A morphological segmentation approach to determining bar lengths

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Outline

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1 Introduction

1.Introduces the significance of galactic bars, highlighting their crucial role in the physical, dynamical, and morphological evolution of galaxies.

2. Bars are common in many galaxies, especially in spiral galaxies, with about 55% to 70% of galaxies exhibiting bars.

3. The length of the bar is an important physical property in studying galaxy evolution, providing insights into the galaxy's current state and future evolution.

4. Bar length is commonly measured through methods like isophotal ellipse fitting or Fourier analysis.

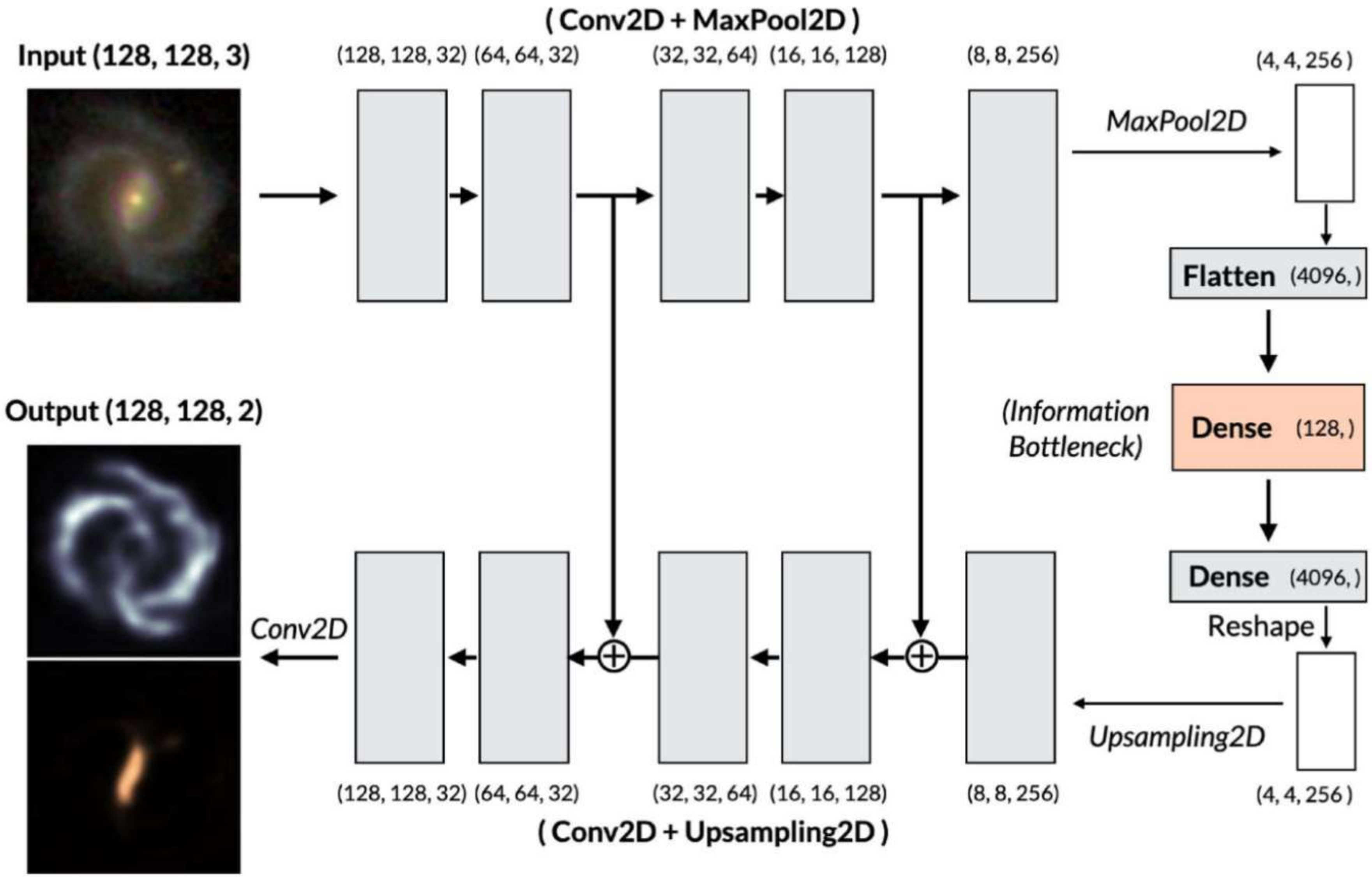
5. Recent studies have also started using deep learning models to identify and measure bar structures.

2 METHODS
Data sets

- The study utilizes three main datasets: **GZ3D**, **NA10**, and **SAMI DR3**.
  - **GZ3D Dataset**: This dataset involves crowdsourced pixel masks of galaxy images, where spiral arms and bar structures are labeled. It is used to train the U-Net model.
  - **NA10 Dataset**: Contains visually classified galaxies for analyzing bar structures. The study focuses on 2,612 barred galaxies from this catalog.
  - **SAMI DR3 Dataset**: Provides spectroscopic data of low-redshift galaxies. Although this dataset lacks explicit bar classifications, a deep learning model was applied to classify these galaxies as barred or unbarred.

