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Letter to the Editor

A Presentation of Galaxies with Polar Structures

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ABSTRACT

Certain galaxies exist that exhibit kinematically and photometrically decoupled systems that are inclined to an extreme angle as compared to the major planar axis of the host galaxy. Historically, these have been identified and studied, however, they are quite rare and difficult to catalogue. In this work, I examined a sample of over 10,000 galaxies from the Sloan Digital Sky Survey (SDSS) Strie 82 for the presence of galaxies with these polar structures described. With the deep SDSS Stripe 82, the DESI Legacy Imaging Surveys, and the Hyper Suprime-Cam Subaru Strategic Program, 143 exceptional candidates with polar structures were found. The results indicate that the occurrence rate for which polar structures are found in galaxies is underestimated, and may total to 1.43%

Key words. galaxies: structure – galaxies: elliptical and lenticular – galaxies: formation – galaxies: evolution

1. Introduction

Polar-ring galaxies (PRGs) were identified first in a series of studies by Schechter & Gunn (1978), Bertola & Galletta (1978), and Schweizer et al. (1983), and are a rare type of galaxy that has a pronounced ring of stars and gas orbiting nearly orthogonal to the plane of the host galaxy. A more generalized class of polarized galactic structures were proposed which made space for polar/tilted discs, (Bertola et al. 1999; Mosenkov et al. 2020b), polar bulges (Corsini et al. 2012; Reshetnikov et al. 2015), halos that are perpendicular to the disc (Crnojević et al. 2016; Mosenkov et al. 2020a; Martínez-Delgado et al. 2021), and tidally disrupted material from nearby satellites (Martínez-Delgado et al. 2010; Müller et al. 2019; Martínez-Delgado et al. 2023). The class of polar structures has proven useful in exploring properties of dark matter (Whitmore et al. 1987; Sackett et al. 1994; Combes & Arnaboldi 1996; Iodice et al. 2003; Moiseev et al. 2011; Snaith et al. 2012; Khoperskov et al. 2014; Moiseev et al. 2015) as well as galactic accretion dynamics (Brook et al. 2008) and merger events (Bekki 1998; Bournaud & Combes 2003). To date, PRGs are generally understood to form from tidal accretion events, where matter from a donor galaxy is given to the host (Schweizer et al. 1983; Reshetnikov & Sotnikova 1997) which also includes the disruption of a (gas-rich) satellite into the plane perpendicular of the host (Rix & Katz 1991; Katz & Rix 1992), major mergers of galaxies (Bekki 1997, 1998; Bournaud & Combes 2003), and lastly, cosmological filament accretion (Macciò et al. 2006; Brook et al. 2008). Modern simulations conform the possibility of these structures forming in any of these manners (Liao & Gao 2019; Wright et al. 2021; Smirnov et al. 2023). While past catalogues of PRGs have experienced severe limitations in their photometric depth, more modern observations have allowed for much more careful analysis of structures previously unidentifiable. While it is unfortunate that many of these galaxies have very low average surface brightness, which has caused variance in predicted occurrence rates (See Reshetnikov et al. (2011), Reshetnikov & Mosenkov (2019)), polar structures are still discernible with deep imaging from the Sloan Digital Sky Survey. In this article, we aim to continue the study by Mosenkov et al. (2022), adding to (Mosenkov et al. (2024)) and the examination of Stripe 82 data to identify additional, previously unrecognised galaxies with polar rings. Surprisingly, we have found a total of 143 galaxies with polar rings, polar bulges and polar halos, many more than previously spotted using regular imaging, demonstrating that PRGs are more common than expected.

2. Data and sample selection

A sample of 10,000 galaxies was obtained from the Siena Galaxy Atlas (John Moustakas (2020/2023)), which is a compilation of of galaxies using the Hyperleda database. The galactic sample was randomly selected from the database. All of the images from the Siena Galaxy Atlas were downloaded from the DESI Legacy Survey and enhanced using the method described in Mosenkov et al. (2024). We note that the results of this classification are preliminary because they may be subject to our erroneous interpretation of the observed structures, so a quantitative analysis of the selected objects by means of host+ring decomposition (similar to that in Mosenkov et al. 2022) will be performed in a subsequent work. In this paper, this classification is provided only for reference, and we do not use this separation into sub-classes in the following sections. Here, we focus only on the statistics of polar rings or related objects, whereas in future paper, we will present an atlas of all selected candidates for galaxies with polar structures and explore their morphological features in detail. In Fig. 1, we present typical examples of candidates for galaxies with polar structures from the selected sample[1].

