

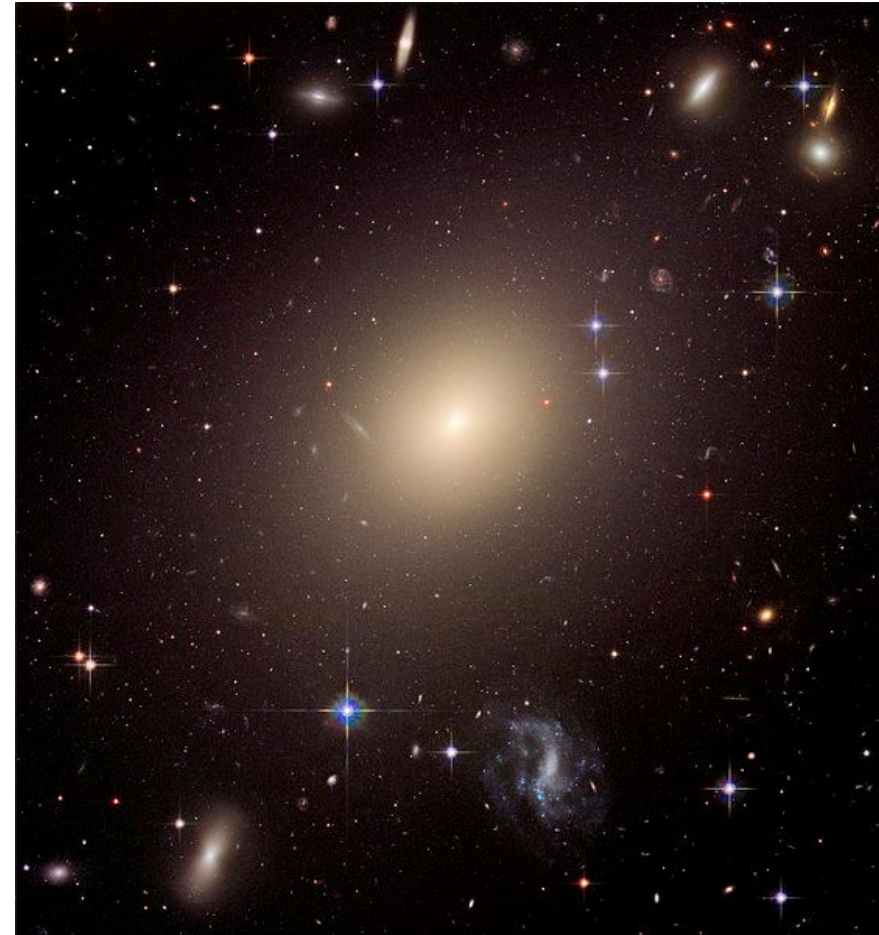
Artificial Intelligence for Astronomical Images

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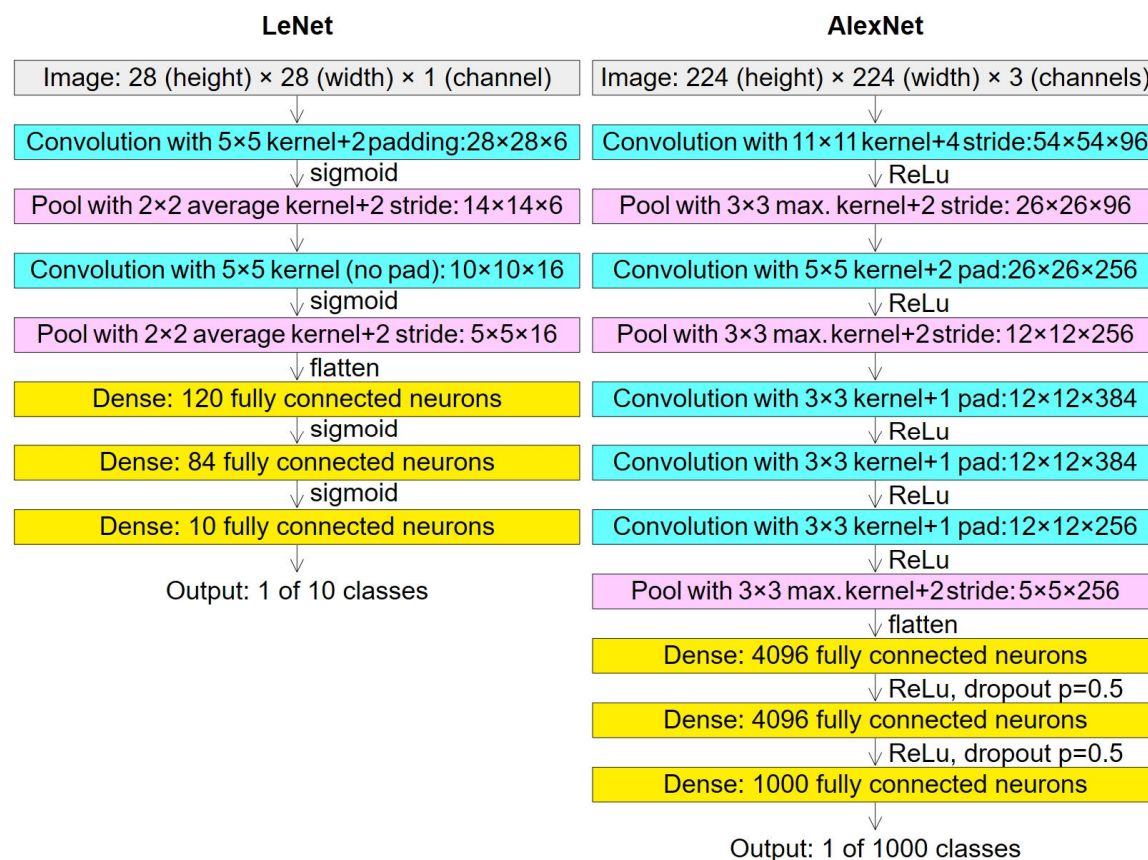
» Extract morphological information of galaxies

