# GALAXY CLUSTER MASS ESTIMATION FROM CONVOLUTIONAL NEURAL NETWORKS

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## INTRODUCTION

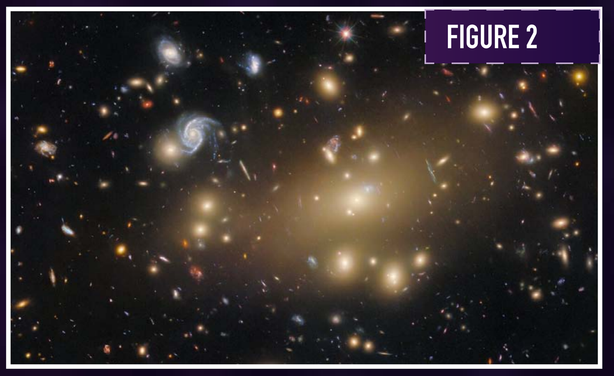

Dark Matter

Gas Clouds

Galaxy clusters are the most massive gravitational bound structures in the universe. They have vast amounts of cold dark matter, hot ionized gas, and up to a thousand visible galaxies. approximately 85% of the mass of a given cluster is from dark matter, 14% from gas and 1% from luminous matter, with masses betwee $10^{14}$ to $10^{15}$ solar masses.

## OBSERVATIONS

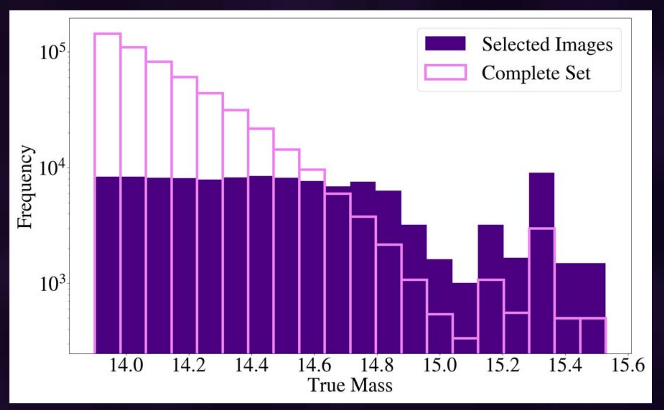
- Hubble Telescope and James Webb Space Telescope have imaged galaxy clusters in visible and infrared wavelegnths respectively
- Chandra X-Ray telescope has also imaged galaxy clusters in X-Ray wavelength
- The CLASH Survey measures 25 galaxy clusters using the Hubble Space Telescope, including Abell 209 cluster, in Figure 2




Abell 209 cluster, imaged via the Hubble Telescope

## SIMULATIONS

- We use the results of Uchuu N-Body simulations using Planck cosmology, as well as the UniverseMachine galaxy catalog, for redshift z = 0.209
- These simulations provide mass of clusters in regions of density on average 200 times the critical density of the universe




Galaxy cluster-mass distribution for simulation and selected galaxies for training and validation

## METHODS

- We plot a spacial projection versus a line of sight phase portrait of individual galaxies within a cluster. We use a Gaussian Kernel Density Estimation to generate a probability distribution of the galaxies in this phase portrait. To ensure similarily between our simulation and observational data, we select for galaxies within a cluster by weighting the stellar mass and position KDE to the stellar mass and position KDE of the simulation data.
- Figure 3 represents the convolutional layers and fully connected layers used
- We use the Adam optimizer, with a weight decay of 1e-4, following L2 regularization to avoid overfitting. Our loss function is the following:

$$\mathcal{L} = \frac{1}{N}\sum_{i=1}^{N}\left(\hat{\sigma}^2 - \left(M_{200c} - \hat{M}_{200c}\right)^2\right)^2$$