2 METHODS

The U-Net model: Model architecture

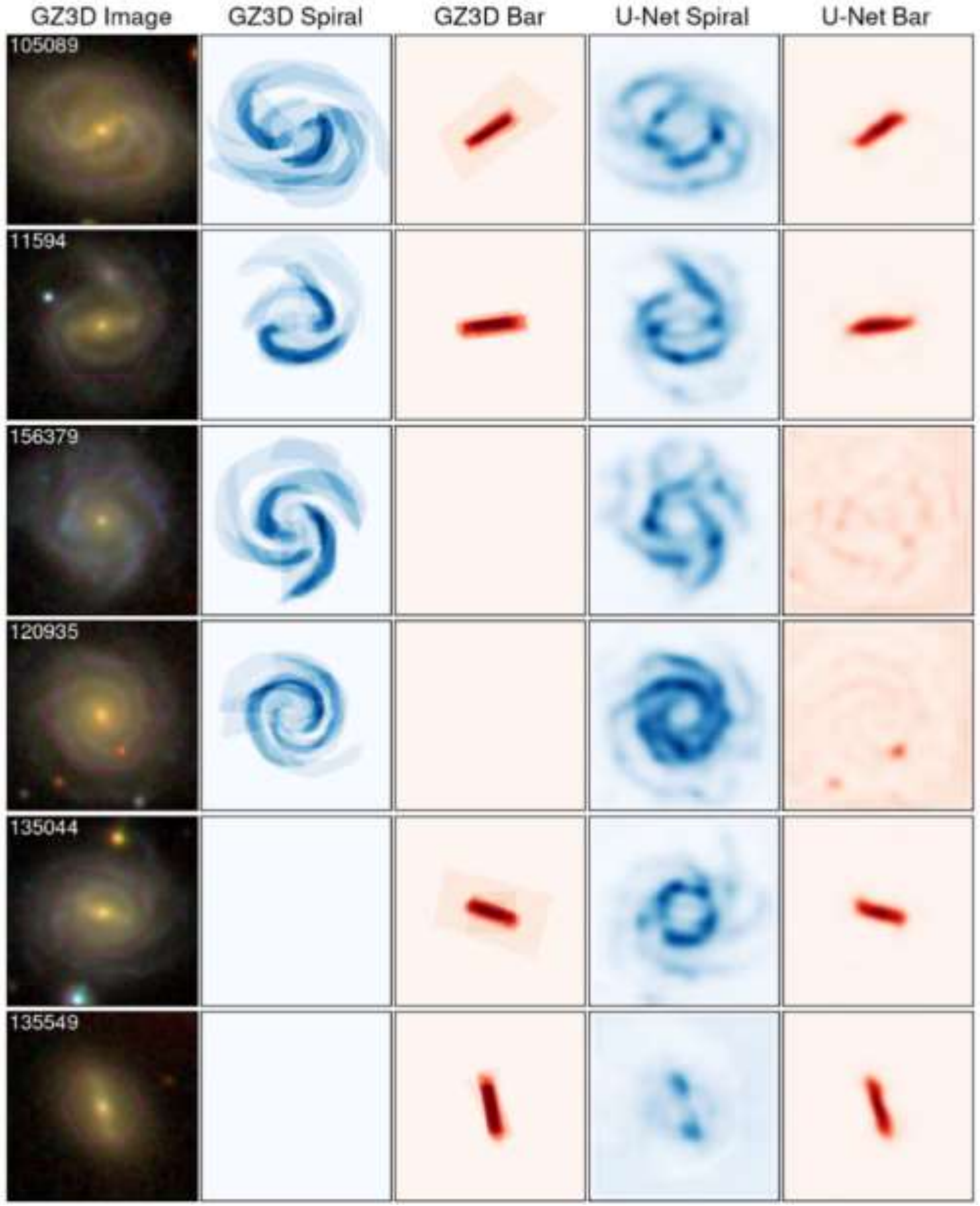


2 METHODS
The U-Net model: Model architecture

Fig. 2 demonstrates the capabilities of the fully trained U-Net at replicating the GZ3D count masks. One immediately noticeable difference is the smoothness of the predicted spiral masks

Fig. 2 also illustrates the importance of having configured the U-Net to output separate masks for bars and spirals. In general, the predicted bar and spiral masks are well separated.

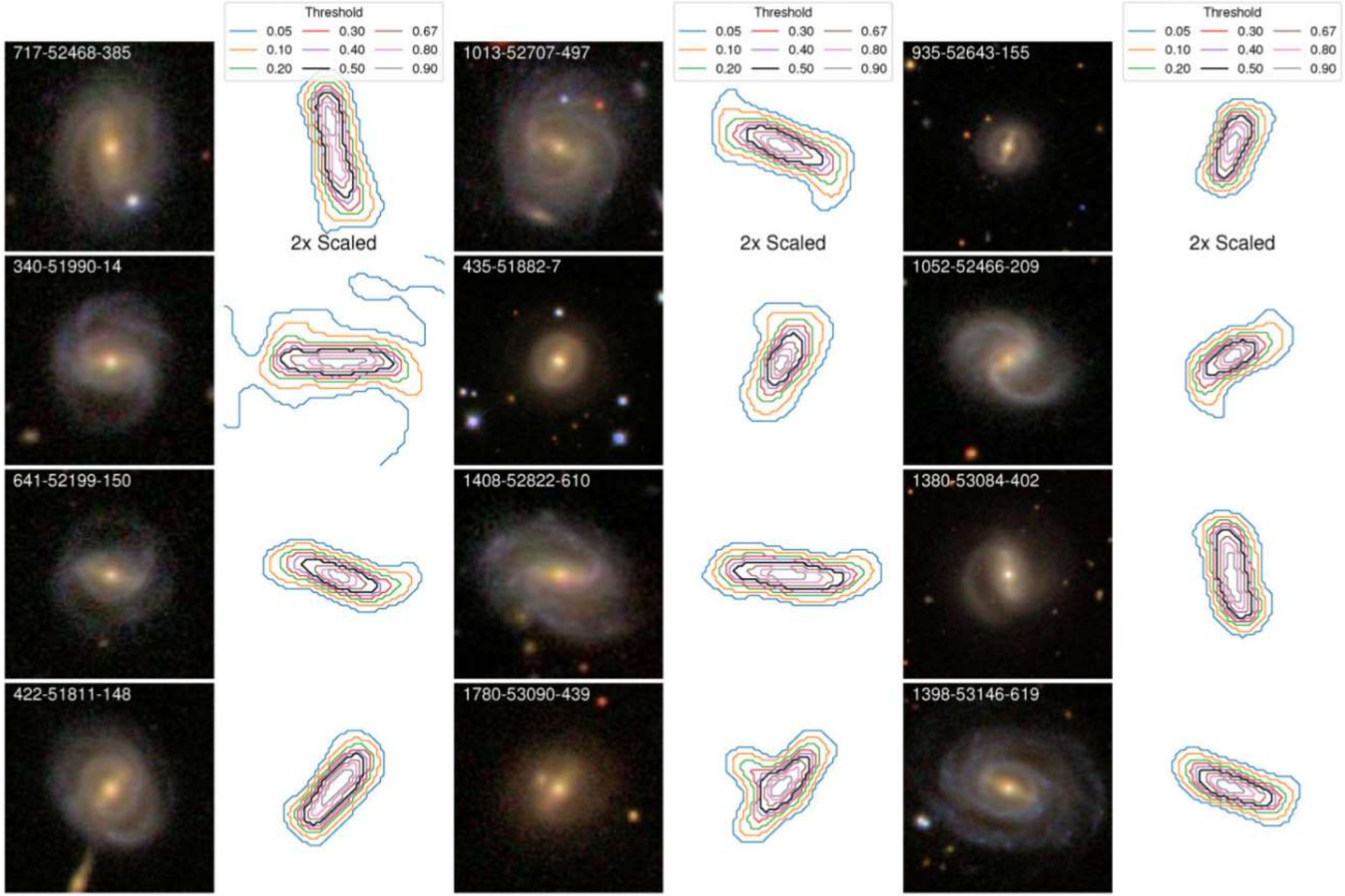
Different shades in the GZ3D count masks correspond to different numbers of classifiers; darker colours indicate higher degrees of overlap. The U-Net outputs attempt to emulate the count masks as closely as possible, but are much smoother since the pixel values are continuous.



2 METHODOLOGY
Bar length estimation

global threshold in order to discard bar masks whose pixel values are too small.

local threshold to decide which pixels to keep in the current bar mask.



