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EUCLID: EARLY RELEASE OBSERVATIONS – DENSITY PROFILES OF THE FAR OUTSKIRTS OF GALAXIES IN THE PERSEUS CLUSTER

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Abstract. The Early Release Observations (ERO) of the Perseus Cluster, obtained by the Euclid mission, provide us with an unprecedented deep view of a massive galaxy cluster environment. With high-resolution imaging in both the VIS and NISP bands, over 1,000 dwarf galaxies have been identified, contributing to the most complete luminosity function catalog for Perseus to date. This study investigates the structural properties of 102 massive disk galaxies within the cluster, focusing on the spatial distribution and environmental dependence of Type II (truncated) and Type III (anti-truncated) profiles. The results reveal a concentration of Type II galaxies near the cluster core, suggesting that mechanisms such as ram-pressure stripping and bar-induced resonances play a role in truncating disks. Meanwhile, Type III profiles are more evenly distributed, indicating that accretion events and minor mergers may drive their formation. Future studies, including kinematic analysis, will further explore the influence of galaxy mass, morphology, and cluster dynamics on these profiles.

Keywords: Galaxies: clusters: individual: Perseus, Galaxies: interactions, evolution

1 Introduction

The Euclid mission (Collaboration et al. 2024) has delivered its first significant results through the Early Release Observations (ERO) program (Cuillandre et al. 2024a), offering new insights into the structure of galaxies across diverse environments. The ERO data deliver deep imaging in both the optical (VIS) and near-infrared (NISP) bands, allowing for the exploration of faint, extended structures in galaxies, as well as the detection of low-surface-brightness features previously inaccessible. This first release represents a major milestone in achieving Euclid's mission goals of probing dark matter and dark energy by improving our understanding of cosmic structures.

Among the ERO observations, the Perseus Cluster was imaged in exceptional details, revealing a wide variety of galaxy morphologies, ranging from massive ellipticals to low-mass dwarfs. One of the most significant discoveries was the identification of over 1,000 dwarf galaxies, contributing to the deepest and most complete luminosity function catalog for this cluster to date (Marleau et al. 2024; Cuillandre et al. 2024b). These data offer a unique opportunity to study galaxy evolution within the dense environment of a massive galaxy cluster, where interactions between galaxies and the intracluster medium play a critical role in shaping galaxy structure. The colour image of the Perseus Cluster in Figure 1, combining VIS and NISP bands, beautifully illustrates the diversity of structures observed.

A key aspect of galaxy evolution that can be studied using these deep observations is the surface brightness profile of galaxies. The structure of galaxy disks is often characterized by different types of surface brightness profiles, which reflect both internal dynamics and external environmental influences. Early models assumed that galaxy disks follow a simple, exponentially declining surface brightness profile (Freeman 1970). However, more recent studies have shown that the profiles of galaxy disks can exhibit more complex behavior, especially at large radii, leading to the classification of disk profiles into three main types (Pohlen & Trujillo 2006):

- **Type I:** A pure exponential decline, extending smoothly beyond the 25th magnitude isophote, typically observed in galaxies with minimal external disturbance.

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- **Type II:** A truncated, or down-bending, profile where the surface brightness drops sharply beyond a certain radius. This truncation is often linked to dynamical phenomena such as bar resonances or star formation thresholds (Kennicutt 1989; Elmegreen & Hunter 2006).
- **Type III:** An anti-truncated, or up-bending, profile where the surface brightness increases beyond a certain radius, possibly due to accretion of material or external interactions such as minor mergers (Erwin et al. 2008).

The Perseus Cluster, located at a distance of 72 Mpc, provides us with an ideal environment to study the effects of such external influences on galaxy structures. Previous studies of clusters, such as Virgo and Coma, have shown that dense environments can significantly alter the outer regions of galaxies. In Virgo, Erwin et al. (2012) found a lack of Type II profiles in the cluster core, suggesting that truncations may be disrupted by tidal interactions and ram-pressure stripping. In contrast, Head et al. (2015) found that in Coma, truncated profiles persist even in the core, suggesting that internal factors, such as bars or resonances, may stabilize these structures despite the harsh cluster environment. Here, I will present the distribution of different profile types within the 0.5 deg^2 image, covering 25% of the cluster's r_{200}, as inferred from the surface brightness profiles of the disk galaxies.

