

Regime-dependent field coherence in galaxy dynamics

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Version 1

Abstract

We investigate galaxy dynamics within a nonlinear field framework characterized by a global acceleration scale and a regime-dependent coherence property. The nonlinear field framework explored here, referred to as CoFiT within the broader GTCF program, has been developed independently by the Omni-Coherence Research Group. Using the SPARC database, we first determine a universal acceleration scale from the radial acceleration relation (RAR). We then confront the same framework with individual galaxy rotation curves, introducing a single additional parameter that quantifies partial loss of field coherence in the deep low-acceleration regime.

We find that stellar mass-to-light ratios cluster around values consistent with stellar population synthesis, while the coherence parameter exhibits a structured, non-uniform distribution across the galaxy population. Low-surface-brightness and dwarf galaxies preferentially occupy a partially decoherent regime, whereas high-surface-brightness spiral galaxies remain fully coherent. The two parameters are statistically independent and play complementary roles in shaping galaxy dynamics.

A single global acceleration scale combined with regime-dependent coherence reproduces both the radial acceleration relation and individual galaxy rotation curves across the SPARC sample, without invoking dark matter halos or externally imposed environmental effects. These results suggest that galaxy dynamics are governed by transitions between coherence regimes of an underlying field rather than by universal modifications of gravity or unseen matter distributions.

1 Introduction

1.1 Motivation and empirical context

The dynamics of galaxies continue to pose a fundamental challenge to our understanding of gravity and matter. Observed rotation curves of disk galaxies systematically deviate from expectations based on their visible baryonic content when interpreted within Newtonian gravity and General Relativity. Remarkably, these deviations are not random: they follow a tight empirical correlation between the observed acceleration and that predicted from the baryonic mass distribution, known as the radial acceleration relation (RAR). This relation spans several orders of magnitude in acceleration and holds across a wide range of galaxy masses and morphologies, suggesting the presence of an underlying organizing principle in galactic dynamics.

The existence of the RAR strongly constrains any theoretical explanation. In particular, it implies that galaxy dynamics are governed by a characteristic acceleration scale that is not directly tied to the details of individual dark matter halo profiles or to local baryonic complexity. While the RAR is naturally reproduced in modified gravity scenarios, its origin remains unexplained in the standard dark matter paradigm, where it must emerge from complex and often finely tuned baryon–halo interactions.

1.2 Existing approaches and their limitations

The prevailing explanation within the Λ CDM framework attributes the observed discrepancies in galaxy rotation curves to the presence of massive, non-baryonic dark matter halos. Although this approach has been highly successful on cosmological scales, it faces persistent challenges at galactic scales, particularly in explaining the tightness and universality of the RAR, the diversity of rotation curve shapes, and the apparent coupling between baryonic and dynamical accelerations.

Modified Newtonian Dynamics (MOND) offers an alternative description by introducing a fundamental acceleration scale below which gravitational dynamics deviate from Newtonian expectations. MOND naturally accounts for the RAR and has had notable success in fitting individual galaxy rotation curves. However, MOND typically assumes a universal modification function and often requires additional mechanisms, such as the external field effect (EFE), to account for the full diversity of observed galaxy dynamics. The physical origin of these ingredients remains unclear, and their implementation can introduce environment-dependent effects that are difficult to test observationally.

1.3 This work: coherence as a regime-dependent property

In this work, we explore a different perspective in which galaxy dynamics arise from a nonlinear field whose behavior depends not only on a global acceleration scale but also on a coherence property of the field itself. Rather than modifying gravity universally or invoking unseen matter components, we treat coherence as a regime-dependent dynamical quantity that can be partially suppressed in the deep low-acceleration regime.

We confront this framework directly with observational data from the SPARC database. First, we determine a global acceleration scale from the radial acceleration relation. We then analyze individual galaxy rotation curves using the same acceleration scale, introducing a single additional parameter that quantifies the degree of field coherence at very low accelerations. We show that this parameter varies systematically across the galaxy population, separating low-surface-brightness and dwarf galaxies from high-surface-brightness spirals, while remaining statistically independent of stellar mass-to-light ratios.