2 METHODOLOGY

Bar lenath estimation

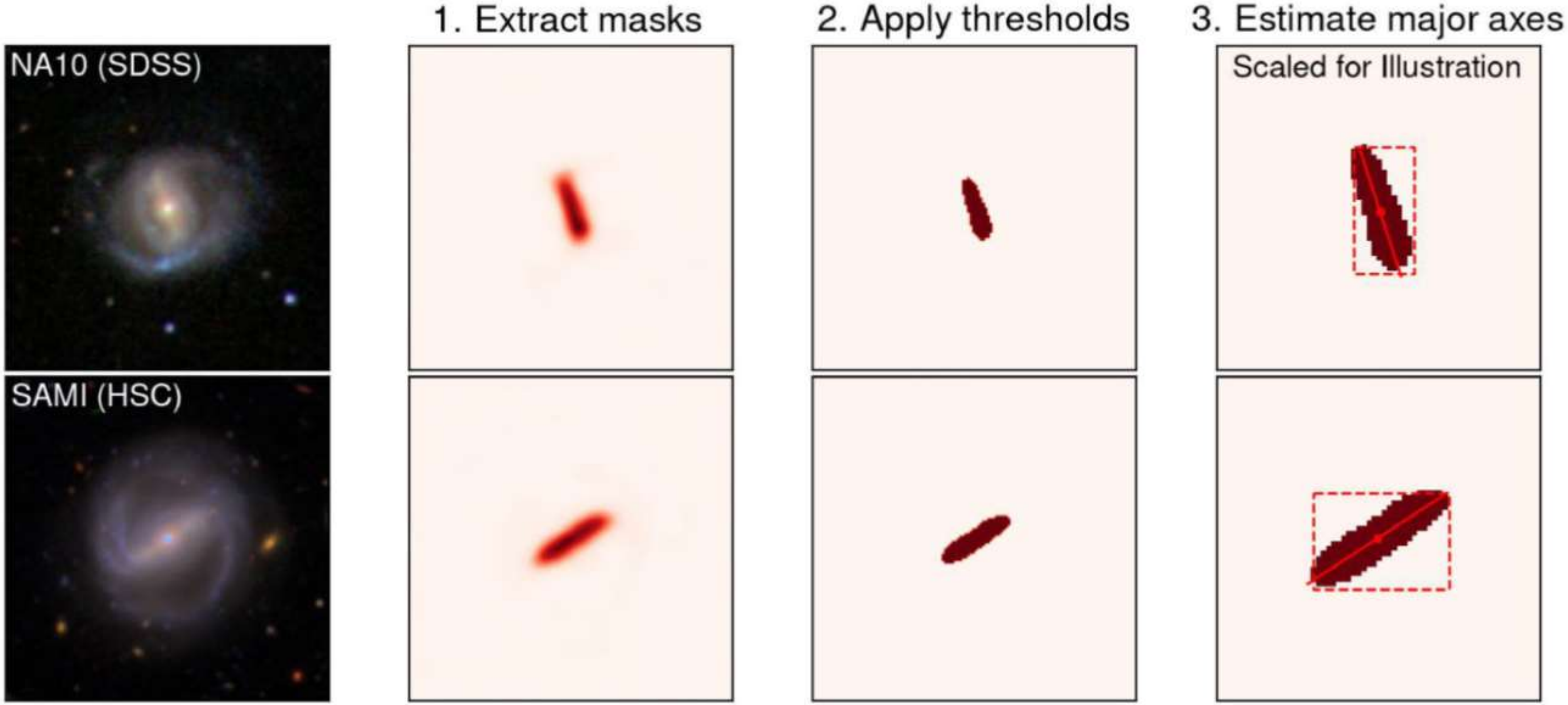
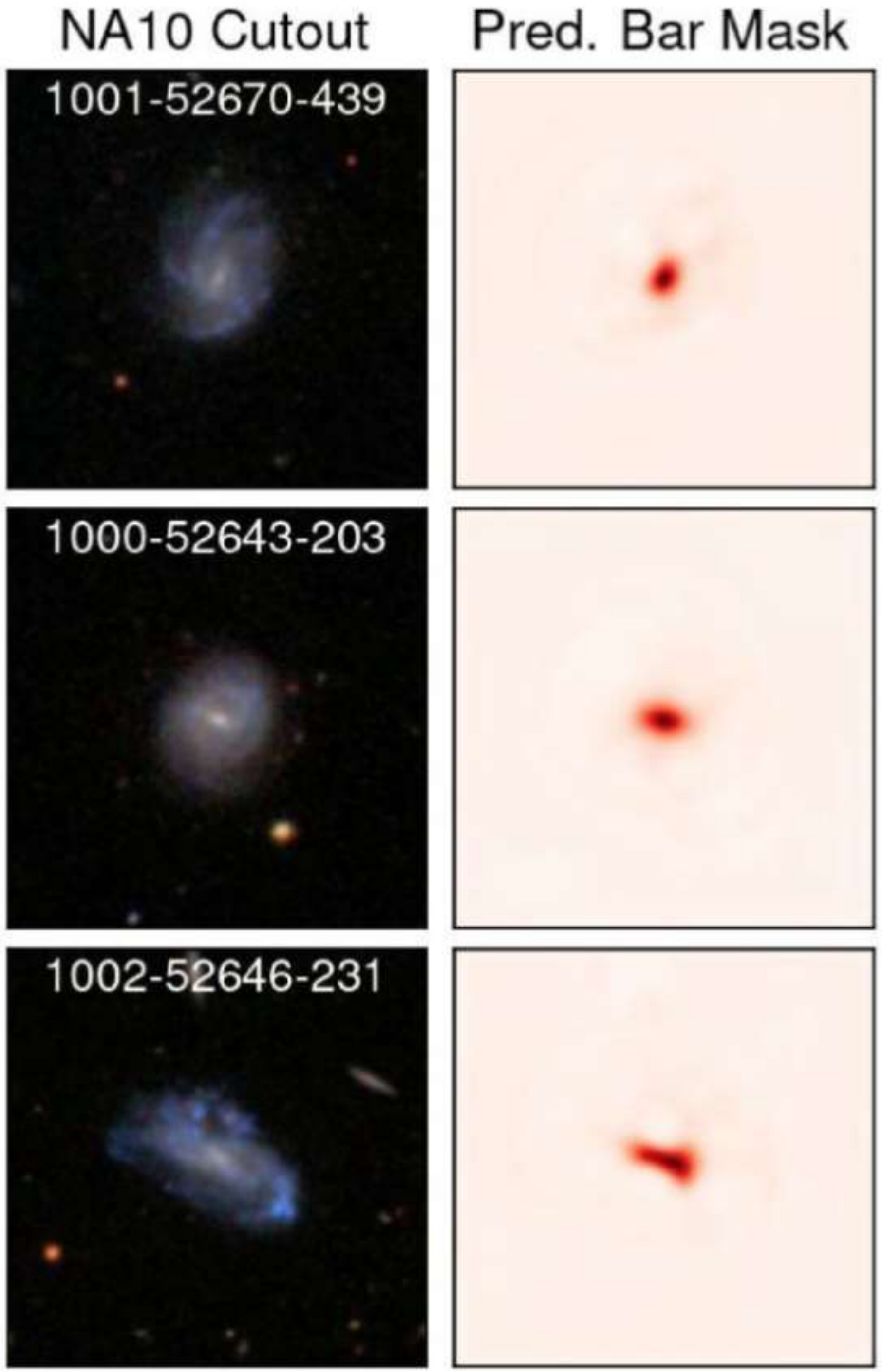


Figure 4. Overview of the full sequence of steps in our bar length estimation pipeline. First, the U-Net is applied to an image of a galaxy. The U-Net subsequently outputs a smooth bar mask with continuous pixel values that are proxies for different levels of confidence. The next step is to choose a threshold with which to convert this continuous bar mask into a binary pixel mask. The final step involves ellipse fitting of the integer-valued pixel mask to calculate the length of the major axis.

