Detecting Low Surface Brightness Galaxies with Mask R-CNN

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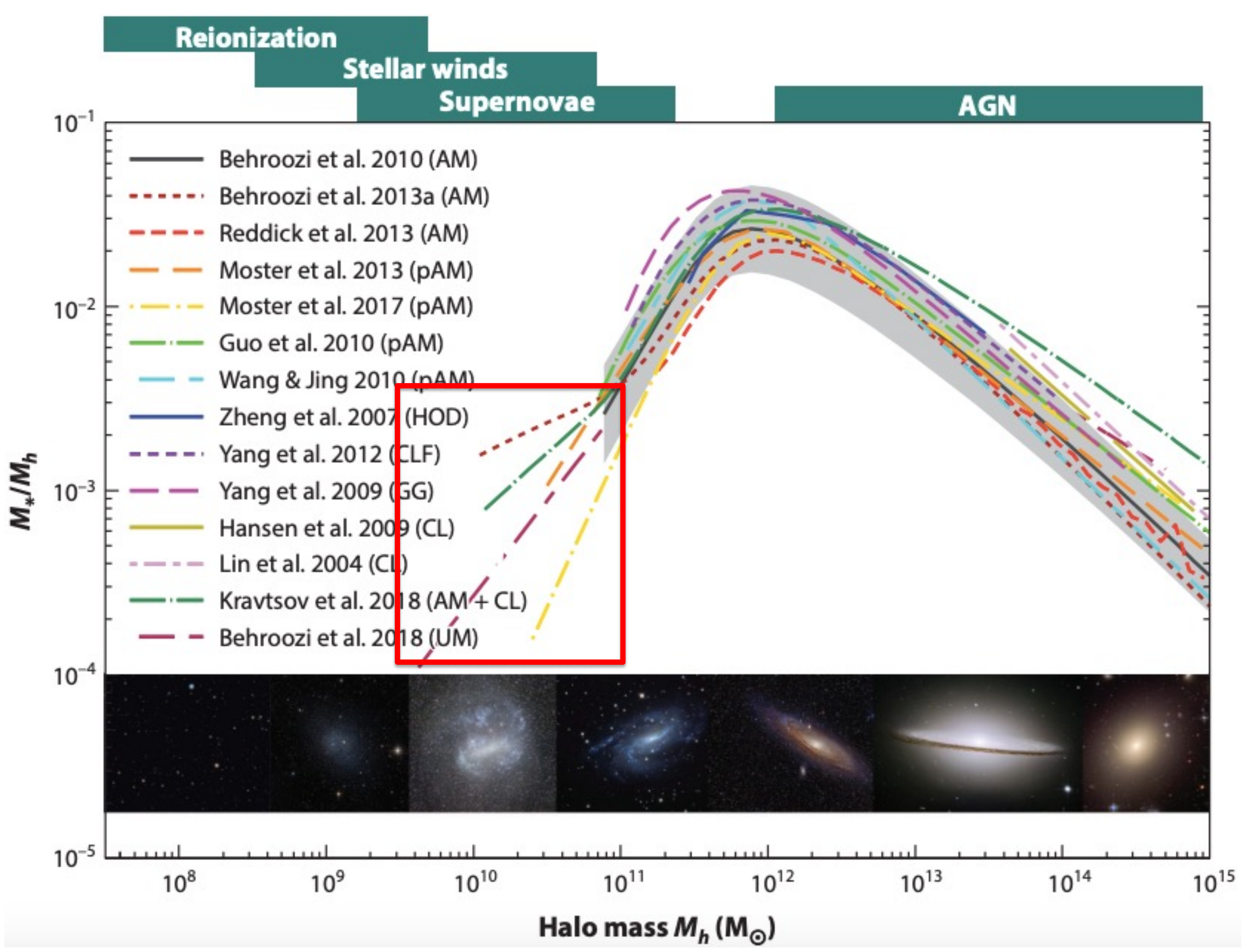
Introduction

An important aspect of understanding the role of dark matter in our universe is the relationship between galaxies and the dark matter halos hosting them, the galaxy-halo connection [2]. One way to understand this relationship is to constrain the association between halo mass and stellar mass. Observing bright and massive galaxies has allowed astronomers to do this well for massive dark matter halos. However, the low-halo-mass space is poorly constrained, owing to the difficulty of detecting faint galaxies.



