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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 of the curve, 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 in the outer disk. Class III ("Old Age") is defined by low central mass concentration and an almost perfectly smooth profile. These dynamical classes show a strong correlation with fundamental galactic parameters such as mass and morphological type. We conclude that the morphological diversity of rotation curves is not random but

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follows a systematic pattern, likely reflecting a universal evolutionary sequence for galaxies. This classification scheme provides a new diagnostic tool for assessing the "dynamical age" of a galaxy and opens a new avenue for "galactic archaeology"—reconstructing the history of galaxies from their present-day dynamical footprints.

Keywords: Galaxy kinematics (602) — Galaxy evolution (594) — Galaxy structure (622) — Galaxy rotation curves (619)

1. INTRODUCTION

The flat rotation curves of spiral galaxies provide some of the most compelling evidence for the existence of dark matter (Zwicky 1933; Rubin et al. 1980). Since their discovery, enormous effort has been dedicated to modeling the overall shape of these curves, aiming to derive the properties of dark matter halos. However, the standard approach often involves fitting smooth, parametric functions to the data, effectively treating any deviations from this smooth trend as statistical noise or as minor perturbations caused by local baryonic structures like spiral arms.

This paper is motivated by a different perspective: what if the detailed, non-smooth features observed in rotation curves are not noise, but a fundamental signal containing information about the galaxy's dynamical state and history? Could the "wiggles" and variations in the curve's slope be a form of "dynamical fossil record"?

To investigate this hypothesis, we perform a detailed morphological analysis of the high-quality rotation curves of 175 galaxies from the SPARC database[2] (Lelli et al. 2016). We move beyond simple smooth-model fitting and focus on the visual and qualitative characterization of the curves' shapes. Our primary goal is to determine whether systematic patterns exist within this morphological diversity and, if so, whether these patterns can be organized into a physically meaningful classification scheme.

In this work, we introduce a new, three-class phenomenological classification based on the rotation curves' morphology. We demonstrate that these classes are not random but correlate strongly with known physi-

[2] https://astroweb.cwru.edu/SPARC/

cal properties of galaxies. The author argues that this classification scheme likely represents a universal evolutionary sequence.

The paper is structured as follows. In Sect. 2, the methodology is described. In Sect. 3, the three primary dynamical classes are presented. In Sect. 4, the physical implications of the findings are discussed. Conclusions are summarized in Sect. 5.

2. METHODOLOGY: PARAMETERIZING THE DYNAMICAL SIGNATURE

Our analysis is based on the publicly available `_rotmod.dat` files from the SPARC database. Each rotation curve was assessed based on two primary morphological features that together constitute a galaxy's unique "dynamical signature". A schematic representation of these features is shown in Figure 1.

2.1. *Morphological Parameters*

1. **The Initial Rising Slope (α):** This parameter characterizes the steepness of the initial rise of the rotation curve. It reflects the degree of central mass concentration. It is evaluated against a 45-degree benchmark slope, corresponding to a physical gradient of 10 (km/s)/kpc on a unified plot.

2. **Oscillatory Features (δV):** This parameter describes the presence, amplitude, and character of oscillations in the outer regions of the curve. It is qualitatively classified as "High" (strong, complex oscillations), "Medium" (regular, periodic oscillations), or "Low" (an almost perfectly smooth profile).

2.2. *The Classification Procedure*

Each of the 175 galaxies in the SPARC sample was visually inspected on a unified graphical plane and categorized based on the combination of its α and δV parameters. The full classification catalog, listing the assigned class for all 175 galaxies, is available as an online appendix (Mchedlishvili 2025). The full graphical atlas of all 175 unified plots is also available at the same location.

