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Quantitative analysis of spirality in elliptical galaxies

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HIGHLIGHTS

- Computer image analysis was applied to galaxies classified as elliptical by human observers.
- The analysis shows that many galaxies classified manually as elliptical have a certain slope in their arms.
- The radial intensity plot of the galaxy provides a more detailed view for detecting and measuring galaxy spirality.

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ABSTRACT

We use an automated galaxy morphology analysis method to quantitatively measure the spirality of galaxies classified manually as elliptical. The data set used for the analysis consists of 60,518 galaxy images with redshift obtained by the Sloan Digital Sky Survey (SDSS) and classified manually by *Galaxy Zoo*, as well as the RC3 and NA10 catalogues. We measure the spirality of the galaxies by using the Ganalyzer method, which transforms the galaxy image to its radial intensity plot to detect galaxy spirality that is in many cases difficult to notice by manual observation of the raw galaxy image. Experimental results using manually classified elliptical and S0 galaxies with redshift <0.3 suggest that galaxies classified manually as elliptical and S0 exhibit a nonzero signal for the spirality. These results suggest that the human eye observing the raw galaxy image might not always be the most effective way of detecting spirality and curves in the arms of galaxies.

1. Introduction

Galaxy morphology is studied for the purpose of classification and analysis of the physical structures exhibited by galaxies in wide redshift ranges in order to get a better understanding of the structure and development of galaxies. While significant research has been done to study the morphology of galaxies with spiral arms (Loveday, 1996; Ball et al., 2008; Nair, 2009; Nair and Abraham, 2010), research efforts have been focused also on the analysis of elliptical and S0 galaxies using photometric measurement of the electromagnetic radiation, ellipticity, position angle, shape, and colour (Djorgovski and Davis, 1987; Dressler et al., 1987; Scorza and Bender, 1990; van den Bergh, 2009; Kormendy et al., 2009; Kormendy and Bender, 2012). These analyses were successful in acquiring information regarding the structure and development of some of these galaxies. However, these studies have done little analysis of the spirality of galaxies that were classified as elliptical.

Studying the morphology of large datasets of galaxies have attracted significant attention in the past decade (Conselice, 2003; Abraham et al., 2003; Ball et al., 2008; Shamir, 2009; Banerji et al., 2010; Huertas-Company et al., 2011), and was driven by the increasing availability of automatically acquired datasets such as the data releases of the Sloan Digital Sky Survey (York et al., 2000). However, attempts to automatically classify faint galaxy images along the Hubble sequence have been limited by the accuracy and capability of computer learning classification systems, and did not provide results that met the needs of practical research (Thorsten, 2008; Lintott et al., 2008). This contention led to the *Galaxy Zoo* (Lintott et al., 2008) project, which successfully used a web-based system to allow amateur astronomers to manually classify galaxies acquired by SDSS (Lintott et al., 2011), and was followed by other citizen science ventures based on the same platform such as *Galaxy Zoo 2* (Masters et al., 2011), *Moon Zoo* (Joy et al., 2011), and *Galaxy Zoo Mergers* (Wallin et al., 2010).

While it has been shown that amateurs can classify galaxies to their basic morphological types with accuracy comparable to professional astronomers (Lintott et al., 2008), manual classification may still be limited to what the human eye can sense and the human brain can perceive. For instance, the human eye can sense only 15 to 25 different levels of gray, while machines can identify 256 gray levels in a simple image with eight bits of dynamic range. The inability of the human eye to differentiate between gray levels

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can make it difficult to sense spirality in cases where the arms are just slightly brighter than their background, but not bright enough to allow detection by casual inspection of the galaxy image. In fact, this limitation might affect professional astronomers as much as it affects citizen scientists.

Since the human eye can only sense the crude morphology of galaxies along the Hubble sequence, and since the classification of galaxies is normally done manually, morphological classification schemes of galaxies are based on few basic morphological types. However, as these schemes are merely an abstraction of galaxy morphology, some galaxies can be difficult to associate with one specific shape, and many in-between cases can exist.

Here we use the Ganalyzer method to transform the galaxy images into their radial intensity plots (Shamir, 2011a), and analyze the spirality of galaxies classified manually as elliptical and S0 by the *Galaxy Zoo*, RC3, and NA10 catalogues.

2. Image analysis method

The method that was used to measure the spirality of the galaxies in the dataset is the Ganalyzer method (Shamir, 2011a,b). Unlike other methods that aim at classifying a galaxy into one of several classes of broad morphological types (Abraham et al., 2003; Conselice, 2003; Ball et al., 2008; Shamir, 2009; Banerji et al., 2010; Huertas-Company et al., 2011), Ganalyzer measures the slopes of the arms to determine the spirality of a galaxy. Ganalyzer is a model-driven method that analyzes galaxy images by first separating the object pixels from the background pixels using the Otsu graylevel threshold (Otsu, 1979). The centre coordinates of the object are determined by the largest median value of the 5×5 shifted window with a distance less than $0.1/\sqrt{\frac{S}{\pi}}$ from the mass centre, where S is the surface area (Shamir, 2011a, 2012). This method allows the program to determine the maximum radial distance from the centre to the outermost point, as well as the major and minor axes by finding the longest distance between two points which pass through the centre for the major axis, and then assigning the perpendicular line as the minor axis (Shamir, 2011a). The ellipticity is defined as the ratio of the lengths of the minor axis to the major axis (Shamir, 2011a). Comparison of the ellipticity of 1000 galaxies to the ellipticity computed by SDSS (using isoA and isoB) shows a high Pearson correlation of ~0.93 between the two measurements.