3 RESULTS
Application of the U-Net

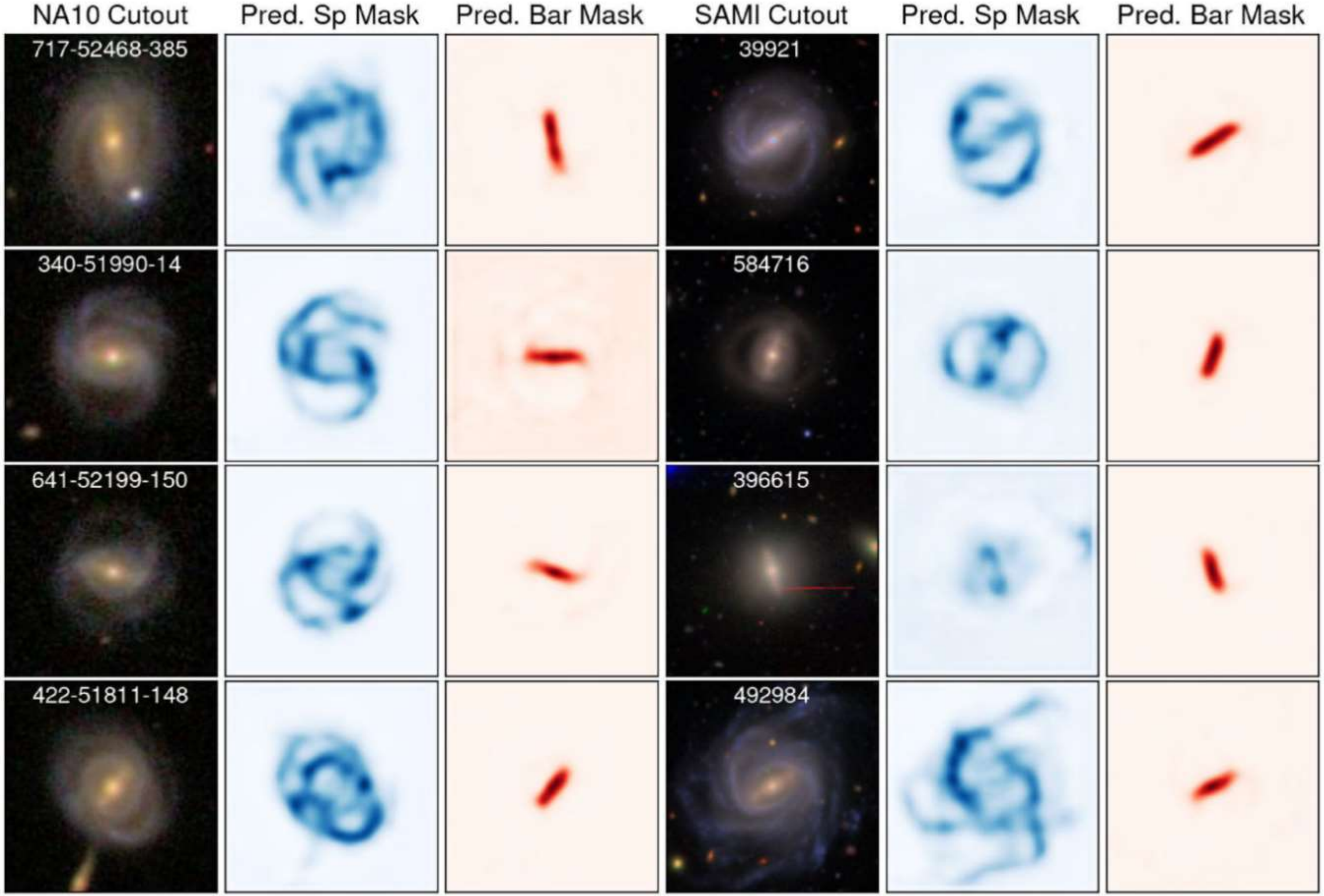
Apply our fully trained U-Net to extract bar masks for galaxies from the NA10 morphological catalogue and SAMI DR3. As an additional measure of confidence, before processing each image with the U-Net, we verified that the image is barred by classifying it with our bar CNN identification method.

Fig. 5 shows a selection of NA10 bars that were excluded from the main analysis under the aforementioned selection criteria. For the sake of illustration, we also passed these excluded samples through the U-Net to obtain their predicted bar masks, from which we can see the model struggles to suitably extract the bar.

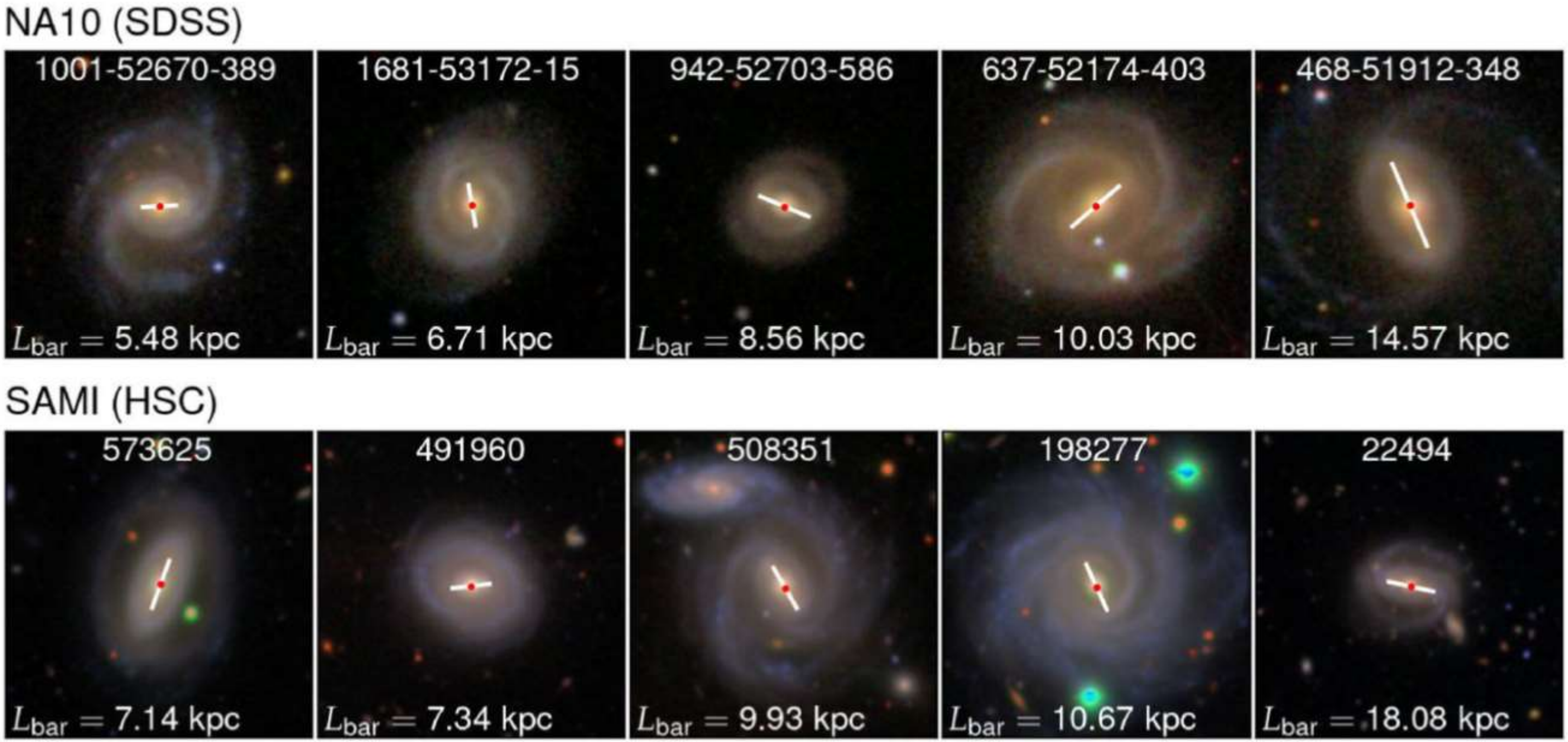


3 RESULTS
Application of the U-Net

Predicted bar and spiral masks as directly outputted by the U-Net for a random selection of NA10 galaxies and SAMI galaxies. There is, however, a higher degree of overlap in the predicted spiral masks with the central bar region.



3 RESULTS
Application of the U-Net



3 RESULTS
Physical properties

Bar length, also denoted L_{bar}, is a key physical property of stellar bars.