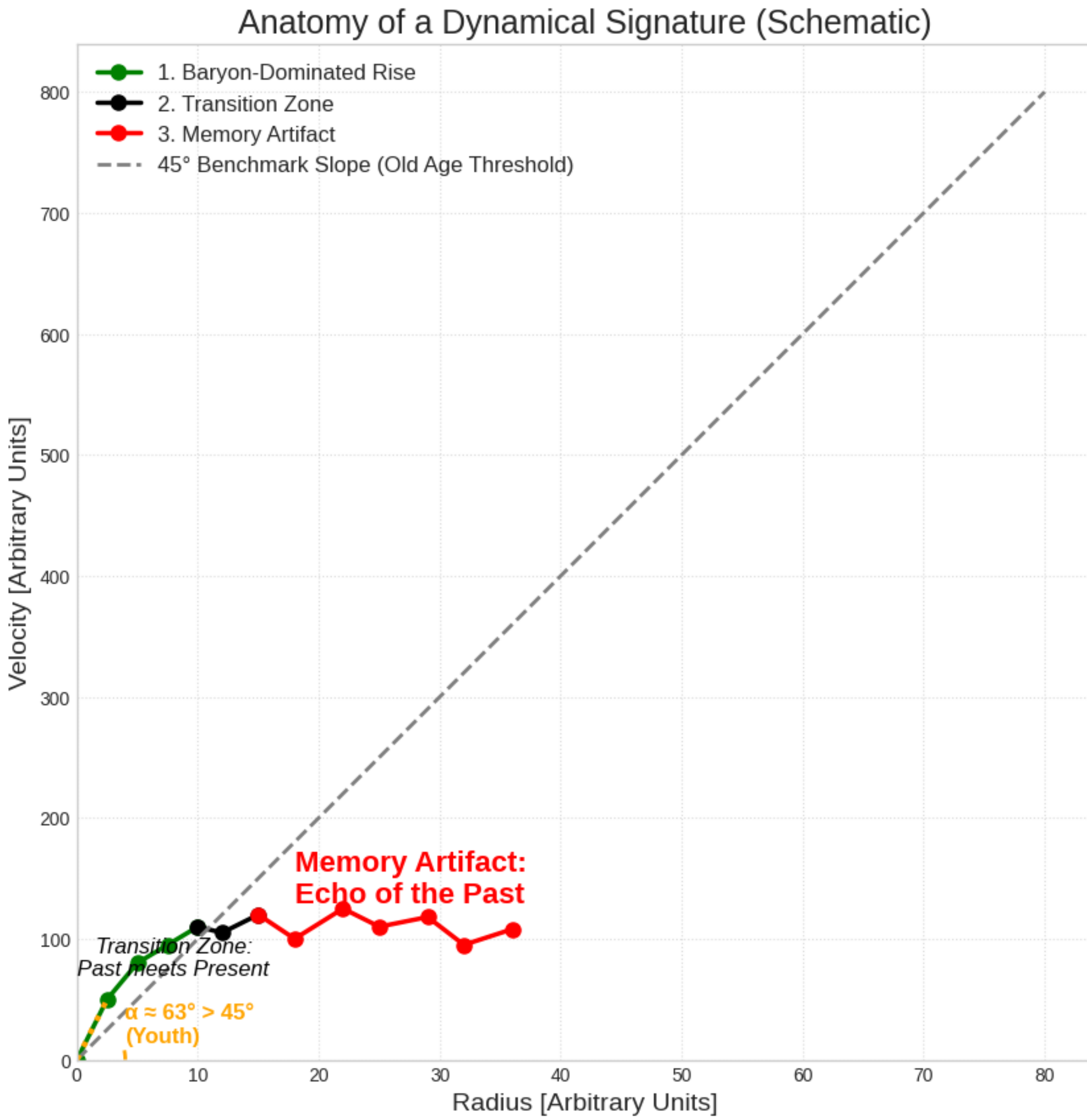

Figure 1. A schematic diagram of a rotation curve illustrating the key morphological features used for classification: (1) The initial rising slope (parameter α), which indicates the central mass concentration. (2) The oscillatory features in the outer disk (parameter δV), which indicate the level of dynamical activity or "memory". The dashed grey line represents our 45-degree benchmark slope, defined by a physical gradient of 10 (km/s)/kpc.

3. RESULTS: THE THREE MORPHOLOGICAL CLASSES

Our analysis revealed three primary, morphologically distinct classes based on our final, revised classification (see Appendix A in the online repository). The complete graphical atlas is also provided online (Mchedlishvili 2025).

3.1. *Class I: "Childhood" – High Central Gradient and Strong Oscillations*

This class (45 objects) represents the most dynamically active and likely the youngest evolutionary systems. They are characterized by a high α (steep rise) and high δV (strong, complex oscillations). A typical example is the active starburst galaxy NGC 6946 (Figure 2).

