Resolving the Rise and Fall of Star Formation in Galaxies
Proceedings IAU Symposium No. 373, 2023
T. Wong & W.-T. Kim, eds.
doi:10.1017/S1743921322004732

Break type and interactions from ultra-deep optical imaging of isolated galaxies

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Abstract. In the standard cosmological model of galaxy evolution, mergers and interactions play a fundamental role in shaping galaxies. Galaxies that are currently isolated are thus interesting, allowing us to identify how internal or external processes impact galactic structure. However, current observational limits may be obscuring crucial information in the low-mass or low-brightness regime. We use the AMIGA catalog of isolated galaxies to explore the impact of different factors on the structure of these galaxies. In particular, we study the type of disk break based on the degree of isolation and the presence of interactions which are only detectable in the ultra-low surface brightness regime. We present the first results of an extensive observational campaign of ultra-deep optical imaging targeting a sample of 25 low-redshift ($z < 0.035$) isolated galaxies. The nominal surface brightness limits achieved are comparable to those to be obtained in the 10-year LSST coadds ($\mu_{r,\rm lim} \gtrsim 29.5\,\rm mag\,arcsec^{-2}$; 3σ; 10" × 10"). We find that isolated galaxies have a considerably higher fraction of purely exponential disk profiles and a lower presence of up-bending breaks than field or cluster galaxies. Our extreme imaging depth allows us to detect the presence of previously unreported interactions with minor companions in some of the galaxies in our sample (∼40% of the galaxies show signs of interaction). The results of our work fit with the general framework of galactic structure in which up-bending breaks (Type III) would be produced by mergers and down-bending breaks (Type II) due to a threshold in star formation that would tend to become single exponential disk (Type I) in case of cessation or decrease of star formation.

Keywords. galaxies: evolution - galaxies: photometry - galaxies: spiral - galaxies: structure

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1. Results and Implications

Our work is based on the Analysis of the interstellar Medium of Isolated Galaxies (AMIGA) sample (Verdes-Montenegro et al. 2005). The latest revision of the AMIGA catalog was carried out by Argudo-Fernández et al. (2013), a work on which we based our selection of the sample. We used the INT, VST, Jeanne-Rich Telescope, and HSC-SSP archival data (see Snchez-Alarcn et al. 2023, in prep.). Through careful processing of the data to preserve the low surface brightness features, the surface brightness limits achieved are of $\mu_{r,\rm lim} \gtrsim 29.5\,\rm mag\,arcsec^{-2}$, ($3\sigma$; 10" × 10") following the nominal depth description by Román et al. (2020). In Fig. 1, we show the galaxy CIG 340 comparing with SDSS and Legacy Survey data. While the morphology of CIG 340 appears similar in SDSS and the Legacy Survey, in our data we detect a clear tidal stream to the south of

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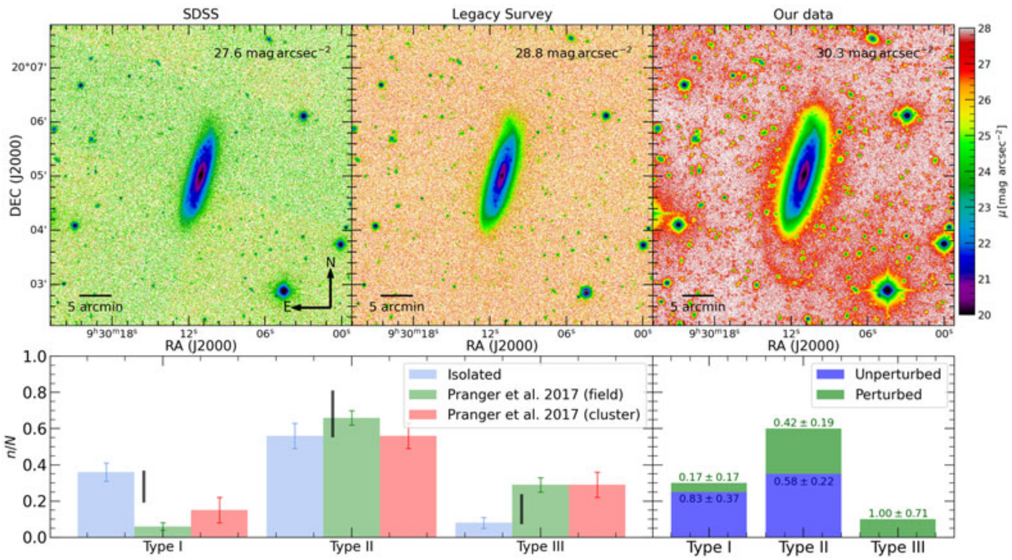

Figure 1. Upper panel: Comparison between the Sloan Digital Sky Survey (left), the Legacy Survey (middle) and our data for the CIG 340 (IC 2487) galaxy. The upper right value indicates the surface brightness limits (3σ, $10'' \times 10''$). Our work shows that the HI asymmetries detected in CIG 340 (Scott et al. 2014) are most likely due to an interaction with a satellite that we detected for the first time in the form of a tidal stream. Lower left panel: Normalized distribution on the frequency of disk break type for isolated galaxies (left, blue color), and field galaxies (middle-green) and cluster galaxies (right-red) according to work by Pranger et al. (2017). Lower right panel: Frequency of perturbed and unperturbed isolated galaxies for each disk break type.