- Similar morphologies imply comparable evolutionary paths
- Hubble sequence
- Concentration(C), Sersic index, ...
- Ellipticity, Asymmetry(A), boxy/disky-shaped, ...
- Clumpiness(S), ...
- Computer vision: [feature detection](#)



Convolutional Neural Network(CNN)

- CNN: $y = \text{CNN}(x)$
 - dimension reduction
 - preserve spatial relationships
- Component
 - Convolution layer
 - Pooling layer
 - Fully connected layer
 - (Backpropagation)



» Convolution layer: extracts features

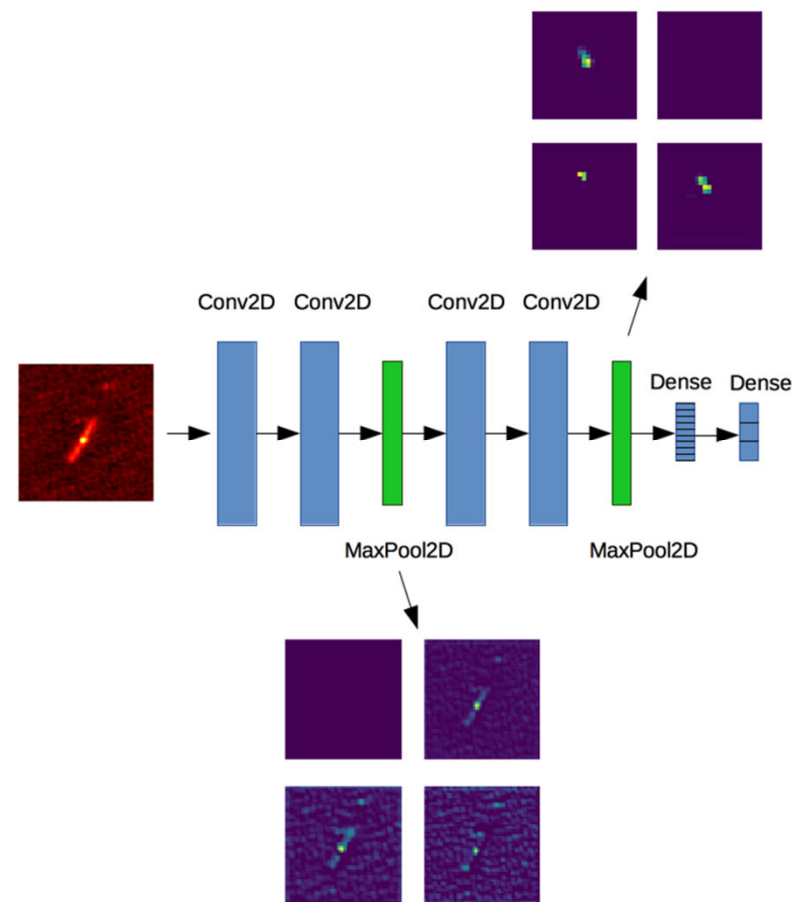
- 3*3 kernel, 0 padding, 1 stride
- Extracts features

1 _{x1}	1 _{x0}	1 _{x1}	0	0
0 _{x0}	1 _{x1}	1 _{x0}	1	0
0 _{x1}	0 _{x0}	1 _{x1}	1	1
0	0	1	1	0
0	1	1	0	0

