

Euclid Quick Data Release (Q1)

A first look at the fraction of bars in massive galaxies at $z < 1$ *

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ABSTRACT

Stellar bars are key structures in disc galaxies, driving angular momentum redistribution and influencing processes such as bulge growth and star formation. Quantifying the bar fraction as a function of redshift and stellar mass is therefore important for constraining the physical processes that drive disc formation and evolution across the history of the Universe. Leveraging the unprecedented resolution and survey area of the *Euclid* Q1 data release, combined with the Zoobot deep-learning model trained on citizen science labels, we identified 7711 barred galaxies with $M_* \gtrsim 10^{10} M_\odot$ in a magnitude-selected sample ($I_E < 20.5$) spanning 63.1 deg^2 . We measured a mean bar fraction of $0.2 - 0.4$, consistent with previous studies. At fixed redshift, massive galaxies exhibit higher bar fractions, while lower-mass systems show a steeper decline with redshift, suggesting earlier disc assembly in massive galaxies. Comparisons with cosmological simulations (e.g. TNG50, Auriga) reveal a broadly consistent bar fraction, but highlight overpredictions for high-mass systems, pointing to potential over-efficiency in central stellar mass build-up in simulations. A semi-empirical model (Decode) in which bar formation is regulated by the gas fraction broadly reproduces the observed bar fractions. These findings demonstrate the transformative potential of *Euclid* for galaxy morphology studies and underscore the importance of refining theoretical models to better reproduce observed trends. Future work will explore finer mass bins, environmental correlations, and additional morphological indicators.

Key words. Galaxies: evolution - Galaxies: fundamental parameters - Galaxies: high-redshift

1. Introduction

Stellar bars, which are elongated stellar structures extending from the central regions of disc galaxies, represent a fundamental dynamical component of galaxies. They play a critical role in redistributing angular momentum within galaxies, driving secular evolution processes such as central bulge growth, fuelling active galactic nuclei (AGN), and triggering episodes of star formation (e.g. Athanassoula 2003; Kormendy & Kennicutt 2004).

The formation of bars is primarily governed by disc instabilities. Classical theoretical studies and simulations suggest that bars can form naturally in dynamically cold discs over timescales of a few gigayears, with their strength and longevity depending on factors such as the galaxy gas content, dark matter halo, and internal stellar velocity dispersion (e.g. Debattista & Sellwood 2000; Athanassoula 2003). However, the discovery of barred galaxies at very early epochs following the launch of the *James Webb* Space Telescope (JWST) has triggered new interest in the physical mechanisms responsible for bar formation (e.g. Méndez-Abreu et al. 2023; Costantin et al. 2023; Guo et al. 2024; Le Conte et al. 2024). The high gas fractions and turbulent conditions of the early Universe disfavour bar formation according to the classical view, which is supported by observational evidence from the local Universe (Masters et al. 2012). Recent simulations suggest that the ratio between dark matter and baryonic matter might play a key role in regulating bar formation (e.g. Fujii et al. 2018; Reddish et al. 2022; López et al. 2024; Fragkoudi et al. 2025).

Understanding the fraction of barred galaxies as a function of redshift and stellar mass thus provides valuable insights into the formation and growth of stellar discs across cosmic time and

baryon assembly more generally (e.g. Jogee et al. 2004; Sheth et al. 2008; Cameron et al. 2010; Masters et al. 2011; Simmons et al. 2014; Melvin et al. 2014; Erwin 2018; Guo et al. 2024).

Identifying bars in galaxies typically requires high-resolution imaging to discern the distinct morphology of barred structures. Historically, visual classification has been a powerful tool for bar identification (e.g. Eskridge et al. 2000; Elmegreen et al. 2004; Masters et al. 2011; Simmons et al. 2014), complemented by quantitative methods such as ellipse fitting (Knapen et al. 2000; Aguerri et al. 2009), Fourier decomposition (Ohta et al. 1990), and more recently machine learning (e.g. Domínguez Sánchez et al. 2018; Walmsley et al. 2022a). Previous studies using data from space facilities such as the *Hubble* Space Telescope (HST) and JWST have significantly advanced our understanding of barred galaxies, particularly beyond the local Universe (e.g. Sheth et al. 2008; Melvin et al. 2014). However, these studies are often constrained by limited area coverage, which hinders a comprehensive statistical analysis across diverse galaxy populations.

The *Euclid* space telescope represents a transformative step forward in this field. *Euclid* combines high spatial resolution and sensitivity with an unprecedented survey area for a space-based observatory, enabling a detailed study of galaxy morphology on a new scale (Laureijs et al. 2011; Euclid Collaboration: Scaramella et al. 2022; Euclid Collaboration: Bretonnière et al. 2022, 2023; Euclid Collaboration: Mellier et al. 2025; Euclid Collaboration: Aussel et al. 2024). The *Euclid* Q1 data release, which provides high-quality imaging over 63.1 deg^2 (Euclid Quick Release Q1 2025; Euclid Collaboration: Aussel et al. 2025), already represents a dramatic increase of the area probed by previous space observatories such as HST and JWST. The largest optical HST survey, the Cosmic Evolution Survey (COSMOS, Scoville et al. 2007), covers an area of only about 2 deg^2 .

In this work, we leverage the unique capabilities of *Euclid* to provide a first measurement of the fraction of barred galaxies in massive systems (stellar masses $M_* \gtrsim 10^{10} M_\odot$) up to redshift $z \sim 1$ using deep-learning classifications trained on visual inspections. This work increases the number of barred galaxies

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by more than an order of magnitude compared to prior studies based on HST and JWST data, providing a robust reference of the abundance of bars in massive galaxies over half of cosmic history.

The paper proceeds as follows. Section 2 describes the data used for this work, namely the *Euclid* Q1 data release. Section 3 details the procedure used to select the bars. The main results explore the evolution of the bar fraction as a function of stellar mass and redshift. These results are presented in Sect. 4 and discussed in Sect. 5, where we compare them with previous observational and simulated results.

2. Data and measurements

2.1. *Euclid* Q1 data release

This work uses data from the *Euclid* Q1 data release (Euclid Collaboration: Aussel et al. 2025). An extended description of the *Euclid* mission and scientific objectives can be found in Euclid Collaboration: Mellier et al. (2025). The Q1 data release comprises an area of 63.1 deg² distributed in three distinct fields: Euclid Deep Field North (EDF-N); Euclid Deep Field South (EDF-S); and Euclid Deep Field Fornax (EDF-F). All fields are observed with both the VIS (Euclid Collaboration: Cropper et al. 2025) and NISP (Euclid Collaboration: Jahnke et al. 2025) instruments. A detailed description of the Q1 data release is presented in Euclid Collaboration: Aussel et al. (2025), and specific details about the VIS and NISP data products can be found in Euclid Collaboration: McCracken et al. (2025) and Euclid Collaboration: Polenta et al. (2025), respectively. For this work, we used a number of data products accompanying the data release, accessible from the *Euclid* Science Archive System (SAS), which we detail below.