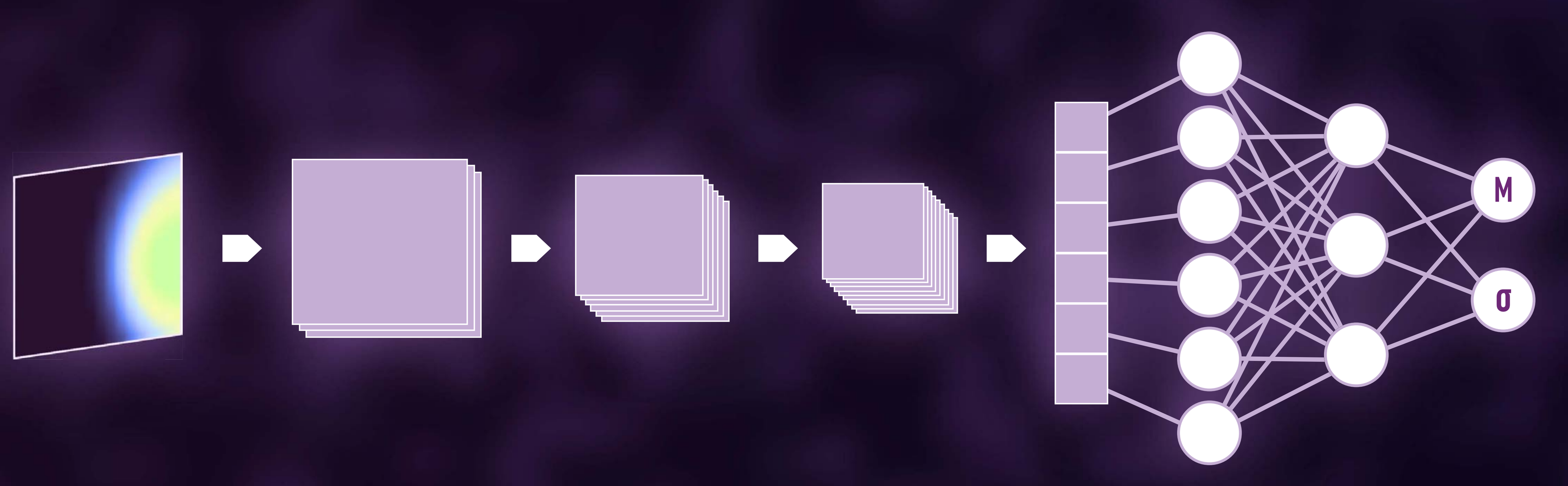
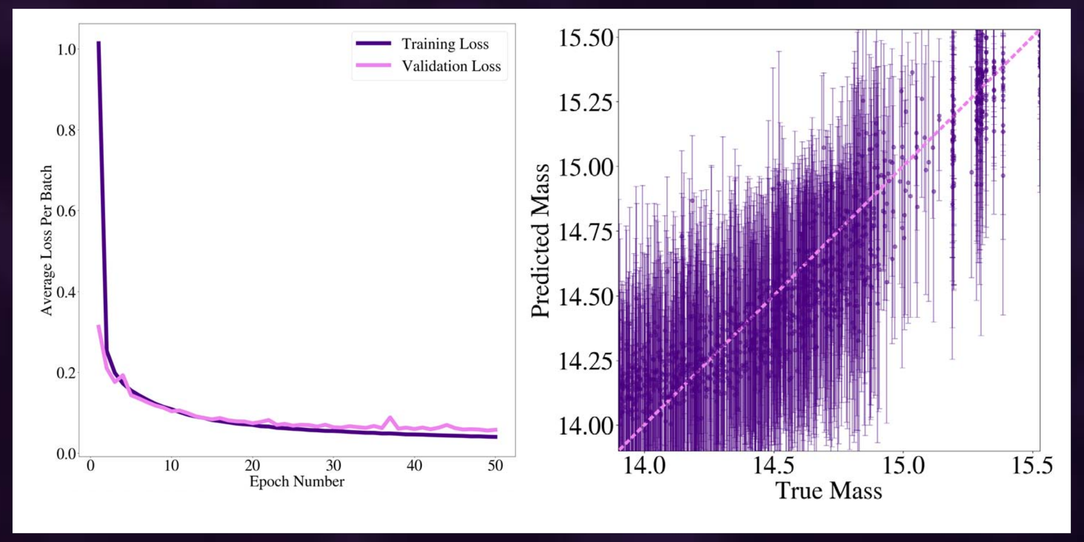