2 Methodology

The detailed methodology and results of this analysis are provided in Mondelin et al. (in prep). However, I present here some key elements and tools that enabled me to obtain these initial results.

Surface brightness profiles of galaxies in the Perseus Cluster were extracted using two complementary photometric tools: `AutoProf` and `AstroPhot`, both developed by Stone et al. (2021) and Stone et al. (2023). The choice of tool depended on the complexity of the galaxy's environment.

For isolated galaxies, `AutoProf` was employed due to its efficiency in fitting elliptical isophotes and generating surface brightness profiles with minimal computational cost. This tool is well-suited for galaxies with little to no interference from nearby objects, allowing rapid and precise extraction of disk parameters.

In contrast, for galaxies in denser regions, where the outer envelopes overlap with neighboring galaxies, `AstroPhot` was used. `AstroPhot` provides more advanced deblending capabilities to separate overlapping light profiles, ensuring accurate photometric measurements even in crowded environments. While more computationally intensive, its application was crucial in areas like the cluster core where galaxy superposition is common.

Once the profiles were extracted, they were fitted with single and double exponential models to identify truncations (Type II) and antitruncations (Type III). The break radii were measured in both the VIS and NISP bands, allowing for cross-band consistency checks. Despite the challenges posed by the high density of galaxies and contamination from foreground stars, this combination of tools enabled a detailed analysis of surface brightness profiles across different environments within the cluster, from the dense core to the more relaxed outskirts.

3 Results

3.1 *Type II and Type III Profiles*

Our analysis identified both Type II and Type III profiles within the Perseus Cluster, consistent with previous classifications by Pohlen & Trujillo (2006). The truncations (Type II) occur around 25-26 magnitudes per arcsecond in both the VIS and NISP bands, while antitruncations (Type III) show distinct up-bending breaks at similar surface brightness levels. These breaks are key to understanding how internal mechanisms, such as bars or resonances, and external factors like interactions within the cluster, contribute to shaping these profiles.

3.2 *Environmental Dependence*

The spatial distribution of the profiles, shown in Figure 2, reveals a clear correlation between environment and profile type. Type II galaxies are primarily located near the cluster core, where stronger tidal forces and ram-pressure stripping dominate. Out of the four Type II galaxies identified, three are within a few hundred kiloparsecs of the cluster's central galaxy, reinforcing the idea that environmental mechanisms probably contribute to maintaining the truncation of their disks.

Fig. 1. Colour image of the Perseus Cluster released worldwide by the ESA in November 2023, created by combining VIS and NISP *Euclid images using the I_E band in the blue, Y_E in the green, and H_E in the red. Credit: ESA/Euclid/Euclid Consortium/NASA, image processing by J.-C. Cuillandre, G. Anselmi.*

On the other hand, Type III galaxies are more evenly distributed throughout the cluster, with a significant proportion located in the outskirts, where accretion events or minor mergers may drive the formation of their anti-truncated profiles (Younger et al. 2007). The distribution of Type III profiles suggests that these galaxies experience less disruption from the core's gravitational forces, allowing for a sustained star formation beyond the break radius.

4 Discussion

The spatial distribution and structural analysis of Type II and Type III profiles in the Perseus Cluster provide important insights into the mechanisms shaping galaxy disks in dense environments.

