

AI/ML Applications in A&A
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Identifying lopsidedness in spiral galaxies using a Deep Convolutional Neural Network (DCNN)

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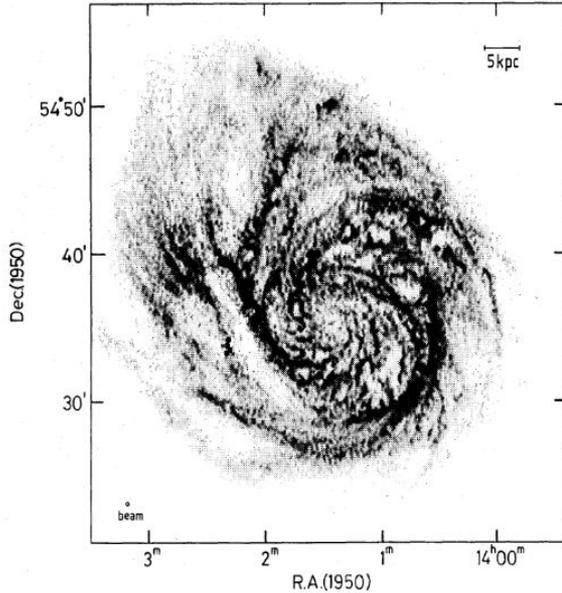
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Plan of the talk

- Introduction
- Motivation and objectives
- Application of the ML technique: **Deep Convolutional Neural Network**
- Results
- Summary

Lopsidedness in galaxies : A large-scale asymmetric feature



HI intensity distribution of M101 (Braun, 1995)

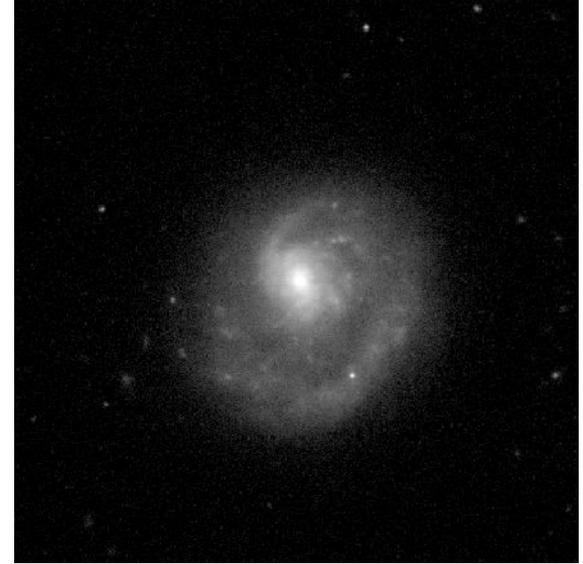
A significant fraction ($\sim 30\%$) of disk galaxies show lopsidedness in their stellar and/or gas distribution.*

Quantifying lopsidedness:

$$I(R, \phi) = I_0(R) + \sum_m a_m \cos(m\phi) + b_m \sin(m\phi)$$



$$A_1 = \frac{\sqrt{a_1^2 + b_1^2}}{I_0}$$



Lopsided spiral galaxy, seen face-on (i-band SDSS DR 18 image)

Lopsidedness takes part in the outward angular momentum transport and contribute to the secular evolution of the galaxy.

Origin and evolution of lopsidedness in galaxies - An Enigma

Minor Mergers
(Zaritsky and Rix, 1997)

Tidal Encounter
(Kornreich et al., 2002)

Ram Pressure Stripping
and flybys
(Mapelli et al., 2005)

“Nurture” scenario

Asymmetric gas accretion
(Bournaud et al., 2005)

Disk response to a Lopsided
DM halo (Jog et al., 1998)

Off-centered DM halo
(Bournaud et al., 2005)

“Nature” scenario

- Disentangling these processes requires more observational data.
- Lopsidedness correlates more with internal parameters than any particular external driving source.
- Key generating mechanism and the role of DM halo ? - needs to be investigated.
- Rigorous observational studies coupled with controlled simulation is required for a robust, systematic understanding.

