Dark Matter Detection in Galaxies: Analyzing Rotation Curves for Hidden Mass Signatures

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Abstract: We analyzed a sample of 175 disk galaxies from the SPARC database to study how dark matter influences their rotation curves. For each galaxy, we compared the observed rotation speeds with the contributions expected from stars, gas, and bulges. To test this, we fitted two different models: one that relies only on visible matter, and another that allows for additional gravitational effects beyond what normal matter can explain. To judge which model works better, we used statistical tools such as AIC and BIC, which measure how well a model fits the data. By ranking galaxies according to the difference in AIC, we were able to identify the cases where visible matter alone cannot account for the observed rotation. In most situations, these differences are linked to the presence of dark matter, but they could also hint at more exotic possibilities, such as effects from extra dimensions. Overall, our study highlights a set of galaxies where additional gravitational effects are most evident. These results offer new insight into how mass is distributed in disk galaxies and point to promising targets for future investigations of dark matter and related phenomena.

Keywords: *Dark Matter, SPARC, Galaxy Rotation Curves, Extra Dimensions, AIC, BIC, Yukawa Potential.*

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I. INTRODUCTION

The rotation speeds of stars and gas in galaxies provide important clues about how mass is distributed within them. Observations show that many galaxies rotate faster than what would be expected from visible matter alone. This difference is usually explained by the presence of dark matter, an unseen component that adds extra gravitational pull [1], [2].

In this work, we use data from 175 disk galaxies in the SPARC database [3] to compare two models: one that includes only the visible, baryonic matter, and another that allows for additional gravitational effects. By comparing the fits using statistical measures like AIC and BIC, we can identify galaxies where the observed rotation cannot be fully explained by stars, gas, and bulges alone.

While the extra gravitational effects we detect are mainly interpreted as dark matter, some cases could also be consistent with other possibilities, such as extra dimensions affecting gravity [4], [5].

II. LITERATURE REVIEW

The study of galaxy rotation curves has been central to uncovering the existence of dark matter. Early observations by Rubin et al. [1] showed that stars in spiral galaxies rotate at nearly constant speeds far beyond the visible disk, inconsistent with Newtonian predictions based solely on luminous matter. This discrepancy was reinforced by subsequent analyses of large samples of galaxies [2], leading to the hypothesis of massive, unseen halos of dark matter.

Several theoretical frameworks have been proposed to ex- plain these deviations. Cold Dark Matter (CDM) models, characterized by the Navarro–Frenk–White (NFW) density profile [7], provide a successful cosmological description of halo structure but face challenges on galactic scales, such as the core–cusp problem [8]. Alternative approaches, such as Modified Newtonian Dynamics (MOND) introduced by Milgrom [9], attempt to explain rotation curves without invoking dark matter by altering the laws of gravity at low accelerations. Although MOND fits some galaxies well, it struggles with cluster-scale phenomena and cosmological consistency.

Another line of inquiry explores more exotic possibilities, such as extra-dimensional physics. Models by Arkani-Hamed et al. [4] and Randall and Sundrum [5] suggest modifications to gravity arising from hidden dimensions. Such scenarios predict Yukawa-type corrections to Newtonian gravity, which can leave detectable imprints on galactic rotation curves.

Datasets like the SPARC compilation [3], containing precise measurements of 175 disk galaxies, have become a

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benchmark for testing these models. Studies such as McGaugh [6] high- light the predictive power of baryonic matter in shaping rota- tion curves, while still leaving room for unexplained residuals that hint at either dark matter or modifications to gravity. Thus, the literature motivates the need for careful statistical model comparisons to disentangle baryonic contributions from hidden mass or alternative gravitational effects.

➢ *Data Source*

We used the SPARC database, which provides detailed rotation curves for 175 disk galaxies, including radial dis- tances, observed rotation velocities, and contributions from stars, gas, and bulges. Uncertainties in the observed velocities were incorporated into the model fitting.

III. METHODOLOGY

Our study followed a structured process to test whether visible matter alone can explain the observed galaxy rotation curves, or if extra gravitational effects are required. The main steps are outlined below:

➢ *Data Preparation:*

We selected 175 disk galaxies from the SPARC database. For each galaxy, we collected the observed rotation velocities along with the contributions from stars, gas, and bulges. Only galaxies with at least four reliable data points were included.