Low-surface-brightness galaxies (LSBGs), defined as galaxies fainter than the night sky, inhabit this low halo mass space and thus detecting and constraining their properties is a key aspect in understanding dark matter.

Fig. 1 – Relationship between the ratio of stellar-to-halo mass and the total halo mass for central galaxies at zero redshift. The large-halo-mass region is well constrained due to the brightness of the galaxies that occupy these halos. The low-halo-mass region, surrounded by the red box where most models diverge, is poorly constrained and requires efficient ways for detecting low surface brightness galaxies to statistically distinguish between models.

The purpose of this project is to develop a deep-learning model trained on simulated LSBGs to detect faint objects in the data of the Dark Energy Survey (DES). We hope to train the model to find very large, diffuse features that are virtually undetectable in traditional source detection methods.

Methods

The model used is a variation of a Convolutional Neural Network (CNN) called Mask R-CNN [1]. We trained this model on images from the Dark Energy Survey containing two classes of objects: LSBGs (simulated) and artifacts (noisy compact sources). Images are preprocessed by removing compact sources, replacing them with a gaussian-distributed background, convolution with a gaussian kernel, and image binning.

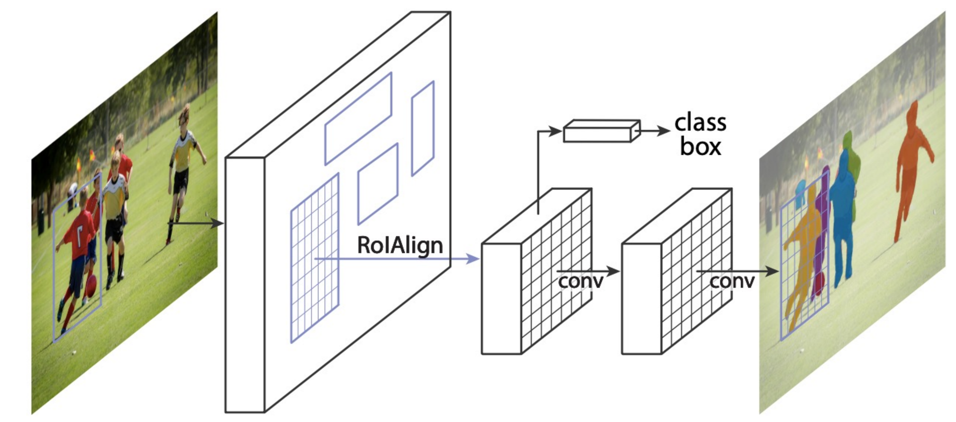


Fig. 2 – Object instance segmentation framework for the Mask R-CNN model. The model takes an image and first passes it to a pre-trained CNN, which outputs a feature map. This feature map is then fed into a region-proposal network that produces possible locations of objects. These regions are resized before being passed to the final stage of training where the network simultaneously learns to classify the object, find the optimum bounding box region, and create per-pixel associations with the class (masks).

Technical Training Info:

