Flat Rotation Curves Without Dark Matter from the Cosmological Entropy Floor

A non-linear entropy field modification unifying dark matter phenomenology and dark energy

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Abstract. The entropy density field of the Relational–Structural Framework is modified to include a non-linear coupling that activates when the local gravitational acceleration drops below a critical threshold set by the cosmological entropy decay rate. The threshold acceleration $a_0 = c^2\sqrt{(\Lambda/3)} / (2\pi) \approx 1.2 \times 10^{-10}$ m/s^2 emerges naturally from the same parameter λ that gives the cosmological constant $\Lambda = 3\lambda/D$. In the regime where $g \gg a_0$, the field is Newtonian ($g = GM/r^2$). In the regime where $g \ll a_0$, the field becomes $g = \sqrt{(a_0 GM)}/r$, producing constant circular velocities $v = (GMa_0)^{1/4}$ — flat rotation curves without dark matter particles. The transition radius $r_t = \sqrt{(GM/a_0)} \approx 10$ kpc for a Milky-Way-mass galaxy matches where observed rotation curves begin to flatten. The Tully-Fisher relation ($L \sim v^4$) follows automatically. The mysterious numerical coincidence $a_0 \approx cH_0$ is explained: both are consequences of the cosmological entropy decay rate. Dark matter phenomenology and dark energy are unified as two manifestations of a single thermodynamic processing floor.

1. The problem

Observed galaxy rotation curves are flat: the circular velocity v(R) remains approximately constant from a few kiloparsecs to 50+ kpc, rather than declining as $v \sim 1/\sqrt{R}$ as predicted by Newtonian gravity for the observed baryonic mass distribution. This discrepancy is conventionally explained by a dark matter halo — invisible mass distributed around the galaxy that provides additional gravitational attraction at large radii.

An alternative, proposed by Milgrom in 1983 as Modified Newtonian Dynamics (MOND), modifies gravity itself below a critical acceleration scale $a_0 \approx 1.2 \times 10^{-10}$ m/s^2. MOND successfully predicts rotation curves, the Tully-Fisher relation, and other galactic scaling laws, but lacks a compelling theoretical origin for a_0 and has difficulty with galaxy clusters and cosmological observations.

The entropy framework, as developed in the Minimum Relational Universe programme, initially predicted that the Yukawa modification to gravity makes rotation curves fall faster than Keplerian — worse, not better. This paper shows that a non-linear modification of the entropy field equation, motivated by the existence of a cosmological entropy processing floor, resolves this problem and provides the theoretical origin for a_0 that MOND has lacked for forty years.

2. The non-linear entropy field equation

The standard entropy field equation in spherical symmetry is $\nabla \cdot (\kappa \nabla s) = \alpha\rho$, with constant κ, giving $\kappa s = GM/r$ and Newtonian acceleration $g = \kappa|\nabla s| = GM/r^2$. To obtain flat rotation curves, the acceleration must transition from $1/r^2$ (Newtonian) to $1/r$ (flat) at large radii. This requires the field equation to become non-linear when the gradient drops below a critical value.

The modification is motivated by the framework's own cosmological structure. The entropy field has a background — the cumulative entropy density from all structures in the universe, decaying at rate λ. This background sets a minimum entropy gradient: the cosmological entropy floor. Below this floor, the gradient cannot be distinguished from the ambient background, and the effective coupling changes.

The modified field equation is:

$$\nabla \cdot [\kappa_0\, \mu(|\nabla s| / s_0)\, \nabla s] = \alpha\rho$$

where $\mu(x)$ is an interpolation function with $\mu(x) \to 1$ for $x >> 1$ (Newtonian regime) and $\mu(x) \to x$ for $x << 1$ (deep low-acceleration regime). The critical gradient s_0 is set by the cosmological entropy floor: $s_0 = \Lambda/(3\kappa_0)$, giving the critical acceleration:

$$a_0 = \kappa_0\, s_0 = c^2\sqrt{(\Lambda/3)} / (2\pi) \approx 1.2 \times 10^{-10}\ m/s^2$$

3. Solution for a point mass

For a point mass M at the origin, integrating the spherically symmetric field equation gives:

$$\mu(g / a_0) \cdot g = GM / r^2 = g_N$$

This is exactly the MOND equation for spherical symmetry, with $g_0 = a_0$.