FIGURE 3

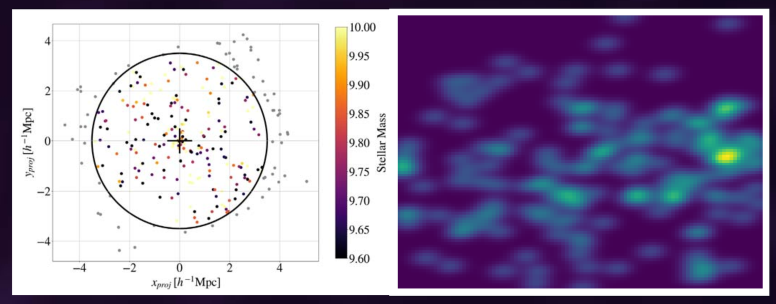
## TRAINING RESULTS



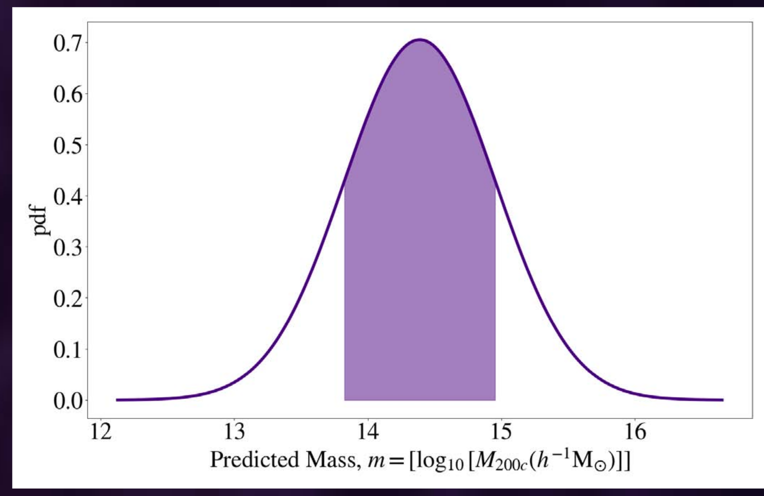

- Left figure is the average training and validation loss per epoch
- Right figure is validation set's true log mass versus predicted log mass and uncertainty of final epoch

We cease training when the validation loss begins to stall, and have identified 50 epochs as an ideal stopping point.

## RESULTS



The left plot is the location and solar mass of galaxies in the cluster Abell 209. The right plot is the KDE of position and velocity




The inferred mass of Abell 209 is $10^{14.3896}$ solar masses, with uncertainty in log scale, 0.5655 The resultant Gaussian is plotted, with the shaded region representing the region of ± σ.

Previous mass constraints of Abell 209 have been reported as falling between ranges 14.80 and 15.10 log solar masses.

## CONCLUSION

We were able to produce a mass estimate and uncertainty of the Abell 209 cluster, and were able to train our neural network on cluster data similar to Abell 209's data. We find that our estimated mass of Abell 209 is noticably lower compared to previous mass constraints. Future work will look to refine the training process to avoid errors concerning low-mass bias.

## REFERENCES

FIGURE 1 NASA, ESA, CSA, STScI, CXC, J. Jee, S. Cha, K. Finner.

FIGURE 2 ESA/Hubble & NASA, M. Postman, P. Kelly. ID potw2527a

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NSF REU in Physics in AI
Funding From NSF Award #2244348