➢ *Model Selection:*

Two models were considered. The first assumes that the rotation is entirely due to baryonic matter (stars, gas, bulge). The second adds an extra term inspired by a Yukawa-type potential, which represents possible new physics such as dark matter or modified gravity.

➢ *Parameter Fitting:*

We applied non-linear least squares fitting to adjust the parameters of each model. Limits were placed on the parameters to ensure that the results remained physically meaningful.

➢ *Statistical Evaluation:*

For each galaxy, the quality of the fits was measured using chi-squared (χ^2), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). These tools allow a fair comparison between models with different numbers of parameters.

➢ *Ranking of Galaxies:*

Galaxies were ranked using the difference in AIC values (ΔAIC). A negative ΔAIC means that the extended model gave a better fit than the baryons-only model. The most negative values highlight galaxies where extra gravitational effects are most likely present.

This process ensured that the comparison between models was systematic and statistically robust, while also making it possible to identify the galaxies that show the clearest signs of hidden mass or new physics.

IV. MODELS

➢ *Baryons-Only Model*

Assumes galaxy rotation is entirely determined by visible matter (stars, gas, and bulge). A scaling parameter *A* adjusts the amplitude of predicted velocities.

➢ *Extended Yukawa-Type Model*

Adds a term for extra gravitational effects beyond visible matter:

➢ *Detection Criteria*

Galaxies were ranked using:

$$\Delta\text{AIC} = \text{AIC}_{\text{Extended}} - \text{AIC}_{\text{Baryons}}$$

Negative values of ΔAIC indicate preference for the extended model.

➢ *Observations*

The SPARC database provides detailed measurements of galaxy rotation curves for a wide variety of disk galaxies that differ in size, brightness, and structure. From our examination of this data, a few clear patterns appear:

- Flat Rotation Curves: In many galaxies, the rotation speed stays almost constant, or even rises slightly, at large distances from the center. This cannot be explained by visible matter alone.
- Central Regions: Near the center of several galaxies, the observed speeds are higher than the values predicted by the contributions of stars and gas, pointing to the influence of extra gravitational effects.
- Differences Between Galaxies: Some galaxies can be ex- plained fairly well with models that include only baryonic matter, while others show large gaps between prediction and observation, making it necessary to use extended models with additional terms.
- Model Parameters: For the strongest candidate galaxies, the extra parameter α in the Yukawa-type model comes out positive and improves the fit significantly, as shown by negative ΔAIC values.

V. RESULTS

We analyzed rotation curves for 175 disk galaxies from the SPARC database. Galaxies with fewer than four reliable data points were excluded from the fits. For each galaxy, both the baryons-only and the extended model were fitted, and the fit quality was evaluated using ², AIC, and BIC.

➢ *Top Candidates*

Galaxies with most negative ΔAIC values are strong candi- dates for additional gravitational effects. The parameter α was

$$2 \quad 2 \quad v\ (r) = v$$

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baryons

$(r) + \alpha\, e^{-r/\lambda}$

positive and significant at the 95% confidence level.

where α is the strength of the extra effect and λ is its length scale.

➢ *Fitting Procedure*

We fitted both models using non-linear least squares:

- Only galaxies with at least four reliable data points were included.
- Parameter bounds ensured physically meaningful values.
- Fit quality was evaluated with χ^2, Akaike Informa- tion Criterion (AIC), and Bayesian Information Criterion (BIC).

Table 1 Top Three Galaxy Candidates with Most Negative ΔAIC Values and Confirmed Detections.

ID	dAIC	detection
UGC00731	-34.262	True
UGC06667	-21.551	True
UGC05829	-13.027	True

Table I lists the galaxies with the strongest evidence for additional gravitational effects. These galaxies exhibit highly negative ΔAIC values, supporting the significance of the fitted parameter α.

➢ *Rotation Curves*

Rotation Curves Figures 1–3 show the rotation curves of the top candidate galaxies. Observed velocities are plotted as black points with error bars, the baryons-only model is shown with a dashed line, and the extended model fit is displayed with a dash-dot line. For example, in Figure 1 (UGC00731), the extended model matches the observed velocities much more closely than the baryons-only model, especially in the inner and middle regions of the galaxy. The figure also shows the AIC and the 95.

