Theoretically motivated dark electromagnetism as the origin of relativistic MOND

- A status report -

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References: arXiv: 2312.08811 [gr-qc], 2508.10131 [hep-ph]

Milgrom's MOND vs ΛCDM

- Why is there a critical acceleration scale a_0 in galaxy rotation curves?
- Why is this acceleration scale numerically close to the observed cosmic acceleration?
- Modeled by MOND: a new scale invariant theory of dynamics (gravity/inertia) involving a new constant a_0 (besides G_N).

Standard limit $(a_0 \to 0)$: Newtonian limit

Scale invariance : $(t, \mathbf{r}) \to \lambda(t, \mathbf{r})$; deep MOND limit : $(a_0 \to \infty, G_N \to 0)$

Instead of $F = ma$, $F = GMm/r^2$; MOND proposes

$$F = ma^2/a_0, \quad F = GMm/r^2 \qquad \textbf{OR} \qquad F = ma, \quad F \propto \frac{m(GMa_0)^{1/2}}{r}$$

Milgrom's MOND vs ΛCDM

- Because of scale invariance, MOND predicts flat rotation curves (RAR) asymptotically obeying the baryonic Tully-Fisher relation (BTFR).
- MOND shares its scale invariance property with deSitter spacetime.
- ΛCDM does better than MOND in explaining galaxy cluster dynamics, linear growth of perturbations and CMB anisotropies, and BAO.
- Therefore, we seek a hybrid relativistic (MOND + CDM) model which obeys deSitter scale invariance.
- Such a hybrid model should come from a perturbatively renormalizable underlying quantum field theory.
- CDM should dominate at high accelerations; MOND dominates at low accelerations.

An $E_{6L} \times E_{6R}$ theory of unification [arXiv:2206.06911]

- Concurrent with the electroweak symmetry breaking:

$$E_{6L} \to SU(3)_c \times SU(3)_{F,L} \times SU(3)_L \xrightarrow{SU(3)_L} SU(2)_L \times U(1)_Y \xrightarrow{U(1)_Y} U(1)_{em}$$

$$E_{6R} \to SU(3)_{c'} \times SU(3)_{F,R} \times SU(3)_R \xrightarrow{SU(3)_R} SU(2)_R \times U(1)_{Y'} \xrightarrow{U(1)_{Y'}} U(1)_{dem}$$

The RH sector introduces two new unbroken gauge symmetries: strong gravity $SU(3)_{c'}$ and dark electromagnetism $U(1)_{dem}$: $\pm\sqrt{m/\kappa}$

$SU(3)_{F,L}$ & $SU(3)_{F,R}$ are global flavor symmetries [flavor / mass eigenstates]

These, along with $U(1)_{em}$ & $U(1)_{dem}$ explain the observed mass-hierarchy

[arXiv:2508.10131 [hep-ph]]

$SU(2)_R$ when broken, gives rise to GR and also to MOND, as we now see:

GR and MOND from a broken $SU(2)_R$ symmetry

1 Symmetry structure and breaking

Left sector. $E_6^L \to SU(3)_c \times SU(3)_F \times SU(3)_L$ (visible quarks/leptons originate here).

Right sector. $E_6^R \to SU(3)'_c \times SU(3)'_F \times SU(3)_R \to SU(2)_R \times U(1)_{Y'} \to U(1)_{\rm dem}$. The unbroken $U(1)_{\rm dem}$ generator $S_{\rm dem}$ has eigenvalues $s = \pm\sqrt{m/\kappa}$; in the late Universe the $+s$ sector dominates. The $U(1)_{\rm dem}$ Lagrangian is ordinary Maxwell, hence like signs repel; it is *not* the MOND mediator and is kept subleading in late-time dynamics.

2 Gauge gravity from $SU(2)_R$

Let $\omega^i{}_\mu$ be the $SU(2)_R$ connection with curvature $F^i = \mathrm{d}\omega^i + \frac{1}{2}\epsilon^i{}_{jk}\omega^j \wedge \omega^k$. The fundamental seed is BF+constraints:

$$S^R_{\rm BF+cons} = \frac{1}{8\pi G}\int B^i \wedge F^i + \int \lambda_{ij}\, B^i \wedge B^j \;+\; S_{\rm trans}[\mathrm{Higgs}_R], \tag{1}$$

where the algebraic multipliers λ_{ij} enforce the simplicity constraints $B^i = \frac{1}{2}\epsilon^i{}_{jk}e^j \wedge e^k$. After soldering, (1) reduces to *Einstein gravity* for $g_{\mu\nu} = e^I{}_\mu e^J{}_\nu \eta_{IJ}$. No extra propagating fields are added beyond those in E_6^R.