3. Results and discussion

Out of 10,000 galaxies, 143 total were labeled as exhibiting polar structures. This is consistent with Mosenkov et al. (2024), where they gave an approximate value of 1-3%. The best polar structures are presented in Figure 1. Polar structures can be formed in

[1] Mosaic images for all candidates, along with their coordinates, are available in the supplementary material.

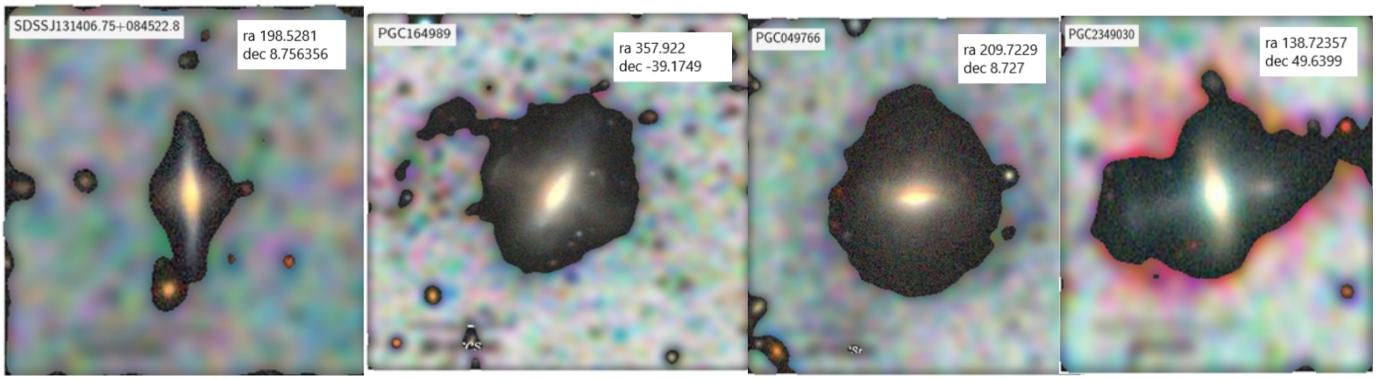

Fig. 1. Examples of candidates for galaxies with polar structures from our sample as seen in the DESI Legacy from left to right: a polar bulge structure, another galaxy with a polar bulge, a polar-halo galaxy, and a galaxy forming another polar bulge structure. The coordinates for each galaxy are given in the upper right corner of each plot, with the reference name in the upper left.

