Leaving no branches behind:

Accurate models for predicting galaxy properties from full sets of merger trees of host dark matter halos

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Introduction

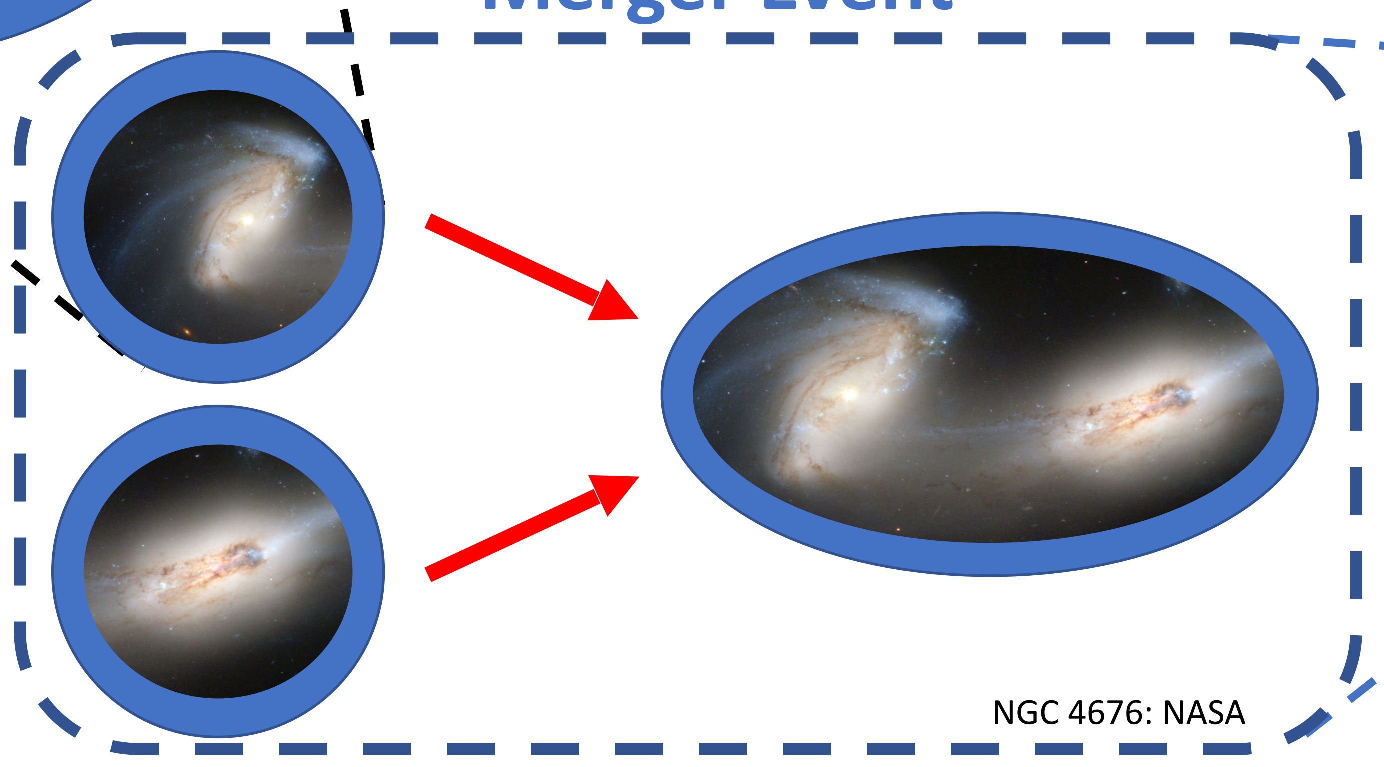
Background

- Galaxies are believed to form in dark matter halos, which began as low-mass entities and grew in mass by mergers and accretion of matter
- Such a hierarchical growth for any given dark matter halo at the present day can be visualized as a "merger tree"

