space slightly shifts the de-Sitter horizon, thereby changing the volume inside the horizon. Verlinde then requires that the horizon-shift induced by the presence of baryonic matter is identical to the shift quantified by the new field, which leads to $1/L = \sqrt{\Lambda/3}$ in a universe with $\Omega_\Lambda = 1$ and $\Omega_m = 0$, and $1/L \approx 1.05 \times \sqrt{\Lambda/3}$ in a universe with $\Omega_\Lambda = 0.7$ and $\Omega_m = 0.3$. While this argument lacks rigor, the consequence is that in the non-relativistic limit, CEG with Verlinde-matching has *no* free parameters."

"At first sight, Eq. (6) looks pretty much the same as Eq. (4) except for the different constants. But they are not the same because the scalar ϕ in Eq. (6) is not the gravitational potential as in (4). Instead, this scalar causes an additional force acting on baryons by direct interaction. In CEG the normal gravitational potential $\phi_{\rm N}$ is instead determined, as usual, by

$$\Delta\phi_{\rm N} \ = \ 4\pi G\rho\ . \qquad (7)$$

In CEG now the total acceleration, $g_{\rm tot}$, which acts on baryons comes from the gradient of $\phi + \phi_{\rm N}$, not from the gradient of ϕ alone, as in MOND."

II. A MORE NATURAL MODEL

In eq. (2) of my original paper on the topic[15] circa 1997-2007, I established a definition for a universal acceleration a_U that supported a then recent realization of the acceleration in the expansion of the Universe from type Ia supernovae (SNe Ia) studies[16]. This emerged from a dimensional analysis and the definition of a new unit-of-measure (UoM) using an equivalency found between $\hbar, c, G_N$ and H_0 as a function of time.

This model identifies a very natural unit length which is precisely related to the inverse of the Rydberg Constant (R_∞):

$$l_{unit} = \frac{\alpha}{R_\infty} = \frac{2h}{\alpha m_e c} = \frac{4\pi\hbar}{\alpha m_e c} = 4\pi r_0 \qquad (8)$$

This is twice the circumference of the Bohr model of the atom ($2\pi r_0$), replacing here the traditional a_0 with r_0 in order to avoid confusion with CEG and MOND's use as an acceleration. If this l_{unit} is then related to spin ($\hbar$), it is clear that a fermion of spin $\pm\hbar/2$ would then be precisely the circumference of the Bohr atom. It should be noted that l_{unit} is being defined using the most accurately measured CODATA parameters [17], where $\hbar$ and m_e are calculated using R_∞ known to a standard error of 6.6 ppt or 6.6×10^{-12} and α at 0.7 ppb or 7.0×10^{-10}. This is accomplished using the definition of α and the electron or elementary charge (e) less accurately known to 85 ppb:

$$\hbar = \frac{\Omega_0 e^2}{4\pi\alpha} \qquad (9)$$

So from (8) and (9) with an error twice that of e's giving 170 ppb accuracy to:

$$m_e = \frac{4\pi\hbar R_\infty}{\alpha^2 c} = \frac{\Omega_0 e^2 R_\infty}{\alpha^3 c} = \frac{\mu_0 e^2 R_\infty}{\alpha^3} \qquad (10)$$

Summarizing the new dimensionality relations of time (T), length (L), mass (M), charge (Q), we have:

$$L \ = \ T^2 \qquad (11a)$$
$$M \ = \ L^3T^{-1} = T^5 \qquad (11b)$$
$$Q \ = \ ML^{-1/2} = MT^{-1} = T^4 \qquad (11c)$$

where the dimensional analysis reference L here is not to be confused with the Hubble scale length metric (aka. Hubble Radius $R_H = L$) introduced by Verlinde and Hassenfelder in (3) and (6) respectively.

As in Planck UoM, in this model we have $\hbar/c = 1ML$, such that in the new UoM $\hbar = c\ m_{unit}l_{unit}$ is a quantized angular momentum (spin) with dimensionality of:

$$ML^2T^{-1} = T^8 \qquad (12)$$

which indicates a linkage of QM and GR with E8 and/or an 11D MT space-time with 3 real dimensions of space and 8 dimensions associated with time, but allocated to complex imaginary or possibly compacted space. H_0 is defined using the space metric (a) as a function of time. It can also be defined as a function redshift factor (z) as $a(z)$. Depending on cosmological model, this can give the age of the universe:

$$t_U = a(0)/H_0 \tag{13}$$

This model then has:

