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Preliminary study of isolated spiral galaxies using the bidimentional fast Fourier transform.

Estudio preliminar de galaxias espirales aisladas utilizando la transformada bidimensional de Fourier rápida

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ABSTRACT

We conducted a morphological analysis of the spiral structure in two isolated spiral galaxies: NGC 2756 and NGC 2776. The primary objective of this research is to gain a deeper understanding of how spiral structure is distributed in disk galaxies. To achieve this, we employed the two-dimensional fast Fourier transform method and conducted a comprehensive analysis of the Fourier spectra and radial density functions (RDF) to examine their patterns and characteristics. The results indicate that the main mode of the spiral structure is m = 2. However, using RDFs, we identified that other modes may be relevant in certain regions of the galactic disk, such as m = 3. This result suggests the existence of multiple spiral structures depending on the analyzed region.

Keywords: Spiral Structure, Fourier Transform.

RESUMEN

Realizamos un análisis morfológico de la estructura espiral a dos galaxias espirales aisladas: NGC 2756 y NGC 2776. El objetivo fundamental de esta investigación es lograr una comprensión más profunda de cómo se distribuye la estructura espiral en las galaxias de disco. Para esto, Utilizamos el método de la transformada rápida de Fourier en dos dimensiones y realizamos un análisis exhaustivo de los espectros de Fourier y las funciones de densidad radial (RDF) para examinar sus patrones y características. Los resultados indican que el modo principal de la estructura espiral es m = 2. Sin embargo, utilizando las RDF identificamos que los otros modos pueden ser relevantes en algún punto del disco galáctico como m = 3, este resultado sugiere la existencia de múltiples estructuras espirales según la región de análisis.

Palabras Clave: Estructura espiral, Espectros de Fourier.

1 INTRODUCTION

In astronomy, the morphology of isolated galaxies represents a fundamental and continually evolving research topic. The isolated galaxies, identified by their apparent lack of gravitational interaction with other galaxies, provide unique scenarios for studying morphological evolution in disk galaxies. Through detailed morphological characterization, information about the evolution and dynamics of galaxies in different environments can be obtained.

Spiral galaxies exhibit a wide variety of shapes when observed, posing a challenge to theories attempting to explain their origins. Among the different types of spiral galaxies, it is possible to identify a group that displays multiple spiral structures within the disk. These kinds of galaxies are frequently in observations, but more extensive studies have been conducted on grand-design galaxies. Because, in these galaxies, the resolution of the images and the spiral structure are much better defined.

In this study, we conducted a morphological analysis of isolated spiral galaxies with multiple arms using image processing techniques, including IRAF routines and the Fourier method. The images of the galaxies were obtained from the Sloan Digital Sky Survey (SDSS) database, which provides high-resolution images for processing.

We aimed to identify isolated spiral galaxies suitable for our study. To achieve this, we established three key criteria. First, we selected galaxies with a low redshift ($z < 0.05$) for optimal resolution and confirmation of their full evolution. Second, we focused on galaxies with multiple arms, adhering to the classifica-

tion criteria outlined in [1]. Finally, we prioritized g-band images (wavelength of 4686) for their ability to reveal morphological features associated with young stellar populations in galaxies. Following these selection guidelines, we identified spiral galaxies from UNAM-KIAS Catalog of Isolated Galaxies [2].

2 IMAGE ANALYSIS

In IRAF[1], we conducted image reduction following standard procedures for each galaxy, aiming to visualize their morphological properties more clearly and obtain an accurate count of their spiral arms. The adjustment process involves removing field stars from each image and deprojecting to the line of sight (Figure 1). After the adjustment is complete, we apply the Fourier transform algorithm [3, 4, 5, 6].

The Fourier method, especially the Two-Dimensional Fourier Transform, is employed to extract the dominant modes on the galaxy's disk, the corresponding pitch angle, and their significance as a function of radius. The Fourier transform can expressed as given in [4]:

$$\mathscr{F}[\mathbf{I}(\mathbf{v},\theta)] = A(p,m) = \frac{1}{D}\int_{-\pi}^{\pi}\int_{-\infty}^{\infty} I(v,\theta)e^{-i\gamma}dvd\theta, \quad (1)$$

Where $A(p,m)$ corresponds to the Fourier coefficients and $\gamma = (m\theta + vp)$. Furthermore, $I(v,\theta)$ is the numerical representation of the galaxy's image in the (v,θ) plane, where $v = \ln r$. Here, r and θ are polar coordinates, m represents the number of arms or harmonic modes, and p is the winding parameter related to the Pitch Angle α of the spiral by the equation $\alpha = \arctan\left(\frac{-m}{p}\right)$. D is a normalization factor.

