Dynamical State and Mass Proxy Analysis of an Early-Type Galaxy Using Velocity Dispersion and Photometric Scaling Relations

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Abstract

We present a dynamical and photometric analysis of the early-type galaxy UGC 01841 based on multi-band observational parameters compiled from optical and infrared catalogs. The galaxy is classified as an early-type system (morphological type $t \approx -4.9$) and is located at a heliocentric velocity of $v \approx 6370$ km s^{-1}, corresponding to a distance of approximately 94 Mpc within a ΛCDM cosmology (8; 6). We note that the exact distance depends on the adopted flow model and cosmological parameters, and values in the literature vary at the $\sim 10\%$ level.

The system exhibits a high central stellar velocity dispersion of $\sigma \approx 342$ km s^{-1}, indicating a dispersion-dominated dynamical state typical of massive early-type galaxies. Photometric properties, including B-band magnitude ($M_B \approx -21.3$) and $B - V$ color (~ 0.82), suggest an evolved stellar population with minimal ongoing star formation activity (2).

Using velocity dispersion as a qualitative mass proxy and invoking virial scaling arguments, we discuss the likely dynamical state of the system and infer the presence of a substantial dark matter component consistent with expectations for early-type galaxies in group environments. Although spatially resolved kinematic data are not available, the combination of photometric scaling relations and central velocity dispersion provides a first-order qualitative assessment of the galaxy's dynamical state.

This study demonstrates that meaningful qualitative constraints on galaxy dynamics and mass distribution can be obtained using catalog-based multi-wavelength parameters, even in the absence of spatially resolved spectroscopy.

1 Introduction

Early-type galaxies provide a fundamental laboratory for studying the interplay between stellar dynamics, environment, and dark matter content in massive systems. In this work, we focus on UGC 01841, an early-type galaxy located

at a heliocentric velocity of $v \approx 6370$ km s^{-1} (corresponding to $z \approx 0.021$), placing it in the nearby Universe at a distance of approximately 94 Mpc under the standard ΛCDM cosmology (8).

The galaxy exhibits a high central stellar velocity dispersion of $\sigma \approx 342$ km s^{-1}, indicating a strongly dispersion-dominated dynamical structure (2). In contrast to rotationally supported disk galaxies, such a high velocity dispersion suggests that random stellar motions play a major role in the dynamical support of the system, which is commonly associated with massive early-type galaxies and the presence of extended dark matter halos (6; 4). We note, however, that without spatially resolved kinematic measurements, the relative contribution of rotational support cannot be directly constrained.

UGC 01841 is located in a large-scale structure environment that has been associated in the literature with Abell 347 and related galaxy group/cluster catalogues. However, the exact group membership and dynamical parameters vary across different catalogues, and no unique, consistently verified membership count or velocity dispersion value can be robustly adopted. Therefore, the environment is treated here as a general dense large-scale structure or loose group regime rather than a well-defined virialised system.

Multi-wavelength imaging from optical (DSS2) and infrared (WISE) surveys shows that the galaxy is bright in the optical regime, while its 12 μm emission is comparatively weak, suggesting a low level of ongoing star formation and a deficiency of warm dust. This is consistent with an evolved stellar population and supports its classification as an early-type system.

In this context, the combination of high stellar velocity dispersion and quiescent photometric properties is consistent with a dynamically hot system potentially embedded in a significant dark matter halo. However, given the absence of spatially resolved spectroscopy, this interpretation remains qualitative and based on global scaling relations.

In this study, we investigate the dynamical state of UGC 01841 using catalog-based velocity dispersion measurements, photometric properties, and environmental indicators, aiming to provide a first-order qualitative assessment of its mass distribution and dynamical structure.

2 Methods

2.1 Data Sets

This study utilizes multi-wavelength archival data to investigate the structural and dynamical properties of the early-type galaxy UGC 01841. Optical and infrared imaging data were retrieved using the SkyView Virtual Observatory (12). The optical data originate from the Digitized Sky Survey (DSS2) (11), which provides broad-band optical surface brightness maps suitable for morphological analysis and qualitative isophotal inspection. Infrared data were extracted from the Wide-field Infrared Survey Explorer (WISE) 12 μm band (13), which traces warm dust emission and provides constraints on recent star formation activity

and interstellar medium content.