2.1.1. *Euclid* Q1 detailed morphology catalogue

The Q1 data release contains a variety of morphological measurements for detected galaxies, including non-parametric morphologies, parametric Sérsic fits, and deep learning-based detailed visual-like morphologies. We refer the reader to Euclid Collaboration: Romelli et al. (2025) for an extensive description of the *Euclid* photometric catalogue.

For this work, we primarily used the detailed morphological catalogue (see Euclid Collaboration: Walmsley et al. 2025 for more details). In brief, the catalogue contains Galaxy Zoo (GZ) type classifications, following the tree structure of the GZ-CANDELS project (Simmons et al. 2017), which uses data from the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS). The classifications were performed using the Zoobot deep-foundation model (Walmsley et al. 2022b). The model was fine-tuned with volunteer classifications of *Euclid* galaxies obtained between August and September 2024. As detailed in Euclid Collaboration: Walmsley et al. (2025), three different images were shown to the GZ volunteers to label the galaxies: an RGB image where the R channel is Y_E , the B channel is I_E , and the G channel is the mean, following a clip and an arcsinh stretch; a greyscale image where the single channel is the same as the I_E/B channel of the RGB image, for maximising resolution; and a greyscale image where the single channel is again from I_E , but adjusted to highlight low-surface-brightness features in the outskirts of the galaxies. A complete description of the data product, as well as a quantitative assessment of the accuracy, is presented in the accompanying work (Euclid Collab-

oration: Walmsley et al. 2025). In Sect. 3 we describe the procedure employed to select bars in more detail.

2.1.2. *Euclid* Q1 physical properties

In addition to morphologies, we used photometric redshifts and stellar masses from the data release. More details can be found in Euclid Collaboration: Tucci et al. (2025). Briefly, a large grid of synthetic galaxy spectral energy distribution (SED) models was generated using the Bagpipes package (Carnall et al. 2018) with delayed exponential star-formation histories. These models were fit to the Q1 galaxies with the software NNPZ (Euclid Collaboration: Tucci et al. 2025), whereby the closest 30 models in χ^2 are used to form a posterior distribution of the galaxy physical properties. In this work, we used the marginalised medians of the posterior as our point estimate in redshift and stellar mass.

2.2. Sample selection and completeness

The *Euclid* Q1 deep-learning morphological classification (Euclid Collaboration: Romelli et al. 2025; Euclid Collaboration: Walmsley et al. 2025) is provided only for galaxies with $I_E < 20.5$, or with a segmentation area larger than 1200 pixels. Although *Euclid* data allow us to measure accurate morphologies for fainter and smaller galaxies (Euclid Collaboration: Bretonnière et al. 2022), these conservative cuts have been selected to ensure very robust morphologies for this first data release (Euclid Collaboration: Aussel et al. 2024). Therefore, for the remainder of this work, we only use galaxies brighter than $I_E = 20.5$. This stringent selection severely impacts the completeness of the sample, which must be carefully addressed before deriving any scientific conclusion. Figure 1 shows the photometric-redshift – stellar-mass plane. We computed a 90% stellar mass completeness using the method from Pozzetti et al. (2010). We find that the stellar mass above which the sample is 90% complete rapidly increases with redshift, reaching around $10^{11} M_\odot$ at $z > 0.6$. This is a direct consequence of the very bright magnitude cut applied. To maintain sufficient statistics while limiting the impact of incompleteness, we included galaxies with stellar masses larger than $10^{10} M_\odot$ in the analysis. However, since this stellar mass threshold is significantly below the completeness limit, especially at high redshift, we adopted narrow stellar mass bins for analysing evolutionary trends and discuss the impact of this choice on the results of this work.

3. Bar classification

3.1. Zoobot classifications

The main result of this work is a derivation of the evolution of the bar fraction up to $z \sim 1$. Barred galaxies were selected using the Zoobot classifications included in the *Euclid* MER morphological catalogue (see Euclid Collaboration: Walmsley et al. 2025 for more details). Zoobot is a probabilistic deep-learning model trained to reproduce the GZ classification tree. For that purpose, images are pre-processed following the GZ standard. This includes scaling to limit the impact of the large dynamic range, as well as resizing so that all galaxies present a similar apparent size in the image. The model hence estimates, for each galaxy, the fraction of volunteers who would have selected a given morphological feature, had this galaxy been classified by GZ. Full details of the pre-processing, the model used, and the specific training strategy followed for *Euclid* data can be found in Euclid Collaboration: Walmsley et al. (2025).

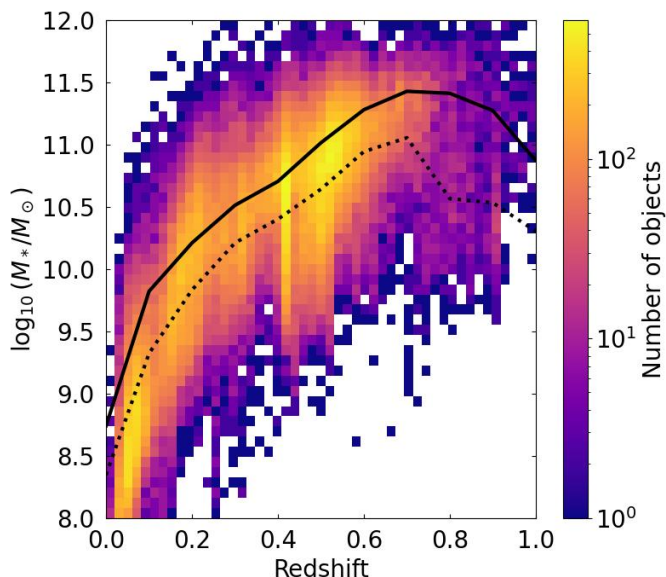


Fig. 1. Photo- z versus stellar mass diagram showing the completeness limits for the Euclid Q1-GZ data set. The 90% and 50% stellar-mass completeness limits are derived following Pozzetti et al. (2010) and are indicated by the solid and dotted black lines, respectively.