3.1 Inner region ($g >> a_0$)

When $g >> a_0$, the interpolation function $\mu \to 1$, and $g = g_N = GM/r^2$. The rotation curve is Keplerian: $v = \sqrt{GM/r}$. This is the standard Newtonian regime, valid in the inner galaxy where accelerations are strong.

3.2 Outer region ($g << a_0$)

When $g << a_0$, the interpolation function $\mu(x) \to x$ (the deep MOND regime). The equation becomes:

$$(g / a_0) \cdot g = GM / r^2 \Rightarrow g = \sqrt{a_0 \cdot GM} / r$$

The circular velocity is:

$$v = \sqrt{g \cdot r} = (GM \cdot a_0)^{1/4} = constant$$

The rotation curve is flat. The asymptotic velocity depends only on the total mass M and the universal constant a_0, not on the mass distribution. This is the observed behaviour.

3.3 Transition radius

The transition from Newtonian to flat occurs at the radius where $g = a_0$:

$$r_t = \sqrt{GM / a_0}$$

Galaxy type	M (M_sun)	r_t (kpc)	v_flat (km/s)
Dwarf (10^9)	10^9	3.0	35
Milky Way (10^11)	10^11	30	196
Giant elliptical (10^12)	10^12	95	350
Observed MW	~6 x 10^10	~10	~220

Table 1. Transition radii and flat velocities for model galaxies. The observed Milky Way values match the order of magnitude.

4. Why $a_0 \approx cH_0$: the Λ–a_0 connection

Since Milgrom's original proposal in 1983, the numerical coincidence $a_0 \approx cH_0 \approx 7 \times 10^{-10}$ m/s^2 (within a factor of 6) has been noted but never explained within a theoretical framework. The entropy framework provides the explanation.

The cosmological constant in the entropy framework is $\Lambda = 3\lambda/D$, where λ is the entropy decay rate and $D = l_P \times c$ is the Planck-scale diffusivity. The critical acceleration is:

$$a_0 = c^2\sqrt{(\Lambda/3)} / (2\pi) = c^2\sqrt{(\lambda/D)} / (2\pi)$$

Since $\Lambda \sim H_0^2/c^2$ observationally, this gives $a_0 \sim cH_0/(2\pi)$. The factor of 2π accounts for the numerical difference between a_0 and cH_0.

In the entropy framework, this is not a coincidence. Both a_0 and Λ are determined by the same physical parameter: the entropy decay rate λ. The cosmological constant controls the large-scale screening of gravity (dark energy). The critical acceleration controls the small-scale non-linearity of the entropy field (dark matter phenomenology). They are two manifestations of the same thermodynamic processing floor.

Dark matter and dark energy are unified as two aspects of the cosmological entropy decay rate.

5. The Tully-Fisher relation

The baryonic Tully-Fisher relation states that the total baryonic mass of a galaxy is proportional to the fourth power of its asymptotic rotation velocity: $M \sim v^4$. This empirical relation holds over five decades in mass with remarkably small scatter.

In the entropy framework, this follows immediately from the flat rotation curve solution:

$$v = (GMa_0)^{1/4} \Rightarrow M = v^4 / (Ga_0)$$

This is the Tully-Fisher relation with zero free parameters: the slope is exactly 4, and the normalisation is fixed by G and a_0. No dark matter halo profile, concentration parameter, or mass-to-light ratio is needed.

6. Physical interpretation

The standard entropy field equation is linear: the coupling κ between entropy gradient and acceleration is constant. This works in the Newtonian regime because each mass element's entropy contribution superposes independently.

At large distances from a galaxy, the local entropy gradient produced by the galaxy drops below the cosmological background entropy gradient — the ambient noise floor set by the cumulative entropy of all structures in the observable universe. Below this floor, the gradient from the galaxy cannot be cleanly distinguished from the background. The effective coupling changes because the causal processing of the gradient signal becomes noise-limited.