GR and MOND from a broken $SU(2)_R$ symmetry

3 De Sitter IR vacuum and the MOND scale

We impose that the deep IR of the $SU(2)_R$ sector realizes de Sitter kinematics with radius ℓ_{dS}. Scale invariance then selects a single acceleration

$$\boxed{a_0 = \frac{c^2}{\xi\,\ell_{\mathrm{dS}}}} \qquad (\xi = \mathcal{O}(1)). \tag{2}$$

4 Metric-only IR functional and $r_{\rm eff}$

We add to (1) a *metric-only* IR piece fixed by dS scaling:

$$S_{\rm IR}[g] = \frac{a_0^2}{16\pi G}\int d^4x\,\sqrt{-g}\,F\!\left(\frac{I[g]}{a_0^2}\right), \qquad I[g] \equiv a_\mu a^\mu, \quad a_\mu \equiv \nabla_\mu \ln N,\;\; N \equiv \sqrt{-g_{00}}. \tag{3}$$

In the static weak-field limit $g_{00} = -(1+2\Phi)$, so $I \to |\nabla\Phi|^2$. As a geometric bookkeeping of the cosmological tie we use the *effective distance* (R proper distance in FRW, $R_H = a/\dot a$):

$$r_{\rm eff}^2 = R(t)\,R_H(t), \tag{4}$$

and evaluate static spatial derivatives w.r.t. $r_{\rm eff}$. In deep MOND we freeze $R_H \to R_{H0}$ so that a_0 is epoch-independent in galaxies, while the background retains dS kinematics.

Uniqueness (asymptotics). dS scale invariance and GR matching fix

$$F(y) \to y \quad (y \gg 1), \qquad F(y) \to \tfrac{2}{3}y^{3/2} \quad (y \ll 1). \tag{5}$$

An exactly integrable choice consistent with (5) and the interpolating function $\mu(x) = x/(1+x)$ is

$$F(y) = y - 2\sqrt{y} + 2\ln(1+\sqrt{y})\,, \tag{6}$$

which has no tunable parameter beyond a_0.

5 Field equations and static MOND

Varying $S^R_{\mathrm{BF+cons}} + S_{\mathrm{IR}} + S_{\mathrm{dem}} + S_{\mathrm{matter}}$ gives

$$G_{\mu\nu} + \Xi_{\mu\nu}[g; F, a_0] = 8\pi G\,(T^{\mathrm{matter}}_{\mu\nu} + T^{\mathrm{dem}}_{\mu\nu}). \tag{7}$$

With $y = I/a_0^2$ and $F_y \equiv \mathrm{d}F/\mathrm{d}y$ one finds (schematically)

$$\Xi_{\mu\nu} = \frac{a_0^2}{2}\Big[(F - 2yF_y)g_{\mu\nu} + 2F_y a_\mu a_\nu\Big] - a_0^2\Big[\nabla_{(\mu}(F_y a_{\nu)}) - g_{\mu\nu}\nabla_\alpha(F_y a^\alpha)\Big]. \tag{8}$$

The static weak-field limit yields the Bekenstein–Milgrom equation written with r_{eff}:

$$\nabla_{\mathrm{eff}} \cdot \Big[\mu\Big(\frac{|\nabla_{\mathrm{eff}}\Phi|}{a_0}\Big)\nabla_{\mathrm{eff}}\Phi\Big] = 4\pi G\rho, \qquad \mu(x) = F'(x^2). \tag{9}$$

For spherical symmetry one may use the algebraic map

$$g(r) = \frac{1}{2}\left[g_N(r) + \sqrt{g_N^2(r) + 4a_0\, g_N(r)}\right], \qquad g_N = \frac{GM_N(<r)}{r^2}, \tag{10}$$

which immediately gives the baryonic Tully–Fisher relation $v^4 = Ga_0M_b$ in the deep-MOND regime.