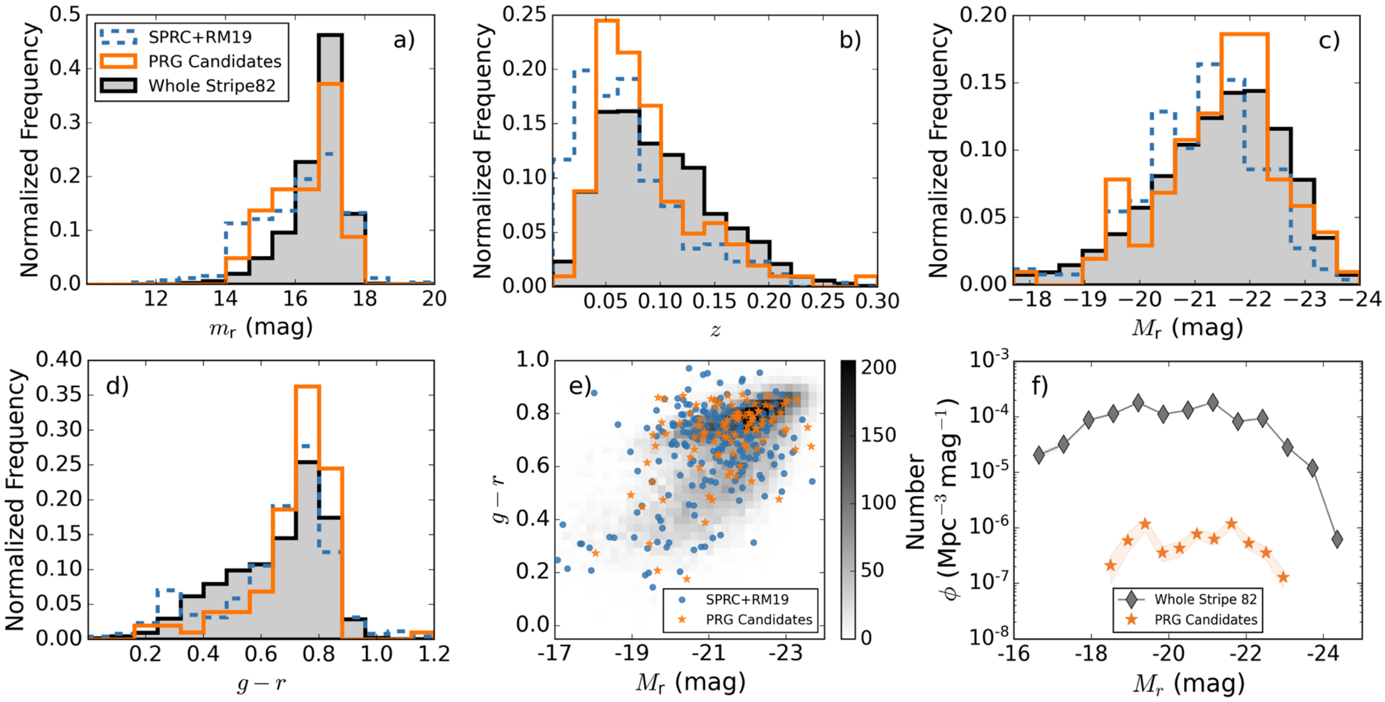

Fig. 2. Normalized histograms comparing *a)* apparent magnitude in the r band, *b)* redshift z, *c)* absolute magnitude in the r band, and *d)* galaxy colour $g-r$. The black filled histograms represent the entire Stripe 82 sample, while the SPRC+RM19 (see text) and our new candidates are shown as blue dashed and orange solid histograms, respectively. Plot *e)*: a colour-magnitude diagram (the underlying density plot depicts the distribution of the entire Stripe 82 sample of the 18,362 galaxies). All magnitudes have been corrected for K-correction (Chilingarian et al. 2010; Chilingarian & Zolotukhin 2012) and Galactic extinction using the conversions from Schlafly & Finkbeiner (2011) applied to $E(B-V)$ from Schlegel et al. (1998). Plot *f)*: luminosity functions of our new PRG sample and the entire Stripe 82 sample calculated with Chołoniewski's method (Choloniewski 1986).

a variety of different methods. Firstly, polar structures can form via tidal accretion. As two galaxies interact gravitational, polarities can form 3. Secondly, polar structures have been observed to form as repercussions of major merging. Extreme gravitational interactions yield such structures as can be viewed in 4. Thirdly, we can observe polar structures observe in starburst events. As gravitational perturbations or other phenomena trigger star burst in the host galaxy, either the gravitational perturbations themselves or the extreme increase in interstellar winds can generate polar structures. Such can be viewed in figure 5.

A final method we discuss in here (and this list is by no means exhaustive), is accretion from cosmic filaments. As a galaxy passes through filaments in large scale cosmological structures, it may develop polar structures as the intergalactic gas can frictionally force polar structures out of the host galaxy, as seen in figure 6.

Out of the 143 candidates, we can identify 70 'strong' candidates, which we consider to be those candidates that exhibit polar structures with a high confidence interval.

4. Conclusions

In this letter, we present the findings from a systematic review over the course of 10 weeks to categorize 143 galaxies with polar structures, 70 of which are highly probable candidates. This entails a PRG occurrence rate of about 1.43%. This is highly consistent with the findings of Mosenkov et al. (2024), which means the occurrence rate of galaxies with polar structures are much

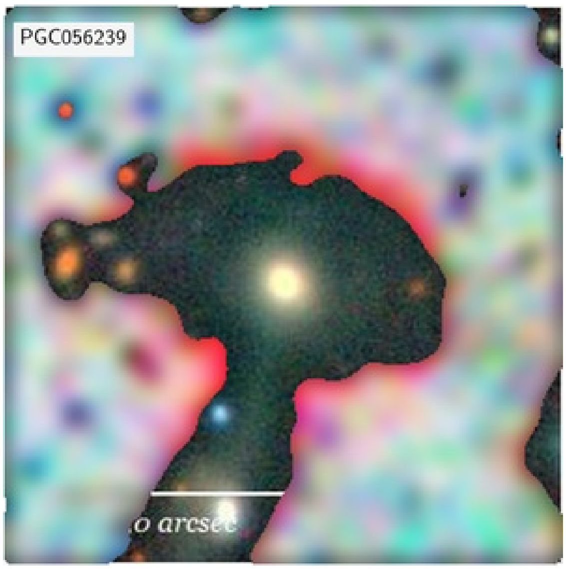

Fig. 3. A demonstration of tidal accretion– the target galaxy PGC 56239 is see to gain material from a neighbor, which forms a structure perpendicular to the plane of the galaxy.