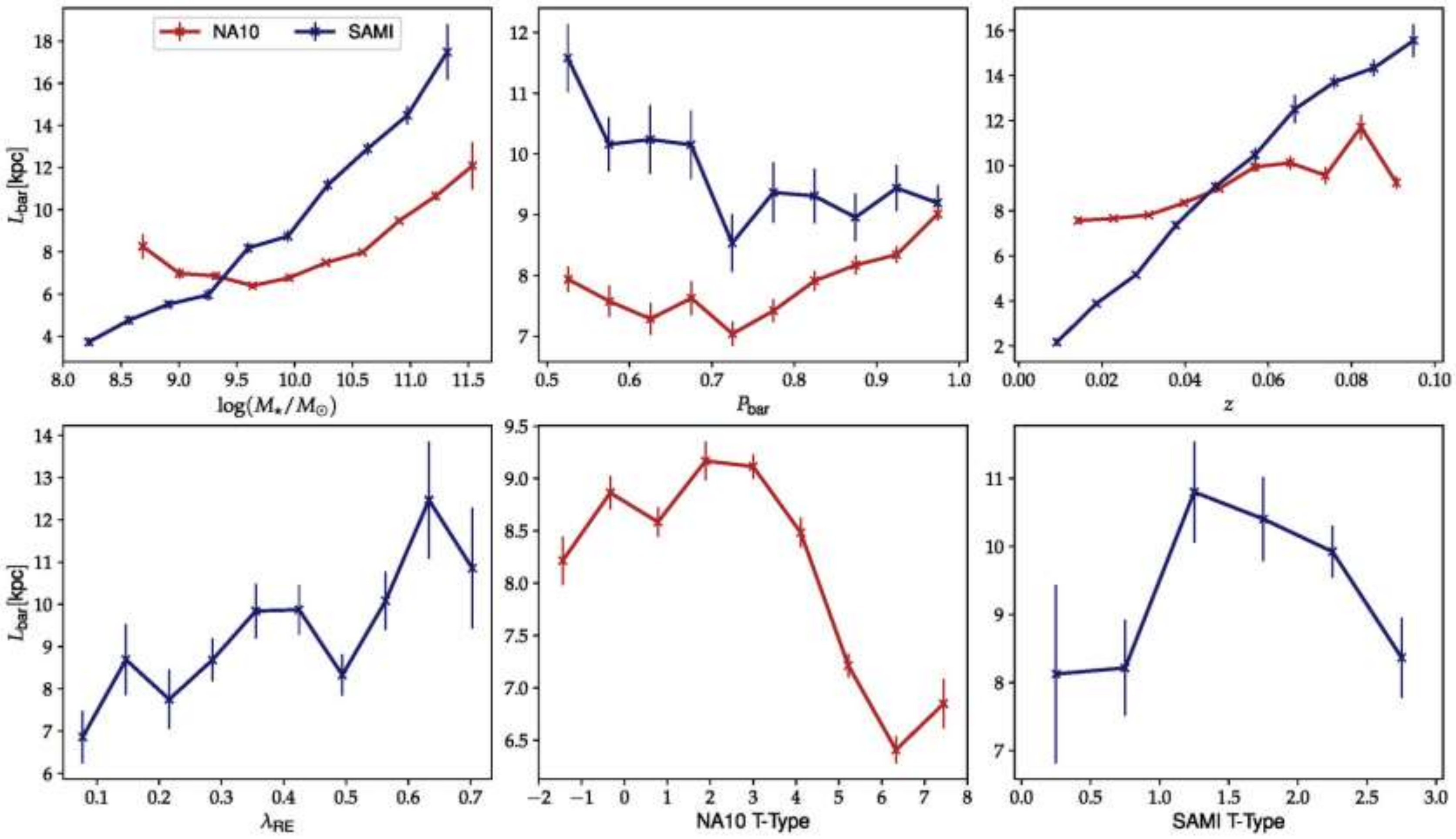
Previous studies have shown that the bar length tends to scale with the mass of the host galaxy, and may also change depending on the morphology of the galaxy with larger bars in early-types and shorter bars in late-types

It is worth noting that the absolute bar length L_{bar} is not necessarily the ideal quantity to meaningfully study the lengths of bars across different galaxies with different physical properties. In particular, a large bar in a small galaxy may share the same, absolute length as a small bar in a large galaxy, but they are clearly sized differently in relation to their host galaxy.

To take the size of the host galaxy into consideration, we can define a normalized, relative bar length by considering the dimensionless quantity L_{bar}/R_d where R_d is the scale radius of the galaxy disc, also known as the scale length. In the case of the SAMI galaxies, R_d is calculated from the effective radius R_e as $R_d \approx R_e/1.68$. For the NA10 galaxies, R_d is similarly calculated from the effective radius R_e, which is approximated from the Petrosian half-flux radius R_{50} and concentration R_{90}/R_{50} using the method in Graham et al. (2005).

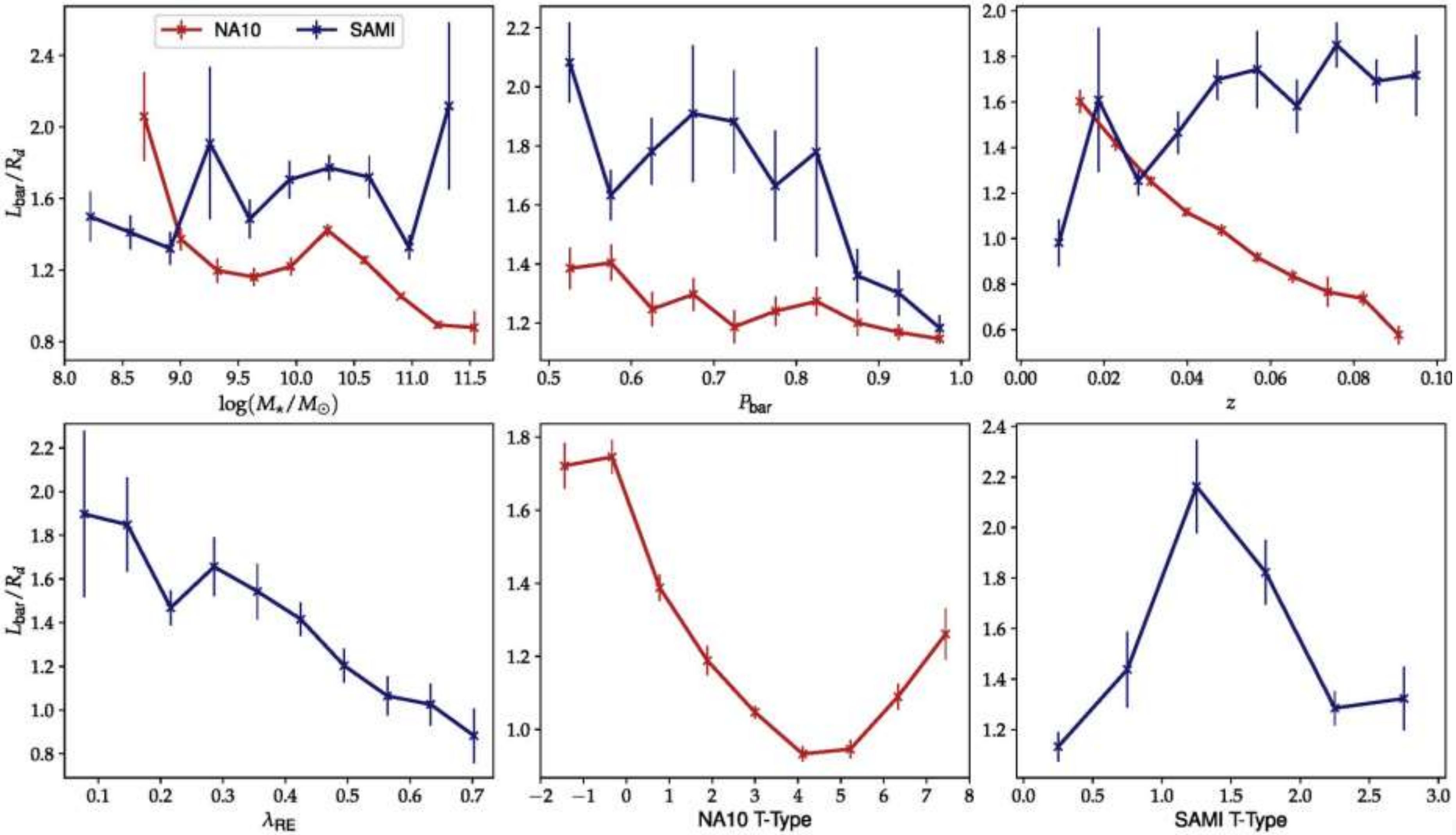
3 RESULTS

Physical properties



The absolute bar length L_{bar} in terms of stellar mass, bar classification confidence P_{bar}, redshift z, the spin parameter proxy λ_{R_e}, NA10 T-Types and SAMI T-Types. NA10 and SAMI galaxies are coloured in dark red and dark blue, respectively. Error bars denote one standard error σ. See Table B1 for the correspondence between numerical T-Types and morphological type.