Image

4		

Convolved
Feature



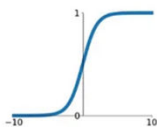
Convolution layer: extracts features

- 3*3 kernel, 0 padding, 1 stride
- Extracts features

Activation Functions

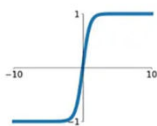
Sigmoid

$$\sigma(x) = \frac{1}{1+e^{-x}}$$



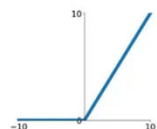
tanh

$$\tanh(x)$$



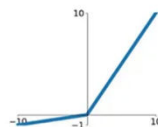
ReLU

$$\max(0, x)$$



Leaky ReLU

$$\max(0.1x, x)$$

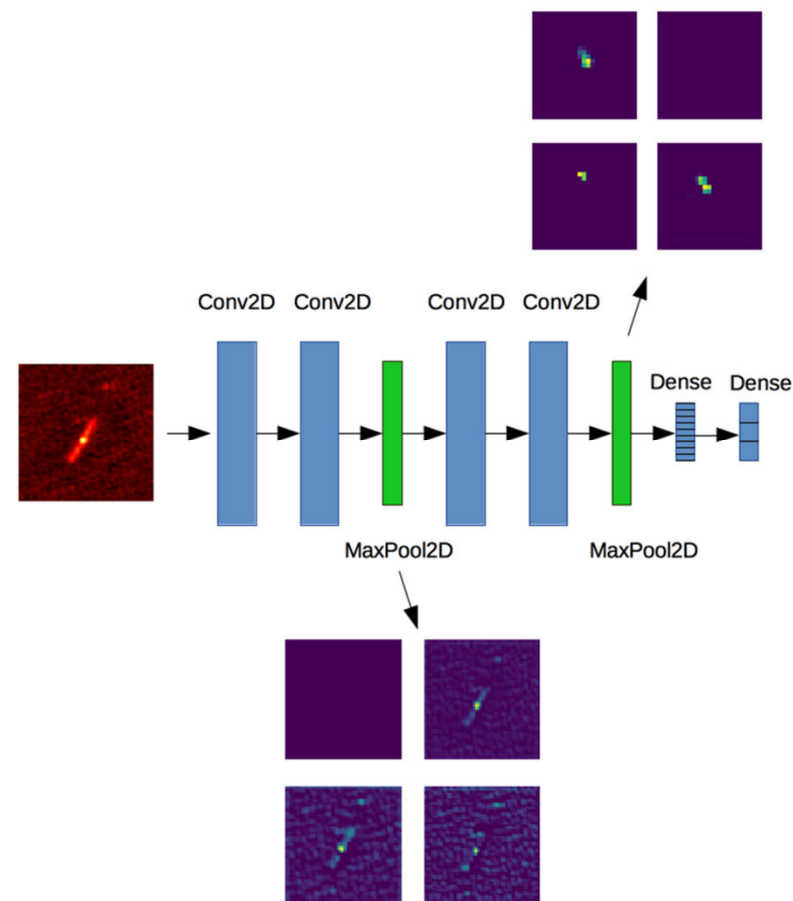
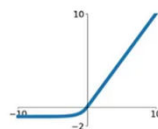