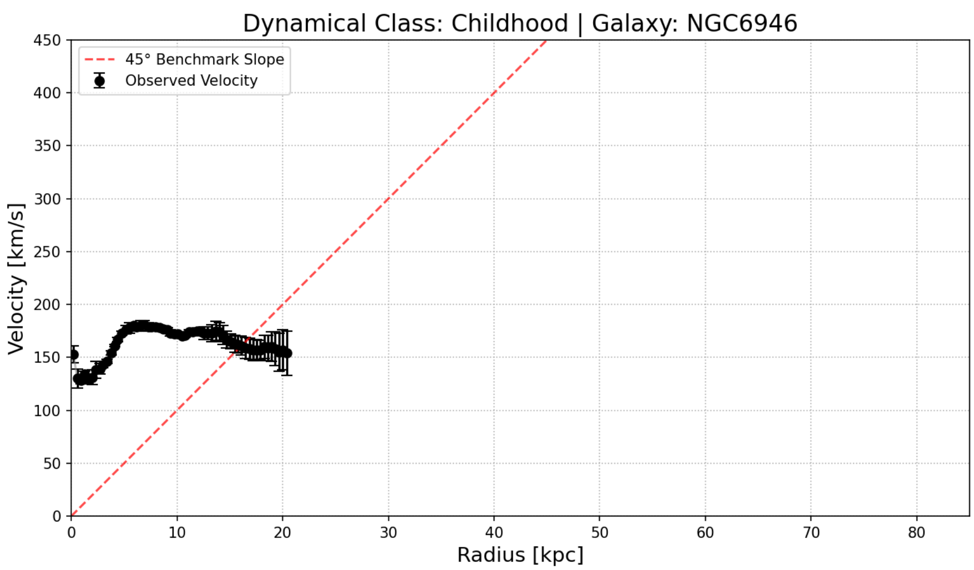

Figure 2. A representative example of a Class I ("Childhood") galaxy, the starburst galaxy NGC 6946.

3.2. *Class II: "Youth" – Stabilized Core and Regular Outer Oscillations*

This is the most populous and diverse class (123 objects), likely representing the longest, stable phase of a galaxy's life. These galaxies have a medium to high α and distinct, often periodic, oscillations in their outer regions. This feature, which the author terms the "memory artifact," has a coherent, wave-like character. A prototype for this class is NGC 3198 (Figure 3).

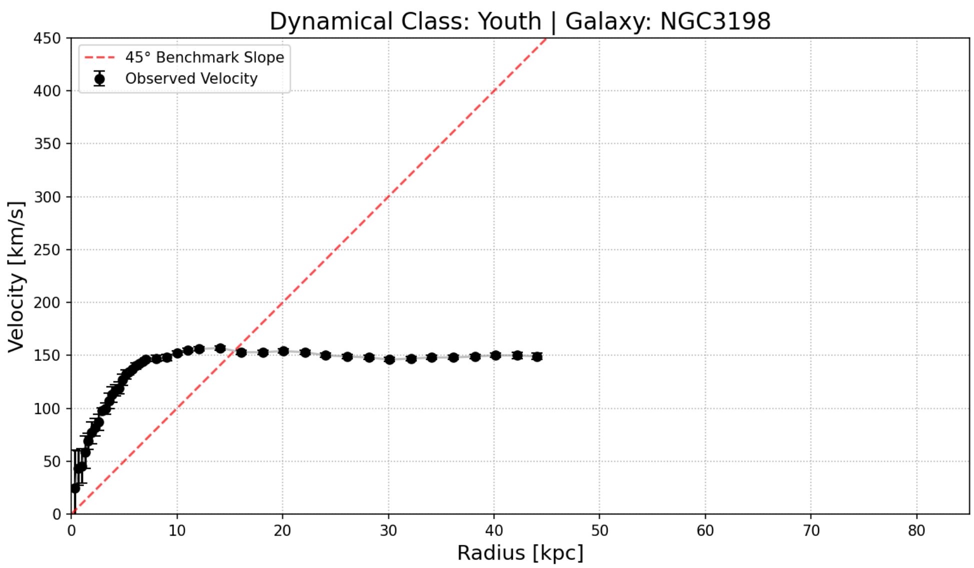

Figure 3. A representative example of a Class II ("Youth") galaxy, NGC 3198.