What we aim to achieve ?

- **Identify a large sample of lopsided galaxies** from the present and future surveys - this will contribute towards understanding their origin and evolution.

How do we do it ?

- Using the Machine Learning Technique - **Deep Convolutional Neural Network (DCNN)** based on AlexNet architecture (Krizhevsky et al., 2012)

Train the supervised ML network with labelled images



Test the network's performance after training



Large number of new predictions using the trained model.

Sample selection

Face-on spiral galaxies from
SDSS DR 18.
400 galaxy images

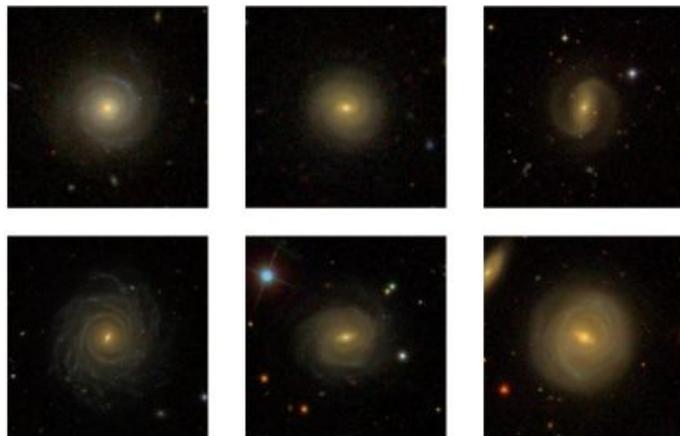
petrosian radius > 20 arcsec;
 $\theta_i \leq 50^\circ$

Using visual inspection,
We selected : **106 lopsided
galaxies** (median $A_1 = 0.12$)
and **105 symmetric** (median
 $A_1 = 0.04$).

*Reichard et al. (2008) considered
galaxies with $A_1 < 0.08$ as least lopsided.