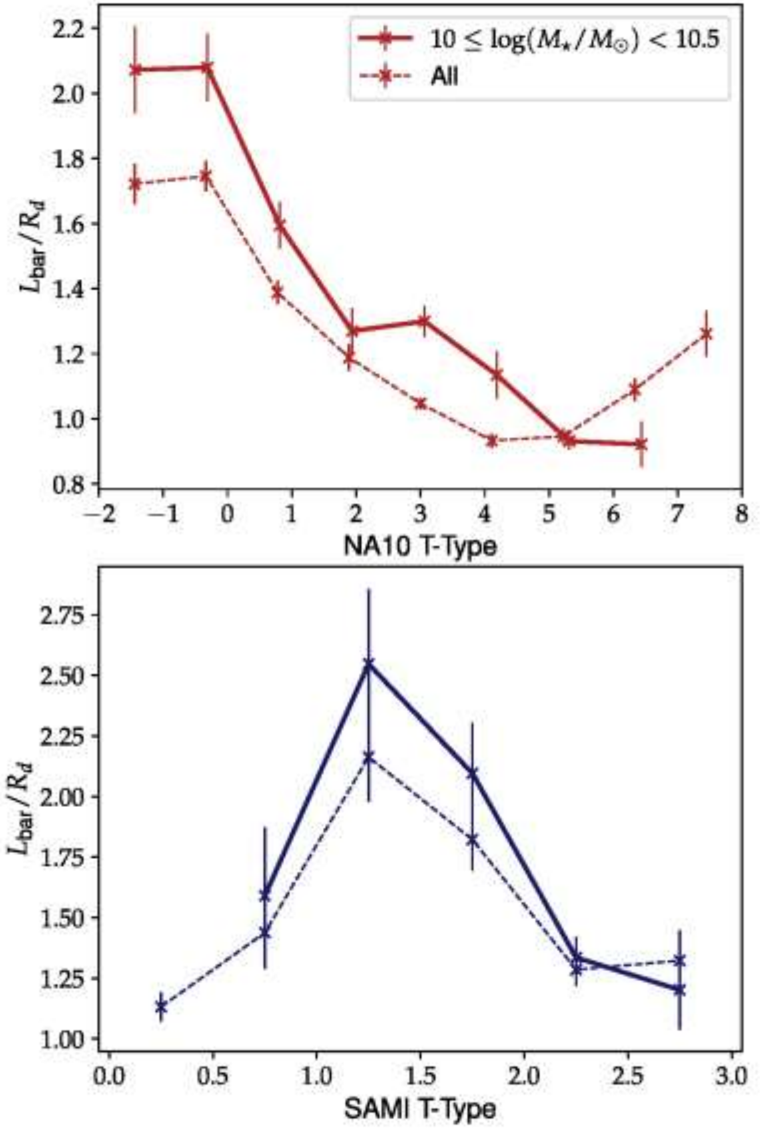
3 RESULTS
Physical properties

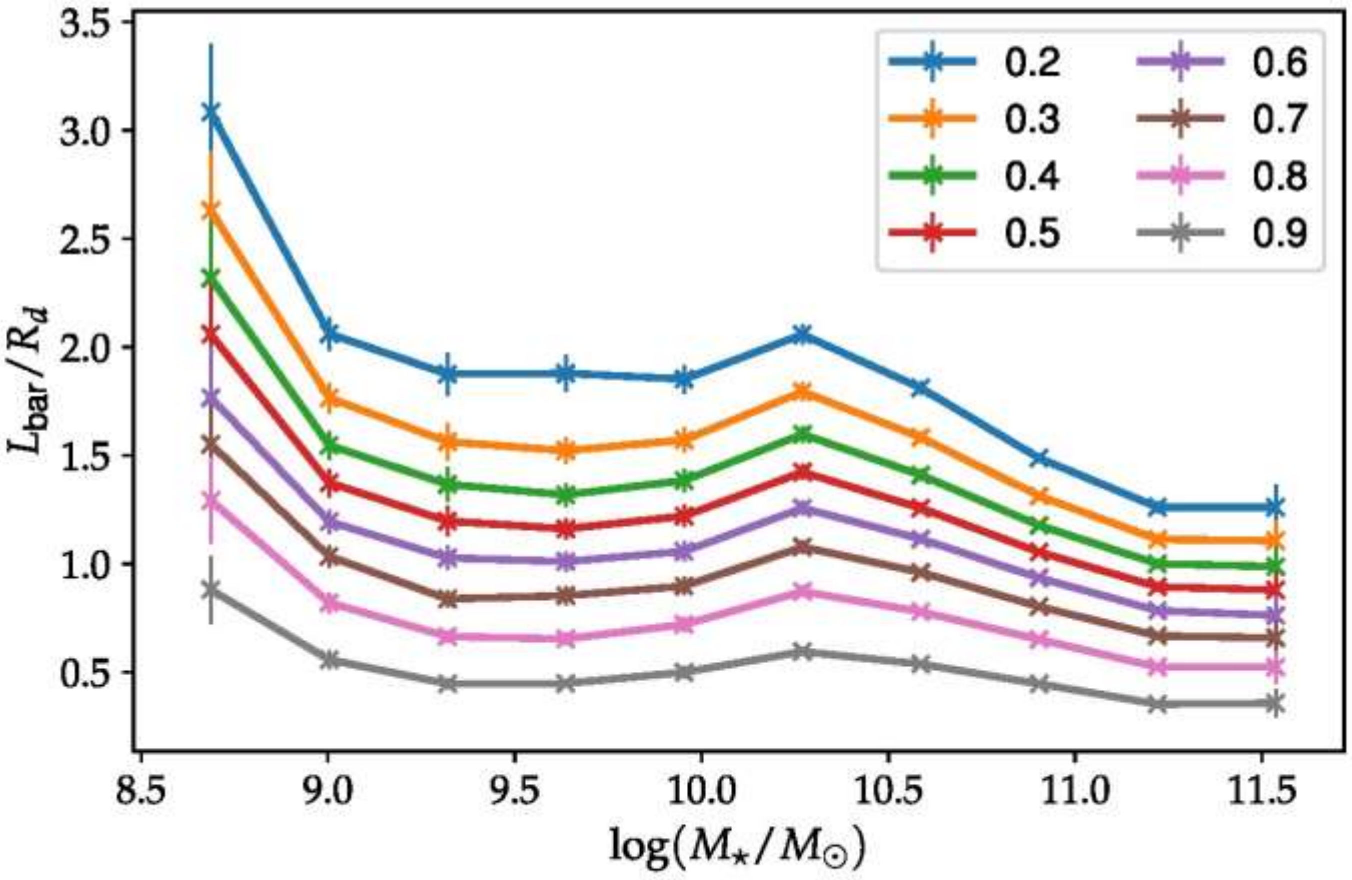


The same plots as in Fig. 9, but instead showing the normalized, relative bar length L_{bar}/R_d.