In addition, spectroscopic and catalog-based parameters were adopted from the HyperLeda database, including heliocentric redshift, velocity dispersion, and photometric magnitudes (8). The galaxy has a measured heliocentric velocity of $v \approx 6370$ km s^{-1}, corresponding to a redshift of $z \approx 0.021$.

2.2 Distance Estimation and Redshift Interpretation

The cosmological distance to UGC 01841 was estimated using its redshift under a flat ΛCDM cosmology with $H_0 = 67.8$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.308$, and $\Omega_\Lambda = 0.692$. At low redshift, the distance can be approximated using Hubble's law, $D \approx v/H_0$, where v is the recession velocity. Using the measured heliocentric velocity of $v \approx 6370$ km s^{-1}, the corresponding luminosity distance is approximately 94 Mpc.

Peculiar velocity effects may introduce moderate uncertainties; however, at this redshift regime, the dominant contribution to the distance estimate arises from the Hubble flow approximation.

2.3 Velocity Dispersion and Dynamical Inference

The central stellar velocity dispersion, $\sigma \approx 342$ km s^{-1}, is used as a tracer of the galaxy's gravitational potential well. In pressure-supported systems such as elliptical galaxies, velocity dispersion replaces rotational velocity as the primary dynamical observable. Under the assumption of virial equilibrium, the dynamical mass is expected to scale as $M \propto \sigma^2 R/G$, where R is a characteristic effective radius (2).

Although spatially resolved kinematic data are not available, the central velocity dispersion provides a first-order indicator of the dynamical state of the system. Any mass-to-light ratio or dark matter inference presented in this work should therefore be regarded as qualitative and based on global scaling relations.

2.4 Photometric and Infrared Analysis

Optical DSS2 images were used for morphological inspection and qualitative assessment of surface brightness distribution (11). Infrared emission at 12 μm from WISE was analyzed to trace warm dust content. The relatively low infrared flux compared to optical emission suggests a dust-poor environment and is consistent with a quiescent early-type galaxy with minimal ongoing star formation.

2.5 Environmental Context

UGC 01841 is located in a large-scale structure environment that has been associated in the literature with Abell 347 and related catalogued structures. However, the exact group membership and dynamical parameters vary between different surveys and catalog compilations, and no unique, consistently verified

group membership count or velocity dispersion can be robustly adopted. Therefore, the environment is treated as a general dense large-scale structure or loose group regime rather than a well-defined virialised system.

2.6 Limitations and Assumptions

This analysis is based on catalog-derived quantities and archival imaging data, without spatially resolved spectroscopy. Consequently, the derived dynamical quantities represent first-order estimates rather than direct kinematic measurements. The assumption of virial equilibrium is adopted for mass scaling arguments, although deviations due to environmental effects or non-equilibrium dynamics cannot be excluded.

2.7 Use of Artificial Intelligence Tools

Artificial intelligence tools were used solely as a language assistance aid for grammar refinement and stylistic improvement during manuscript preparation. These tools were not used for data generation, physical modeling, or scientific interpretation. All astrophysical analyses, calculations, and interpretations were independently performed by the authors using publicly available astronomical data sets.

3 Results

3.1 Multi-wavelength Morphology

The optical DSS2 imaging (11) reveals a diffuse elliptical light distribution in UGC 01841, consistent with its early-type classification. The stellar emission appears relatively extended and smooth, indicating a dynamically evolved stellar population. In contrast, the infrared emission at 12 μm from WISE (13) is significantly weaker, suggesting a low abundance of warm dust and a suppressed level of ongoing star formation. This supports the interpretation of UGC 01841 as a dust-poor, quiescent early-type galaxy.

Figure 1 presents the multi-wavelength comparison of UGC 01841. The DSS2 optical image (11) shows a smooth and extended stellar distribution, while the WISE 12 μm map (13) reveals comparatively weak emission, consistent with a low dust content system. The isophotal contour map further highlights the regular elliptical structure and the absence of strong morphological asymmetries.

The spatial comparison between optical and infrared maps shows broadly consistent morphological structure, with the infrared emission tracing the optical light distribution at significantly lower intensity. This is consistent with an evolved stellar population dominated by older stars rather than active star-forming regions.