Similarly, the density functions are calculated through the:

$$\mathbf{S_m}(\mathbf{v}) = \frac{D}{4\pi^2 e^{2v}}\int_{-\infty}^{\infty} G_m(p)A(p,m)e^{ipv}dp, \quad (2)$$

With $G_m(p)$ is a high-frequency filter defined by:

$$\mathbf{G_m}(\mathbf{p}) = \exp\left[-\frac{1}{2}\left(\frac{P-P_{max}}{25}\right)^2\right]. \quad (3)$$

3 RESULTS

We applied the Fourier method to analyze the spiral structures of two isolated galaxies: NGC 2756 and NGC 2776. These galaxies were specifically chosen due to their interesting spiral features. For reference, NGC 2756 is located at coordinates $09h\ 09m\ 00.926s$ (right ascension) and $+53d\ 50m\ 58.32s$ (declination). According to the Hubble system, it's classified as a SABc galaxy [7].

In figure 1, the image of galaxy NGC 2756 is presented after the noise extraction, centering, deprojection, and the removal of the brightness produced by the bulge with inverted colors. Through visual inspection after the reduction process, it is apparent that the winding character of the spiral arms is of type S [8]. The morphological classification implies that this galaxy is considered intermediate, with a possible bar in the core. The spiral arms of this galaxy exhibit an apparent symmetry in the disk distribution and a possible bifurcation near the nucleus, located at approximately 4.5 Kpc in the vertical direction.

The Fourier spectra of NGC 2756 reveal that the $m = 2$ mode dominates significantly over the other modes, indicating the presence of a two-armed spiral symmetry in this galaxy. The $m = 3$ mode is slightly dominant in some regions of the disk, and the $m = 4$ mode, with an amplitude of approximately 0.5, is the second most relevant mode.

Figure 2 shows the Fourier spectra of galaxy NGC 2776 after the reduction process. The spiral structure of this galaxy is of type S [8], and it exhibits fragmented spiral patterns, especially in the southeast region. In the image, there is evidence of symmetry in parts of the disk with at least two spiral arms in the northeast and southwest. The Fourier spectra reveal that the $m = 2$ mode is dominant, and the $m = 1$ mode prevails in a specific region, along with the $m = 4$ mode, which holds some significance as its amplitude is 0.5. This result is important because one of the characteristics of galaxies with multiple arms is that they often have a dominant spiral structure resembling that of a two-armed spiral galaxy.

3.1 *The density functions*

When identifying the dominant modes in the Fourier spectra, a theoretical spatial distribution or density function is constructed using complex functions, which allows for determining the theoretical radial distribution of each mode [2], as shown in figures 3 and 4. In this way, the objective is to establish whether the galaxy can be considered as having multiple arms throughout the entire disk or only in specific regions.

With the radial density functions obtained for galaxy NGC 2756 (Figure 3), it is possible to identify that the $m = 2$ mode dominates in regions close to the core, while at approximately 7.3 Kpc, this mode becomes less relevant as the $m = 4$ mode increases. The functions for this galaxy exhibit some peculiar characteristics in a region of the disk, as they seem to converge in the vicinity of 9 Kpc to 10 Kpc, where the $m = 2$ mode gains prominence. In the outer regions, the $m = 4$, $m = 3$, and $m = 1$ modes oscillate to the outermost point, indicating that the galaxy may have multiple arms in different regions of the disk, not necessarily in the central or outer regions with $m = 1$

For galaxy NGC 2776 (Figure 4), it is interesting to note that, although the $m = 3$ mode does not exhibit very high amplitude in the Fourier spectra (see Figure 2), upon examining the density functions shown in Figure 4, it becomes evident that this mode is dominant in various areas of the disk. The first identified region spans from approximately 6 Kpc to 11 Kpc, while the second region extends from 23 Kpc to the outermost limit of the spiral structure. A potential bifurcation around 9.5 Kpc can be observed