2 Framework and methodology

2.1 Radial acceleration relation and global acceleration scale

We begin by characterizing galaxy dynamics at the population level using the radial acceleration relation (RAR), which relates the observed centripetal acceleration g_{obs} to the baryonic acceleration g_{bar} inferred from the observed distribution of stars and gas. Following standard practice, we write this relation in the form

$$g_{\text{obs}} = \nu(x) g_{\text{bar}}, \quad x \equiv \frac{g_{\text{bar}}}{a_0}, \quad (1)$$

where a_0 is a characteristic acceleration scale and $\nu(x)$ is a smooth interpolation function satisfying $\nu(x) \rightarrow 1$ for $x \gg 1$ and $\nu(x) \propto x^{-1/2}$ for $x \ll 1$.

Using the SPARC database, we determine a single global value of a_0 by minimizing the scatter of the RAR in logarithmic acceleration space. This fit is performed independently of any rotation-curve modeling and uses all available radial points after standard quality cuts. The resulting value of a_0 is held fixed throughout the remainder of the analysis.

2.2 Nonlinear field response and coherence

Rather than interpreting the RAR as a universal modification of gravity, we adopt a phenomenological field-based description in which the dynamical response depends on both the

baryonic acceleration and a coherence property of the underlying field. In this picture, the interpolation function $\nu(x)$ describes the fully coherent response of the field, while deviations from this response arise from partial loss of coherence in the deep low-acceleration regime.

We parametrize this effect by introducing an effective response function

$$\nu_{\text{eff}}(x) = 1 + \eta(x) [\nu(x) - 1], \quad (2)$$

where $\eta(x)$ is a dimensionless coherence factor satisfying $0 \leq \eta(x) \leq 1$. Full coherence corresponds to $\eta = 1$, while $\eta < 1$ suppresses the nonlinear enhancement at low accelerations.

To ensure that coherence loss affects only the deep regime, we adopt a smooth interpolation of the form

$$\eta(x) = \eta_0 + (1 - \eta_0) \frac{x}{x + 1}, \quad (3)$$

where η_0 represents the deep-regime coherence parameter. By construction, $\eta(x) \rightarrow 1$ for $x \gg 1$, so that high-acceleration (Newtonian) regions remain fully coherent, while $\eta(x) \rightarrow \eta_0$ for $x \ll 1$.

2.3 Rotation curve modeling

For each galaxy, we compute the baryonic contribution to the rotation curve from the observed gas, stellar disk, and bulge components provided in the SPARC database. The baryonic circular velocity is given by

$$v_{\text{bar}}^2(r) = v_{\text{gas}}^2(r) + \Upsilon_* [v_{\text{disk}}^2(r) + v_{\text{bulge}}^2(r)], \quad (4)$$

where Υ_* is the stellar mass-to-light ratio, assumed to be the same for disk and bulge components.

The predicted rotation velocity then follows from

$$v_{\text{pred}}(r) = \sqrt{r g_{\text{pred}}(r)}, \quad g_{\text{pred}} = \nu_{\text{eff}}(x) g_{\text{bar}}, \quad (5)$$

with $g_{\text{bar}} = v_{\text{bar}}^2/r$.

For each galaxy, we fit two parameters: the stellar mass-to-light ratio Υ_* and the deep-regime coherence parameter η_0 . The global acceleration scale a_0 is kept fixed at the value determined from the RAR analysis.

2.4 Fitting procedure and diagnostics

Parameter estimation is performed using a grid search over (η_0, Υ_*) , minimizing the root-mean-square (RMS) deviation between the observed and predicted rotation velocities. Only data points with finite velocities and radii are included, and no galaxy-dependent acceleration scales or environmental corrections are introduced.