Given the tree-like structure of the Zoobot classification, we apply the following criteria to select bars:

$$p_{\text{feature}} > 0.5; p_{\text{edge-on}} < 0.5; p_{\text{bar}} > 0.5,$$

where p_{feature} , $p_{\text{edge-on}}$, and p_{bar} are the outputs of the Zoobot classification, measuring the fraction of votes for a galaxy to be classified as featured, edge-on, and hosting a bar, respectively. The first cut selects galaxies with resolved features as opposed to smooth galaxies for which the question on bars is not asked. The second cut removes edge-on discs for which identifying stellar bars is difficult. Given that this is a pure random projection effect, it should not induce any bias. Finally, the last cut selects galaxies that likely host a bar. The exact threshold used can be changed, resulting in different values of purity and completeness (Euclid Collaboration: Walmsley et al. 2025). The edge-on probability from Zoobot only removes the very inclined discs. In order to avoid any other potential bias due to inclination effects, we additionally remove all galaxies with an axis ratio lower than 0.5, measured from the parametric Sérsic fits.

Figure 2 shows some random examples of barred galaxies selected using the criteria above. The vast majority shows a clear stellar bar, confirming the soundness of the classification. For a more detailed quantification, we refer the reader to the accompanying work Euclid Collaboration: Walmsley et al. (2025). The figure also suggests that the classification is mostly sensitive to strong bars. The impact of bar strength on the inferred bar fraction has triggered extensive debate over the past decades. It is well established that works based on GZ in the local Universe (Masters et al. 2011) tend to report a systematically smaller bar fraction (around 30%) than many morphological classifications on local samples with visual inspections done by professional astronomers (e.g. Eskridge et al. 2000), which report fractions larger than 60%. A first-order explanation for this discrepancy, put forward by Masters et al. (2011), is that the 30% value found by GZ works mostly refers to strong bars and that weakly barred galaxies account for the difference with local studies. Sheth et al. (2008) also showed that the fractions of

barred galaxies at low redshift vary from about 60% to 30% if weak bars are excluded from the sample. This, however, is not a fully settled story, since the concept of a strong bar is not very well defined in the literature. In addition, Geron et al. (2021) showed that GZ classifications can be used to find weak bars with proper selection. Another possibility is that GZ might trace prominent rather than strong bars (Erwin 2018) and hence fails to detect bars in low-mass, blue, and gas-rich galaxies; however, the appendix of Kruk et al. (2018) provides more evidence linking GZ bars with strong bars only. Finally, the wavelength of observation has a significant impact on the sensitivity to identify bars. Emission from young stars, stronger in blue filters, and absorption by dust, tend to outshine or hide the presence of a stellar bar. This is why near-infrared observations are generally more suitable for exploring the abundance of bars (Eskridge et al. 2000; Knapen et al. 2000). Although the images used in this work are a composite of the I_E and Y_E bands (Sect. 2.1.1), the higher spatial resolution of VIS likely dominates the classification. We further discuss the impact of these limitations when discussing the results in Sect. 5.

3.2. Detection biases

In addition to the Zoobot classification accuracy, which mimics the visual classification, it is important to quantify intrinsic biases due to S/N and resolution differences. This is crucial for analysing redshift trends because classification biases could falsely mimic such trends. Galaxies at high redshift appear smaller, and bar sizes are expected to evolve with redshift. These factors could make it harder to detect bars, leading to an apparent decrease in the bar fraction.

To quantify these effects, we first examined the apparent and physical size distributions of galaxies in our sample as a function of redshift (Fig. 3). Interestingly, the bright magnitude cut keeps the apparent effective radius (r_e) of the sample relatively constant with redshift ($r_e \sim 1-2$ arcsec). As long as the relationship between bar length and effective radius (Erwin 2019) remains stable, bar detection is unlikely to be significantly affected by declining resolution at higher redshifts. Our selection implies that the galaxies we analyse are, on average, intrinsically larger and more massive (Fig. 1) at higher redshifts, and hence host larger bars that compensate for the degradation of resolution. Figure 3 shows that the ratio r_e/θ (where θ is the full width at half maximum of the point spread function) in physical units remains essentially constant over the redshift range explored.

Even though the size distributions are similar at different redshifts and galaxies are bright, there might be differences in the ability to detect bars between small and large galaxies and/or between faint and bright galaxies in our sample, which can cause additional biases. We attempted to quantify the impact of S/N and spatial resolution, as presented in Fig. 4. The figure shows the bar fraction (see Sect. 4 for a formal definition) as a function of I_E magnitude, observed effective radii, and surface brightness (μ_E) in a narrow redshift bin ($z < 0.2$). Surface brightness was computed by dividing half of the total flux by the area within one effective radius. Since we were exploring a narrow bin of stellar mass ($\log_{10}(M_*/M_\odot) > 10$) and redshift, we assumed that, for an unbiased classification, the bar fraction should not depend on apparent size or magnitude, as we were considering at a subset of galaxies with similar physical properties. Figure 4 indeed shows almost no dependence of the bar fraction on I_E , r_e , or μ_E , suggesting that the bar classification is unbiased for the conservative sample explored in this work. We therefore did not apply any correction to the measured bar fraction in the forthcoming



Fig. 2. Random example colour cutouts of barred galaxies selected using the *Euclid* Q1 morphology classification. Most galaxies show a clear bar structure. The cutouts have been rescaled based on the effective radii of the galaxies so that they appear with a similar size to the volunteers (see Euclid Collaboration: Walmsley et al. 2025 for more details).

analysis. However, this comes at the expense of completeness, as the sample is complete only for massive galaxies at $z > 0.5$.

4. Results: Evolution of the bar fraction at $z < 1$

The bar fraction measures the frequency of barred galaxies (N_{bar}) in a given population of galaxies (N_{gal}):

$$f_{\text{bar}} = \frac{N_{\text{bar}}}{N_{\text{gal}}}.$$

The numerator N_{bar} is computed using the selection criteria defined in Sect. 3. Given the tree-like structure of the Zoobot classifications, we define N_{gal} as the number of featured galaxies, excluding edge-on galaxies:

$$N_{\text{gal}} = |\{p_{\text{feature}} > 0.5\} \cap \{p_{\text{edge-on}} < 0.5\}|.$$

The first selection identifies featured galaxies that, according to the GZ classifications, are objects with clearly defined internal structure as opposed to smooth galaxies. This separation is similar, but not identical, to the more traditional late-type versus early-type classification. As noted in previous work (Simmons et al. 2017; Domínguez Sánchez et al. 2022), some featureless discs can be classified as smooth. This distinction is important when comparing the results on the bar fraction with previously published work in Sect. 5.1.