[1] Image Reduction and Analysis Facility. `https//iraf.net/`

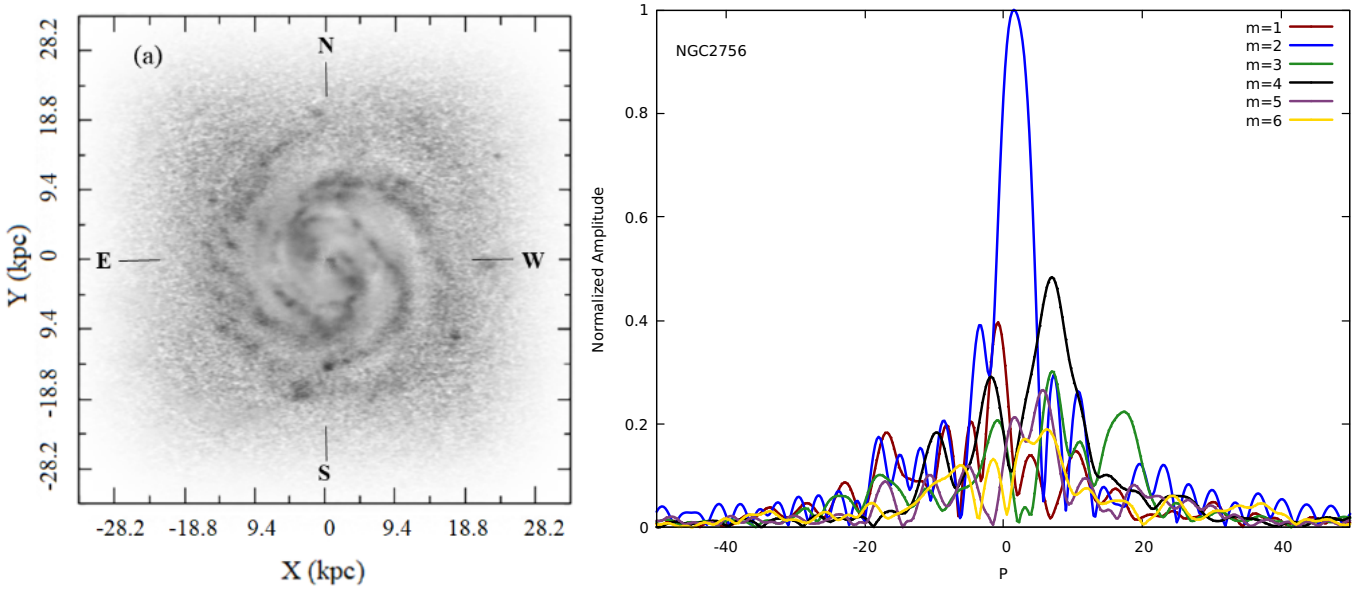

Fig. 1. Spiral Galaxy NGC 2756. The image on the left is the deprojected galaxy without field stars. The image on the right corresponds to the Fourier spectra.