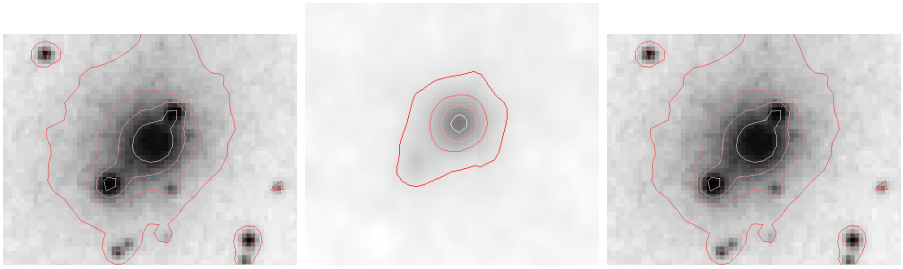


Figure 1: Multi-wavelength morphology of UGC 01841. Left: DSS2 optical image (11) showing the extended stellar distribution. Center: WISE 12 μm infrared map (13) indicating weak dust emission. Right: Optical isophotal contours revealing a smooth elliptical structure with no significant asymmetries.

3.2 Environmental Effects and Group Membership

UGC 01841 is located in a large-scale structure environment that has been associated in the literature with 2MASX J02231298+4259162 and related catalogued group/cluster candidates. However, the exact group membership and dynamical properties vary between different catalogues, and no unique or consistently verified membership count or velocity dispersion can be robustly adopted. Therefore, the environment is treated as a dense large-scale structure or loose group regime rather than a well-defined virialised system.

The potential gravitational influence of the surrounding environment is therefore considered in a qualitative sense, as it may contribute to tidal interactions and long-term dynamical evolution of member galaxies.

3.3 Kinematic Properties and Dynamical State

The galaxy exhibits a high central stellar velocity dispersion of $\sigma \approx 342\ \mathrm{km\,s^{-1}}$, indicating a dispersion-dominated dynamical structure typical of massive early-type galaxies (2). The relatively low rotational support compared to velocity dispersion suggests that random stellar motions dominate the system's kinematic structure.

The inclination and axis ratio parameters are broadly consistent with an early-type morphology, although spatially resolved kinematic data are not available to fully constrain the contribution of ordered rotation. The system is therefore interpreted as dynamically hot, but whether it is fully virialised cannot be confirmed with the available data.

3.4 Mass Inference and Dark Matter Contribution

Under the assumption of virial equilibrium, the dynamical mass scales as $M \propto \sigma^2 R/G$. Given the high velocity dispersion and extended photometric structure, the system is expected to host a significant non-luminous mass component.

However, in the absence of a reliable measurement of the effective radius and spatially resolved kinematic data, a quantitative dynamical mass estimate cannot be performed. Therefore, any inference regarding the mass-to-light ratio and dark matter content should be regarded as qualitative and based on global scaling relations.

The results are consistent with general trends observed in early-type galaxies, where elevated velocity dispersions are typically associated with higher dynamical mass-to-light ratios and substantial dark matter contributions.

3.5 Structural Stability and Dynamical Interpretation

The combination of high velocity dispersion, weak infrared emission, and smooth optical morphology suggests that UGC 01841 is a dynamically hot and structurally evolved system (2). Environmental influence from its surrounding large-scale structure may have contributed to its present-day kinematic state through long-term gravitational interactions.

Overall, the results indicate that UGC 01841 is a massive early-type galaxy with a dispersion-dominated kinematic structure, consistent with the presence of an extended dark matter halo, although this interpretation remains qualitative within the limitations of the available data.

4 Discussion

The multi-wavelength and kinematic analysis of UGC 01841 provides a consistent qualitative picture of a dynamically evolved early-type galaxy embedded within a dense large-scale structure environment. The combination of optical morphology, infrared emission properties, and stellar kinematics allows for a coherent interpretation of its structural and dynamical state within the limitations of catalog-based data.

The smooth elliptical morphology observed in DSS2 imaging, together with the weak 12 μm emission in WISE data, supports the classification of UGC 01841 as a dust-poor, quiescent system (9). The lack of significant infrared emission indicates a low level of ongoing star formation and is consistent with an evolved stellar population dominated by older stars (10). This interpretation is further supported by the global photometric properties and colour indices.