Figure 5 shows the bar fraction as a function of redshift in bins of stellar mass. Table 1 lists the number of featured and barred galaxies, as well as the bar fraction in each redshift and stellar mass bin. Since the completeness of our sample strongly depends on stellar mass, we show the bar fraction for four different stellar-mass bins and indicate the region of the parameter space where incompleteness begins to have a stronger impact,

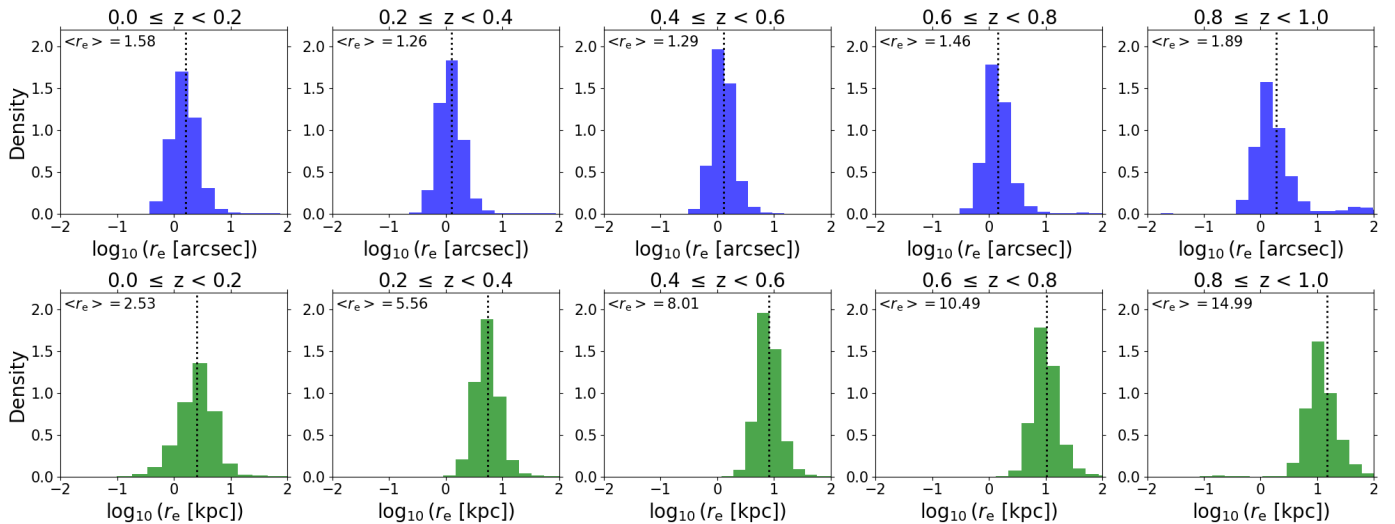


Fig. 3. Distribution of apparent (top row) and physical sizes (bottom row) in different redshift bins, as labelled. The vertical dashed lines indicate the mean values of each distribution, whose numerical value is also indicated in each panel. The bright magnitude cut applied implies a roughly constant apparent size with redshift.

based on the results of Fig. 1. We emphasise that Fig. 5 does not report a true evolution of the bar fraction along the progenitors, which should take into account mass growth. Rather, it shows variations of the bar fraction at fixed stellar mass. The precise impact of incompleteness on the measured bar fraction is difficult to quantify, as it depends on several unknowns, including the dependence of the bar fraction on effective radius and magnitude at fixed stellar mass and redshift. In addition, as previously mentioned, the exact normalisation of the bar fraction depends on a number of assumptions, such as the exact threshold used to select barred galaxies or the denominator used. These systematic effects are particularly important because they dominate the error budget, given the small statistical errors of *Euclid* data. The shaded region in Fig. 5 illustrates the impact of changing the Zoobot probability threshold to select barred galaxies from 0.4 to 0.6, which can alter the bar fraction by 20%, while preserving the main trends.

Despite these known limitations, Fig. 5 reveals some interesting trends. We observe a moderate decrease in the bar fraction with increasing redshift in all stellar-mass bins, with a more pronounced decline at lower masses. In the low stellar mass bin ($10 < \log_{10}(M_*/M_\odot) < 10.3$), the fraction falls from around 35% for $z \sim 0$ to 20% at $z \sim 0.3$. For the most massive galaxies ($\log_{10}(M_*/M_\odot) > 11$), the fraction remains almost constant over the same redshift range and only starts to noticeably decrease around $z \sim 0.7$. Additionally, we observe a slight dependence of the bar fraction on the stellar mass at all redshifts. Massive galaxies present a slightly higher bar fraction than low-mass galaxies at similar redshifts.

5. Discussion

We now discuss the results presented in this paper in light of previous observational work and predictions from cosmological simulations.

5.1. Comparison with previous observational results

Several previous publications have examined the evolution of the bar fraction over a similar redshift and stellar-mass range,

primarily using HST and JWST data (Elmegreen et al. 2004; Jogee et al. 2004; Sheth et al. 2008; Cameron et al. 2010; Simmons et al. 2014; Melvin et al. 2014; Guo et al. 2024). Performing a robust, like-for-like comparison with published results remains challenging, given the variety of detection methods and sample selections. Some of these works are based on visual inspections by experts (e.g. Sheth et al. 2008), ellipse fitting (e.g. Cameron et al. 2010; Jogee et al. 2004), and GZ classifications (e.g. Melvin et al. 2014; Simmons et al. 2014). We note that, although Sheth et al. (2008) used two independent methods, we only report here the results from visual classifications, which should be more directly comparable with our measurements. However, a first-order comparison can still be informative to illustrate the scatter in the bar fractions resulting from different methodologies and to place the new Q1 data in a broader context. Figure 6 compares the Q1 measurements from this work with a compilation of other results, and Table 2 lists the number of galaxies in each redshift bin. For simplicity in the comparison, we include all galaxies more massive than $10^{10} M_\odot$. This choice reflects that some works rely on luminosity-selected samples, each subject to different biases, making a fully homogenised stellar-mass selection unfeasible. However, all data shown in Fig. 6 broadly target the massive or bright end of the galaxy population, approximately beyond the knee of the luminosity function. We emphasise that, for the *Euclid* data, selecting all galaxies more massive than $10^{10} M_\odot$ may cause severe incompleteness (see discussion in Sect. 3.2), so evolutionary trends need to be analysed in bins of stellar mass, following the approach in Sect. 4.

The unprecedented sample size from *Euclid* significantly reduces statistical errors compared to HST or JWST studies. This showcases one of *Euclid*'s key strengths, combining high spatial resolution with a wide field of view. Indeed, the total number of barred galaxies in the Q1 survey (7711) already surpasses, by more than an order of magnitude, that in any previously published study beyond the local Universe. As a result, the error budget of the *Euclid* measurements is likely to be dominated by systematics, such as classification errors and incompleteness, as previously discussed.