Maxout

$$\max(w_1^T x + b_1, w_2^T x + b_2)$$

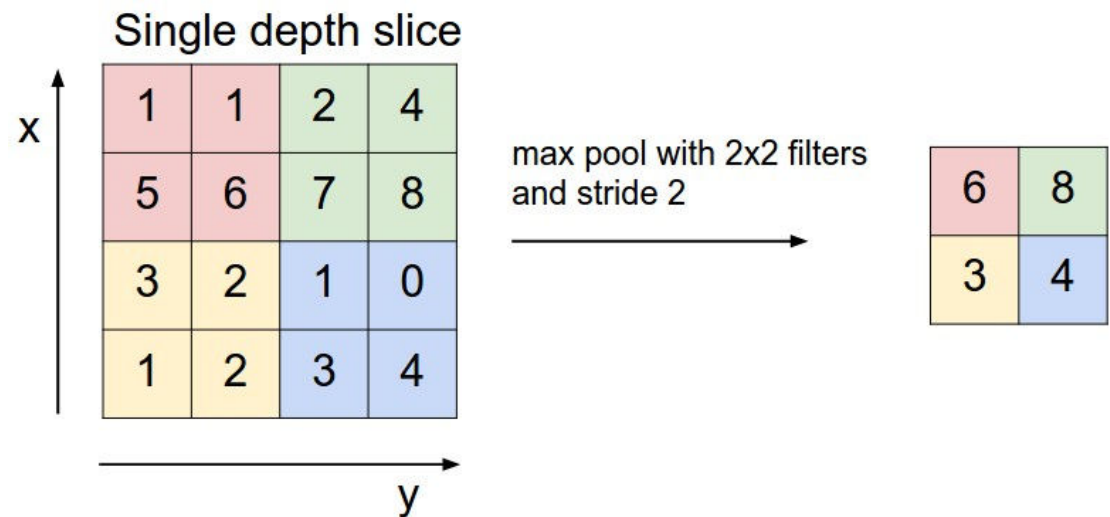
ELU

$$\begin{cases} x & x \geq 0 \\ \alpha(e^x - 1) & x < 0 \end{cases}$$

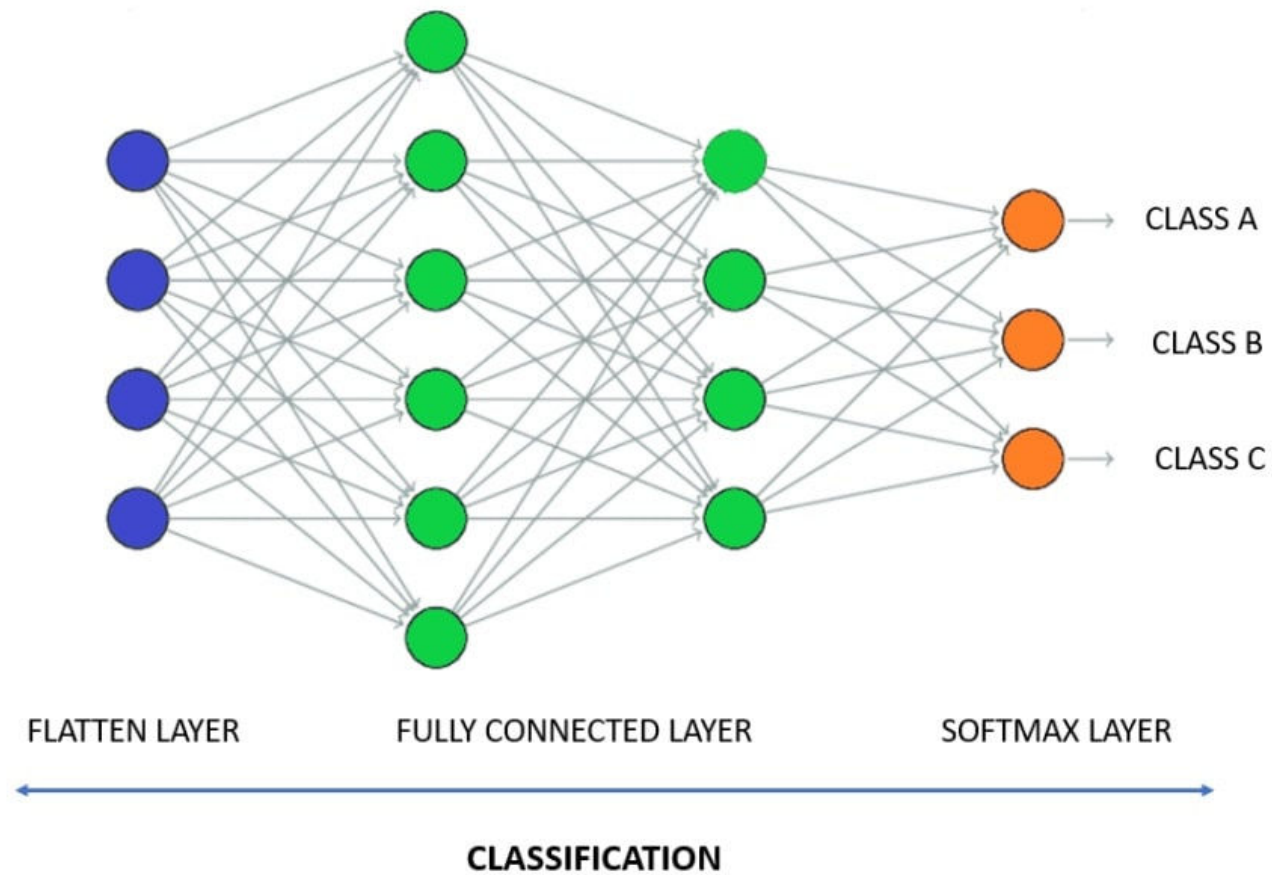


» Pooling layer

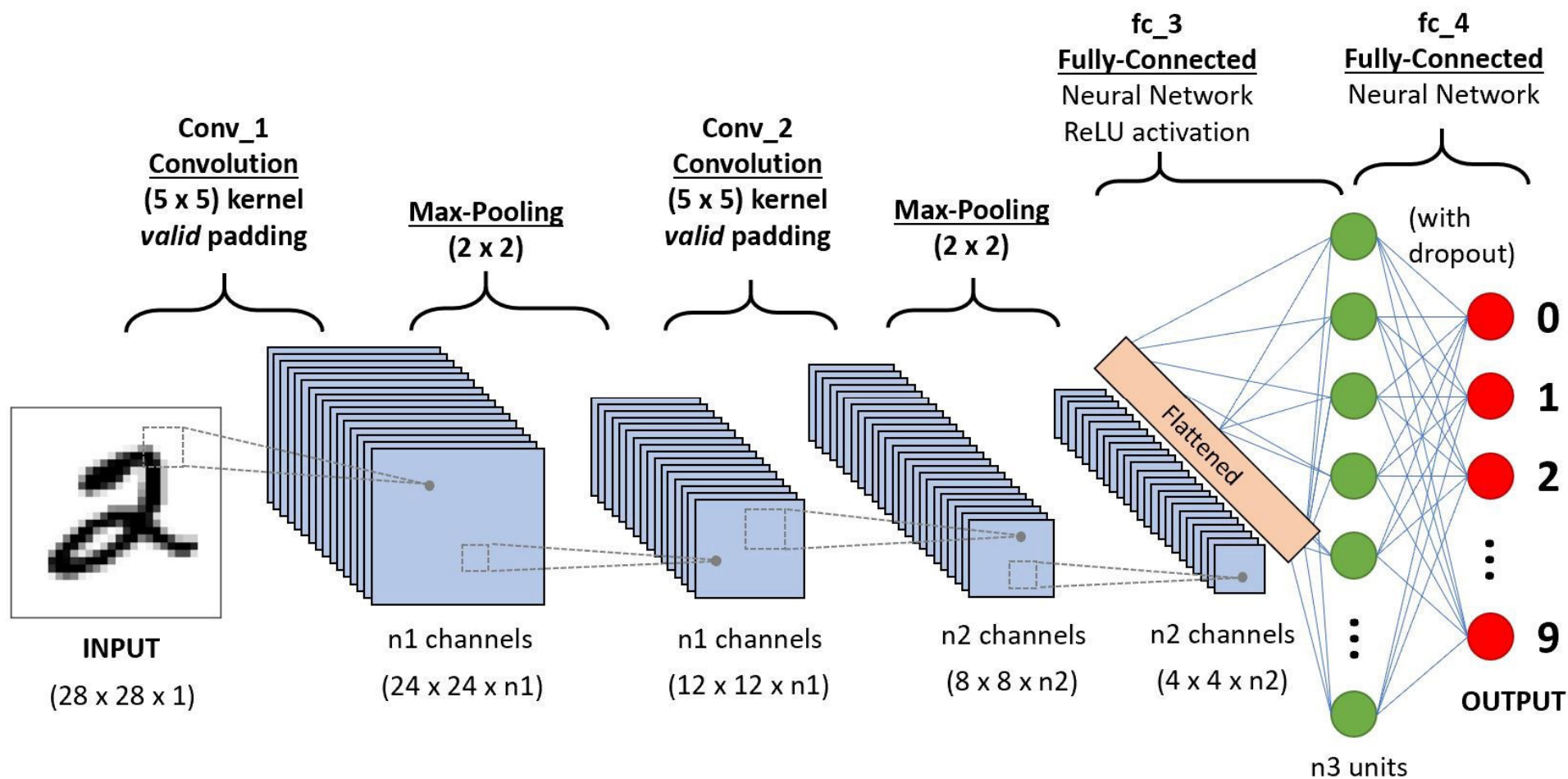
- Reduces the size of the feature maps
- Emphasize important features