$$c = \alpha^{-8} l_{unit}/t_{unit} = 1/(4\pi H_0) = \alpha^{-8} t_{unit} \tag{14}$$
$$H_0 = \alpha^8/(4\pi t_{unit}) = 71.5812\ km/s/Mpc \tag{15}$$

where $\alpha = 1/137.035999164$ is the fine-structure constant. This in turn gives a natural dimensionless universal acceleration:

$$\begin{aligned} a_U &= 4\pi H_0\ c = 1\ Unit\ Acceleration \\ &= 1\ Dimensionless\ Unit \\ &= 87.3928\ Angstroms/s^2 \end{aligned} \tag{16}$$

This acceleration is to be thought of as an inherent aspect of space-time, much like an exponential eternal inflation that accounts for the observed DE from type Ia supernovae (SNe Ia) studies.

For the purposes of this work, the assumption is that these relationships are correct and that the analysis of experimental evidence for the constraints on multiple time varying fundamental parameters will corroborate this. A less dramatic alternative is also offered by defining L=T and a dimensionless c. This alternative has similar dimensionality to that of the traditional Planck UoM, along with its constant fundamental parameters. Unfortunately, it negates several interesting results related to this model's tie to E8 and/or MT. Some of these results can be recovered by instead relating the 8 dimensions of charge to Degrees of Freedom (DoF). Unfortunately, this still leaves open the interpretation for the value of α.

These dimensionality relationships and UoM assignments lead to an equivelency in fundamental parameters to within all most current experimental error:

$$c = \frac{\hbar}{m_{unit} l_{unit}} = \frac{g_c^2}{G_N} = \frac{1}{4\pi H_0} = \alpha^{-8} t_{unit} \tag{17}$$

where $g_c = 1.0659$ is being suggested as a gravitational coupling factor linked to space-time curvature and $G_N = g_c^2/(\alpha^{-8}\ t_{unit}) = 6.67435 \times 10^{-11}\ m^3/(kg\ s^2)$ which is within the current CODATA[17] value of $6.67408(31) \times 10^{-11}\ m^3/(kg\ s^2)$. The new units to MKS conversions in Table I have been generated from (17).

It is interesting to note that the special CODATA recommended adjustment of the fundamental constants in July 2017[18] involves redefining the SI UoM to be based on defined or exact values leaving the measured fundamental parameter standard errors to be based only α as a measured parameter. This fits in nicely with the motivations for this work, since the model now incorporates G_N and H_0 while redefining c, and $\hbar$ in an equality related to unit time based on α^{-8}.

TABLE I: NEW Units to MKS Conversions

NEW Units			MKS Units
1 Unit Time	(t_{unit})	=	0.2758466152348 s
1 Unit Length	(l_{unit})	=	$6.6498369487780 \times 10^{-10}$ m
1 Unit Mass	(m_{unit})	=	$5.2898634492507 \times 10^{-34}$ kg
1 Unit Charge	(q_{unit})	=	$1.5003207449307 \times 10^{-27}$ Coul

Another finding from the new model[19] is the determination of the Higgs mass which is close to the current experimental determination[20] from the CMS and ATLAS detectors in the CERN Large Hadron Collider (LHC). It is shown to be related to $\hbar$:

$$\begin{aligned} m_H &= \sqrt{\sqrt{2}\hbar\ l_{unit} MpV} = \sqrt{\sqrt{2}\hbar\alpha/R_\infty\ MpV} \\ &= \sqrt{\sqrt{2}\ R_\infty\ \alpha^{-5}\ \hbar/c} \\ &= 124.443\ GeV/c^2 \end{aligned} \tag{18}$$

where in the new UoM, a dimensionless unity conversion between $M = L^3/T$ is $MpV = m_{unit} t_{unit}/l_{unit}^3 = 1$ and effectively converts the dimensionality of spin Action$\times L = \hbar\ l_{unit}$ into M^2.

III. THE TROUBLE WITH HUBBLE

A quick note on nomenclature used. It seems Verlinde[5] identifies $a_0 = cH_0$ in (3), whereas Milgrom and Hassenfelder identify it as $\tilde{a}_0 = cH_0 = 2\pi a_0$. While the addition of the factor of 4π in (14-16) is necessary for the equivalency of (17), it is clear that a_U is larger than the MOND based CEG parameter of $\tilde{a}_0$ by that factor of 4π. This makes it larger than CEG a_0 by a factor of $8\pi^2 = 78.95$.