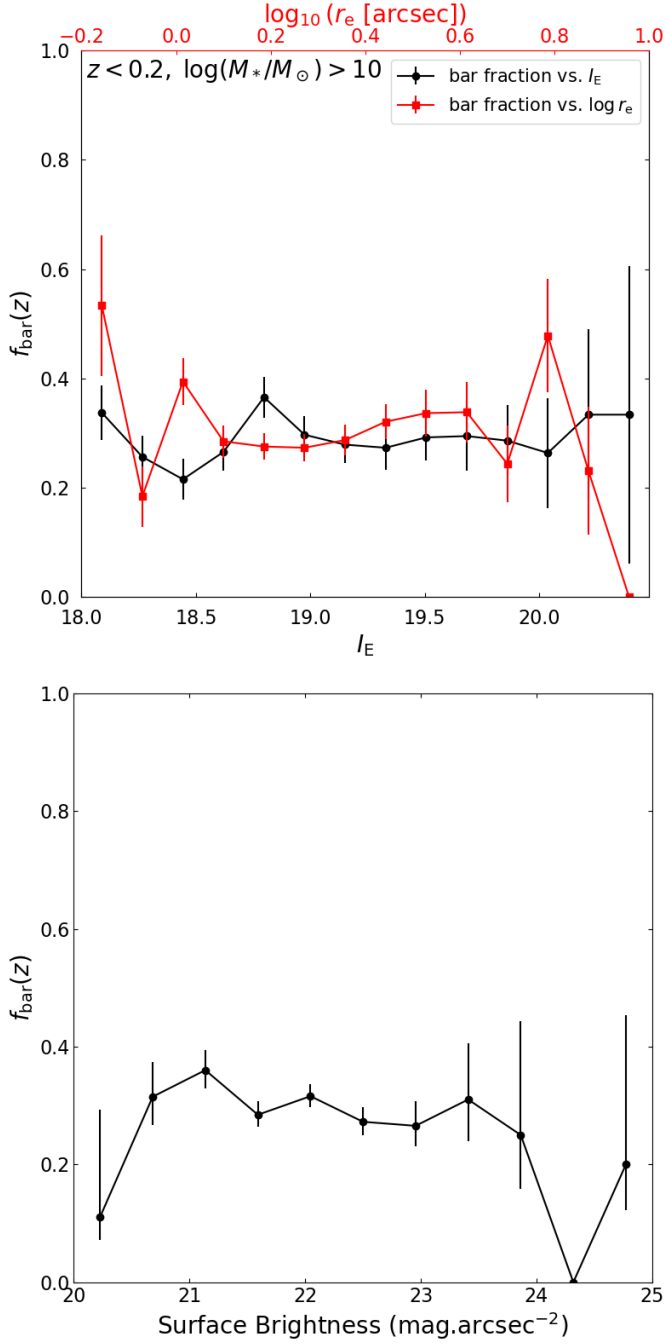


Fig. 4. Detection bias of bars. Top panel: The solid red and black lines show the bar fraction as a function of apparent effective radius (top x-axis) and apparent I_E magnitude (bottom x-axis), respectively, for galaxies at $z < 0.2$. Error bars indicate the 68% confidence interval under a beta-binomial posterior. Bottom panel: Bar fraction as a function of surface brightness. The lack of trend suggests that the detection of bars is not affected by S/N and spatial resolution variations in the selected sample.

Apart from the results of Sheth et al. (2008), all measurements consistently yield bar fractions of 0.1–0.3 within the explored redshift range, despite the varied methods and selection criteria, including recent JWST findings (Guo et al. 2025), using a similar stellar mass selection ($> 10^{10} M_{\odot}$). This consistency reinforces the reliability of the *Euclid* classifications used here and suggests that the bar fraction in massive galaxies out to $z \sim 1$ is

Table 1. Number of barred and featured galaxies in different redshift and stellar mass bins.

$z_{\text{min}}-z_{\text{max}}$	N_{featured}	N_{bar}	f_{bar}
$10 < \log_{10}(M_*/M_{\odot}) < 10.3$			
0.00–0.10	102	37	0.363
0.10–0.20	974	249	0.256
0.20–0.30	1435	339	0.236
0.30–0.40	1063	220	0.207
0.40–0.50	2664	500	0.188
0.50–0.60	802	201	0.251
0.60–0.70	69	27	0.391
0.70–0.80	63	18	0.286
0.80–0.90	58	13	0.224
0.90–1.00	22	7	0.318
$10.3 < \log_{10}(M_*/M_{\odot}) < 10.6$			
0.00–0.10	28	8	0.286
0.10–0.20	509	180	0.354
0.20–0.30	1214	316	0.260
0.30–0.40	1267	386	0.305
0.40–0.50	3369	598	0.178
0.50–0.60	1729	354	0.205
0.60–0.70	140	30	0.214
0.70–0.80	83	16	0.193
0.80–0.90	71	23	0.324
0.90–1.00	53	11	0.208
$10.6 < \log_{10}(M_*/M_{\odot}) < 11$			
0.00–0.10	13	4	0.308
0.10–0.20	175	62	0.354
0.20–0.30	753	234	0.311
0.30–0.40	1033	349	0.338
0.40–0.50	3083	784	0.254
0.50–0.60	3696	893	0.242
0.60–0.70	608	127	0.209
0.70–0.80	236	36	0.153
0.80–0.90	104	23	0.221
0.90–1.00	52	11	0.212
$\log_{10}(M_*/M_{\odot}) > 11$			
0.00–0.10	2	0	N/A
0.10–0.20	18	6	0.333
0.20–0.30	157	54	0.344
0.30–0.40	236	75	0.318
0.40–0.50	1013	343	0.339
0.50–0.60	2649	801	0.302
0.60–0.70	954	262	0.275
0.70–0.80	413	76	0.184
0.80–0.90	105	27	0.257
0.90–1.00	64	11	0.172

Notes. The shaded rows indicate the areas of the parameter space most affected by incompleteness.

well constrained to about 30%, providing a robust test for galaxy formation models. We stress that, although there is only one data point from JWST observations within the redshift range explored in this work, it is consistent, within the uncertainties, with the *Euclid* measurements presented here. This is particularly important because, as described in Sect. 3, the abundance of bars is known to decrease at shorter wavelengths owing to outshining from young stellar populations and the effect of dust (Knapen

