Resolving the Rise and Fall of Star Formation in Galaxies
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Galaxy Zoo 3D: Identifying Bars, Spirals and Foreground Stars in MaNGA Galaxy Data

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Abstract. Galaxies, particularly disc galaxies, show a wide variety of internal structures (e.g. spirals, bars, and bulges). Mapping Nearby Galaxies at Apache Point Observatory (MaNGA, part of the fourth incarnation of the Sloan Digital Sky Surveys), obtained spatially resolved spectral maps for 10,010 nearby galaxies. Many results from MaNGA have collapsed this structure into azimuthally averaged radial gradients, or symmetric 2D shapes, but there is significantly more information about the effect internal structures have on the evolution of galaxies available if we can identify different internal structures. One of the simplest ways to identify irregular internal structures in galaxies is by visual inspection. By employing a citizen science technique to ask this question of N independent volunteers we have obtained quantitatively robust masks (and errors) for spirals and bars in MaNGA target galaxies. In addition to internal features the interface asked users to identify foreground stars and foreground/background galaxies.

Keywords. galaxies: structure, galaxies: spiral, techniques: spectroscopic, methods: data analysis, surveys

1. Introduction

The MaNGA survey (Bundy et al. 2015), part of the fourth phase of the Sloan Digital Sky Surveys (SDSS-IV, Blanton et al. 2017) has obtained spatially resolved spectral maps for 10,010 nearby galaxies selected from the SDSS Main Galaxy Sample (Strauss et al. 2002) using an integral field spectrometer (IFS) system on the 2.5m Sloan Telescope at Apache Point Observatory (see Gunn et al. (2006); Smee et al. (2013); Drory et al. (2015) for technical details of the telescope and instrument). These data are now all calibrated and the final public data release happened in SDSS Data Release 17 (Abdurro'uf et al. 2022). MaNGA data can be explored with the *Marvin* software (Cherinka et al. 2019).

Many published results using large samples from MaNGA collapsed this structure into azimuthally averaged radial gradients, or symmetric 2D shapes (for a list of examples see Masters et al. (2021); Section 1), but the MaNGA data contain significantly more information about the effect internal structures have on the evolution of galaxies – if we can identify different internal structures.

The Galaxy Zoo: 3D project (Masters et al. 2021) was conceived with the idea of identifying selected internal structures, galaxy centres (whether the main target or additional galaxies), and foreground stars in MaNGA target objects through a citizen science technique. The project was inspired by Galaxy Zoo (which was first described in Lintott et al. (2008)) and ran on the *Zooniverse* citizen science platform†.

In this Proceedings based on an eTalk for IAU Symposium 373 "Resolving the Rise and Fall of Star Formation in Galaxies", I describe this project, provide a guide on how

