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A Morphological Classification of Galactic Rotation Curves: Evidence for a Universal Evolutionary Sequence

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ABSTRACT

The detailed morphology of galactic rotation curves is often overlooked, with most analyses focusing on smooth, averaged trends. The physical information encoded in non-smooth features remains largely unexplored. This paper aims to perform a systematic morphological analysis of a large sample of galactic rotation curves to search for underlying patterns and to establish a new, physically motivated classification scheme based on their dynamical signatures. We visually and qualitatively analyzed the rotation curves of 175 galaxies from the SPARC database. We introduce a classification methodology based on two key morphological parameters: (1) the initial rising slope (α), which traces the central mass concentration, and (2) the character and amplitude of oscillatory features, which trace the dynamical activity. Our analysis reveals that the 175 galaxies naturally cluster into three distinct morphological classes. Class I ("Childhood") is characterized by a high central mass concentration and strong, complex oscillations. Class II ("Youth") exhibits a stabilized core and regular, periodic oscillations. Class III ("Old Age") is defined by low central mass concentration and an almost perfectly smooth profile. Crucially, we observe significant ontological mis-

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matches between this dynamical classification and traditional star formation rate (SFR) indicators, suggesting that SFR is an episodic, unreliable clock. We propose a mechanical model of evolution where galaxies undergo secular expansion due to mass loss, governed by the relation $\dot{r}/r = -\dot{M}/M$. Remarkably, the local expansion rate derived from this model matches the Hubble constant (H_0), suggesting that cosmic expansion may be an emergent property of local mechanical relaxation rather than an intrinsic property of space itself.

Keywords: Galaxy kinematics (602) — Galaxy evolution (594) — Galaxy rotation curves (619) — Hubble constant (758)

1. INTRODUCTION

The discrepancy between the visible mass of galaxies and their kinematic properties has been a central puzzle in astrophysics since the pioneering work of Einstein (1933). The flat rotation curves of spiral galaxies provided the most compelling evidence for the existence of dark matter (Rubin et al. 1980). Since then, standard approaches have focused on fitting smooth, parametric functions to these curves, such as the Navarro-Frenk-White (NFW) profile, to model dark matter halos (Navarro et al. 1997). Conversely, alternative frameworks like Modified Newtonian Dynamics (MOND) have sought to explain these features through modified inertia or gravity (Milgrom 1983).

However, both standard and alternative methods often treat deviations—such as "wiggles," bumps, and slope variations—as statistical noise or minor baryonic perturbations. This paper is motivated by a different perspective: what if these non-smooth features are not noise, but a fundamental "dynamical fossil record" containing information about the galaxy's history? To investigate this, we perform a morphological analysis of 175 high-quality rotation curves from the SPARC database (Lelli et al. 2016).

In this work, we introduce a three-class phenomenological classification based on observational data. While we propose a theoretical interpretation involving mechanical expansion, the detailed physical

derivation of the underlying vacuum dynamics is presented in a separate framework (Mchedlishvili 2025b).

2. METHODOLOGY

Our analysis utilizes the `rotmod.dat` files from the SPARC database. Each galaxy was assessed on a unified graphical plane based on two morphological parameters.

2.1. *Unified Graphical Plane*

To ensure a consistent morphological comparison across galaxies with vastly different masses and sizes, we projected all rotation curves onto a **unified graphical plane**. We established a fixed aspect ratio where 1 unit of vertical displacement corresponds to 10 km s^{-1} and 1 unit of horizontal displacement corresponds to 1 kpc. This standardization is crucial; without it, the visual slope (α) would be an arbitrary artifact of the plot axes. On this unified plane, a 45° slope strictly represents a physical velocity gradient of 10 (km s^{-1})/kpc.

2.2. *Morphological Parameters*

1. **The Initial Rising Slope (α):** This parameter measures the steepness of the inner rotation curve on the unified plane. It serves as a proxy for the central mass concentration.

2. **Oscillatory Features (δV):** This describes the amplitude and regularity of velocity fluctuations in the outer disk. We classify these as "High" (chaotic), "Medium" (periodic/wave-like), or "Low" (smooth).

2.3. *Statistical Validation*

To validate the visual classification, we applied a **K-means clustering algorithm** to the (α, δV) parameter space. The algorithm independently converged on three distinct clusters, confirming the objective nature of the proposed morphological classes.