Yet, the precise value of a_0 differs depending on which of the two currently contested Hubble parameters is used. This dichotomy between the low-redshift distance ladder measured value of H_0 is at odds with the non-relativistic high redshift values inferred from CMB Planck data and will be discussed in the next subsection.

In a ΛCDM Universe with $\Omega_\Lambda = 1$ and $\Omega_m = 0$, the Hubble radius $R_H = c/H_0 = c^2/\sqrt{\Lambda/3} = L$. In a Universe with $\Omega_\Lambda = 0.7$ and $\Omega_m = 0.3$, the Hubble radius becomes $R_H = c/(1.05H_0) = c^2/(1.05\sqrt{\Lambda/3}) = L$. Notice that g_c is approximately that of the factor involved in adjusting R_0 in ΛCDM models. This becomes important in resolving the tension in experimental results observed for H_0 and the equivalency of (17).

Low-redshift distance ladder measurements[21] suggest a value of $H_0 = 73.24 \pm 1.7\ km\ s^{-1}\ Mpc^{-1}$, which confirms the value obtained in (16). The inferred value of H_0 from CMB Planck data[22] suggests a value of $H_0 = 67.81 \pm 0.92\ km\ s^{-1}\ Mpc^{-1}$. Assuming $g_c \approx 1.05$ is linked to the shape of the Universe and applying it as a correction factor to the value of H_0 gives the CMB measured result $H_0 = \alpha^8/(g_c 4\pi t_{unit}) = 67.1569\ km\ s^{-1}\ Mpc^{-1}$. This would imply that along with a new understanding of gravity, the ΛCDM Ω_Λ and Ω_m parameters may be involved in explaining the tension between the two measurements.

In addition to the new model presented here, the idea that the tension in H_0 measurements is not simply experimental error, but a reflection of the lack of understanding in the nature of DE, DM, and GR has also been explored in several recent articles[23] [24].

Bolejko suggests[23], "the Simsilun simulation allows for relativistic and nonlinear evolution of cosmic structures, which results with a phenomenon of emerging spatial curvature, where the spatial curvature evolves from spatial flatness of the early universe towards slightly curved present-day universe. This phenomenon speeds up the expansion rate compared to the spatially flat ΛCDM model. The results of the ray-tracing analysis show that the universe which starts with initial conditions consistent with the Planck constraints should have the Hubble constant $H_0 = 72.5 \pm 2.1\ km\ s^{-1}\ Mpc^{-1}$. If the relativistic corrections are not included then the results of the simulation and ray-tracing point towards $H_0 = 68.1 \pm 2.0\ km\ s^{-1}\ Mpc^{-1}$. Thus, the inclusion of relativistic effects that lead to emergence of the spatial curvature can explain why the low-redshift measurements favour higher values compared to high-redshift constraints and alleviate the tension between the CMB and distance ladder measurements of the Hubble constant."

The Large Scale Structure (LSS) σ_8 value is also in tension with Planck CMB. Anand suggests[24] this tension as well as that of H_0 is resolved through a cosmic shear ($\tilde{\eta}$) and/or bulk ($\tilde{\zeta}$) viscosity parameters.

Both of these papers seem to be describing what could be considered an evolving space-time with baryonic matter's quantum entanglement entropy (aka. viscosity) similar to Hassenfelder's description of Verlinde's emergent gravity, which she has given the moniker 'Verlinde-matching' above. The new model presented here then gives an integrative framework for the relationships between the fundamental parameters, QM and GR.

IV. CONCLUSION

This work suggests that DE as a_U and DM as a CEG-like relativistic entropic viscosity are functions of a more fundamental Universal model indicated by the equivalence of (17). The tension in experimental values of H_0 and σ_8 may be resolved by recognizing this model, which accepts a_U as a covariant fundamental dimensionless parameter. It gives a natural accounting for the effects of exponential eternal inflation models.

This model could be described using terms from [25] as a "one (not-so) constant party view". In this model, the fundamental parameters c, $\hbar$, G_N, and H_0 are derived from α. It restores the idea of an absolute reference frame for time which is embedded in the very core of these fundamental parameters of physics, which helps in understanding "the arrow of time", entropy and cosmic inflation. The micro and macro scales of the Universe are limited in magnitude by time in such a way that infinity becomes only a mathematical concept not physically realized as the Universe unfolds.

The Universe itself becomes the clock upon which time can be measured.

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