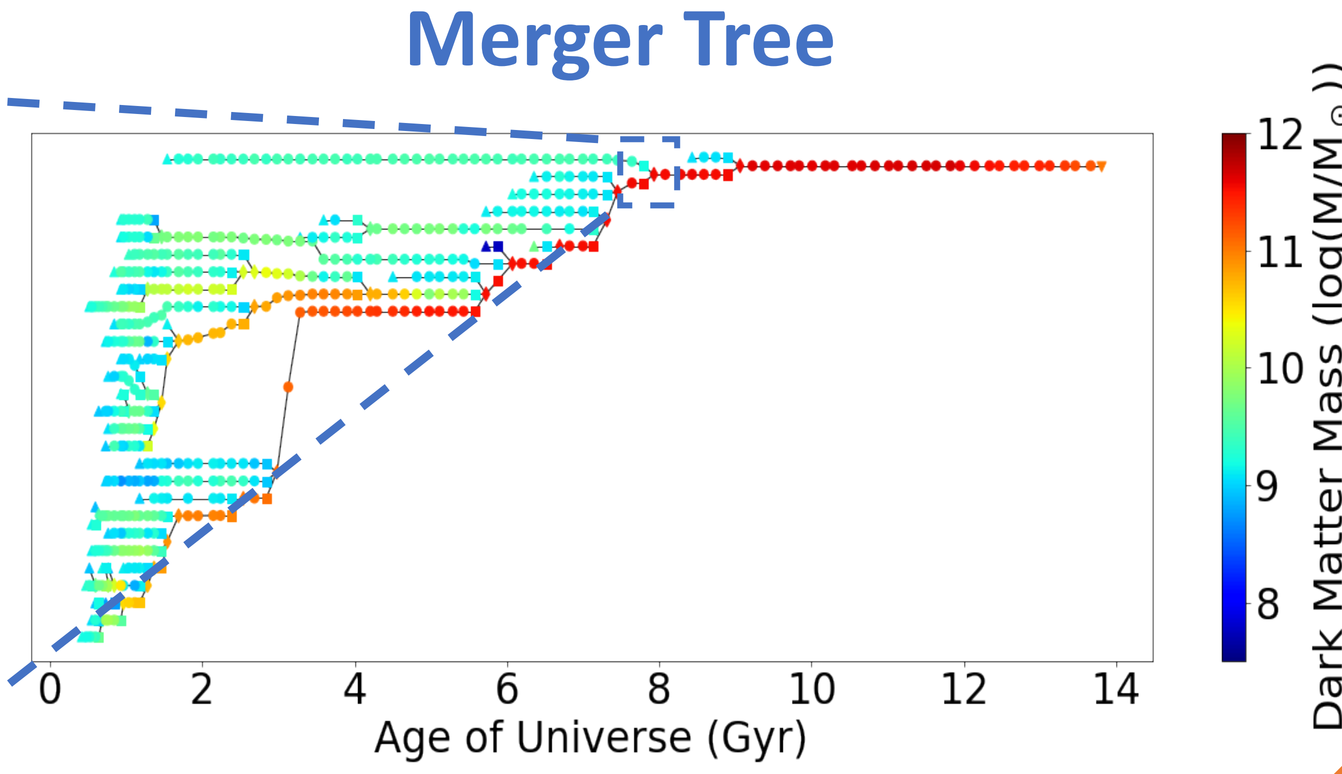
Galaxy – Halo Connection

- Halo growth history is believed to play an important role in shaping the galaxies they host
- However, it is non-trivial to recover the galactic properties solely from merger trees

Merger Event



Merger Tree



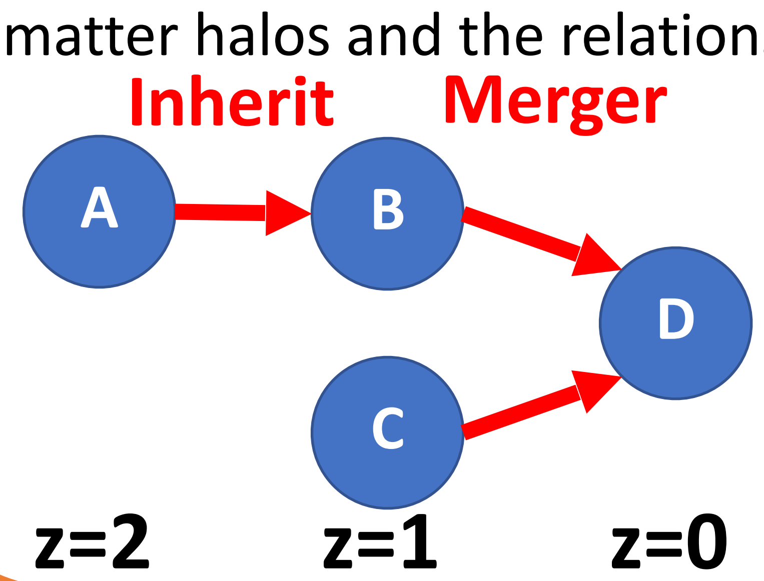
Method

Purpose

- Recover **stellar mass (M*), star formation rate (SFR), color (g – r), gas mass (M_{gas}), gas metallicity (Z_{gas}), stellar metallicity (Z_*)** from merger trees
- Sophisticated models, such as SAMs or hydrodynamic simulations, cost tens of millions of CPU hours