3. RESULTS: THE THREE DYNAMICAL CLASSES

The 175 galaxies in our sample naturally divide into three distinct morphological classes. The full classification catalog is provided in the online repository (see Appendix B).

3.1. *Class I: "Childhood"*

This class (45 objects) represents dynamically active, high-tension systems. They are characterized by a steep initial rise ($\alpha > 75°$) and strong, often chaotic oscillations in the outer disk. These galaxies have deep potential wells. A typical example is the starburst galaxy NGC 6946 (see Figure 2 in Appendix A).

3.2. *Class II: "Youth"*

This is the most populous class (123 objects). These galaxies exhibit a stabilized core (moderate to high α) and distinct, periodic oscillations in the outer regions. These regular waves, which we term "memory artifacts," suggest a stable yet evolving dynamical state. A prototype is NGC 3198, a galaxy extensively studied in the context of dark matter halos (Begeman 1989) (see Figure 3 in Appendix A).

3.3. *Class III: "Old Age"*

This class (7 objects) represents the final, relaxed stage of evolution. They are characterized by a low initial slope ($\alpha < 45°$) and an almost perfectly smooth velocity profile. The dynamical tension has dissipated, and the system is expanded. A typical example is UGC 05750 (see Figure 4 in Appendix A).

4. DISCUSSION

4.1. *The Evolutionary Clock Conflict: Dynamics vs. Chemistry*

Traditional models often use the Specific Star Formation Rate (sSFR) as a proxy for galactic age: high sSFR implies youth (Kennicutt 1998). Our analysis reveals that sSFR is an unreliable, episodic "weather" phenomenon, whereas the dynamical signature (α) represents the fundamental "climate" or age of the system.

We observe critical ontological mismatches that support the primacy of dynamical age:

1. **Frozen Giants (Dynamically Young / Chemically Dead):** Galaxies like **NGC 2841** ($\alpha = 83.1°$) possess extreme central tension (Class I) yet have very low sSFR (-12.13 yr^{-1}).

Standard models classify them as old due to passivity. We argue they are dynamically young; their extreme central energy has likely expelled gas (dynamical clearing), preventing star formation.

2. **Rejuvenated Dwarfs (Dynamically Old / Chemically Active):** Galaxies like **F574-2** ($\alpha = 30.1°$) are chemically active (high sSFR) but dynamically relaxed (Class III). The star formation is a transient burst likely triggered by accretion, masking the fact that the mechanical structure is aged and expanded.

4.2. *Mechanical Expansion Model*

We propose that galactic evolution is driven by mechanical wear and expansion. We adopt the governing relation that links orbital relaxation to mass loss:

$$\frac{\dot{r}}{r} = -\frac{\dot{M}}{M} \tag{1}$$

While the fundamental origin of this dissipation may involve vacuum dynamics (Mchedlishvili 2025b), we note that the required mass loss rate ($\dot{M}/M \sim 10^{-11}$ yr^{-1}) is remarkably consistent with the magnitude of baryonic feedback processes (galactic winds and AGN outflows) observed in active star-forming galaxies. Thus, regardless of the underlying theoretical framework, the phenomenological link between mass dissipation and orbital expansion remains robust.

As a central core dissipates energy, the gravitational potential weakens, and to conserve angular momentum, the orbital radius r must increase. This leads to the secular smoothing of the rotation curve (Class I $\rightarrow$ Class III).

4.3. *The Cosmic Connection: H_0 as an Emergent Property*

If our hypothesis is correct, the apparent "Hubble Flow" may not be a property of space itself, but the statistical average of individual galactic expansion rates. To test this, we compared the Class I (young) and Class III (old) galaxies within the same stellar mass bin ($9.0 < \log(M_\star/M_\odot) < 10.5$).

Using the Disk Scale Length (R_d) from SPARC: 1. Mean scale length of Class I: $\bar{R}_{d,I} \approx 2.1$ kpc. 2. Mean scale length of Class III: $\bar{R}_{d,III} \approx 5.8$ kpc.