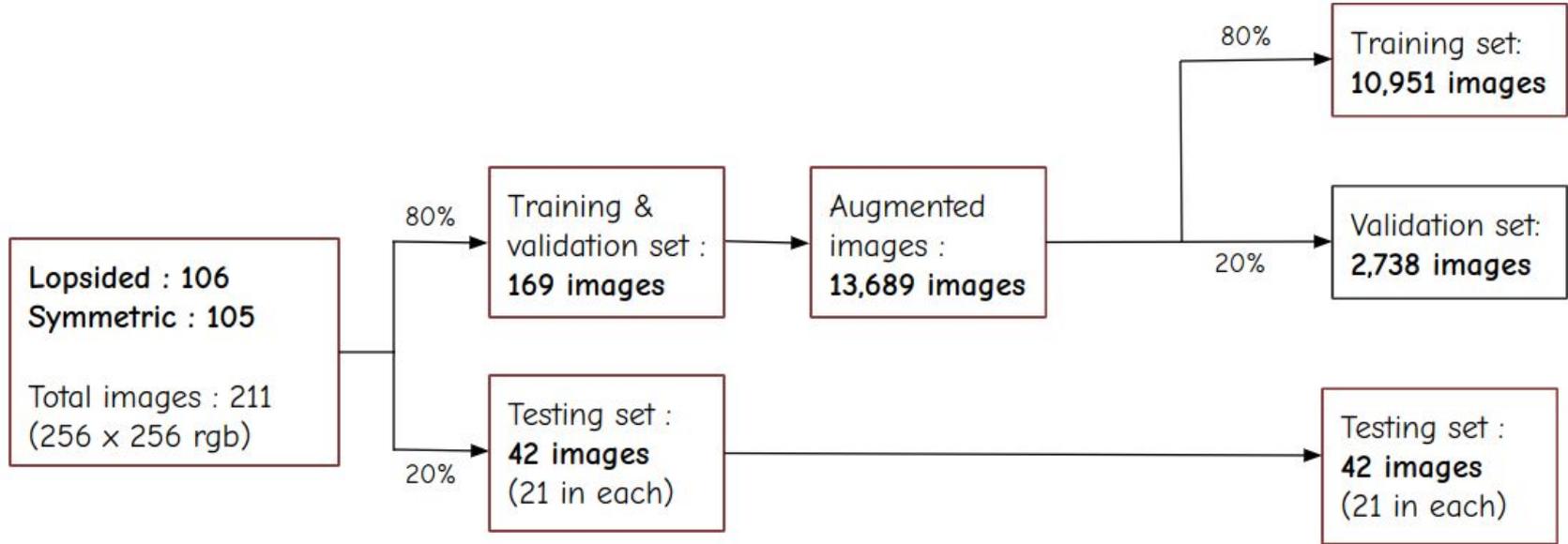


← Lopsided spiral galaxy
samples from the
training set

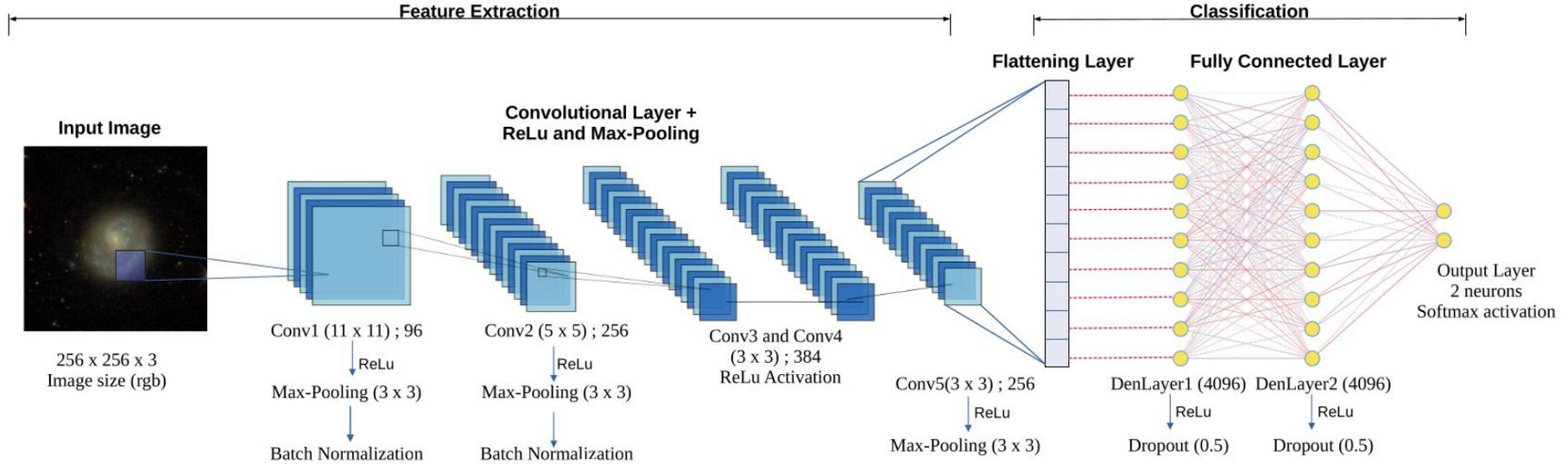


Symmetric spiral
galaxy samples →

Dataset for Training and Testing



DCNN Architecture



The schematic for the AlexNet Architecture for the DCNN used in this study.

Optimization rule:

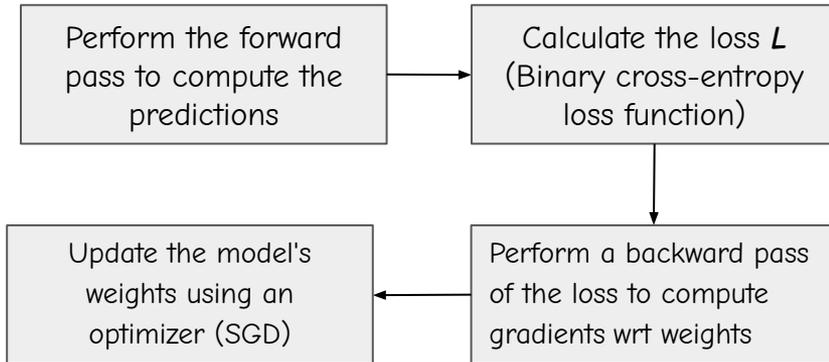
$$w_{\text{new}} = w_{\text{old}} - \eta \cdot \frac{\partial L}{\partial w}$$