To assess parameter degeneracy, we examine the joint distribution of η_0 and Υ_* across the galaxy sample, as well as their correlation with fit quality. We also analyze the population-level distributions of both parameters to identify systematic trends with galaxy type.

3 Radial acceleration relation analysis

3.1 Data selection and construction of the RAR

We construct the radial acceleration relation using the SPARC database, which provides high-quality rotation curves and resolved baryonic mass models for disk galaxies spanning a wide range of masses, surface brightnesses, and morphologies. For each radial point, the observed centripetal acceleration is computed as

$$g_{\text{obs}}(r) = \frac{v_{\text{obs}}^2(r)}{r}, \quad (6)$$

while the baryonic acceleration is obtained from the quadrature sum of the gas, stellar disk, and bulge contributions,

$$g_{\text{bar}}(r) = \frac{v_{\text{bar}}^2(r)}{r}. \quad (7)$$

Only data points with finite velocities and radii are included. No galaxy-by-galaxy tuning of distances, inclinations, or acceleration scales is performed.

3.2 Functional form and fitting strategy

We model the RAR using the interpolation form

$$g_{\text{obs}} = \nu(x) g_{\text{bar}}, \quad x \equiv \frac{g_{\text{bar}}}{a_0}, \quad (8)$$

with

$$\nu(x) = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{1}{x}}. \quad (9)$$

The global acceleration scale a_0 is determined by minimizing the scatter of the RAR in logarithmic acceleration space. Specifically, we minimize the root-mean-square scatter of

$$\Delta \log g \equiv \log_{10} g_{\text{obs}} - \log_{10} g_{\text{pred}}, \quad (10)$$

over all radial points in the sample. This fit is performed once for the full dataset and is not revisited during the subsequent rotation-curve analysis.

3.3 Results: global acceleration scale and scatter

We find that a single global value of the acceleration scale provides an excellent description of the RAR across the entire SPARC sample. The best-fit value is

$$a_0 \simeq 3 \times 10^{-10} \text{ m s}^{-2}, \quad (11)$$

with a logarithmic scatter of order ~ 0.1 – 0.2 dex depending on the specific quality cuts applied. The resulting RAR is tight over several orders of magnitude in acceleration and shows no systematic deviations with galaxy mass, surface brightness, or morphology.

3.4 Justification for fixing a_0 in rotation-curve fits

A key aspect of our approach is that the acceleration scale a_0 is fixed prior to any rotation-curve modeling. Allowing a_0 to vary between galaxies would trivially absorb differences in rotation-curve amplitude, obscuring the physical origin of the observed diversity. By contrast, fixing a_0 forces any remaining discrepancies to be accounted for either by baryonic normalization (through Υ_*) or by genuine modifications of the field response in the low-acceleration regime. As we show below, this strategy reveals a clear pattern: while a_0 remains universal, galaxy-to-galaxy variations are captured by a coherence parameter that becomes relevant only in the deep low-acceleration regime.

4 Rotation curve analysis

4.1 Fitting strategy and parameter space

We analyze individual galaxy rotation curves using the same nonlinear response function and the same global acceleration scale a_0 determined from the RAR analysis. No galaxy-dependent acceleration scales or externally imposed corrections are introduced. For each galaxy, we allow two parameters to vary: the stellar mass-to-light ratio Υ_* and the deep-regime coherence parameter η_0 .