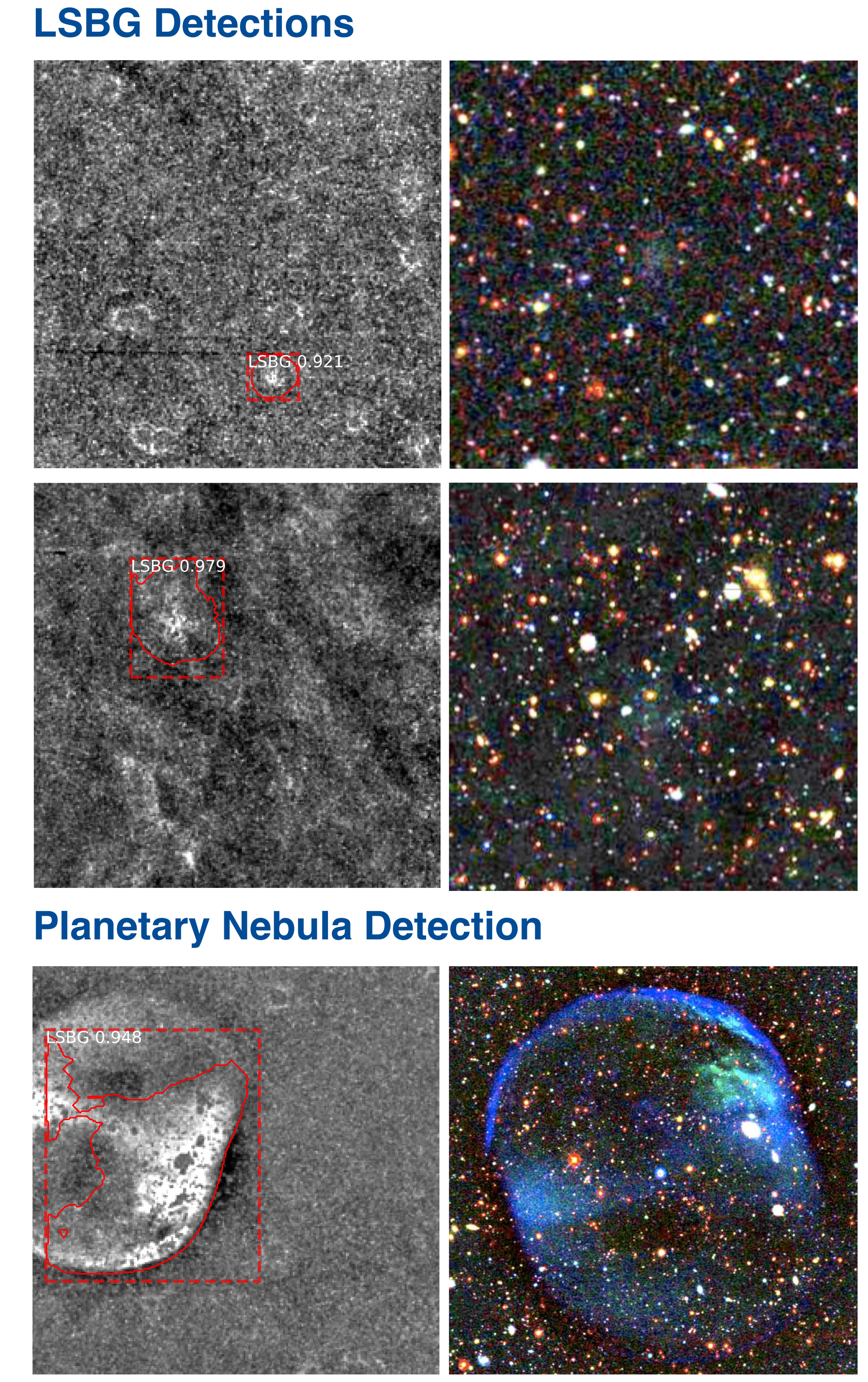
- Processed 100 Tiles on DES cluster, ~16 simulated LSBGs per tile
- Transferred to Google Drive
- Trained on Google Colab
- Used test set to evaluate model

Technical Detection Info:

- Processed 10,000 tiles on DES cluster
- Transferred ~260GB to Google Drive
- Ran detection on Google Colab
- Generated webpage with detections for visual inspection

Results

LSBG Detections



Preliminary results on 1% of the total DES dataset (100 tiles) revealed a variety of low surface brightness features, including:

- LSBGs,
- planetary nebulae,
- and Galactic cirrus.

The figure to the left demonstrates the power of preprocessing and the Mask R-CNN model in detecting ultra-faint objects. Preprocessing exaggerates dim, large-scale features and allows for detection of objects not picked up by traditional compact-source detection algorithms. Some of these features are so faint that they require high contrast of the color image to see.

Fig. 3 – Detection results on 1% sample of DES data showing low surface brightness features discovered. The left panel shows the images outputted by the Mask R-CNN model with bounding boxes, masks, and confidence scores for the objects identified. The right panel is a color image cutout of the object using the DESI Legacy Imaging Sky Viewer (http://legacysurvey.org/).

References

1. He, K., Gkioxari, G., Dollár, P., Girshick, R., 2018. Mask R-CNN.1703.06870.
2. Wechsler, R.H., Tinker, J.L., 2018. The Connection Between Galaxies and Their Dark Matter Halos. ARA&A 56, 435–487. 1804.03097.

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