Hyperparameters

Batch size: 64
 Dropout rate: 0.5
 Learning Rate: 5×10^{-5}
 Decay Rate: 2×10^{-4}

Training phase

- The model processes the training data in batches (mini-batches).



- This process continues until all training data is passed through the model (one epoch).

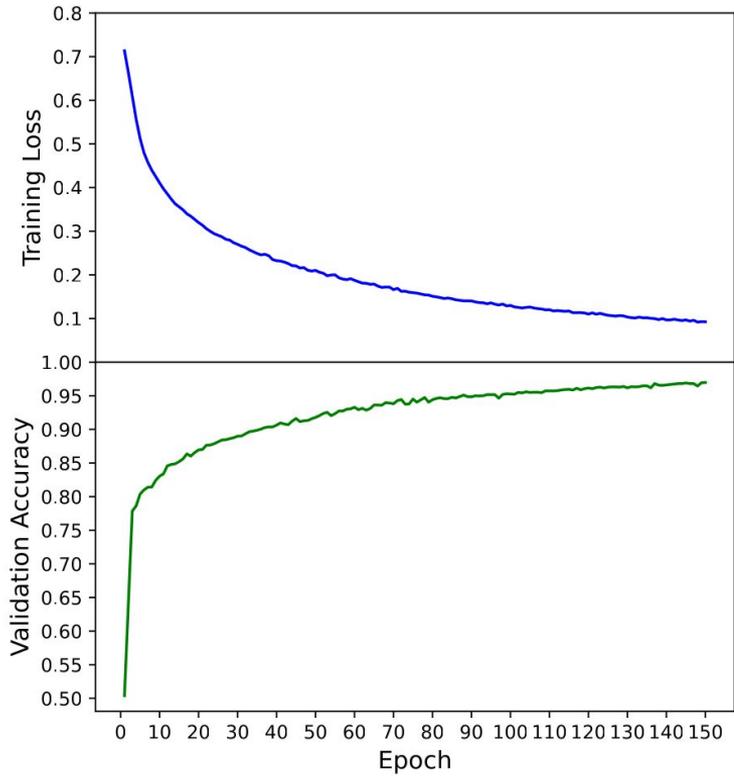
At the end of the epoch, the weights are optimized.

Validation phase

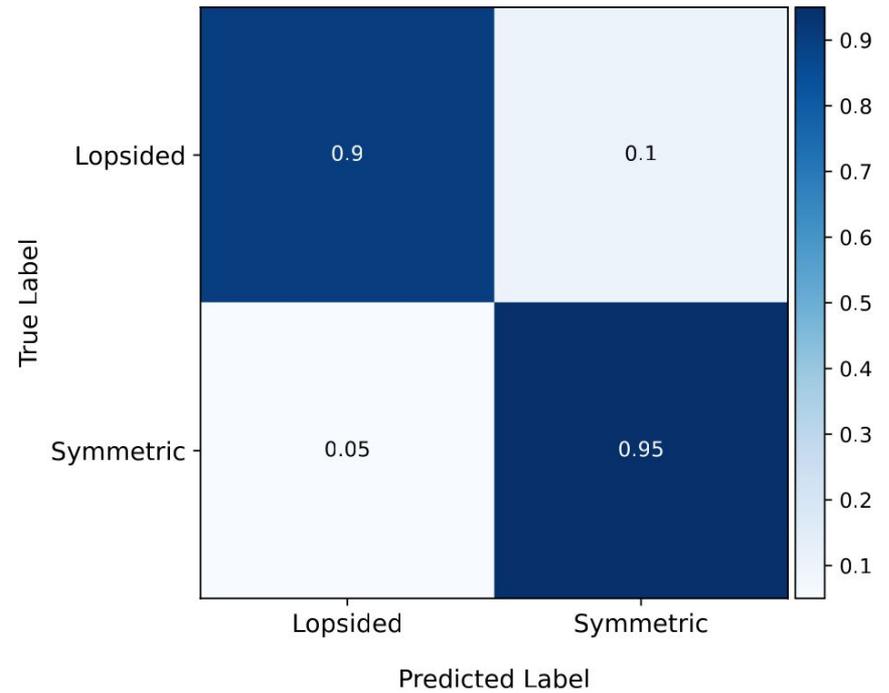
- The model uses the **current set of weights** (optimized during training) to make predictions on the **validation dataset**.
- The loss and accuracy is computed for the validation data (but weights are not updated).