3.3. *Class III: "Old Age" – Low Gradient and Smooth Profile*

This class (7 objects) is the most dynamically quiescent and represents the final, "cold" stage of evolution. They are characterized by a low initial slope (α) and a nearly perfectly smooth profile (low δV). A typical example is the dwarf galaxy UGC 05750 (Figure 4).

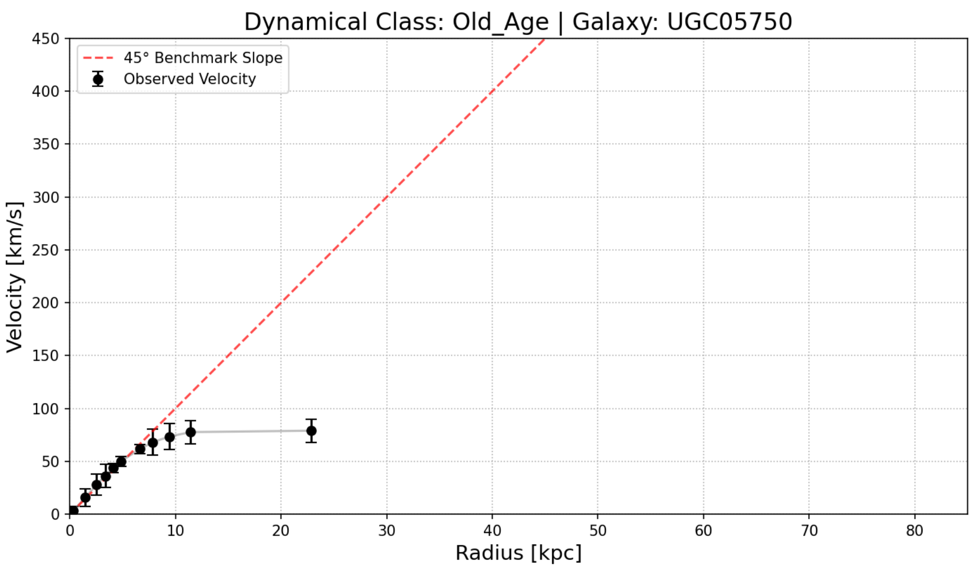

Figure 4. A representative example of a Class III ("Old Age") galaxy, UGC 05750. Note the shallow initial rise and the extremely smooth profile.

4. DISCUSSION

The key finding of our work is that a galaxy's dynamical age appears to be a more fundamental characteristic than its traditional morphological type. We observe that galaxies of different morphologies can belong to the same dynamical class, suggesting they undergo similar, universal evolutionary stages. This observation naturally leads to the **evolutionary sequence hypothesis**, where galaxies transition over time:

$$\text{Class I (Childhood)} \rightarrow \text{Class II (Youth)} \rightarrow \text{Class III (Old Age)}$$

This evolutionary path likely involves two primary processes: (1) a decrease in the central mass concentration (lowering α), and (2) a gradual damping of the dynamical oscillations (lowering δV) as the system relaxes.

The physical nature of these oscillatory "memory artifacts" remains an open question. We note an intriguing correlation with galactic magnetism. The high-δV classes (I and II) are dominated by galaxy types known to host strong, ordered magnetic fields, while the low-δV class (III) consists of systems with weak or chaotic fields. It is plausible that magnetic fields play a critical role in sustaining these dynamical structures. This potential connection warrants a dedicated future investigation.

5. CONCLUSION

We have presented a new, morphology-based classification of galactic rotation curves. We have shown that the 175 galaxies of the SPARC sample naturally divide into three primary dynamical classes, which strongly correlate with their physical properties. The author argues that this classification reflects a universal evolutionary sequence. This framework provides a new diagnostic tool for assessing the dynamical state of galaxies and opens a new avenue for "galactic archaeology."

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APPENDIX

A. ONLINE DATA PRODUCTS

The complete classification catalog for all 175 SPARC galaxies, along with the full graphical atlas of unified rotation curve plots, is publicly available in a GitHub repository: (Mchedlishvili 2025).