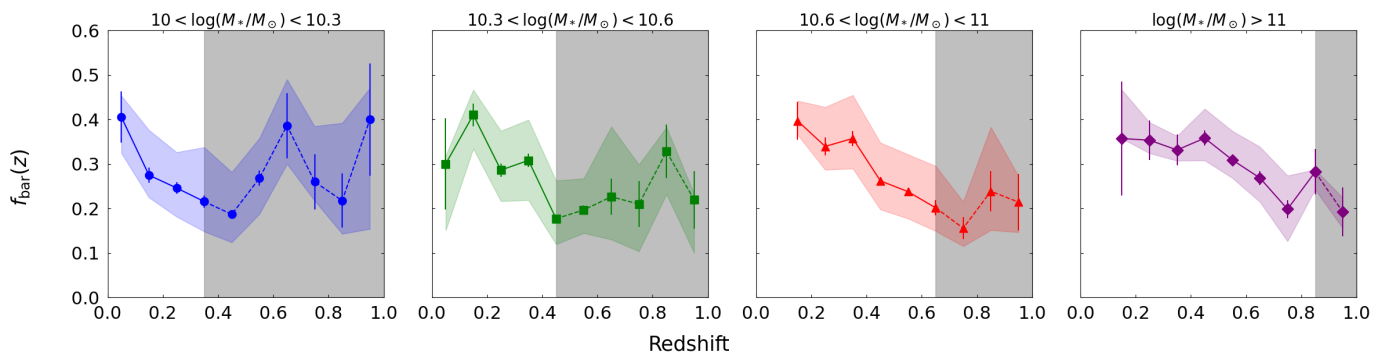


Fig. 5. Evolution of the bar fraction as a function of redshift. Each panel shows a different stellar mass bin, as labelled. The coloured shaded regions indicate the effect of changing the threshold for selecting barred galaxies between 0.4 and 0.6. The shaded grey regions indicate the redshift ranges affected by incompleteness. Error bars indicate the 68% confidence interval under a beta-binomial posterior. The bar fraction shows a dependence on stellar mass, both in the normalisation and evolutionary trends.

et al. 2000; Erwin 2018; Menéndez-Delmestre et al. 2024). With the VIS filter being particularly wide (Euclid Collaboration: McCracken et al. 2025), these effects might be enhanced. The fact that the JWST NIR-based measurements provide similar values, however, suggests that wavelength variations within the redshift range explored do not severely affect our results. Although not explicitly shown in Fig. 6, previous studies (Cameron et al. 2010; Melvin et al. 2014) and our own findings agree that more massive galaxies have systematically higher bar fractions (although see Méndez-Abreu et al. 2012). We expand on this mass dependence in Sect. 5.2.

Nonetheless, the evolutionary trends reported by different authors show significant variation. This likely reflects disparate sample selections and completeness limits, underlining the caution required when interpreting evolution in the bar fraction. For instance, Jogee et al. (2004) studied bars to $z \approx 1$ in the Galaxy Evolution from Morphologies and SEDs (GEMS) survey (Caldwell et al. 2008) and found a nearly constant bar fraction of $30\% \pm 6\%$, based on various absolute-luminosity cuts, suggesting that dynamically cold discs were already established by $z \approx 1$. Similarly, Cameron et al. (2010) reported a flat trend. However, as shown in Fig. 5, the bar-fraction evolution can appear artificially flattened if the sample is luminosity-limited, since brighter, more massive galaxies at higher redshifts intrinsically exhibit a larger bar fraction. This effect is also visible in our Q1 results (Fig. 6). Several studies reported a more pronounced decrease in bar fraction with increasing redshift (e.g. Sheth et al. 2008; Simmons et al. 2014; Melvin et al. 2014). Simmons et al. (2014) employed a redshift-dependent luminosity cut that may counteract the mass dependence, while Melvin et al. (2014) used a stellar-mass selection similar to ours, but with deeper COSMOS data, potentially explaining their stronger evolution at higher redshifts. Notably, Sheth et al. (2008) reported both a higher bar fraction and a steeper redshift dependence, likely due to a combination of selection effects and a classification scheme that includes both strong and weak bars. When only strong bars are considered, their measurements align more closely with ours, implying that our GZ-based classifications primarily capture strong bars.

5.2. Comparison with cosmological simulations

Comparison of observed bar properties with simulations helps identify key processes driving disc assembly over time, which is the focus of this subsection. Guided by the discussion in Sect. 5.1, we restrict our comparison to the two main robust find-

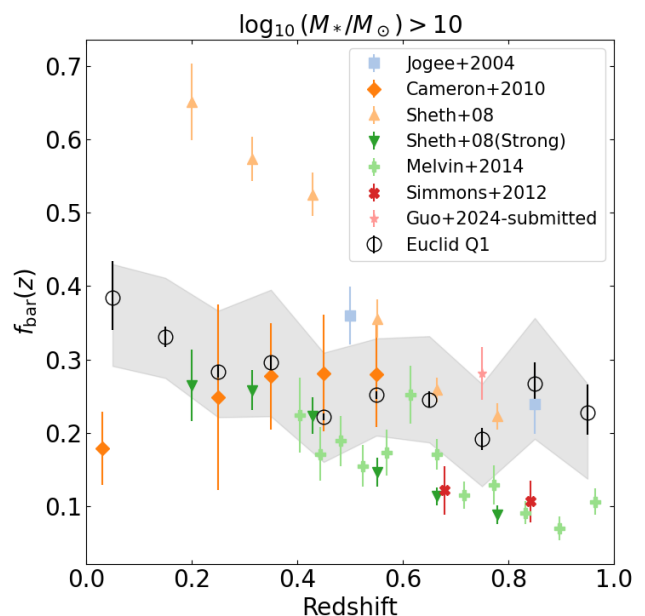


Fig. 6. Bar fraction as a function of redshift. The large black circles show the measurement from Q1 presented in this work. The shaded grey region indicates the effect of changing the threshold for selecting barred galaxies between 0.4 and 0.6. Different colours and symbols indicate previously published results from different space-based surveys, as labelled. The *Euclid* measurements are generally consistent with previous works, but with significantly smaller statistical error bars.

ings of this work: (1) the average bar fraction over $z = 0-1$, and (2) its stellar mass dependence. We consider several recent, state-of-the-art cosmological models: the hydrodynamic simulations TNG50, textttAuriga, and the semi-empirical model Decode (Discrete statistical sEmi-empiriCal mODEl; (Fu et al. 2025). It is important to note that comparing observations and simulations is not free from biases. In particular, as discussed above, observational data are subject to various selection effects that are not present in simulations. A fully robust, like-for-like comparison would require forward modelling of the simulation outputs into the observational plane, which is beyond the scope of this work (e.g. Zanisi et al. 2021). For example, the bar fraction in observations is computed over a sample of featured galaxies (Sect. 3),

Table 2. As in Table 1, but for all galaxies with stellar mass greater than $10^{10} M_{\odot}$.

$z_{\min}-z_{\max}$	N_{featured}	N_{bar}	f_{bar}
$(\log_{10}(M_*/M_{\odot}) > 10)$			
0.00–0.10	145	49	0.338
0.10–0.20	1676	497	0.297
0.20–0.30	3559	943	0.265
0.30–0.40	3599	1030	0.286
0.40–0.50	10 129	2225	0.220
0.50–0.60	8876	2249	0.253
0.60–0.70	1771	446	0.252
0.70–0.80	795	146	0.184
0.80–0.90	338	86	0.254
0.90–1.00	191	40	0.209
0.00–1.00	27 480	7711	0.280

Notes. The last row shows the total amount of barred and featured galaxies in the sample analysed in this work. We emphasize that the bar fraction is severely affected by incompleteness – see text for details.

while in simulations, bars are quantified in disc galaxies selected based on their dynamics. Although the featured label serves as a proxy for disc galaxies, it does not imply a perfect correspondence; this can accentuate certain discrepancies.