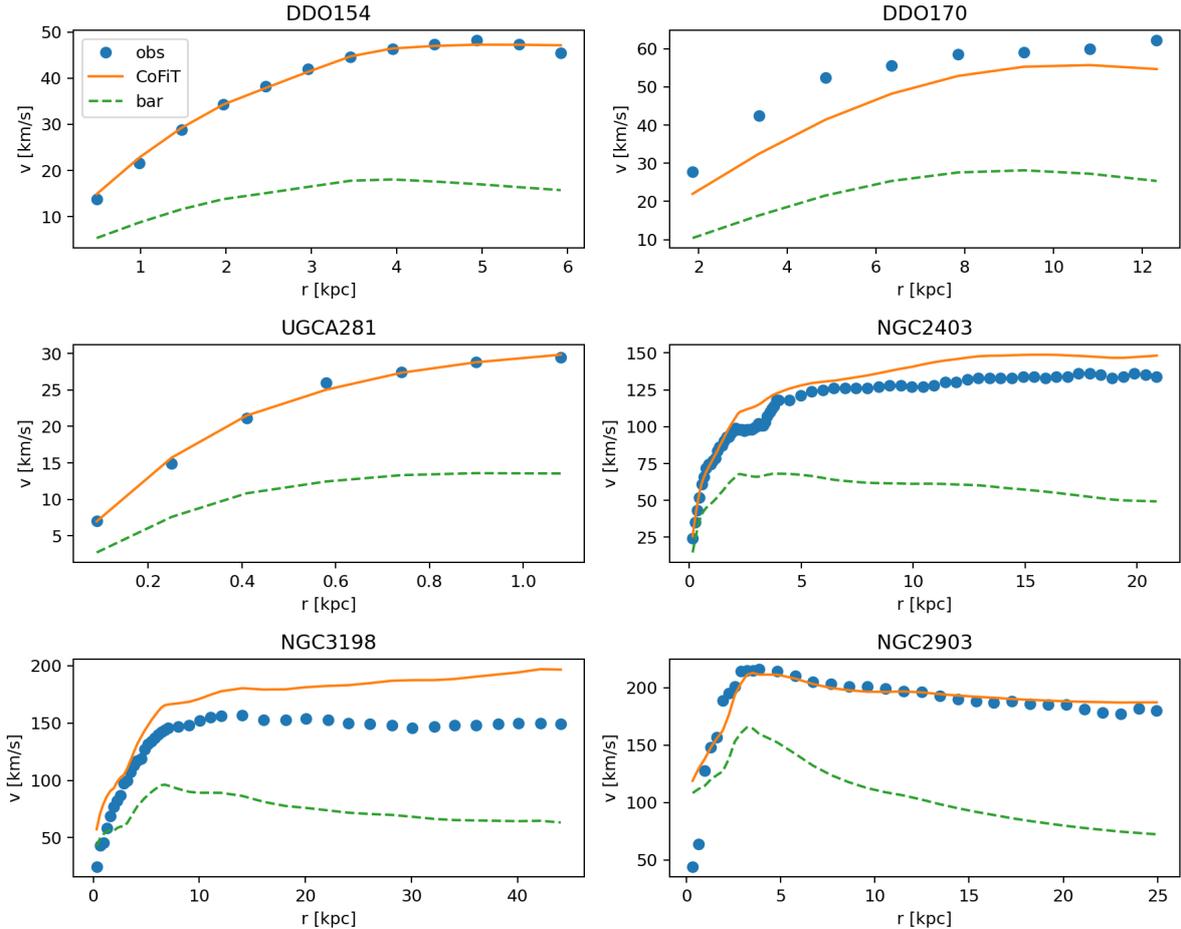


Figure 1: Representative rotation curve fits across low- and high-surface-brightness galaxies.

4.2 Representative rotation curves

Representative rotation curves spanning low-surface-brightness dwarf galaxies and high-surface-brightness spiral systems can be summarized by a compact panel figure (to be inserted). In all cases, the same global acceleration scale and the same functional form of the nonlinear response are used. Low-surface-brightness systems preferentially require partial coherence suppression ($\eta_0 < 1$) to reproduce observed amplitudes, while high-surface-brightness spirals are consistent with full coherence ($\eta_0 \approx 1$).

4.3 Separation of baryonic and coherence effects

A central result is the separation between baryonic normalization and dynamical enhancement. The stellar mass-to-light ratio Υ_* primarily affects the inner and intermediate regions of galaxies where stellar mass dominates, while η_0 governs the behavior in the deep low-acceleration regime. Consistent with this, η_0 and Υ_* exhibit no strong degeneracy across the sample.