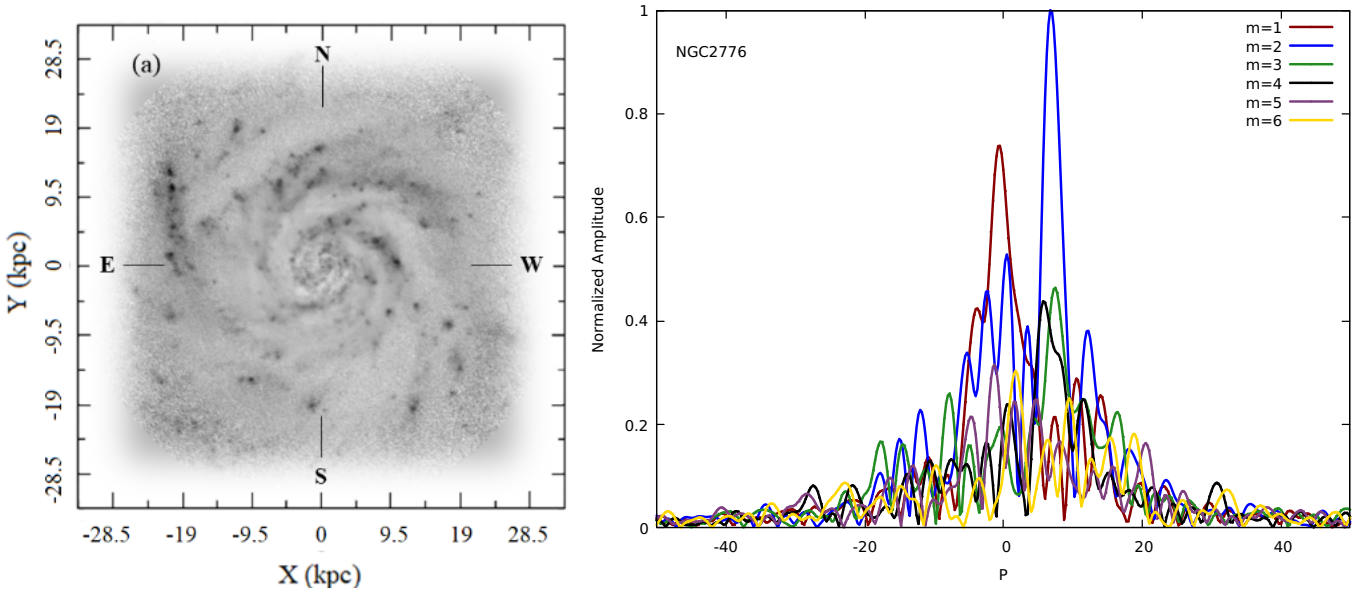

Fig. 2. Spiral Galaxy NGC 2776. The image on the left is the deprojected galaxy without field stars. The image on the right corresponds to the Fourier spectra.

in the first region. On the other hand, the density functions reveal that the $m = 2$ mode is significant across much of the disk due to the strong symmetry of the two spiral arms mentioned earlier. As for the $m = 1$ component, its importance is highlighted in the region from 11 Kpc to 14.3 Kpc.

4 DISCUSSION

We can observe that for galaxy NGC 2756 (Figure 1), based on the Fourier spectra and density functions, a diffuse bar is identified at approximately ~ 4.5 Kpc. Additionally, the presence of a bifurcation in the northern direction of the nuclear region is evident, originating at ~ 4.5 Kpc in the vertical direction, along with segmentations of the spiral structure in the southeast direction. It is demonstrated that the $m = 1$ mode is the most significant due to the broadening of an arm that originates from the inner region of the disk and extends northward. The arms extending from the bifurcation exhibit notably enhanced broadening. In the case of this galaxy, the multiple-armed spiral structure is recorded in the inner regions at approximately ~ 4.5 Kpc due to a bifurcation with a primary spiral arm.