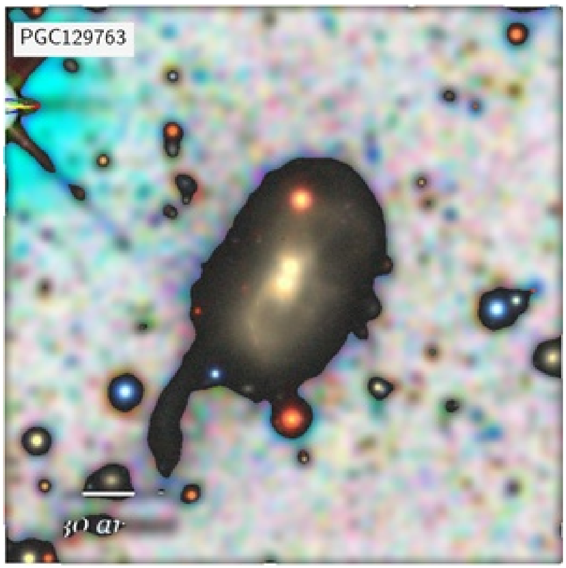

Fig. 4. A major merger is depicted, and polar structures are visible in all directions from the combining cores.

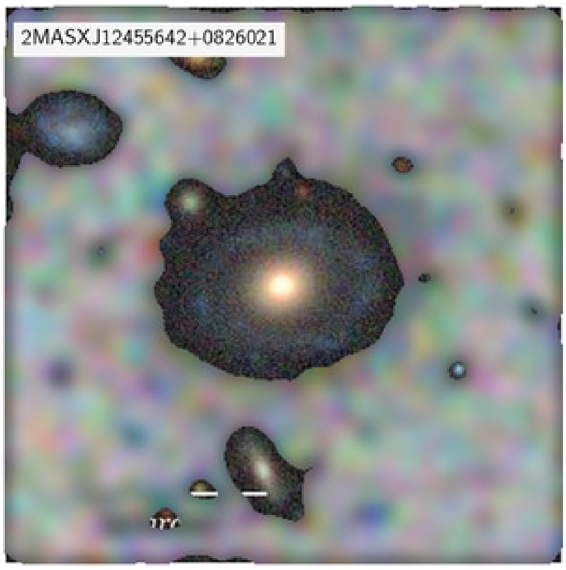

Fig. 5. The starburst event forms a ring of blue gas and star formation around the center, polar with respect to the plane of the galaxy.

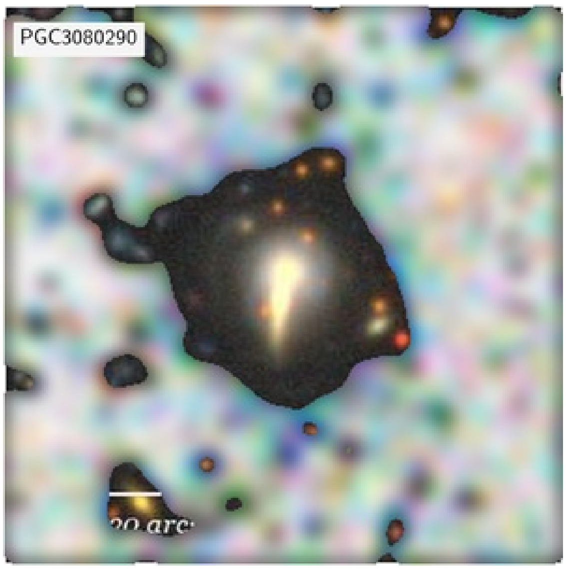

Fig. 6. The bulge/core of the galaxy is pressure stripped as it moves through intergalactic gas in a cosmic filament.

higher than previously thought (Whitmore et al. 1990, Moiseev et al. 2011). These candidates will be used to train a neural network and conduct a rigorous analysis of polar structure galaxies, based on the largest sample to date. We stress, however, that these galaxies are only candidates for polar structures and are yet to be kinematically confirmed. In a future study, we will release a full catalogue of our polar structure candidates, alongside photometric decompositions of some candidate galaxies identified here.

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