This process is repeated for all the epochs, until we have a well-trained model.

Performance



The training loss and validation accuracy of the model against the number of epochs

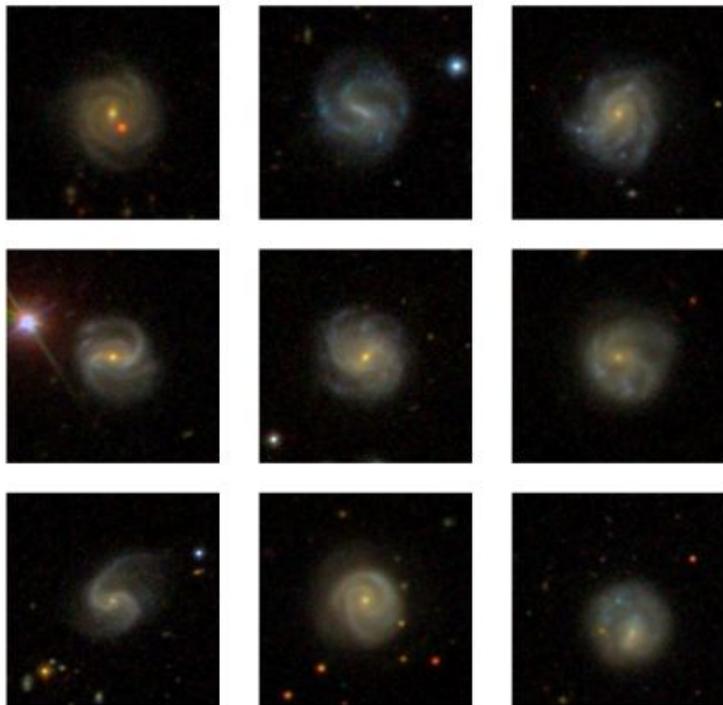


The confusion matrix

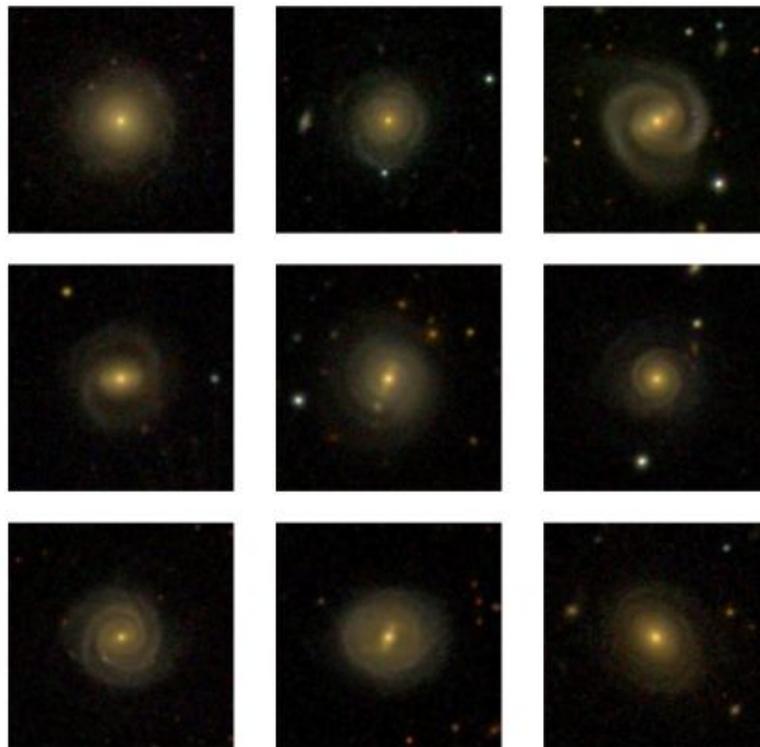
Accuracy on the testing set: 92.8% (Best run) ¹⁰