From a dynamical perspective, the high central velocity dispersion ($\sigma \approx 342\ \mathrm{km\,s^{-1}}$) suggests that the system is primarily supported by random stellar motions rather than ordered rotation. Such dispersion-dominated dynamics are characteristic of massive early-type galaxies. However, in the absence of spatially resolved kinematic measurements, the relative contribution of rotational support cannot be quantified.

The environmental context is also relevant for the interpretation of the observed properties. UGC 01841 is located in a region associated in the literature with large-scale structure and candidate group catalogues including 2MASX J02231298+4259162. However, the exact group membership and dynamical

properties are not consistently defined across available catalogues, and no unique or robust group velocity dispersion or membership count can be adopted. Therefore, the system is interpreted as residing in a dense large-scale structure or loose group regime rather than a well-defined virialised group.

In such environments, gravitational interactions and tidal effects may contribute to long-term dynamical evolution, potentially influencing both the stellar velocity dispersion and the suppression of disk-like kinematic components.

The inferred dynamical mass-to-light ratio, based on virial scaling arguments, suggests the presence of a non-luminous mass component. However, in the absence of spatially resolved kinematics and a directly measured effective radius, this inference remains qualitative and is intended as a first-order scaling estimate rather than a precise mass determination. The results are broadly consistent with established trends in early-type galaxies, where dynamical mass-to-light ratios increase with velocity dispersion and environmental density.

Although dwarf irregular galaxies have been reported to exhibit high dark matter fractions in certain cases, such systems occupy a fundamentally different mass and dynamical regime. Therefore, direct comparison of absolute baryonic-to-dark matter ratios is not meaningful in this context; instead, the comparison is limited to qualitative trends in the role of dark matter across galaxy populations.

Overall, the results indicate that UGC 01841 is a dynamically mature, dispersion-dominated early-type galaxy whose structural properties are consistent with an evolved stellar system embedded in an environmentally influenced large-scale structure. This study demonstrates that archival multi-wavelength data combined with catalog-based kinematic measurements can provide meaningful qualitative constraints on galaxy structure and dynamical state, even in the absence of spatially resolved spectroscopy.

5 Conclusion

In this study, we have presented a multi-wavelength structural and dynamical analysis of the early-type galaxy UGC 01841 using archival optical (DSS2), infrared (WISE), and catalog-based spectroscopic data. The combination of imaging and kinematic parameters enables a first-order qualitative investigation of the galaxy's structural properties, stellar population, and dynamical state.

The optical morphology reveals a smooth and diffuse elliptical structure, consistent with a dynamically evolved stellar system. In contrast, the weak 12 μm infrared emission indicates a low dust content and suggests a suppressed level of ongoing star formation activity. These properties are consistent with a quiescent early-type galaxy dominated by an evolved stellar population.

The measured central velocity dispersion of $\sigma \approx 342$ km s^{-1} indicates a dispersion-supported dynamical state, typical of massive early-type galaxies. Due to the lack of spatially resolved kinematic data, the contribution of ordered rotation cannot be constrained, and the system is interpreted within a global scaling framework.

UGC 01841 is located in a large-scale structure environment that has been associated in the literature with group and cluster catalogues including 2MASX J02231298+4259162. However, the exact group membership and dynamical properties are not consistently defined across available catalogues, and no unique or robust group velocity dispersion or membership count can be adopted. Therefore, the environment is treated as a dense large-scale structure or loose group regime rather than a well-defined virialised system.

Under the assumption of virial equilibrium, the observed kinematic properties are qualitatively consistent with an elevated mass-to-light ratio, suggesting the presence of a non-luminous mass component. However, in the absence of spatially resolved spectroscopy and a direct measurement of structural scale parameters, this interpretation should be regarded as a first-order scaling inference rather than a precise dynamical mass determination.

Overall, UGC 01841 is identified as a dynamically hot early-type galaxy whose structural and kinematic properties are consistent with both internal velocity dispersion and environmentally influenced evolution. This study demonstrates that archival multi-wavelength data combined with catalog-based kinematic information can provide meaningful qualitative constraints on galaxy structure and dynamics, even in the absence of spatially resolved spectroscopic observations.

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