» Fully connected layer

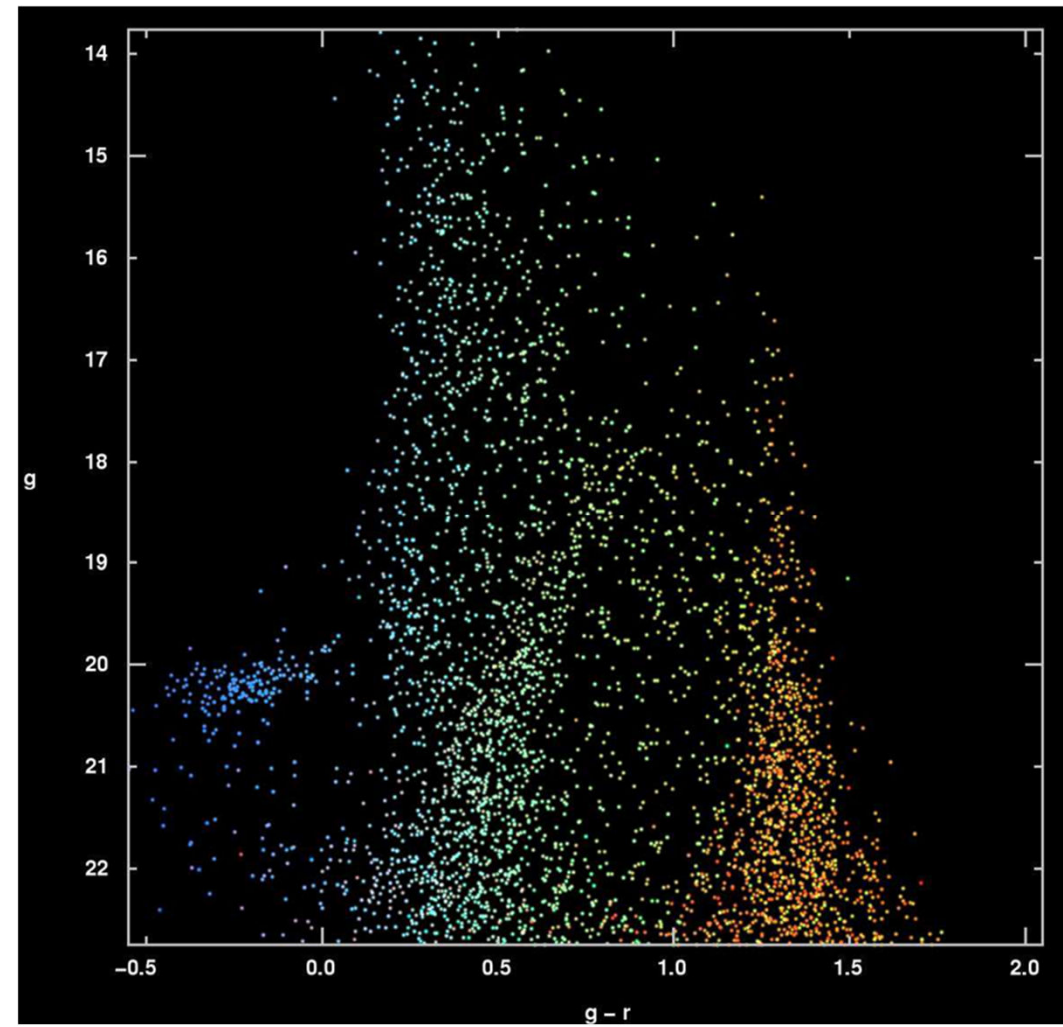
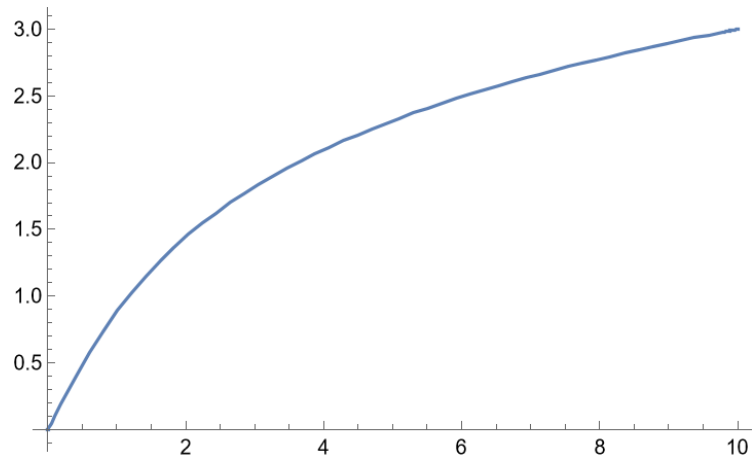