New predictions

Extracted **813** face-on spiral galaxies from SDSS DR18 with petrosian radius between 17 and 20 arcsec.

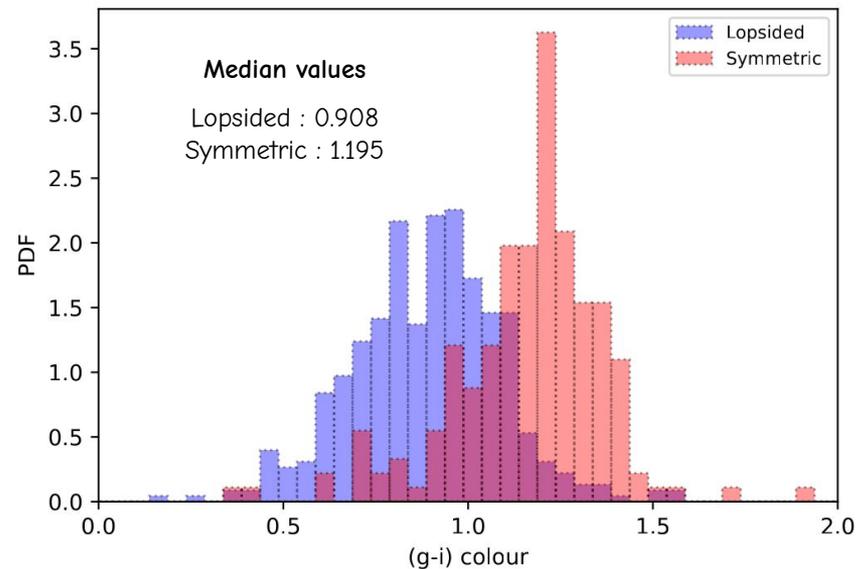
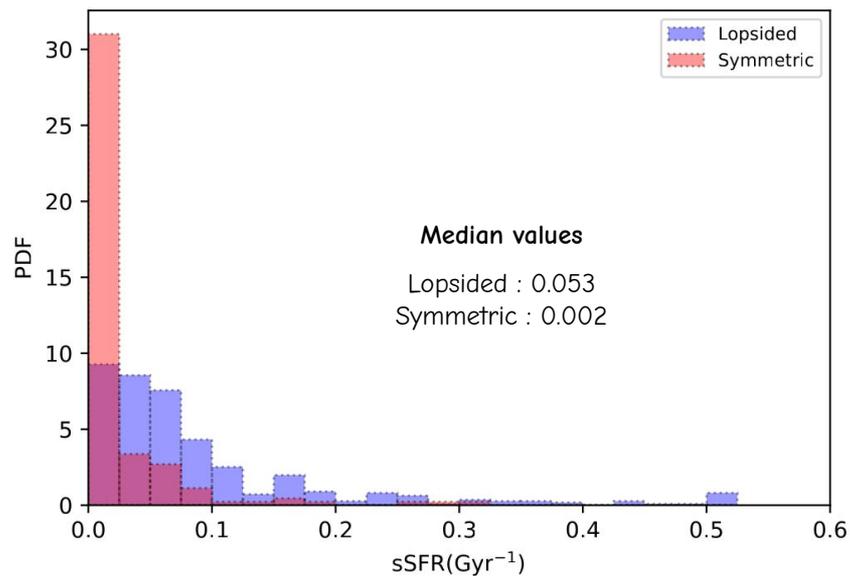


A subset out of the **452 newly predicted lopsided galaxies** (probability score ≥ 0.9)



