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Non Parametric Decomposition of Morphological Structures in Disc Galaxies

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Abstract. Morphological decomposition in galaxies involves separating different structural components (like bulges, discs, bars, and spiral arms) to understand their individual properties and contributions to the galaxy's total light distribution. This technique, typically performed by fitting mathematical functions to galaxy images, is pivotal in understanding galaxy formation and evolution since different components form through distinct physical processes and at different cosmic epochs.
The goal of this project is to deploy a framework to perform a non-parametric decomposition of disc galaxies in modern photometric surveys and use it to analyse a sample of nearby massive disc galaxies. A non-parametric approach makes fewer assumptions about component shapes compared to traditional parametric methods, potentially revealing more complex or unexpected structures.
Preliminary results of galaxy NGC 1087 provided good segmentation of internal structures inside the galaxy, allowing a good study of the SED of each classification group. Next steps of the project involve SED fitting to determine stellar population ages, that will be compared with previous results from spectroscopy.

Resumo. A decomposição morfológica em galáxias envolve a separação de diferentes componentes estruturais (como bojos, discos, barras e braços espirais) para compreender as suas propriedades individuais e contribuições para a distribuição total de luz da galáxia. Esta técnica, tipicamente realizada através do ajuste de funções matemáticas a imagens de galáxias, é fundamental para a compreensão da formação e evolução galáctica, uma vez que diferentes componentes se formam através de processos físicos distintos e em diferentes épocas cósmicas.
O objetivo deste projeto é implementar um *framework* para realizar uma decomposição não-paramétrica de galáxias de disco em levantamentos fotométricos modernos e utilizá-lo para analisar uma amostra de galáxias de disco massivas próximas. Uma abordagem não-paramétrica faz menos suposições sobre as formas dos componentes em comparação com os métodos paramétricos tradicionais, potencialmente revelando estruturas mais complexas ou inesperadas.
Os resultados preliminares da galáxia NGC 1087 forneceram uma boa segmentação das estruturas internas da galáxia, permitindo um bom estudo da SED de cada grupo de classificação. Os próximos passos do projeto envolvem o ajuste da SED (*SED fitting*) para determinar as idades das populações estelares, que serão comparadas com resultados anteriores de espectroscopia.

Keywords. Galaxies: evolution – Galaxies: formation – Galaxies: photometry – Galaxies: stellar content – Galaxies: structure

1. Introduction

The morphological decomposition of galaxies is a fundamental tool for understanding the physical processes that govern galaxy evolution. By separating a galaxy's total light into its structural components, such as bulges, discs, bars, and spiral arms, it is possible to trace their individual assembly histories (Gadotti 2008). Traditionally, this decomposition is performed using parametric methods, such as *GALFIT* (Peng et al. 2010), which fit mathematical functions (e.g., Sérsic profiles) to the light distribution. However, these methods often rely on strong assumptions about the geometry of the components, which may fail to capture complex or asymmetric structures.

Recent advancements in Integral Field Unit (IFU) spectroscopy have allowed for non-parametric approaches based on spectral similarity. One such method is the *Capivara* code (de Souza et al. 2025), which segments data cubes by grouping pixels with similar spectral energy distributions (SEDs) using unsupervised hierarchical clustering. While IFU data provides high spectral resolution, it often faces limitations in spatial coverage and resolution.

In this work, we propose to adapt this non-parametric framework to multi-band photometric data. By using deep imaging from surveys such as PHANGS-HST (Baron et al. 2025), we aim to leverage the superior spatial resolution of photometry to identify structural components without the constraints of predefined geometric models. This paper presents preliminary results of this methodology applied to the galaxy NGC 1087.

2. Data

To validate the proposed non-parametric framework, we utilized high-resolution multi-band imaging from the *Physics at High Angular resolution in Nearby GalaxieS* (PHANGS-HST) survey (Baron et al. 2025). This survey provides a unique combination of spatial resolution and wavelength coverage, which is ideal for testing morphological segmentation without the geometric constraints of parametric fitting.

For this preliminary analysis, we selected the galaxy NGC 1087 (Fig. 1), a nearby star-forming disc galaxy. We retrieved images in five broadband filters: F275W, F336W, F438W, F555W, and F814W. These filters were chosen to provide a broad spectral coverage, from the ultraviolet, dominated by young stellar populations, to the near-infrared, which better traces the older stellar mass.

The individual images were aligned and resampled to a common pixel scale to construct a photometric hyperspectral data cube. In this setup, each spatial pixel (x, y) contains a five-point Spectral Energy Distribution (SED). This high-spatial-resolution cube allows for the identification of small-scale structures, such as star clusters and dust lanes, which are often smoothed out in traditional IFU-based surveys.