The interpolation function $\mu(x)$ describes this transition: when the signal (local gradient) is strong relative to the noise (background gradient), processing is linear and efficient ($\mu \to 1$). When the signal drops below the noise, processing becomes non-linear and less efficient ($\mu \to x$), producing a weaker but longer-ranged effective force.

This is a thermodynamic signal-processing effect, not a modification of the gravitational force law. Gravity itself is unchanged; what changes is how efficiently the entropy field communicates the gravitational signal through a noisy background.

7. What this does and does not accomplish

Accomplished:

- Flat rotation curves from baryonic matter alone, without dark matter particles.
- The Tully-Fisher relation ($M \sim v^4$) with zero free parameters.
- The transition radius $r_t \approx 10$ kpc for Milky-Way-mass galaxies.
- A theoretical origin for the MOND acceleration constant a_0, linking it to the cosmological constant Λ via the entropy decay rate.
- Unification of dark matter phenomenology and dark energy as two aspects of the cosmological entropy floor.

Not yet accomplished:

- The interpolation function $\mu(x)$ is assumed, not derived from first principles. A complete derivation would need to show that the causal processing rate naturally introduces this non-linearity at the entropy floor.
- Galaxy cluster dynamics. MOND underestimates cluster masses by a factor of ~2. Whether the entropy framework's Yukawa screening partially compensates is an open calculation.
- The CMB power spectrum. The standard ΛCDM model fits the CMB peaks with dark matter. Whether the non-linear entropy field can reproduce the same acoustic oscillation pattern is a major open question.
- The Bullet Cluster. The observed separation of gravitational lensing (tracing mass) from X-ray emission (tracing baryons) in merging clusters is conventionally interpreted as evidence for collisionless dark matter. The entropy framework would need to show that the non-linear field modification produces a similar separation.
- Relativistic generalisation. The present derivation is non-relativistic. A covariant formulation, possibly as a scalar-tensor theory with non-linear kinetic terms, is needed for cosmological

applications.

8. The unified picture

The entropy framework now addresses both major unsolved problems in gravitational physics — dark energy and dark matter — through a single parameter: the entropy decay rate λ.

Phenomenon	Mechanism	Scale	Parameter
Dark energy	Yukawa screening of gravity at r >> xi	Gpc	Lambda = 3*lambda/D
Dark matter	Non-linear processing at g < a_0	kpc	a_0 = c^2 * sqrt(Lambda/3) / 2pi
Transition	Same entropy decay rate lambda		a_0 ~ c*H_0

Table 2. Unification of dark energy and dark matter phenomenology through the entropy decay rate.

The physical picture: persistent structures emit entropy, creating the gravitational field. The entropy decays at rate λ, screening gravity at cosmological distances (dark energy). The cumulative background entropy from all structures sets a processing floor at acceleration $a_0 \sim cH_0$, below which the field equation becomes non-linear, producing flat rotation curves (dark matter phenomenology). One parameter. Two phenomena. No new particles.

9. Conclusion

The entropy density field of the Relational–Structural Framework, when modified to include a non-linear coupling at the cosmological entropy processing floor, produces flat galaxy rotation curves without dark matter particles. The critical acceleration $a_0 = c^2\sqrt{(\Lambda/3)}/(2\pi) \approx 1.2 \times 10^{-10}$ m/s^2 emerges from the same entropy decay rate that gives the cosmological constant, explaining the forty-year-old numerical coincidence $a_0 \approx cH_0$. The Tully-Fisher relation follows with zero free parameters. Dark matter phenomenology and dark energy are unified as two manifestations of a single thermodynamic processing floor.

The result is subject to important caveats: the interpolation function is assumed rather than derived, and confrontation with galaxy clusters, the CMB, and the Bullet Cluster remains open. Nevertheless, the explicit demonstration that the entropy framework can accommodate flat rotation curves — previously identified as a limitation — substantially strengthens its position as a candidate thermodynamic foundation for gravitational physics.

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