After the centre coordinates of the galaxy O_x, O_y and the radius r are determined, the galaxy is transformed into its radial intensity plot such that the intensity value of the pixel (x, y) in the radial intensity plot is the intensity of the pixel at coordinates $(O_x + r\sin\theta, O_y - r\cos\theta)$ in the original galaxy image, such that θ is a polar angel of [0, 360], and r is the radial distance that ranges from 0.4 to 0.75 of the galaxy radius, producing an image of dimensionality of 360×35 (Shamir, 2011a, 2012). Fig. 1 shows an example of two galaxies and their transformation such that the *Y* axis is the pixel intensity and the *X* axis is the polar angle.

As the figure shows, in the case of the elliptical galaxy the peaks are aligned on the same vertical line, while in the case of the spiral galaxy the peaks shift. The spirality is then measured by the slope of the groups peaks as described in Shamir (2011a), such that the peak in radial distance r is grouped with the peak in radial distance $r + 1$ if the difference between their polar angles is less than 5°. This transformation makes it easier for machines to detect and measure the spirality, but can also detect spirality in galaxies that might look to the human observer as elliptical since the human eye can only recognise 15–25 gray levels, making it difficult to notice subtle spirality when looking at a raw galaxy image. For instance, Tables 1 and 2 show several SDSS galaxy images classified manually by *Galaxy Zoo* participants as elliptical, with their radial intensity plot transformation and their spirality as measured by Ganalyzer. To test how the method analyzes tidally disrupted elliptical galaxies (van Dokkum, 2005), we used several tidally disrupted galaxies from the NA10 catalogue, displayed in Table 3.

If the radial intensity plot does not feature peaks the galaxy is defined as pure elliptical. Elliptical and lenticular galaxies in some cases can also have peaks in their radial intensity plot due to the position angle, but in these cases all peaks will be aligned on the same vertical line so that the slope will be very close to zero, and therefore the galaxy will be identified as elliptical. An exception can be in cases of S0 galaxies in which the position angle of the disk is different from the position angle of the galaxy, but the difference is not greater than 5°. In that case Ganalyzer might consider the disk and the galaxy as the same arm, but the difference in the position angles will lead to a certain slope in that arm. Therefore, the arms of the galaxy will have a certain slope when measured using Ganalyzer.

The radial intensity plot can allow the detection of subtle curves in the arms that might not be easily detected by manual observation of the raw galaxy image, but becomes noticeable in its radial intensity plot. Therefore, it is possible that many galaxies that were classified manually as elliptical might in fact feature a certain spirality (Shamir, 2011a). As the table shows, while the galaxies seem elliptical to the unaided human eye, the radial intensity plot transformations of the galaxies show that the peaks of maximal intensity shift, meaning that these galaxies feature certain curves in the arms.

By defining spirality and ellipticity thresholds Ganalyzer can also be used for classifying galaxies into their broad morphological types of elliptical, spiral and edge-on, and a thorough discussion

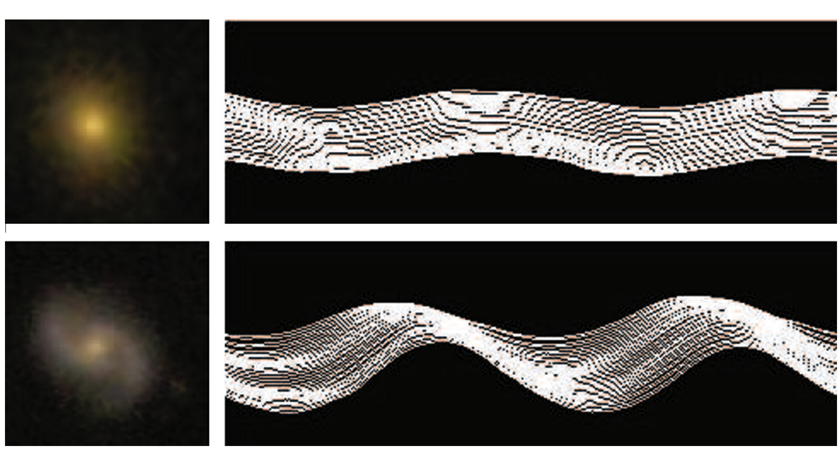

Fig. 1. Galaxy images and their transformation to radial intensity plots such that the *Y* axis is the pixel intensity and the *X* axis is the polar angle.