The TNG50 simulation is part of the IllustrisTNG project, a suite of cosmological simulations aimed at exploring galaxy formation and evolution (Pillepich et al. 2018). These simulations employ the AREPO moving-mesh code (Springel 2010), which accounts for gravitational interactions and incorporates sub-grid models to capture baryonic processes, building upon earlier work from the Illustris project (Genel et al. 2014; Vogelsberger et al. 2014). The TNG50 simulation has the smallest volume (50 comoving Mpc) of the suite but offers higher resolution ($8.5 \times 10^4 M_{\odot}$), making it suitable for probing the internal structure of galaxies. For the comparison presented here, we use the results of Rosas-Guevara et al. (2022) and López et al. (2024), who analysed the bar fraction and discussed bar formation in the TNG50 simulation. The sample in Rosas-Guevara et al. (2022) comprises a complete sample of galaxies more massive than $10^{10} M_{\odot}$ with a disc-to-total ratio (D/T) greater than 0.5 .

The Auriga simulation is another set of cosmological magnetohydrodynamical zoom-in simulations of individual halos spanning $M_{200} \in [0.5, 2.0] \times 10^{12} M_{\odot}$ at $z = 0$ (Grand et al. 2017). They also use the AREPO code, but with a slightly different galaxy formation model (see Vogelsberger et al. 2013; Marinacci et al. 2014; Grand et al. 2017 for details), which includes cooling, background UV fields for reionisation, sub-grid prescriptions for star formation, stellar evolution and feedback, magnetic fields, and black hole seeding, accretion, and feedback. The stellar and gas mass resolution is $5 \times 10^4 M_{\odot}$. We compare with Fragkoudi et al. (2025), who studied the properties of barred galaxies in the Auriga simulation. We stress that since these simulations are zoom-in, the measurements reported correspond to a representative instead of a complete sample of galaxies. All galaxies have stellar masses larger than $10^{10} M_{\odot}$ at $z = 0$ and are, for the vast majority, disc-dominated ($D/T > 0.5$). More details can be found in Grand et al. (2017).

The Decode model is a semi-empirical model that builds galaxies on top of dark matter haloes via a data-driven star formation rate-halo accretion rate (SFR-HAR) relation. This rela-

tion between the galaxy SFR and dark matter HAR is computed via abundance matching, under the assumption that there is a monotonic connection between the two quantities, using theoretically predicted HARs and observationally measured SFR distributions from a combination of a variety of data sets in the UV and IR bands at different redshifts. Galaxy stellar masses are then derived by integrating SFRs and merger contributions along the assembly histories of the host dark matter haloes. Quenched galaxies in this rendition of Decode are included via the popular halo quenching model due to the shock heating in massive haloes above $M_h \gtrsim 10^{12} M_{\odot}$ (e.g. Dekel & Birnboim 2006), which suffices to produce the majority of early-type quenched galaxies. Galaxy bars are formed assuming that galaxies with a gas fraction ($M_{\text{gas}}/(M_* + M_{\text{gas}}) \geq 0.3$) below a certain threshold value, as suggested by simulations, can more easily form a bar (e.g. Athanassoula et al. 2013; Łokas 2020). The gas content in Decode is assigned via empirical relations as a function of stellar mass, SFR, and redshift (e.g. Stewart et al. 2009).

Figure 7 shows the evolution of the bar fraction for the complete Q1 sample with $M_* > 10^{10} M_{\odot}$ alongside the Auriga, TNG50, and Decode predictions, applying the same stellar-mass selection to the simulations. Hence, these bar fractions do not trace the true progenitor evolution. Interestingly, the three models predict a global bar fraction consistent with the observational values of approximately 0.2 – 0.4 . The redshift trends differ, but as stressed above, strong conclusions cannot be drawn without matching selection effects in the simulations and observations. Nevertheless, all models appear to produce a lower fraction at low redshift; this is discussed further below. For TNG50, we also show the bar fraction when all bars are included, even very small ones that may be difficult to detect in the observations. In this case, the bar fraction becomes significantly larger than observational estimates, emphasising the complexity of simulation–observation comparisons and the importance of carefully modelling selection biases.

Another key result from this work is the stellar mass dependence of the bar fraction. Figure 8 repeats the comparison with simulations, now split into two stellar mass bins. While TNG50 uses $\log_{10}(M_*/M_{\odot}) = 10.5$ and Auriga adopts 10.7 , we find that overall trends remain similar regardless of the exact division. All models predict a clear mass dependence in bar fraction, with more massive galaxies hosting more bars. The effect is more pronounced in the hydrodynamic simulations, where approximately 70% of massive galaxies are barred, compared to only 40% in the observations. The global trend with redshift of the Decode bar fraction is more consistent with the observations. The semi-empirical model still slightly predicts a larger bar fraction in massive galaxies compared to observations, but it is compatible within the uncertainties. The difference in normalisation depends on the choice of the input gas-to-stellar mass relation, whose measured value could be affected by systematics.

Early idealised simulations suggested that high gas fractions can inhibit bar formation (e.g. Athanassoula & Sellwood 1986; Athanassoula 2003; Villa-Vargas et al. 2010). This is in good agreement with the predictions of Decode. More recent cosmological simulations such as TNG50 and Auriga, indicate that the ratio of baryonic to dark matter is also a primary factor in regulating bar formation. López et al. (2024) observed that unbarred galaxies consistently have lower central baryonic-to-dark matter ratios than barred galaxies. Similarly, Fragkoudi et al. (2025) found no significant difference in gas fractions between barred and unbarred galaxies at a fixed stellar mass. Interestingly, the latter study also noted that baryon-dominated galaxies without bars often have richer merger histories. Reddish et al. (2022), us-