For **Type II profiles**, the concentration near the core suggests that even environmental effects, such as ram-pressure stripping and tidal interactions, the truncated profile can be maintained. It is possible that these galaxies, particularly those with bars, have experienced additional internal mechanisms, such as resonances (e.g.,

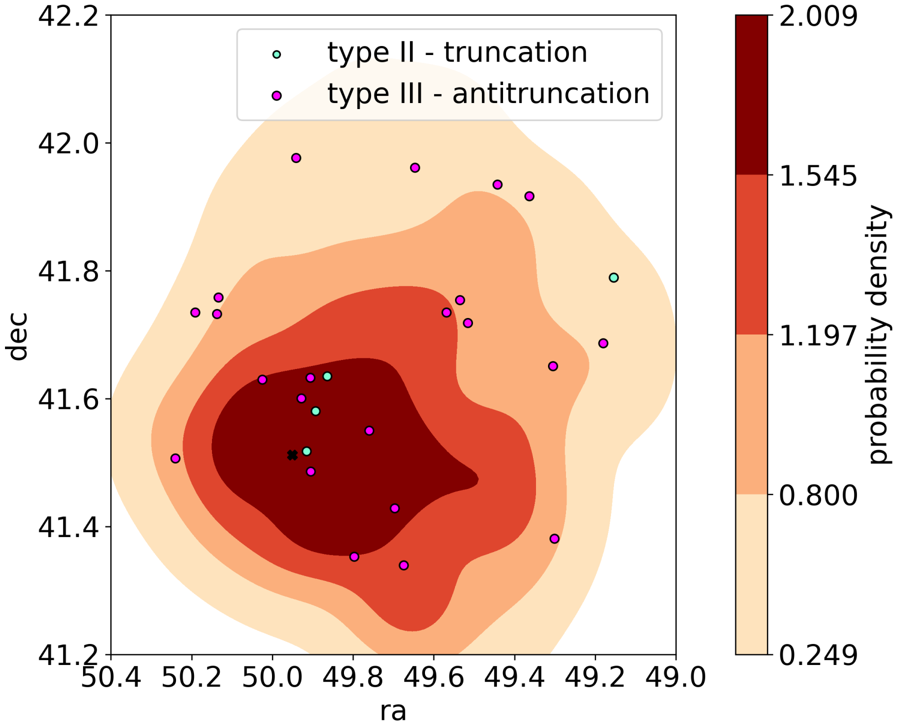

Fig. 2. Kernel Density Estimation plot of the distribution of the complete catalog (dwarfs + bright galaxies) in the right ascension versus declination plane: four probability density bins are indicated in color, showing higher probability density in the center in red and lower density in the outskirts in pale yellow. Dots are overplotted on this distribution to indicate the positions of Type II galaxies in green and Type III galaxies in magenta. The black cross indicates the center of NGC1275.

the Outer Lindblad Resonance), which could stabilize the truncations even in the harsh cluster environment (Elmegreen & Hunter 2006). Of the four Type II galaxies identified, two exhibit strong bar features, indicating that the presence of bars may help to maintain the truncated profile despite external pressures.

In contrast, **Type III profiles** appear more uniformly distributed throughout the cluster, with a substantial fraction located in the outskirts. Approximately one-third of these galaxies show a red color gradient beyond the break, indicating older stellar populations in the outer regions as suggested by Bakos et al. (2008). This is in line with the idea that accretion processes (Helmi et al. 1999) or radial migration (Sellwood & Binney 2002; Roškar et al. 2008) are the primary drivers of anti-truncated profiles in these galaxies (Younger et al. 2007). Notably, none of the Type III galaxies in Perseus were visibly barred, unlike observations in the Coma cluster, where bars are commonly associated with broken disks.

While this study has primarily focused on the spatial distribution of Type II and Type III profiles, a more detailed exploration of the relationship between galaxy mass, morphology, and profile types will be presented in *Mondelin et al. (in prep)*. This forthcoming study will provide a comprehensive analysis of how these factors influence the structural properties of galaxies in the Perseus Cluster, including the role of internal dynamics and external forces in shaping their surface brightness profiles.

As a conclusion, this study has provided new insights into the role of the environment in shaping galaxy disk profiles within the Perseus Cluster. The clear detection of both truncated (Type II) and anti-truncated (Type III) profiles across various regions highlights the complex interplay between internal dynamics and external cluster forces. Expanding the field of study to include a larger region around Perseus would also improve the statistical power of the results and help clarify the broader environmental effects on galaxy evolution. Lastly, acquiring 3D velocity maps would allow for more accurate, non-projected galaxy positions, offering deeper insights into their true dynamical behavior within the cluster.

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