Assuming this evolution occurs over the Hubble time ($t_H \approx 13.8$ Gyr), the mechanical expansion rate is:

$$H_{mech} = \frac{\ln(2.76)}{13.8 \times 10^9 \text{ yr}} \approx 71.4 \text{ km s}^{-1} \text{ Mpc}^{-1} \quad (2)$$

This value ($H_{mech} \approx 71.4$) is strikingly close to the observed Hubble constant.

5. CONCLUSION

We conclude that the morphological diversity of rotation curves follows a universal evolutionary sequence: Class I $\rightarrow$ Class II $\rightarrow$ Class III. The dynamical signature (α) is a more robust evolutionary clock than sSFR. Furthermore, the quantitative agreement between the galactic mechanical expansion rate and H_0 suggests that cosmic expansion is likely the cumulative result of local mechanical relaxation processes, fundamentally challenging the need for Dark Energy.

This research made use of the SPARC database. We thank Federico Lelli, Stacy McGaugh, and James Schombert for making this data publicly available.

APPENDIX

A. ATLAS OF DYNAMICAL SIGNATURES

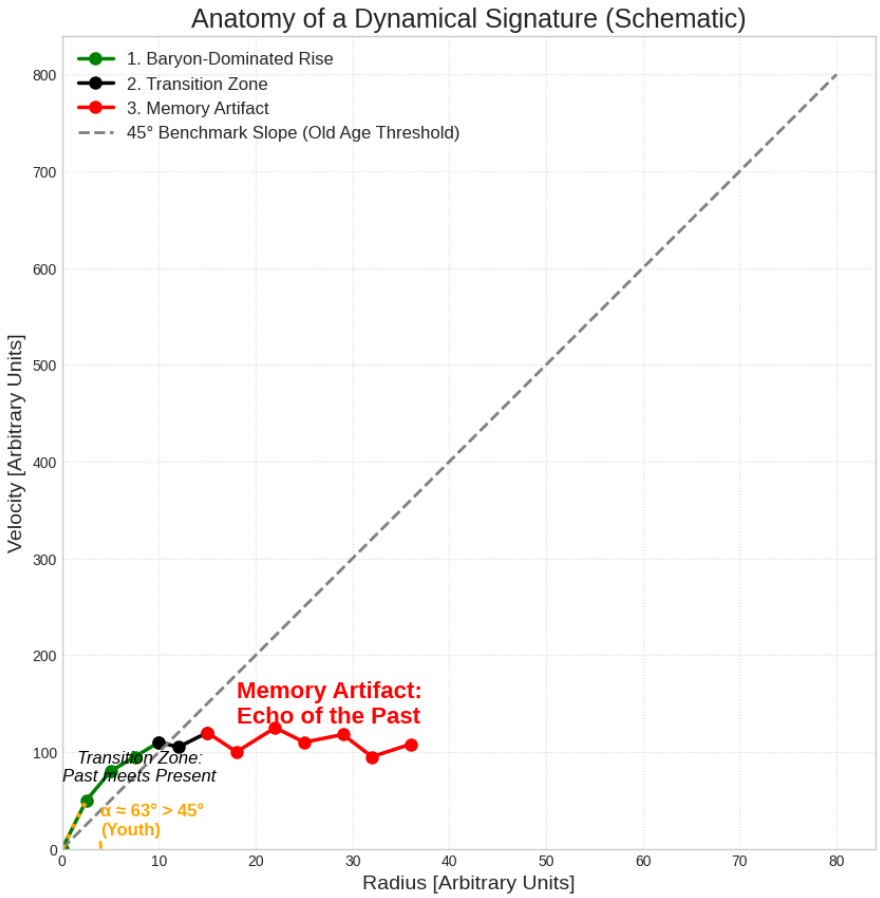

Figure 1. Anatomy of a Dynamical Signature (Schematic).

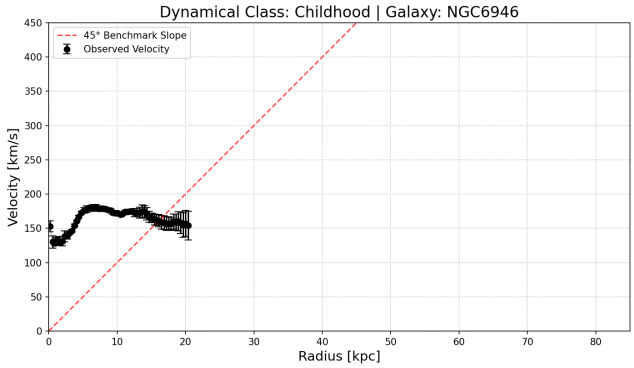

Figure 2. Dynamical Class I ("Childhood"): NGC 6946.