CIG 340 and diffuse light appearing in the direction transversal to the disk. This shows the considerable leap in detection power from previously existing data, and the usefulness of our observations to reveal the presence of minor interactions.

We identify and classify the disk breaks found in the profiles for our sample of 25 isolated galaxies. We assign each galaxy a surface brightness profile Type: Type I $\equiv$ single exponential, Type II $\equiv$ down-bending, and Type III $\equiv$ up-bending. We also classify galaxies according to the presence of interactions, as perturbed and unperturbed. The strong presence of cirrus in galaxies does not allow us to assign a degree of perturbation. We compare the break type of our sample of isolated galaxies to galaxies in other environments, including in high-density (cluster) and low-density (field) environments from Pranger et al. (2017). In total, among our 25 galaxies, we identify 9 Type I with no significant break, 14 Type II, and 2 Type III, corresponding to frequencies of 36% 5%, 56% 7%, and 8% 3%. We estimate the uncertainties using a 95% confidence interval from the sample variance assuming Poisson statistics (as done in Pranger et al. 2017). We find a statistically significant difference between the type distribution of breaks in isolated galaxies as compared to field galaxies or in clusters reported in previous studies. In particular, we find that isolated galaxies have a considerably higher fraction of purely exponential disk, Type I, and a lower presence of Type III than field or cluster galaxies (see Fig. 1, bottom left). We find that 40% of the isolated galaxies in our sample show the presence of interactions, 30% show an asymmetric halo and 15% show some tidal current. Bottom right panel of Fig. 1 we show the fraction of perturbed and unperturbed galaxies for each type of break. We find that for Type I breaks, 6 ($83\% \pm 37\%$) galaxies are unperturbed and 1 ($17\% \pm 17\%$) is perturbed; for Type II, 8 ($58\% \pm 22\%$) are unperturbed and 5 ($42\% \pm 19\%$) perturbed. The two galaxies with Type III are perturbed ($100\% \pm 71\%$).

https://doi.org/10.1017/S1743921322004732 Published online by Cambridge University Press

2. Conclusions

Type III profiles can be produced by mergers of galaxies (e.g., Pfeffer et al. 2022, and references therein). The low number of Type III in our sample of isolated galaxies would be in agreement with this statement. Additionally, the only two Type III found in our sample (CIG 33 and CIG 96) show disturbed morphology with a puffed-up external halo in their outer regions, compatible with a recent major merger. Their appearing isolated would therefore be the consequence of at least one pair of galaxies having merged to produce an isolated galaxy. Type II are widely agreed to be the result of disks truncated by the star formation threshold (e.g., Tang et al. 2020; Pfeffer et al. 2022), cessation or decrease in star formation, through stellar migration effects (Sánchez-Blázquez et al. 2009), would tend to homogenize the stellar populations and produce a Type I (e.g., Pfeffer et al. 2022). We do not have star formation measurements in our sample but an indirect hint that could indicate that this is the case is the considerably higher fraction of perturbed Type II (42%±19%) than Type I (17%±17%) galaxies. While the rate of star formation may depend on various circumstances such as the rate of pristine gas inflow, it is known that satellite interaction are capable of triggering star formation (e.g., Mesa et al. 2021), which would be in accordance with our findings. The high fraction of Type I can be explained by the low ratio of perturbations detected in these galaxies. Additionally, the specific star formation rate in isolated galaxies tends to be lower than in higher-density environments (Melnyk et al. 2015). These arguments would explain the high rate of Type I in isolated galaxies, as unperturbed galaxies, evolving slowly with a low star formation rate. The results of our work thus fit within the general framework of galactic structure.

Acknowledgements

We acknowledge support from the State Research Agency (AEI-MCINN) of the Spanish Ministry of Science and Innovation under the grants "The structure and evolution of galaxies and their central regions" with reference PID2019-105602GB-I00/10.13039/501100011033, and "Thick discs, relics of the infancy of galaxies" with reference PID2020-113213GA-I00, and from the ACIISI, Consejería de Economía, Conocimiento y Empleo del Gobierno de Canarias and the European Regional Development Fund (ERDF) under grant with reference PROID2021010044. LVM acknowledges financial support from the State Agency for Research of the Spanish Ministry of Science, Innovation and Universities through the "Center of Excellence Severo Ochoa" awarded to the IAA (SEV-2017-0709), grant RTI2018-096228-B-C31 and PID2021-123930OB-C21 (MCIU/AEI/FEDER,UE), and IAA4SKA (Ref. R18-RT-3082).

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