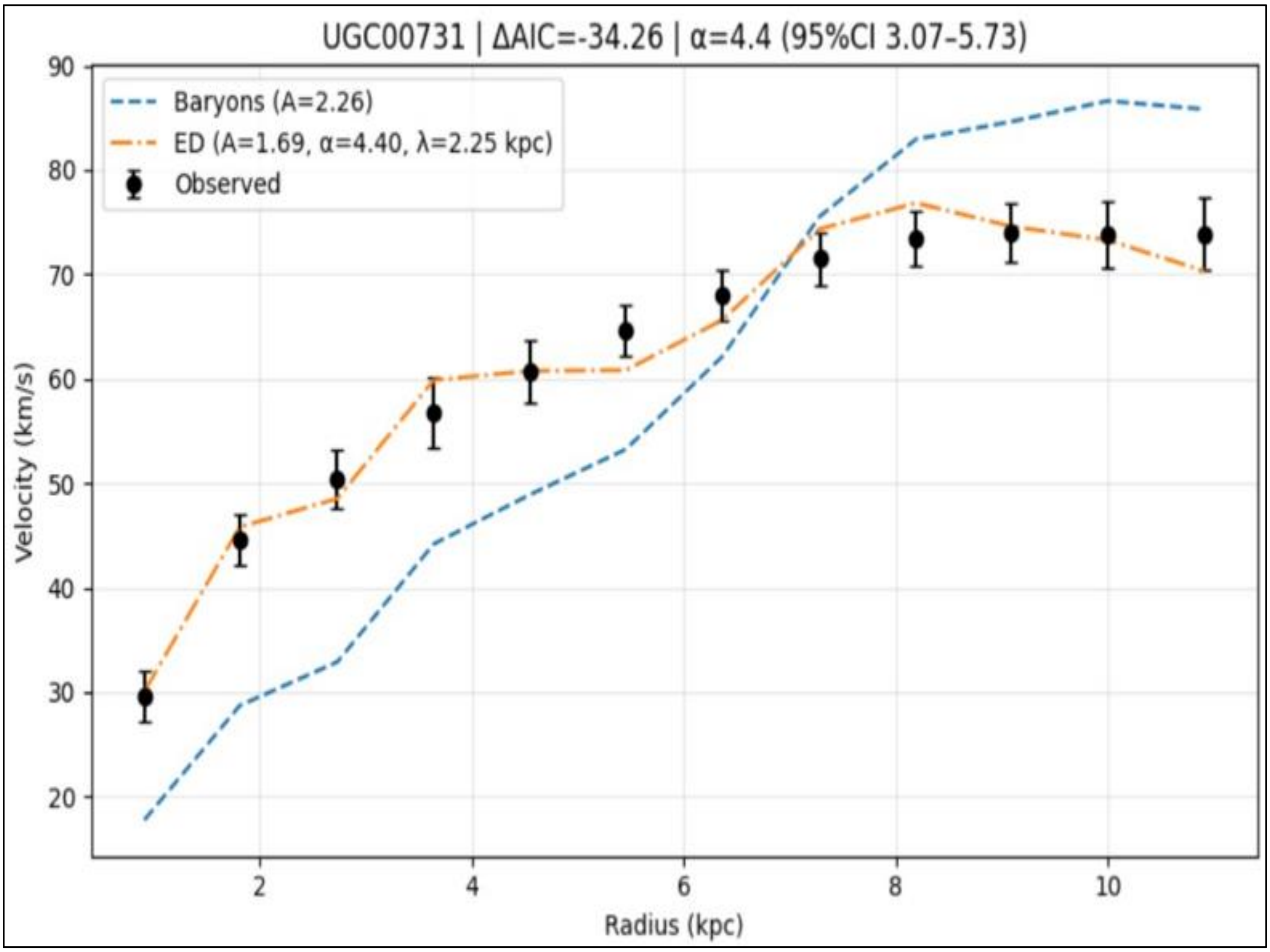

Fig 1Rotation Curve of UGC00731 with Model Fits.