3 RESULTS

Physical properties





4 DISCUSSION
galaxy size

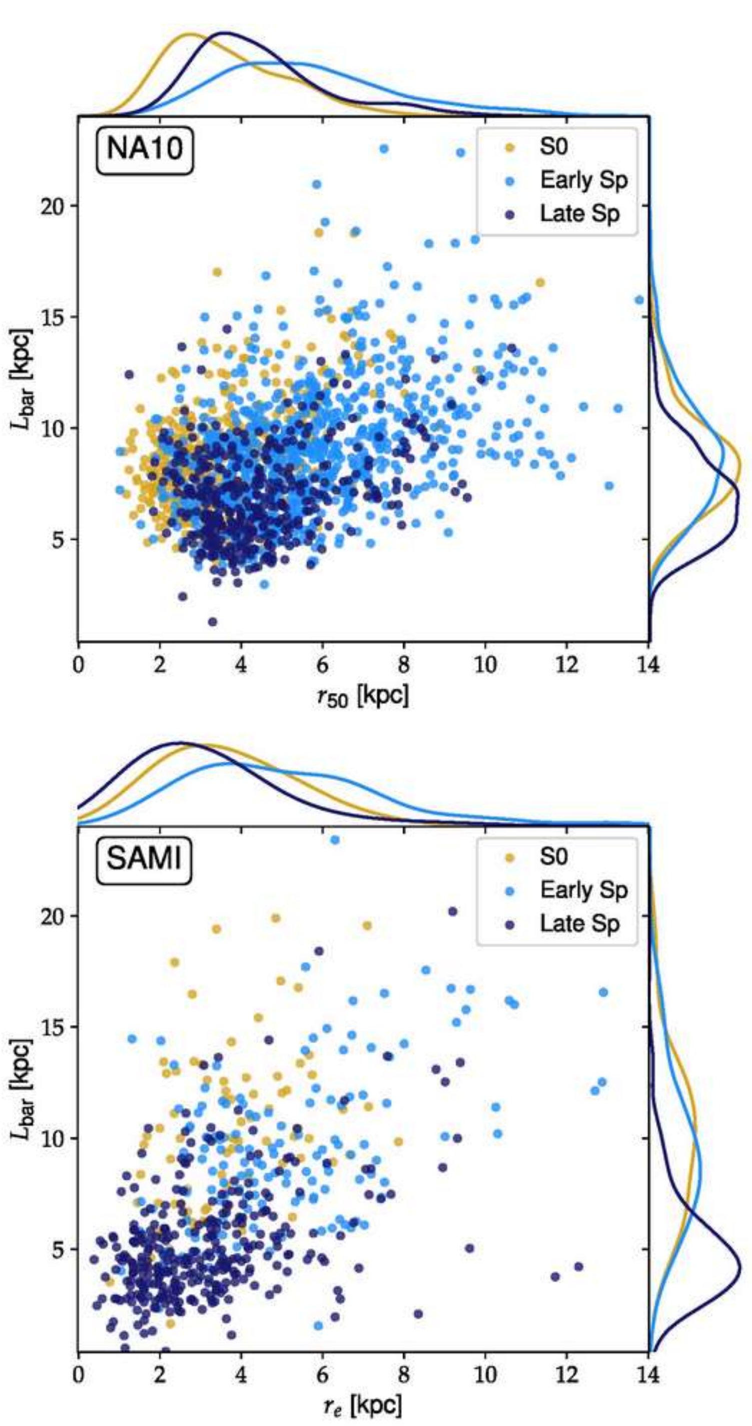


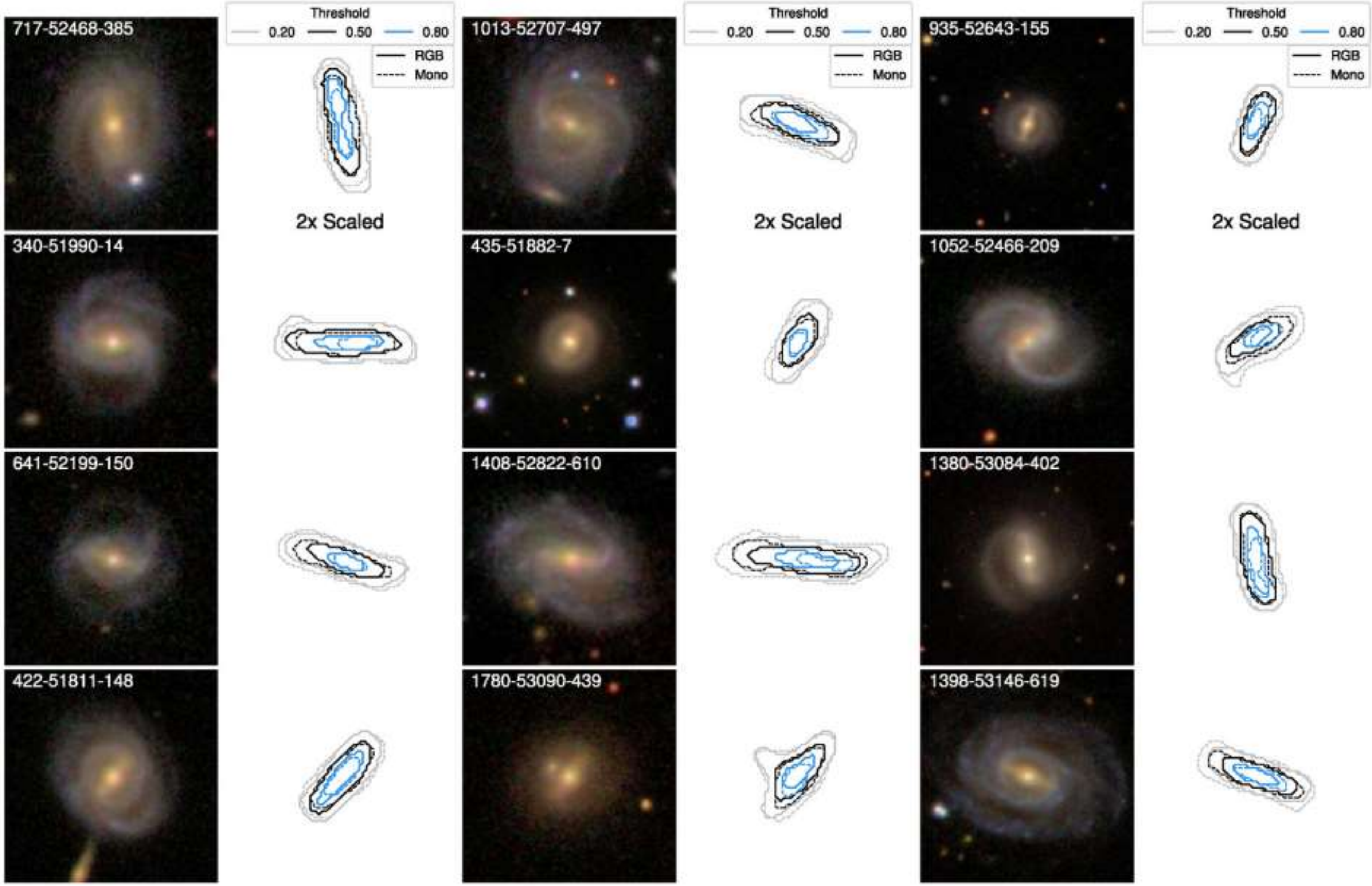
Figure 13.
The absolute bar length L_{bar} in terms of the Petrosian half-flux radius r_{50} for the NA10 galaxies and effective radius r_e for the SAMI galaxies. Points are coloured according to morphology, with the probability densities displayed on the margins.

It can be seen in Fig. 13 that there is significant scatter when it comes to morphology; however, it is still possible to disentangle both the NA10 and SAMI data sets.

the absolute bar length L_{bar} tends to be shortest in late spirals, although the distributions for L_{bar} with respect to S0s and early spirals are a lot tighter. The distribution of L_{bar} is best separated with morphology in the SAMI data set. When it comes to galaxy size, the smallest galaxies in SAMI tend to be late spirals, while the smallest galaxies in NA10 ($r_{50} \leqslant 2$ kpc) are overwhelmingly S0 galaxies. Galaxy size r_{50} acts as fair indicator of morphology.