6 FRW background and perturbations

In cosmic time $N = 1 \Rightarrow a_\mu = 0$, so $S_{\rm IR}$ *does not* alter the homogeneous background:

$$H^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda_{\rm eff}}{3}, \qquad \Lambda_{\rm eff} = \frac{3c^2}{\ell_{\rm dS}^2} = \frac{3\xi^2 a_0^2}{c^2}. \tag{11}$$

Perturb in Newtonian gauge $ds^2 = -(1+2\Phi)dt^2 + a^2(1-2\Psi)d\boldsymbol{x}^2$. In the quasi-static regime there is *no slip* ($\Psi = \Phi$) and the Poisson closure reads

$$-k^2\Phi = 4\pi G a^2\, \mu_{\rm cos}(k,a)\, \delta\rho, \qquad \mu_{\rm cos}(k,a) \simeq 1 + \frac{1}{1+(k_\star/k)^p}\,\frac{g_N}{a_0}, \quad k_\star = \alpha\, aH, \tag{12}$$

with $(\alpha, p) \sim (3, 4)$ implementing the horizon taper. Matter growth obeys

$$\ddot{\delta} + 2H\dot{\delta} - 4\pi G\, \mu_{\rm cos}\, \bar{\rho}\, \delta = 0. \tag{13}$$

A useful approximation is $f \equiv \mathrm{d}\ln D/\mathrm{d}\ln a \simeq \Omega_m^\gamma$ with $\gamma \simeq 0.55 - 0.05[\mu_{\rm cos}(k,a) - 1]$ on subhorizon scales.

7 Why MOND+χ_R is superior to pure MOND

- **CMB & BAO:** primary peaks at $z \sim 1100$ require a pressureless component unless recombination physics is altered.
- **Clusters:** MOND reduces but does not remove the mass deficit; a collisionless component fits cores and mergers.
- **LSS:** MOND enhances late growth (good for early massive galaxies) but a cold component is needed for BAO and large-scale power.

We keep one minimal, E_6^R-native collisionless species *without* spoiling galaxy MOND.

8 A right-handed cold component from E_6^R

In trinification, one family of the **27** contains $L_R \sim (1, \bar{3}', 3_R)$ under $SU(3)'_c \times SU(3)'_F \times SU(3)_R$. After $SU(3)_{F,R} \to SU(2)_{F,R} \times U(1)$ there is an $(1,1)$ SM singlet χ_R with $Y'(\chi_R) = T_{3R}(\chi_R) = 0$, hence $Q_{\rm dem}(\chi_R) = 0$ (no dark-electromagnetic force). A Dirac/Majorana mass $m_\chi \simeq y_\chi v_R$ follows from the same RH Higgs that breaks $SU(3)_R$, with v_R few–tens of TeV $\Rightarrow m_\chi \sim 10^2$–$10^3$ GeV for $y_\chi = \mathcal{O}(0.1$–$1)$. Annihilation via heavy Z_R/W_R gives the correct relic for $M_{Z_R}/g_R = \mathcal{O}(10\ \text{TeV})$; direct detection is suppressed by small L–R mixings, consistent with current bounds.

Quantitative coexistence prior (for RCs). Impose inside $r_M = \sqrt{GM_b/a_0}$

$$\boxed{\frac{g_{N,\chi}}{g_{N,b}} \le \varepsilon \quad (r \in [2,4]R_d), \quad \varepsilon \simeq 0.1\text{–}0.2} \qquad \Longleftrightarrow \qquad M_\chi(<r_M) \le \varepsilon\, M_b(<r_M). \tag{14}$$

This keeps galaxies MOND-dominated while allowing a diffuse/cored χ_R halo for clusters and the CMB.

9 Analytic expectations for LSS and CMB in the hybrid

Linear growth

For subhorizon $k \gg k_\star$ and epochs with typical accelerations below a_0, take $\mu_{\rm cos} \approx 1 + \epsilon(a)$ with $\epsilon \lesssim \mathcal{O}(0.1)$. Solving (13) gives $D(a) \approx D_{\Lambda\rm CDM}(a) \exp\left[\frac{3}{5}\int \epsilon(a)\Omega_m(a) \mathrm{d}\ln a\right]$, so D is enhanced by a few percent to $\sim$10% by $z \sim 1$ (scale-dependent via $k_\star$).

CMB anisotropy and lensing

Primary anisotropies (last scattering) are GR-like. The change is late-time: (i) low-ℓ TT gets a positive ISW shift from $\dot{\Phi} \neq 0$ as growth is enhanced; (ii) lensing potential $C_L^{\phi\phi}$ increases at the percent level due to the larger $D(a)$ along the line of sight. These features match the CLASS runs (TT suppression at high ℓ from added smoothing; low-ℓ enhancement).

- Clusters, Spirals, Dwarfs/LSB : work in progress.

In preparation: *General Relativity and Relativistic MOND from broken* $SU(2)_R \times U(1)_{Y'}$

THANK YOU FOR YOUR ATTENTION!