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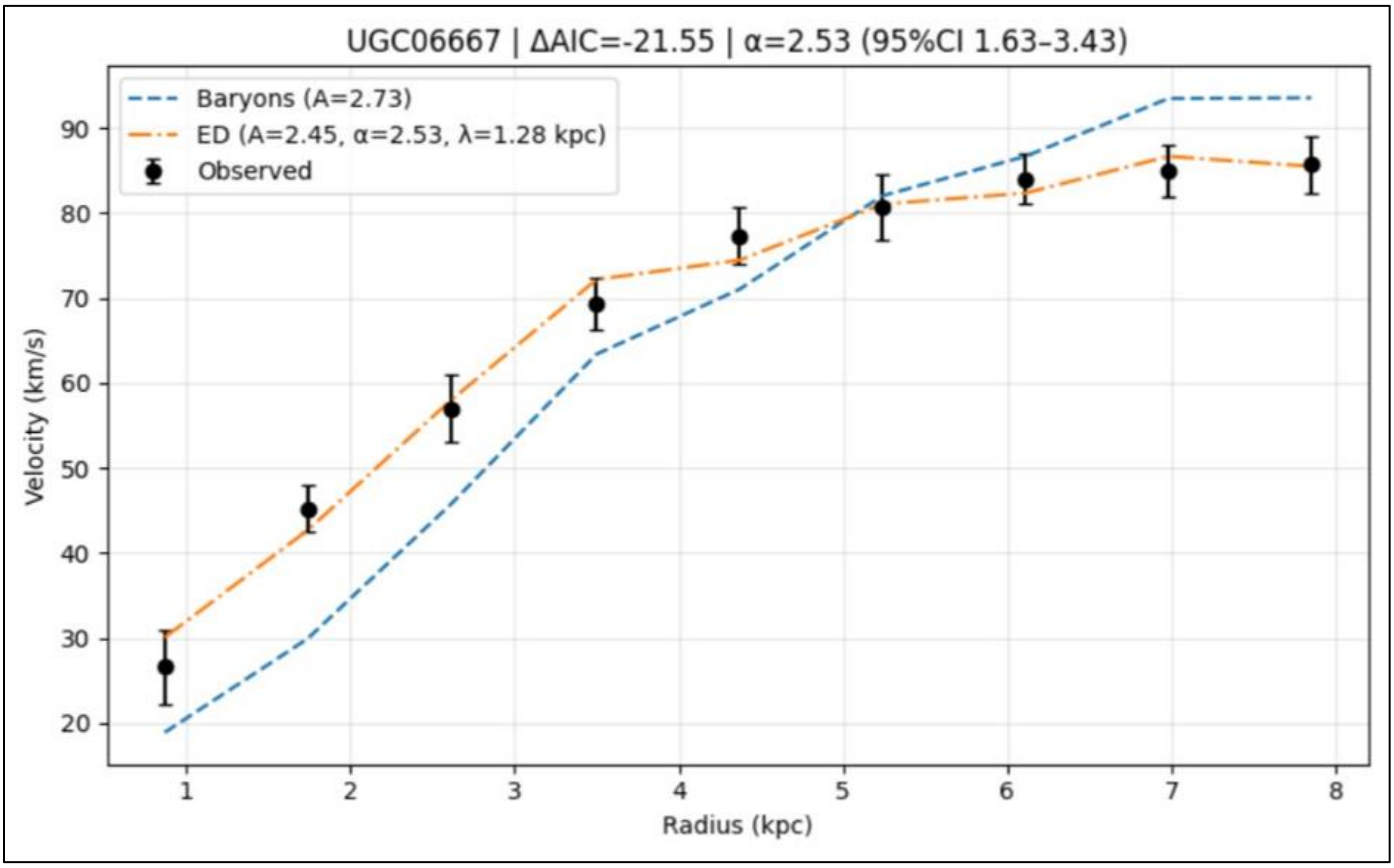

Fig 2 Rotation Curve of UGC06667 with Model Fits.