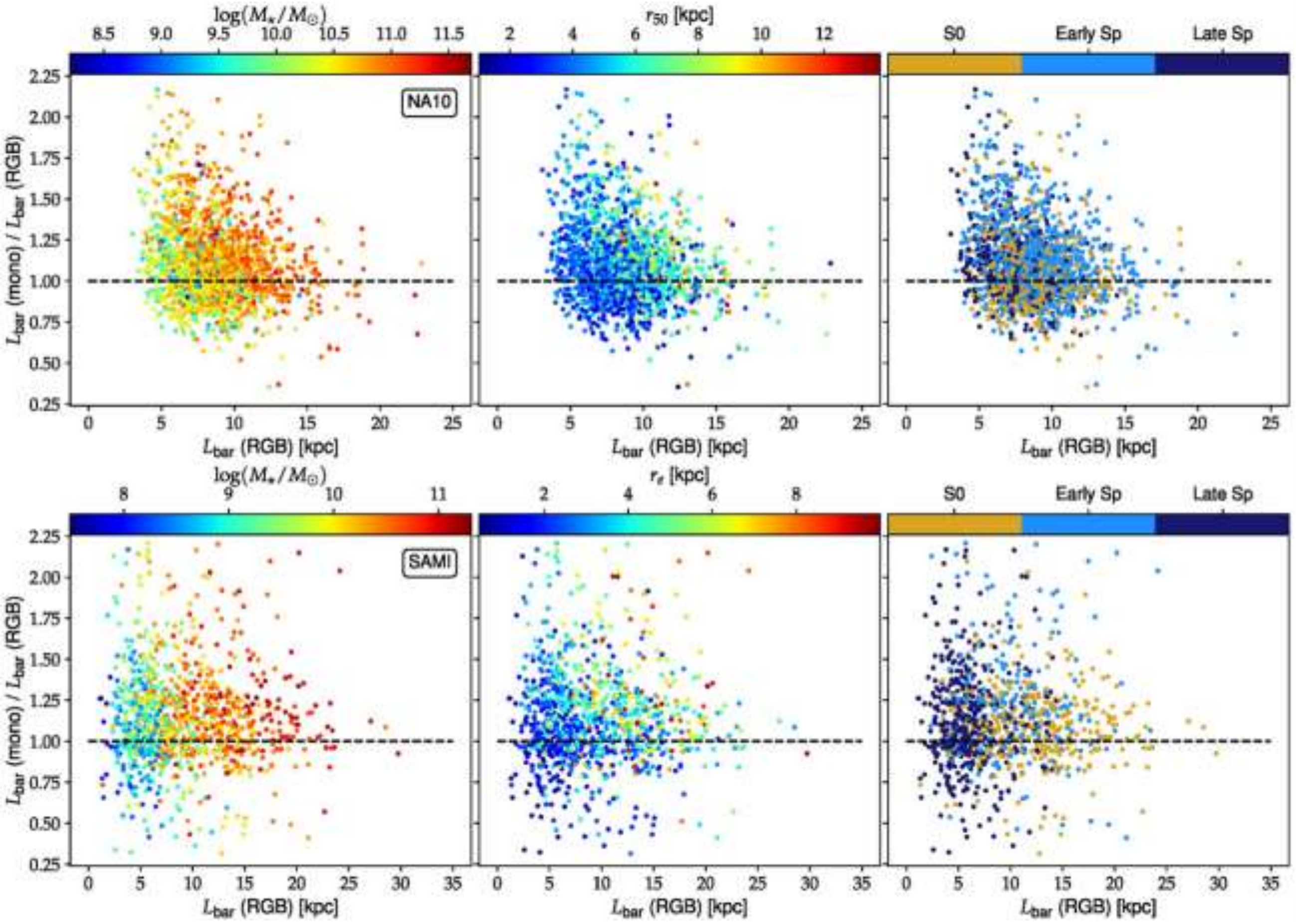
4 DISCUSSION

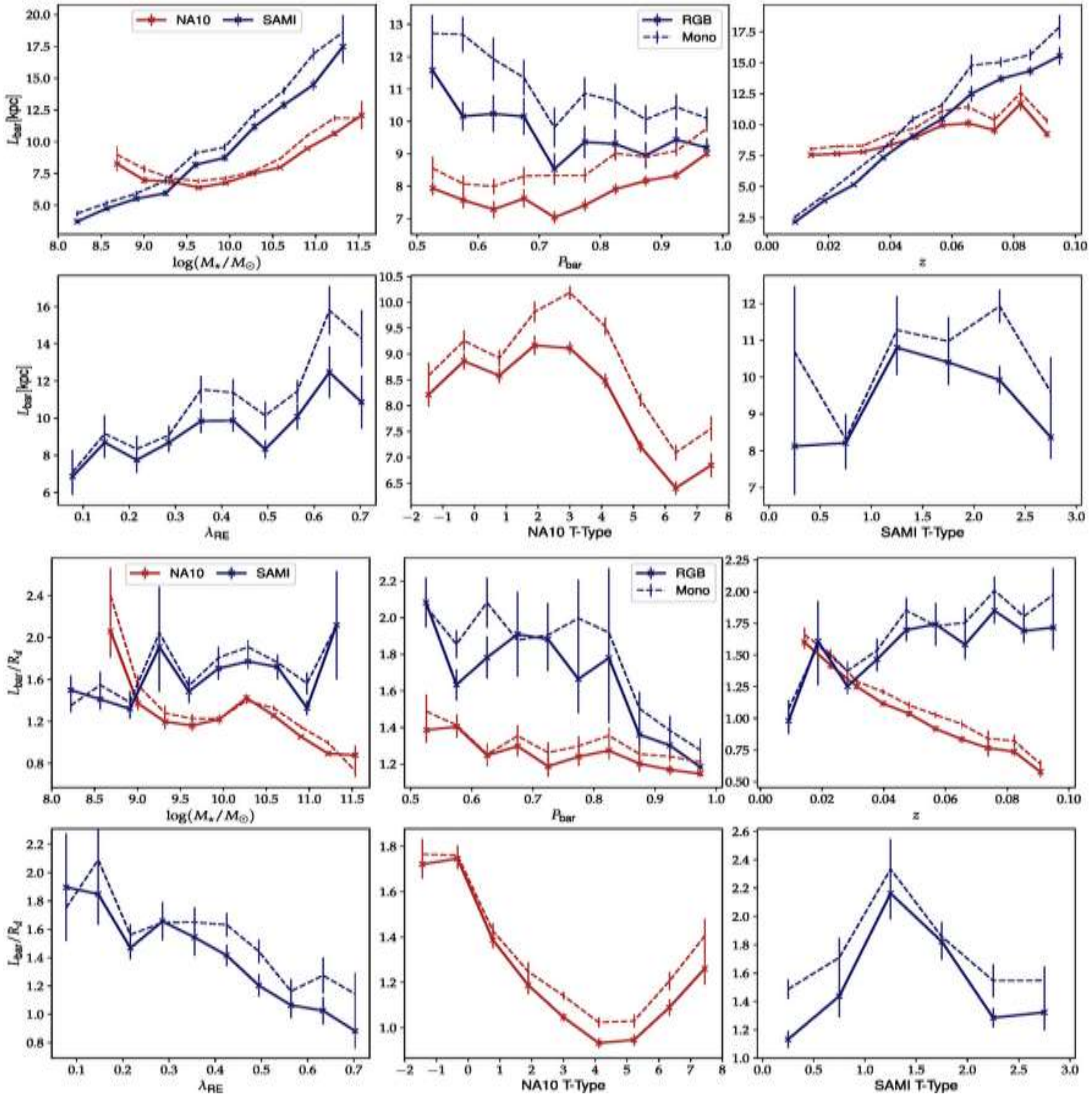
Comparison of the RGB colour and monochromatic U-Nets



4 DISCUSSION

Comparison of the RGB colour and monochromatic U-Nets





5 CONCLUSIONS
Our main results are summarized below:

We have developed a deep learning model to perform morphological segmentation of galaxy imaging in order to estimate the lengths of bars in barred galaxies and examine how both the absolute bar length L_{bar} and normalized bar length $L_{\mathrm{bar}}/R_{\mathrm{d}}$ varies with respect to various physical properties.

We have found that, in terms of absolute length bars in high-mass galaxies are physically longer than in low-mass galaxies.

We have found that bar length also depends strongly on morphology.

We have shown that our U-Net model is able to successfully differentiate between spiral arms and stellar bars in monochromatic imaging.

We note that our U-Net morphological segmentation technique is inherently versatile, and it is possible for the model to be applied to a wider range of observed galaxies.

Thanks