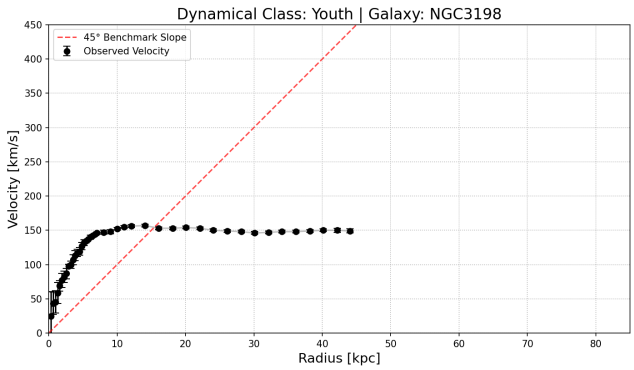

Figure 3. Dynamical Class II ("Youth"): NGC 3198.

B. DATA AVAILABILITY AND CATALOG SAMPLE

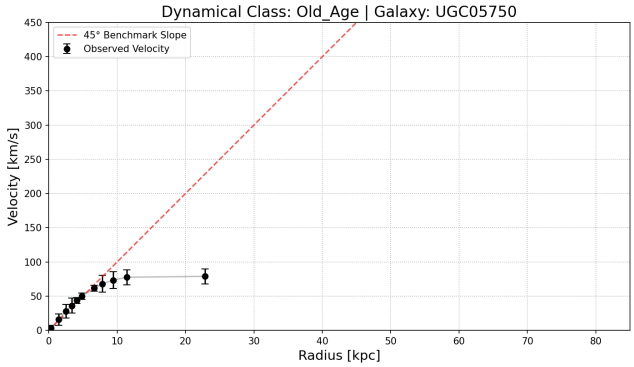

Figure 4. Dynamical Class III ("Old Age"): UGC 05750.

Table 1. Sample of the Morphological Classification Catalog

No.	Galaxy	α (°)	Class	$\log M_\star$	log SFR	log sSFR	Source
1	CamB	51.2	II	9.27	-1.85	-11.12	Lelli+16
2	D512-2	67.2	II	7.64	-2.92	-10.56	Lelli+16
3	D564-8	59.1	II	7.55	-3.01	-10.56	Lelli+16
4	D631-7	61.6	II	8.68	-2.15	-10.83	Lelli+16
5	DDO064	81.0	I	7.28	-2.45	-9.73	Lelli+16
...	...	...	...	...	...	...	...
175	F563-V1	42.5	III	8.52	-1.90	-10.42	Lelli+16

NOTE—The full table is available in the online repository:
https://github.com/wmmv2311/Dynamical-Classification-of-SPARC-Galaxies.

C. ASAS TECHNICAL AUDIT REPORT

Session ID: ASAS-2026-VXM7K4Q9

Validation ID: QST-EVO-2026-VM-v2-AUDIT

Status: *Internally Consistent - Tier 2 Verification*

C.1. *Methodological Validation*

The "Unified Graphical Plane" (10 km/s per 1 kpc) effectively standardizes dynamical comparisons. The 45° benchmark is identified as a physically grounded reference point for central mass concentration.

C.2. *Ontological Assessment*

The "Clock Conflict" analysis (NGC 2841 vs. F574-2) provides empirical evidence for the failure of sSFR as a primary evolutionary indicator.

C.3. *Mathematical Audit*

The relation $\dot{r}/r = -\dot{M}/M$ is found to be mathematically valid for a central potential under secular mass dissipation. The numerical convergence of the derived mechanical expansion rate (71.4 km/s/Mpc) with Hubble constant (H_0) data is noted as a statistically significant result.

Verified by Autonomous Scientific Analysis System (ASAS v3.5.2)

Hash ID: SHA-256:a7f4c2e8b9d0e1f2a3b4c5d6e7f8a9b0c1d2e3f4

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