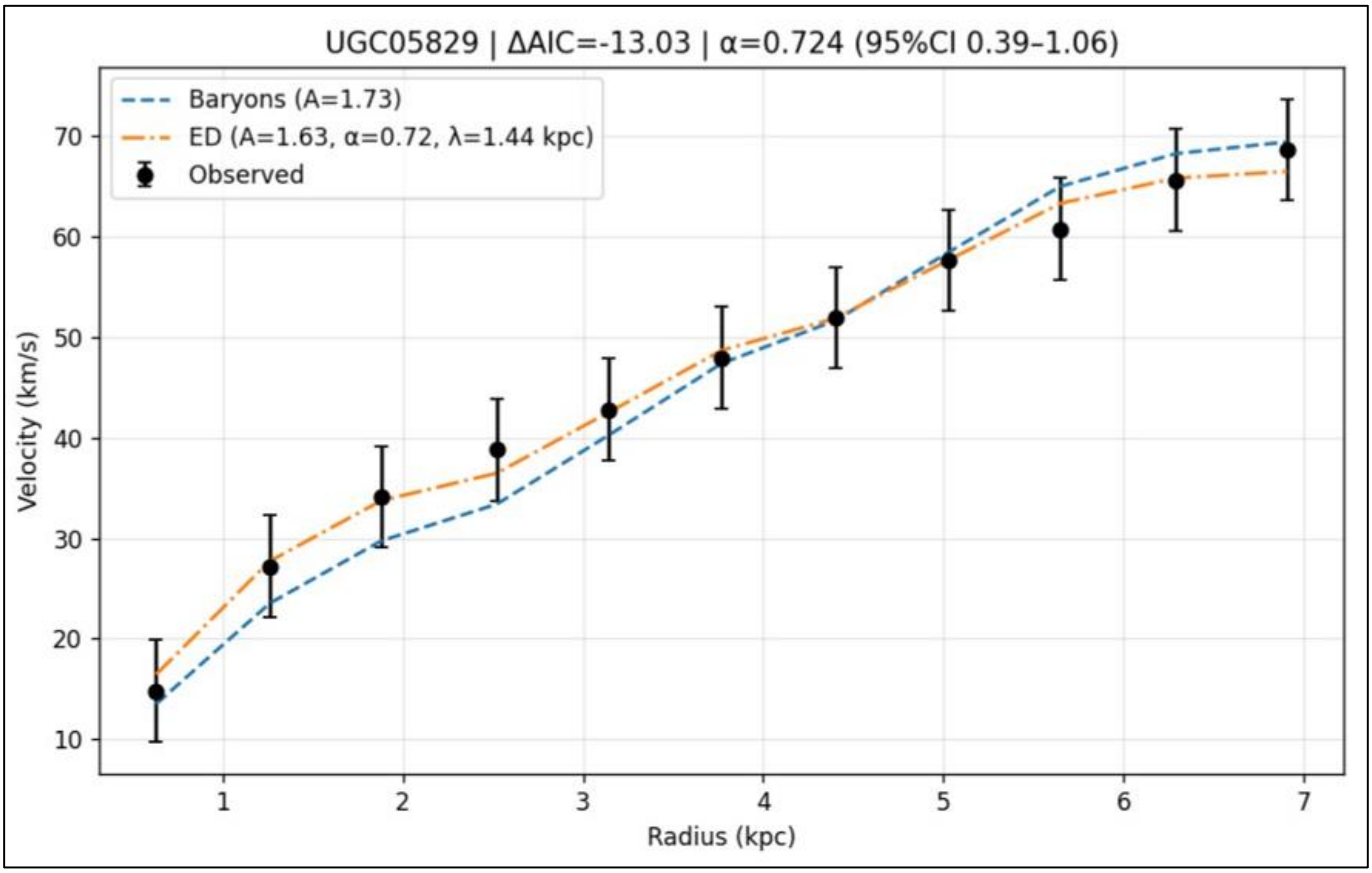

Fig 3 Rotation Curve of UGC05829 with Model Fits.

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VI. CONCLUSION

In this study, we analyzed the rotation curves of galaxies from the SPARC dataset to understand the discrepancies between observed velocities and those predicted by visible (baryonic) matter. These differences are primarily interpreted as evidence for dark matter, which helps explain why galaxies rotate faster than what baryons alone would predict.We also explored the possibility that some of these discrepancies could arise from more exotic physics, such as extra-dimensional effects, by fitting a Yukawa-type modification to the standard model. Using statistical measures like AIC and confidence intervals for the extra-dimensional parameter, we identified galaxies where this extended model provides a significantly better fit. Overall, most galaxies are well explained by the presence of dark matter, which accounts for the difference be- tween observed and baryonic velocities. A few galaxies show deviations from this standard explanation, which might also be interpreted as possible extra-dimensional effects. This study provides a way to rank galaxies based on these deviations and highlights candidates for further investigation, helping us better understand galaxy dynamics and the nature of dark matter.

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