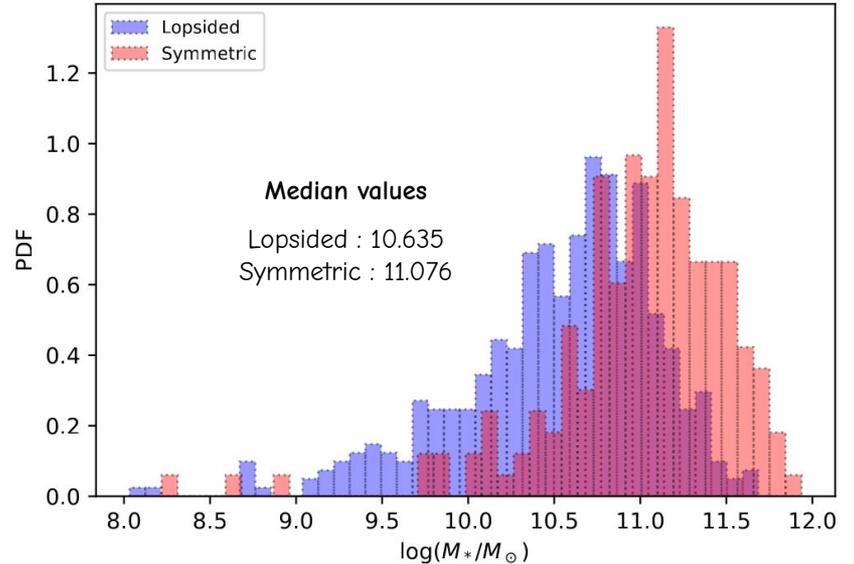
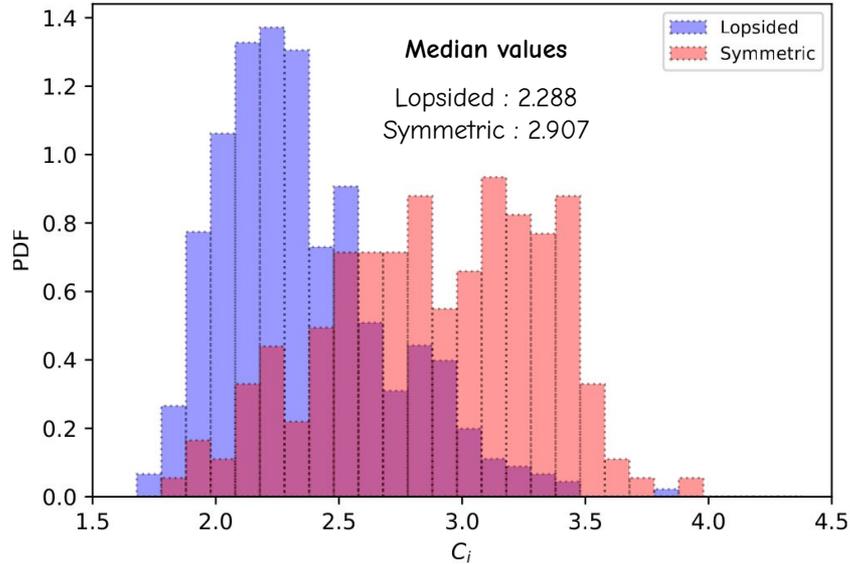
A subset of the newly predicted **symmetric galaxies**

Properties: sSFR and g-i colour



The lopsided galaxies have a **greater specific star formation rate** with an **excessive blue luminosity**.

