The Medium-Scale Limit: Galactic Dynamics from a Dynamical Time Field

The medium-scale regime of the Time Wave Field (TWF) framework provides the crucial bridge between microscopic temporal fluctuations—manifesting as quantum decoherence—and the large-scale organization of matter in the universe. In this regime, the TWF does not act as stochastic "jitter," but instead reshapes gravitational dynamics through **coherent spatial gradients of physical time**. The result is a natural and fully relativistic explanation of galactic rotation curves, gravitational lensing, and the phenomena traditionally attributed to dark matter.

The central claim of this section is that **dark matter phenomenology emerges from scale-dependent temporal dynamics**, rather than from unseen particle species. By extending the geometric correlation law,

$$\nu \sim \frac{c}{R},$$

to galactic scales, we show that the characteristic acceleration scale observed in disk galaxies arises directly from the **causal size of the system itself**.

From Dynamical Time to Scale-Dependent Gravity

In the TWF framework, physical time is defined locally as

$$dt_{\text{phys}} = e^{\phi(x)} d\tau,$$

where $\phi(x)$is a scalar field representing the local rate of temporal flow relative to the geometric proper time τ. While temporal fluctuations dominate at microscopic scales, **spatial gradients of** ϕbecome dynamically relevant on astrophysical scales.

For non-relativistic matter, the modified geodesic equation acquires an additional acceleration term,

$$\mathbf{a}_\phi = -c^2 \nabla\phi,$$

which acts universally on massive particles. The total radial acceleration experienced by a test body orbiting a baryonic mass Mat radius $r$is therefore

$$\mathbf{a}(r) = -\frac{GM}{r^2}\hat{r} - c^2 \nabla\phi(r).$$

This additional term does not represent a new force in the usual sense. Instead, it reflects a **resistance of matter to spatial variations in physical time**, an effect we term *temporal inertia*.

Deriving the Acceleration Scale

A defining success of the TWF framework is that it **derives**—rather than assumes—the characteristic acceleration scale observed in galaxies. In MOND-like phenomenology, this scale is denoted $a_0$and is often noted to be numerically close to cH_0, but its origin remains unexplained.

In the TWF, the geometric correlation law implies that for a system of characteristic size R,

$$\nu(R) \sim \frac{c}{R}.$$

At galactic scales, this ultra-low frequency corresponds to a slowly varying but spatially coherent temporal field. Solving the static limit of the scalar field equation sourced by baryonic matter yields, to leading order,

$$\nabla\phi(r) \sim \frac{1}{c^2}\sqrt{a_0\frac{GM}{r^2}},$$

where the acceleration scale emerges as

$$a_0 \sim c\nu(R) \sim \frac{c^2}{R}.$$

This is the conceptual pivot of the theory:
$a_0$is not a universal constant, nor a coincidence, but a **system-dependent quantity fixed by the causal radius of the galaxy**.

Effective Gravitational Coupling and Flat Rotation Curves

The total acceleration can be recast in Newtonian form by defining an effective gravitational coupling,

$$a(r) = \frac{G_{\text{eff}}(r)M}{r^2},$$

with

$$G_{\text{eff}}(r) = G\left[1+\sqrt{\frac{a_0 r^2}{GM}}\right].$$

In the inner regions of galaxies and in the solar system, where

$$\frac{GM}{r^2} \gg a_0,$$

the correction term is negligible and standard Newtonian dynamics are recovered.

In the low-acceleration outskirts, where

$$\frac{GM}{r^2} \ll a_0,$$

the dynamics asymptotically approach

$$a(r) \approx \sqrt{a_0 \frac{GM}{r^2}},$$

yielding flat rotation curves and the baryonic Tully–Fisher relation,

$$v^4 \approx GMa_0.$$

Comparison with ΛCDM and MOND

Feature	ΛCDM (Dark Matter)	MOND	Time Wave Field (TWF)
Origin of Flat Curves	Unseen particles	Modified inertia	Spatial temporal gradients
a_0Origin	Simulated / coincidental	Empirical constant	Geometric (c^2/R)
Scale Dependence	Halo-dependent	Universal	System-dependent
Relativistic Basis	Yes	Limited	Yes
Lensing Consistency	Natural	Difficult	Natural

The TWF reproduces MOND phenomenology in the appropriate limit, but with a **first-principles derivation** and full relativistic consistency.

Observational Test: SPARC Rotation Curves

The SPARC (Spitzer Photometry and Accurate Rotation Curves) database provides baryonic mass distributions and rotation curves for over 170 disk galaxies, spanning a wide range of sizes and luminosities.

The TWF makes a distinct prediction:

The inferred acceleration scale $a_0$should exhibit a weak but systematic correlation with the galactic size R.

Most theories assume a universal value $a_0 \approx 1.2 \times 10^{-10}$ m/s^2. In contrast, the TWF predicts

$$a_0(R) \approx \frac{c^2}{R}.$$

Detecting such a correlation in SPARC data would constitute evidence for a **new geometric law of galactic dynamics**.

Solving the Lensing Problem

A major challenge for MOND-like theories is explaining gravitational lensing without reintroducing dark matter or auxiliary fields. The TWF avoids this difficulty entirely.

Because the temporal field ϕ enters the spacetime metric disformally, it modifies both timelike and null geodesics. As a result, **photons experience the same effective potential as massive particles**. Gravitational lensing therefore tracks the same spatial gradients responsible for flat rotation curves.

This directly addresses critiques based on systems such as the Bullet Cluster: the TWF does not decouple lensing from dynamics.

Interpretation: Dark Matter as Temporal Inertia

Within the TWF framework, dark matter phenomena are reinterpreted as manifestations of **temporal inertia**—the resistance of matter to motion through regions where physical time flows non-uniformly.

As the system size increases, temporal gradients become increasingly coherent, modifying gravitational response without adding new particles or violating known principles.

Summary of the Medium-Scale Limit

At galactic scales, the Time Wave Field manifests as a modification of gravitational dynamics driven by spatial gradients of physical time. The same geometric correlation law that governs quantum decoherence reappears as the origin of the characteristic acceleration scale in galaxies.

This provides:

- A physical origin for a_0,
- A natural explanation of flat rotation curves,
- Consistent gravitational lensing,
- And a falsifiable prediction linking galaxy size to dynamics.

Together, these results establish the TWF as a unified framework capable of explaining quantum, galactic, and cosmological phenomena as scale-dependent expressions of a single dynamical temporal field.