LeNet

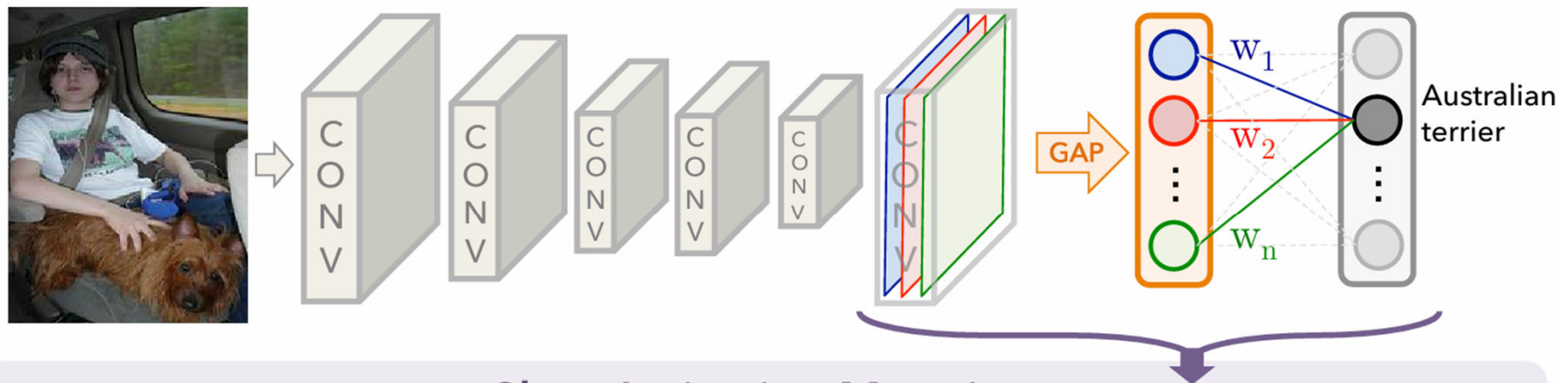


» *Astronomical Image

- $R = r * \text{ArcSinh}(I/C)/I$
- $G = g * \text{ArcSinh}(I/C)/I,$
- $B = b * \text{ArcSinh}(I/C)/I,$
 - where $I = (r+g+b)/3$, C is a constant



Explainable AI: Class Activation Mapping



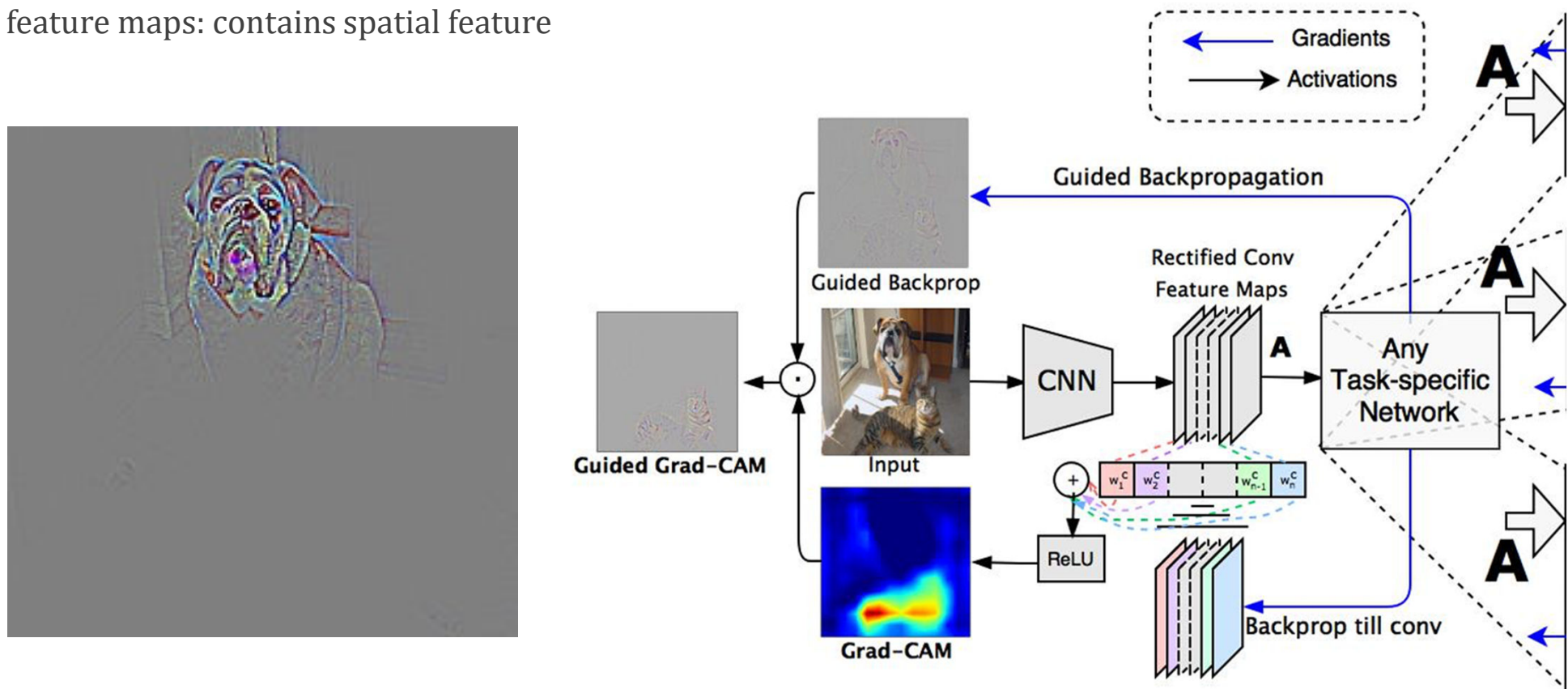
Class Activation Mapping

$$W_1 * \text{Feature Map}_1 + W_2 * \text{Feature Map}_2 + \dots + W_n * \text{Feature Map}_n = \text{Class Activation Map (Australian terrier)}$$

The equation shows the weighted sum of feature maps from different layers, resulting in the Class Activation Map (CAM) for the class 'Australian terrier'. The CAM is a heatmap where the most active regions (red/yellow) correspond to the areas of the input image that most strongly influenced the classification decision.