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† `www.zooniverse.org`

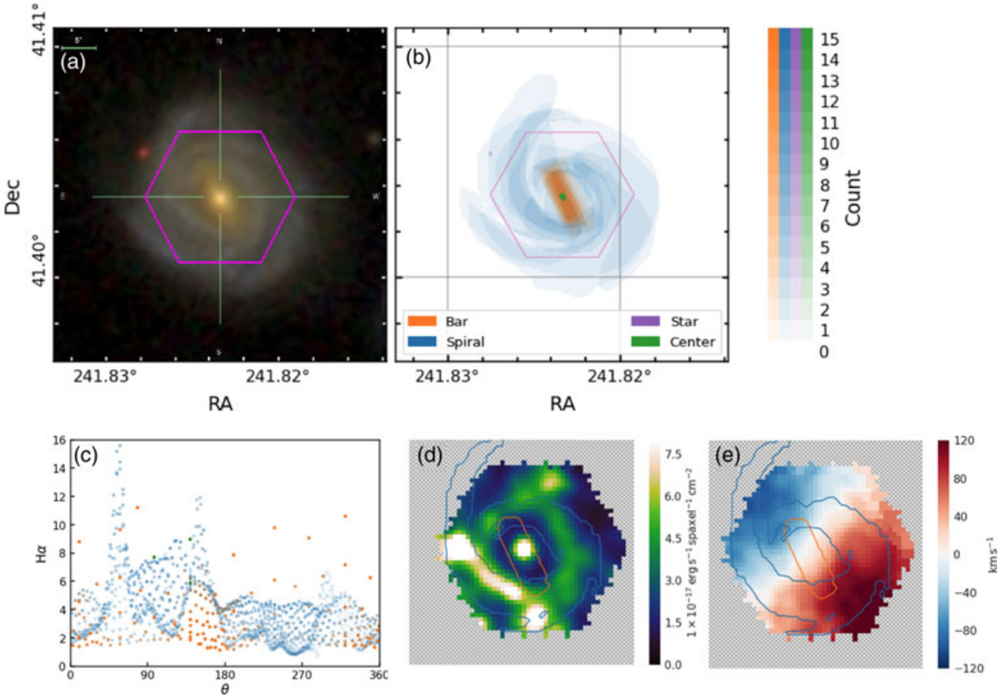

Figure 1. MaNGA galaxy (MaNGA-ID -248420) shown with a GZ:3D bar mask and spiral mask. Panel (a): image shown to *Galaxy Zoo: 3D* volunteers. Panel (b) pixel mask output. Panel (c): scatter plot of the Hα flux in each spaxel, as a function of azimuthal angle olour coded by the GZ:3D identification (e.g. orange for spaxels in the bar, blue for spiral arm spaxels). Panels (d) and (e): outlines of the bar and spiral masks overlayed on the MaNGA Hα emission map and stellar velocity map respectively. The bar contour is at the 7/15, or 47% threshold level, while the spiral is at the 3.5/15, or 23% threshold. Figure published previously as Figure 6 of Masters et al. (2021).

to make use of the results, and hi-light some already published, or in progress projects making use of them.

2. Overview

Galaxy Zoo: 3D collected crowd-sourced information about bars, spirals, galaxy centers and foreground stars for all MaNGA target galaxies. For bars and spirals, a pre-filtering was done using Galaxy Zoo 2 classifications (Willett et al. 2013) to identify MaNGA targets with such features. The images which were shown were based on the SDSS Legacy Imaging Survey (York et al. 2000), overlaid with a hexagon which showed the region covered by the MaNGA IFS. An illustration showing an example image, resulting pixel masks and some examples of how they can be used in combination with MaNGA data is shown in Figure 1. The Galaxy Zoo:3D site collected classifications in the period December 2017-October 2019 (following a beta trial phase). In total each task collected 15 independent classifications per galaxy ($N = 29,831$ galaxies in the galaxy centers/foreground stars task; $N = 5456$ in the bar drawing task, and $N = 7418$ in the spiral drawing task, which were aggregated following the methods described in Masters et al. (2021). Approximately 30% of each of these samples were ultimately observed by the MaNGA survey and therefore have accompanying IFS data.

The pixel masks and clustered galaxy centers and foreground stars were released in Masters et al. (2021) as well as through a Value Added Catalogue (VAC) in SDSS DR17 (Abdurro'uf et al. 2022). The masks were also integrated into the *Marvin* interface.†

To date works which make use of these pixel masks in combination with MaNGA data include use of the foreground star masks to flag regions were the Data Analysis Pipeline (Westfall et al. 2019) will likely fail in MaNGA galaxies; various analysis of bar properties using the bar masks (Fraser-McKelvie et al. 2019, 2020; Krishnarao et al. 2020, 2022) use of the spiral masks to indicate position of spirals (Peterken et al. 2019a,b), and to investigate dust content and star formation rates in and out of spiral arms (Greener et al. 2020; Masters et al. 2021).

The Galaxy Zoo: 3D method could easily be expanded to use samples or data beyond MaNGA, for example applied to other large scale IFS surveys, or for other applications where image segmentation masks of galaxies are desired (e.g. it's use as a training sets for machine learning methods is being explored). Interested researchers with a sample they would like to run through the Galaxy Zoo: 3D method should contact the author.

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† A tutorial showing some functionality is available here: `https://sdss-marvin.readthedocs.io/en/latest/tutorials/notebooks/VAC_GZ3D_tutorial.html`