In galaxy NGC 2776, the Fourier method allows for the identifi-

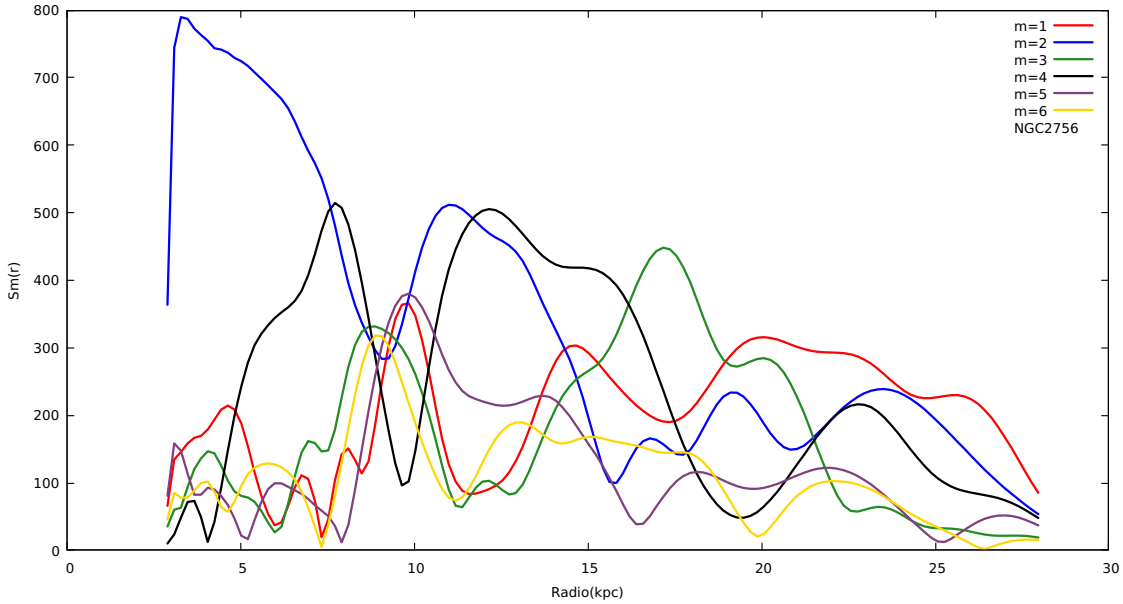

Fig. 3. Radial density functions of spiral galaxy NGC 2756 obtained from the Fourier spectra.

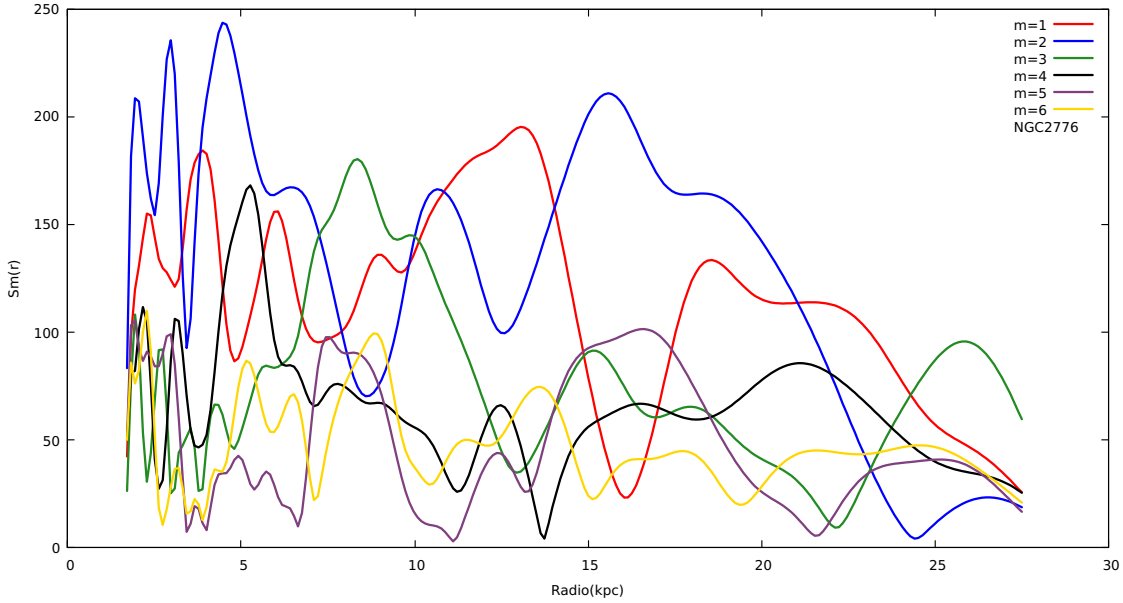

Fig. 4. Radial density functions of spiral galaxy NGC 2756 obtained from the Fourier spectra.

cation of symmetry in the inner regions of the galaxy, extending up to approximately 19 Kpc. The arm originating at 4.5 Kpc in the southwest direction and extending northward is broader. For this reason, the $m = 1$ mode holds some significance in the Fourier spectra. The spiral structure is adequately described when considered as a grand-design galaxie with multiple spiral structures caused by segmentations.

5 CONCLUSIONS

In this study, a morphological classification of two spiral galaxies has been conducted by analyzing their images using the Fourier method, especially the two-dimensional Fourier transform. This approach has allowed us to identify features of the spiral structure, such as the presence and location of bars and the extent of the spiral arms.

It was found that some modes that were not prominent in the spectra turned out to be significant in certain regions of the density functions. This enabled the identification of spiral structures with multiple arms or fragmentations in areas where the $m = 2$ mode was not dominant.

The framework of this work opens up several avenues to further study spiral galaxies with multiple arms. It is crucial to complement the morphological analysis conducted in this study

by adding the examination of Lindblad resonances and rotation curves.

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