» Explainable AI: Grad-CAM

- feature maps: contains spatial feature



AI4AI: S-spin and Z-spin

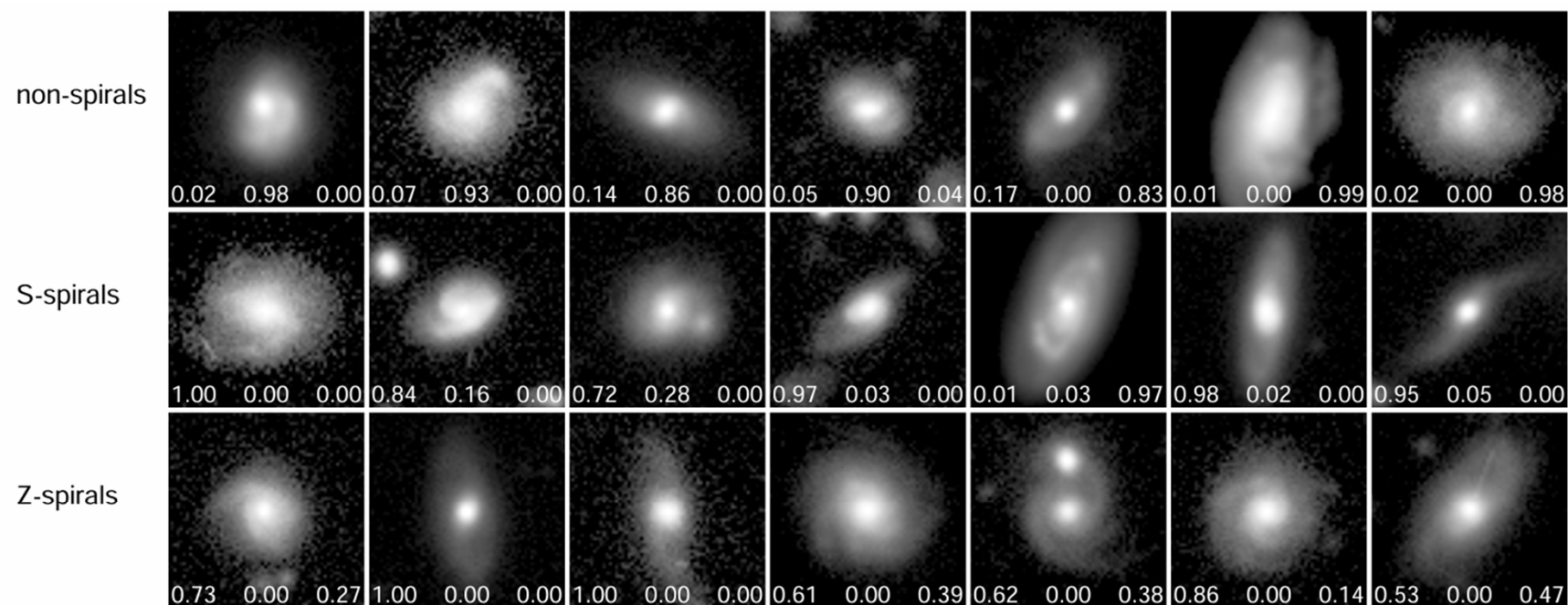
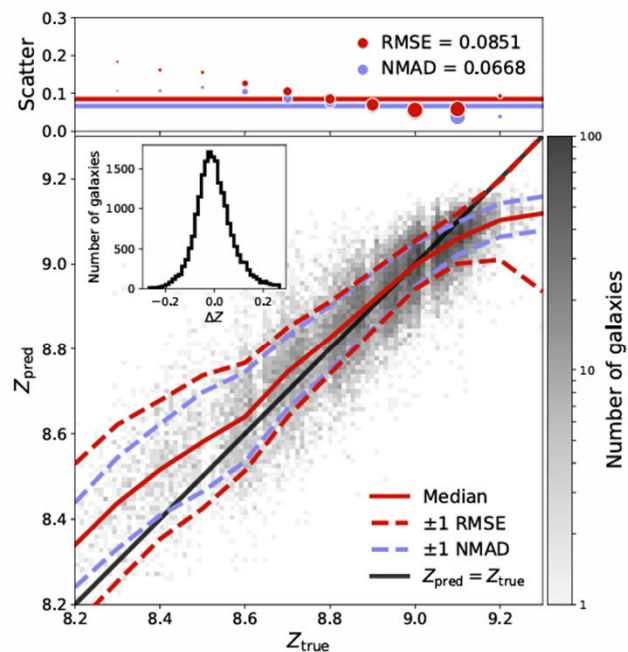


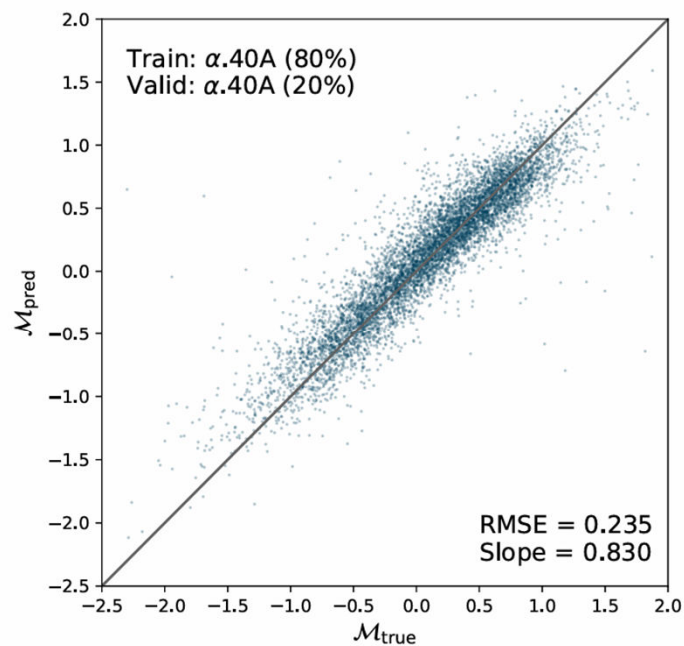
Figure 5. Examples of HSC images of misclassification in each class. From left to right in the bottom of each images, we show the predicted probabilities of non-spiral, S-spiral and Z-spiral.