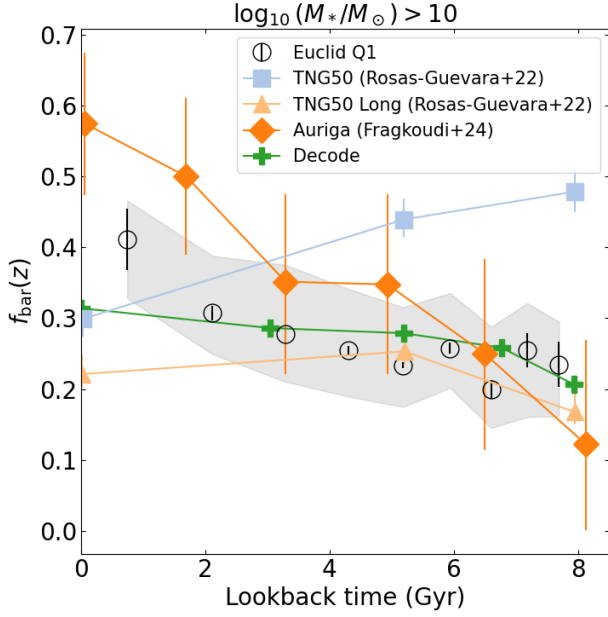


Fig. 7. Comparison of the observed bar fraction in our *Euclid* sample (large empty circles) with cosmological simulations. The cyan squares and pink triangles show the results from the TNG50 simulation when all bars and only long bars are included, respectively. The orange diamond shows the Auriga simulation. The shaded grey region indicates the effect of varying the probability threshold for bar selection between 0.4 and 0.6. The mean bar fraction is globally well reproduced by the simulations.

ing the NEWHORIZON simulation, found that excessive dark matter or large bulges could inhibit bar formation. Therefore, the higher bar fractions in high-mass galaxies predicted by simulations compared to observations may reflect overly efficient central star formation, which boosts the baryonic-to-dark-matter ratio and thus favours bar formation. The effect of the baryonic-to-dark-matter ratio can be tested in a semi-empirical approach such as Decode, which will be tested in future work. Alternatively, simulated galaxies may experience fewer mergers, resulting in lower ex situ fractions. However, recent work on local Universe ex situ stellar mass fractions (Angeloudi et al. 2024) suggests that the integrated merger rate is relatively well reproduced by state-of-the-art simulations.

6. Summary and conclusions

We investigated the abundance of stellar bars in massive disc galaxies ($M_* \gtrsim 10^{10} M_\odot$) up to $z \approx 1$, using data from the Q1 release over an area of 63.1 deg^2 . By applying a deep-learning model trained on citizen science visual labels, we identified barred galaxies in a magnitude-selected sample ($I_E < 20.5$). Our main findings can be summarised as follows.

- We identified 7711 barred galaxies between $z = 0$ and $z = 1$, exceeding by an order of magnitude the samples from previous work over a similar redshift range. This highlights *Euclid*'s unique capability to resolve internal galaxy structures across a wide sky area.
- The mean bar fraction of 0.2–0.4 agrees well with estimates from HST-based surveys, indicating that *Euclid* can robustly reproduce morphological measures over large samples. In

the era of very large surveys such as *Euclid*, proper quantification of systematic effects, such as classification errors, becomes extremely important.

- At a fixed redshift, massive systems exhibit a higher bar fraction than lower-mass galaxies, and the decrease in bar fraction with redshift is more pronounced for lower-mass systems. This suggests an earlier formation and assembly of discs.
- While cosmological simulations match the overall bar fraction, they overpredict it for the most massive galaxies. This discrepancy suggests that the models may overestimate the efficiency of central stellar mass growth. A semi-empirical model in which bar formation depends solely on the gas fraction better matches the observed bar fraction.

Overall, these results illustrate the effectiveness of *Euclid*'s combination of spatial resolution and wide-area coverage in probing the internal structure of disc galaxies. Future work includes incorporating finer mass bins, additional morphological indicators, more detailed comparisons with simulations, and correlation with environmental indicators that have not been addressed in this first study. The *Euclid* data will enable a unique quantification of large-scale structure (Euclid Collaboration: Laigle et al. 2025), allowing for a precise dissection of the role of environment in shaping galaxy structure.

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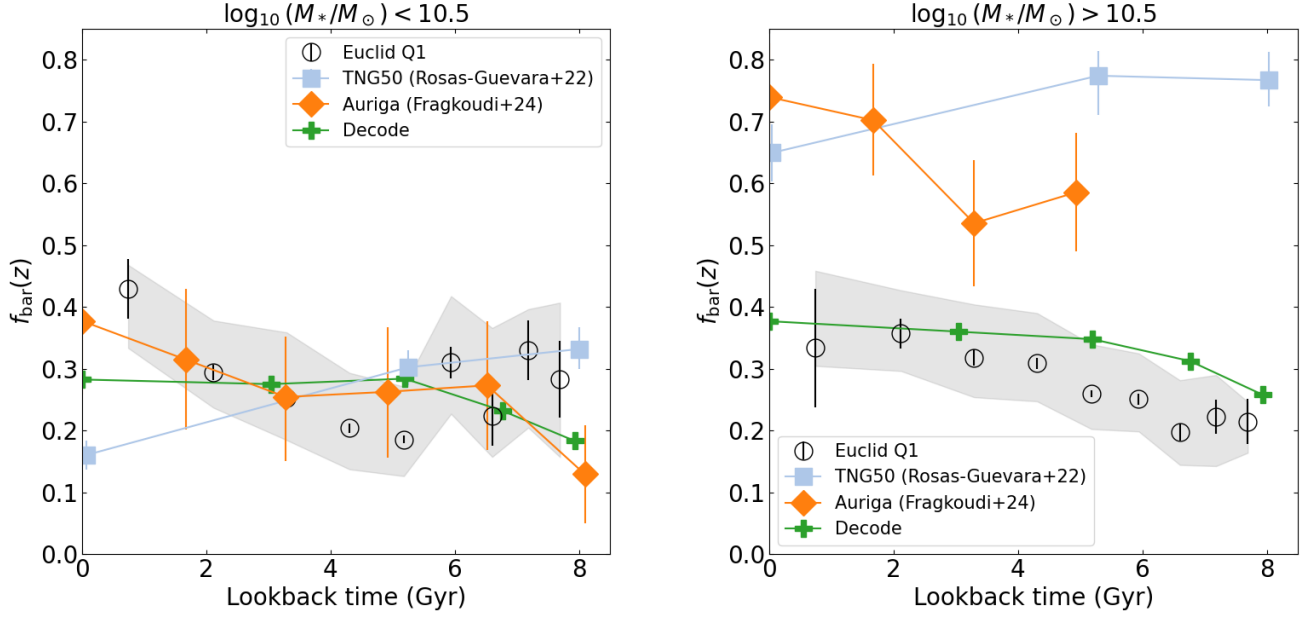


Fig. 8. |As in Fig. 7, but dividing galaxies in stellar mass bins. The left panel shows galaxies with stellar masses between 10^{10} and $10^{10.5} M_{\odot}$. The right panel shows galaxies more massive than $10^{10.5} M_{\odot}$. Simulations tend to overpredict the bar fraction at the high mass end.

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