5 Population-level results

Figure-level summaries show that the coherence parameter η_0 exhibits a structured, non-uniform distribution, while stellar mass-to-light ratios cluster around values consistent with stellar population synthesis. In particular, Υ_* typically falls in the range $\Upsilon_* \sim 0.3$ – 0.6 , with a low- Υ_*

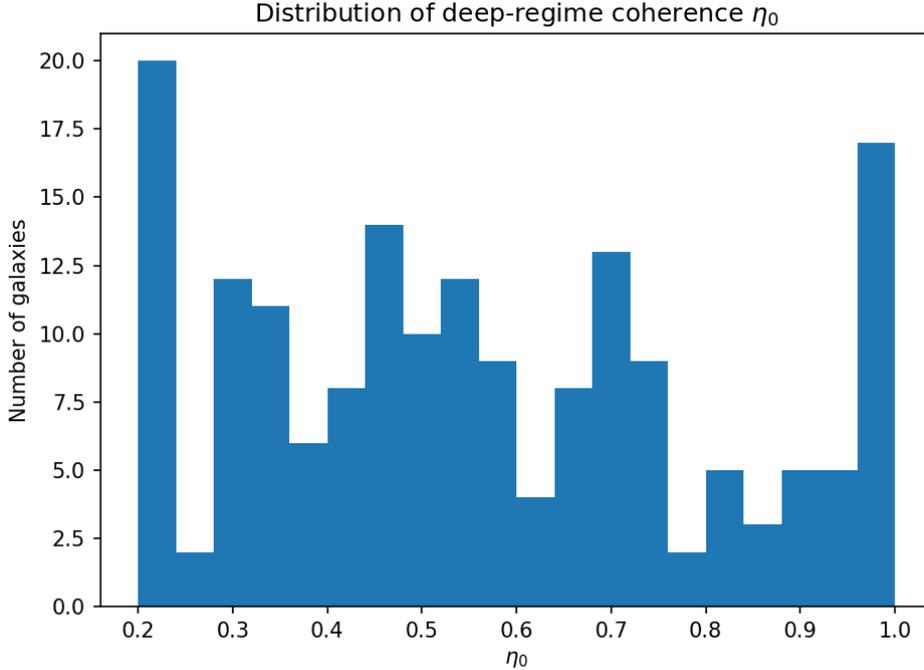


Figure 2: Distribution of the deep-regime coherence parameter η_0 across the SPARC sample.

tail associated with gas-dominated dwarf galaxies, and a smaller fraction of systems near the upper boundary of the explored range.

6 Discussion

The results indicate that galaxy dynamics are governed by a universal acceleration scale and a regime-dependent coherence property of the underlying field. This differs from dark matter halo interpretations, which require galaxy-specific halo properties to reproduce diversity, and from modified gravity approaches relying on externally imposed environmental effects. In the present framework, coherence loss is treated as an intrinsic regime-dependent property rather than an externally driven influence.

7 Conclusions

We have shown that galaxy dynamics across the SPARC sample can be consistently described within a nonlinear field framework characterized by a single global acceleration scale and a regime-dependent coherence property. The acceleration scale, fixed independently from the RAR, remains universal, while individual rotation curves require only one additional parameter describing partial coherence loss in the deep low-acceleration regime. These results motivate further theoretical and observational work aimed at understanding the physical origin of field coherence in galactic dynamics.

Acknowledgements

The authors are members of the Omni-Coherence Research Group.