AI4AI: Morphology to parameters

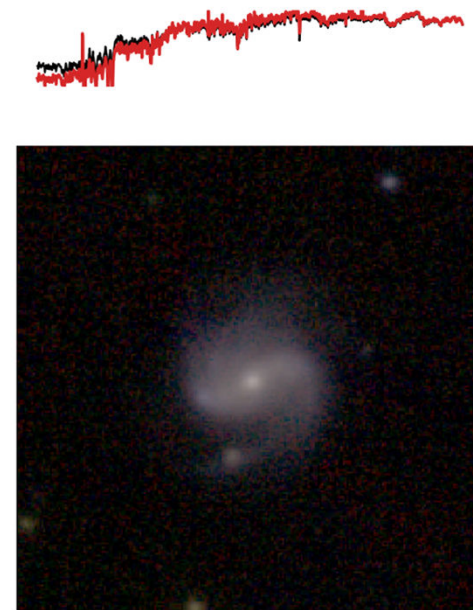
- Optical RGB image \rightarrow M^* , SFR, D4000, metallicity, HI Mass, AGN(75%), spectra ... Statistically



arXiv:1810.12913

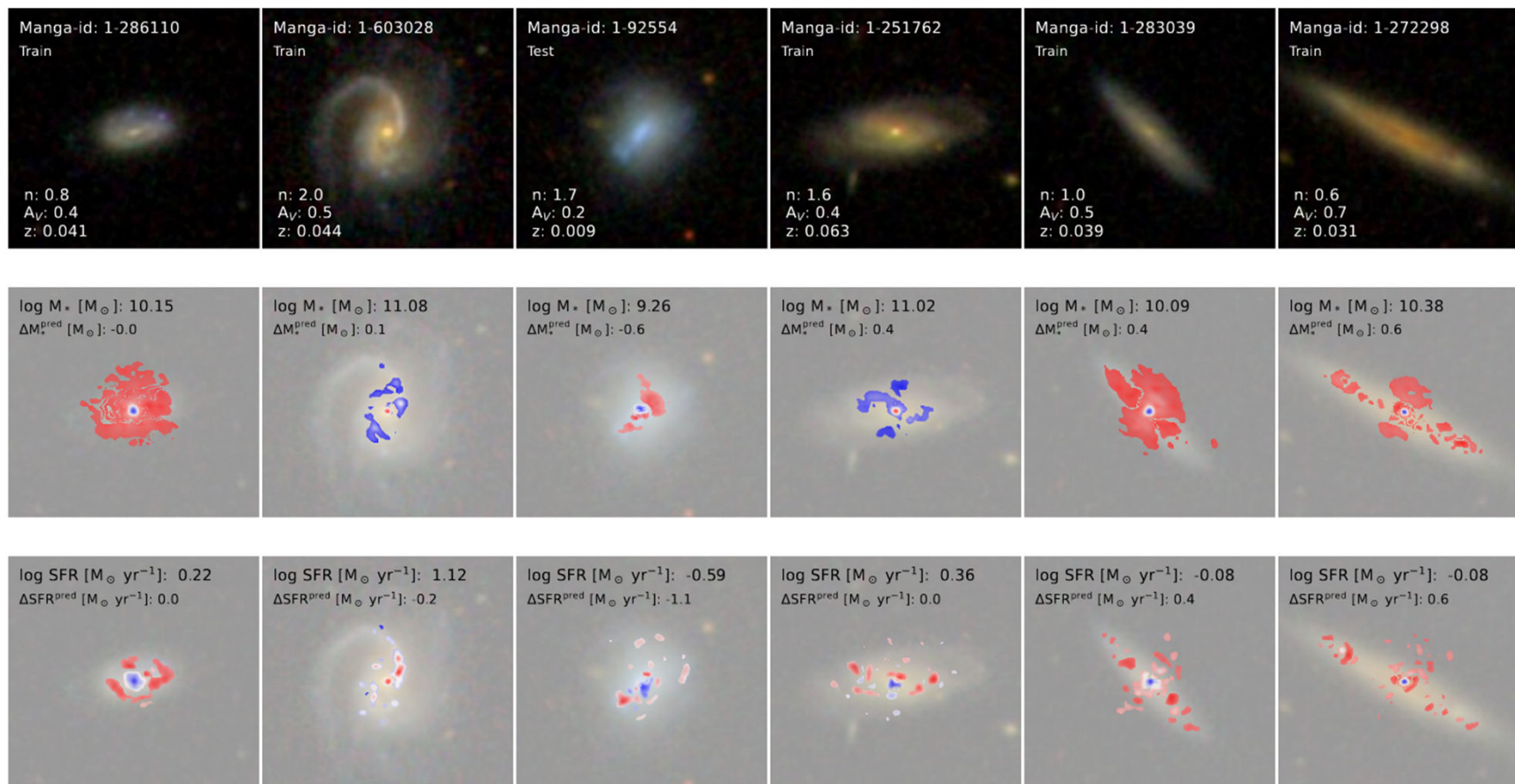


arXiv:2001.00018



arXiv:2009.12318

AI4AI: explainable AI for SFH



» Conclusion

- CNN can help us extract the features of galaxies
- Degrees of freedom of morphology
- Can explainable AI provide new scientific discoveries?