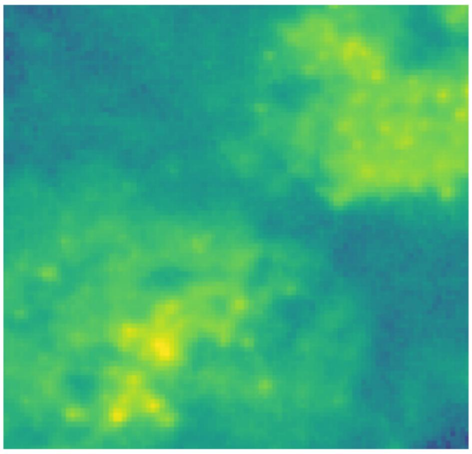

Figure 1. PHANGS Hubble Space Telescope image for filter F275W.

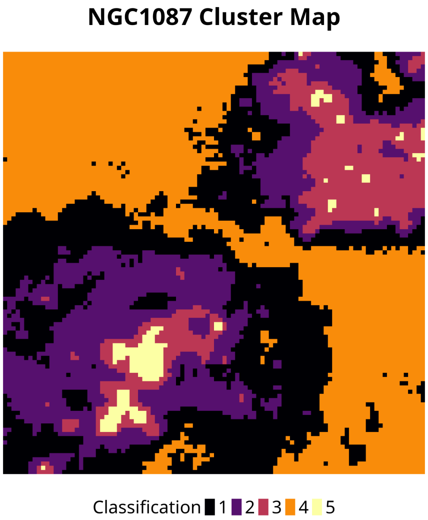

Figure 2. Cluster map for central region of NGC 1087, considering data from PHANGS survey.

3. Methods and Results

The core of our methodology is the adaptation of the *Capivara* framework (de Souza et al. 2025) for photometric data. The procedure begins by concatenating the aligned HST images into a hyperspectral data cube, effectively mimicking an IFU-like structure where each spatial element is a 5-point SED.

To perform the non-parametric decomposition, we estimate a dissimilarity matrix by calculating the pairwise distances between all SEDs in the cube. Based on this matrix, an unsupervised hierarchical clustering algorithm merges pixels into similarity groups, dissecting the galaxy into its structural components based solely on their SED shapes, without prior geometric assumptions.

Applying this method to the central region of NGC 1087, we successfully identified five distinct classification groups (Fig. 2).

Our preliminary analysis of the average SEDs (Fig. 3) reveals that Group 5, which corresponds to the brighter regions in the UV and optical images, shows a higher flux in the bluer filters (F275W and F336W), suggesting the presence of younger stellar populations.

Conversely, Group 4 represents regions between star-forming complexes with redder SEDs, likely indicating older populations or low-metallicity gas. These results demonstrate that the non-parametric segmentation can efficiently isolate structural components even with the limited spectral resolution of broadband photometry.

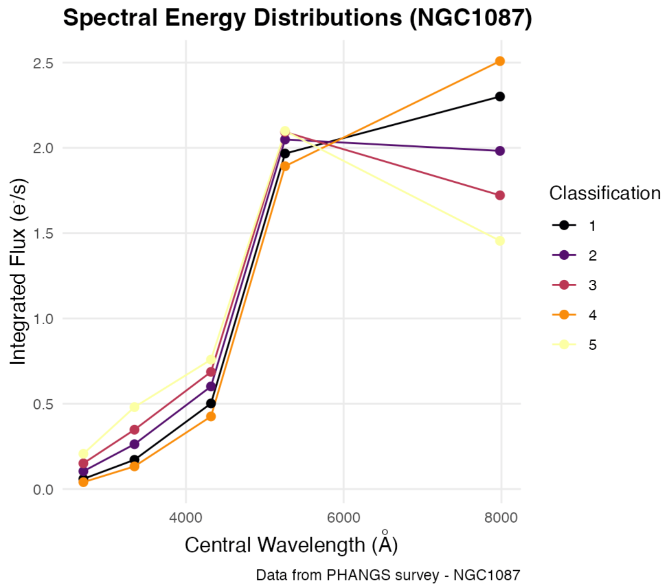

Figure 3. Figure 3: Spectral Energy Distribution for each classification in the cluster map (values normalized by the mean flux value in each segmentation group).

4. Conclusions and Future Work

Preliminary results for NGC 1087 demonstrate that non-parametric segmentation via hierarchical clustering is a powerful tool for identifying galactic structures in multi-band photometric data. By leveraging the high spatial resolution of the PHANGS-HST survey, we successfully isolated regions with distinct SED signatures, identifying young stellar populations in star-forming complexes.

The next stage of this project involves performing a detailed stellar population analysis of each identified similarity group using the Bayesian SED fitting code *ProSpect* (Robotham et al. 2020). We aim to derive star formation histories (SFHs), ages, and metallicities for these structures. Finally, we will perform a systematic comparison between our photometric results and traditional IFU spectroscopy, such as the data from the TIMER survey (Gadotti et al. 2018), to quantify the trade-off between spectral and spatial resolution in morphological studies.

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