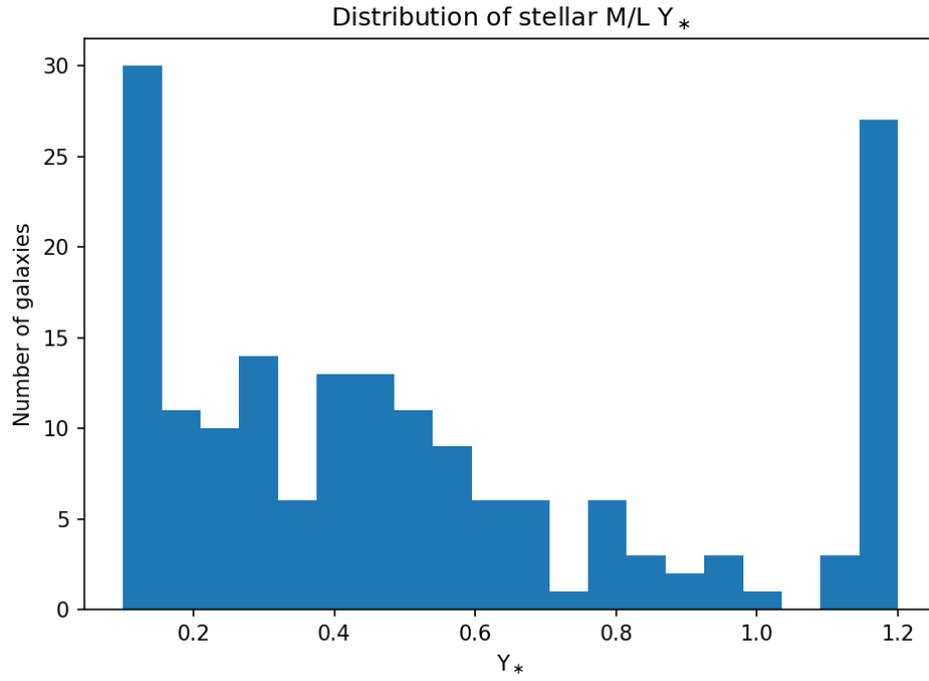


Figure 3: Distribution of fitted stellar mass-to-light ratios Y_* .

References

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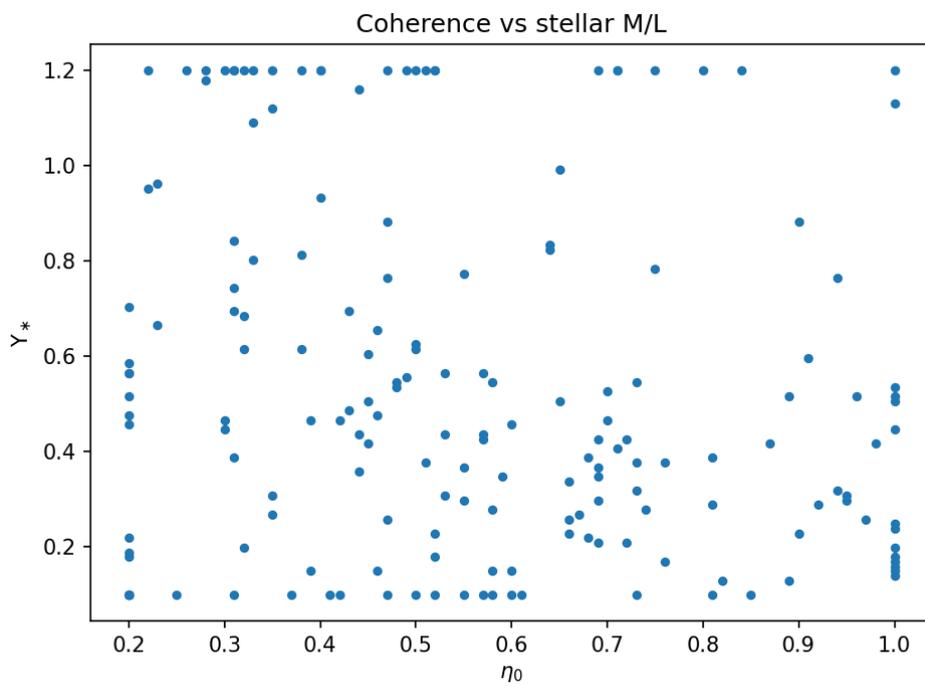


Figure 4: Joint distribution of (η_0, Υ_*) showing lack of strong degeneracy.