Properties: concentration index and stellar mass

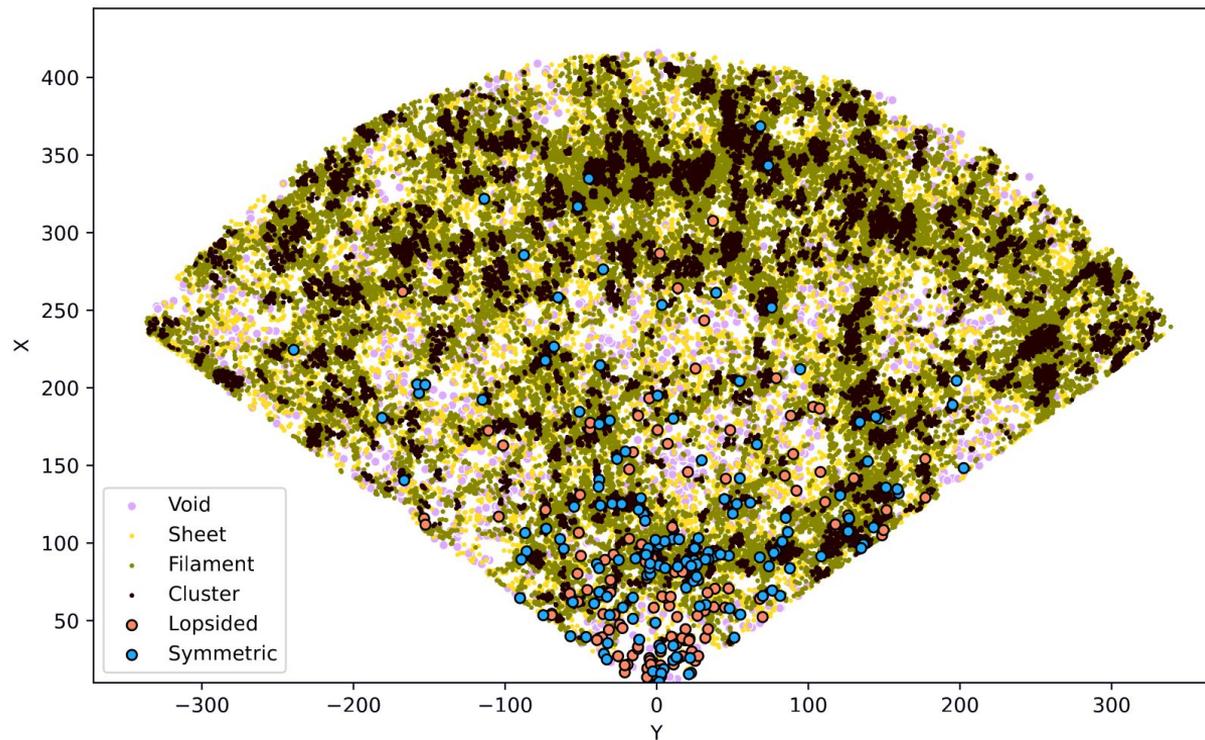


Lopsided galaxies have **lower concentration index (late-type)**
and are **less massive** compared to the symmetric galaxies.

Environmental Analysis

- We used the **T-web classification** scheme to classify the four different cosmic environments: **voids and sheets (sparser); filaments and clusters (denser)**. (Hahn et al. 2007, Forero-Romero et al. 2009)
- Percentage of lopsided galaxies in denser environment : **60%** (out of 450)
- Percentage of symmetric galaxies in denser environment : **74%** (out of 203)
- **Implications:** Impact of environment is not the only parameter driving lopsidedness; the internal parameters like stellar mass, central stellar surface density, etc. are the more fundamental parameters governing lopsidedness.
- **Almost 40% of lopsided galaxies in our sample are present in sparser environments.** (will provide great understanding of development of lopsidedness in isolated galaxies).

Environmental Analysis



Summary

- We identified **452 new samples of lopsided spiral galaxies** from SDSS DR18 using a DCNN.
- The lopsided galaxies in our predicted samples are relatively **high star-forming, bluer, low-concentration (late-type), low-mass galaxies** (consistent with previous studies).
- We classified the cosmic web environments within which the galaxies in our sample reside: voids, sheets, filaments and clusters.
- The environmental analysis reveals that environmental impact alone can not induce lopsidedness.
- **Almost 40% of lopsided galaxies in our sample reside in sparser environment like voids and sheets.**
- The catalogue of newly predicted lopsided galaxies, will help constrain the simulation studies, to provide better understanding of lopsidedness in galaxies.