Graph Neural Networks (GNN)

- Neural networks: Optimize non-linear equations to predict galactic properties from dark matter halo merger trees
- Graph: Consists of nodes and edges, representing the dark matter halos and the relations among the halos, respectively

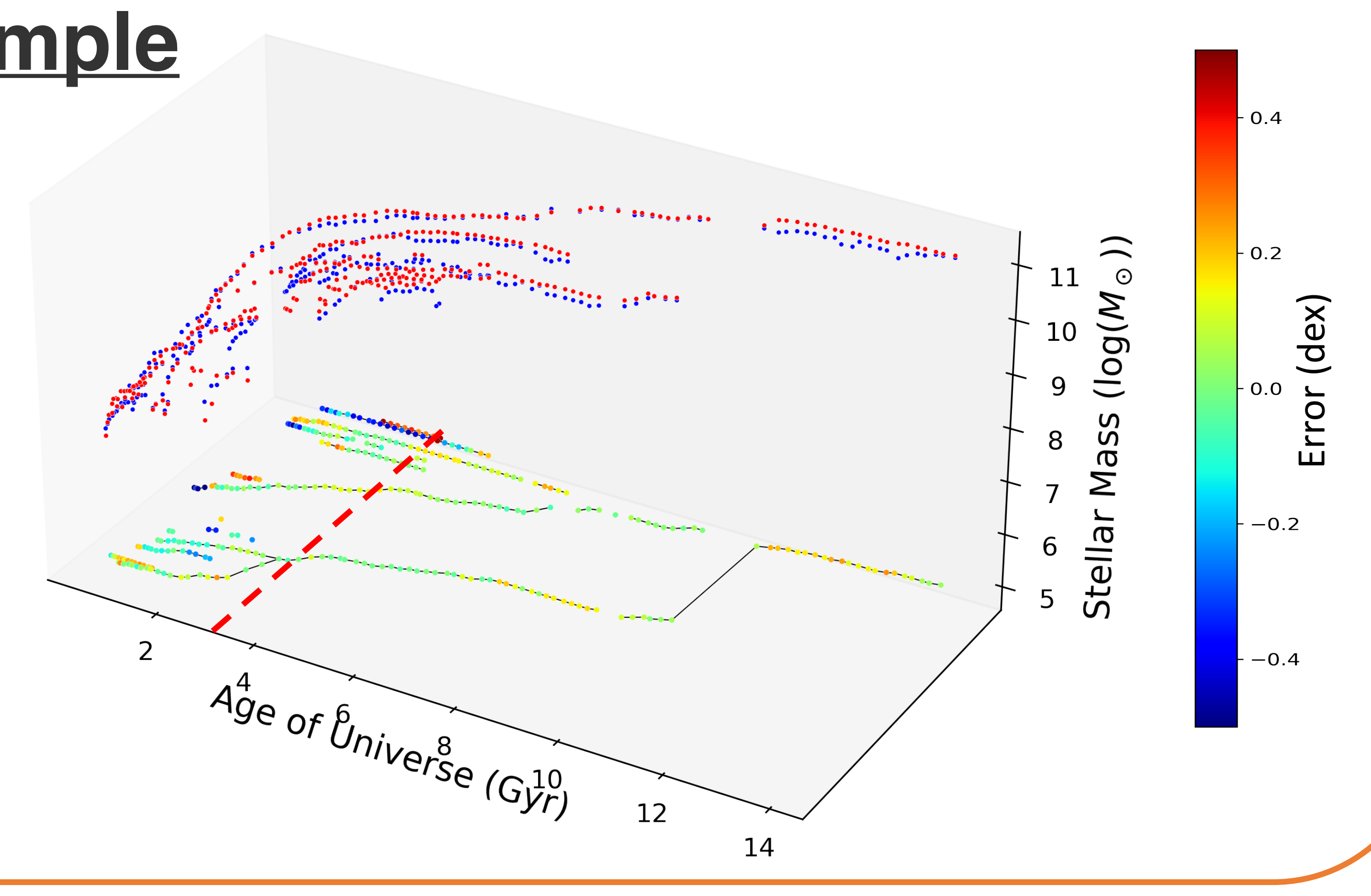


GNN	Tree
Nodes ●	Halos
Edges →	Merger/ Inherit

Model Training

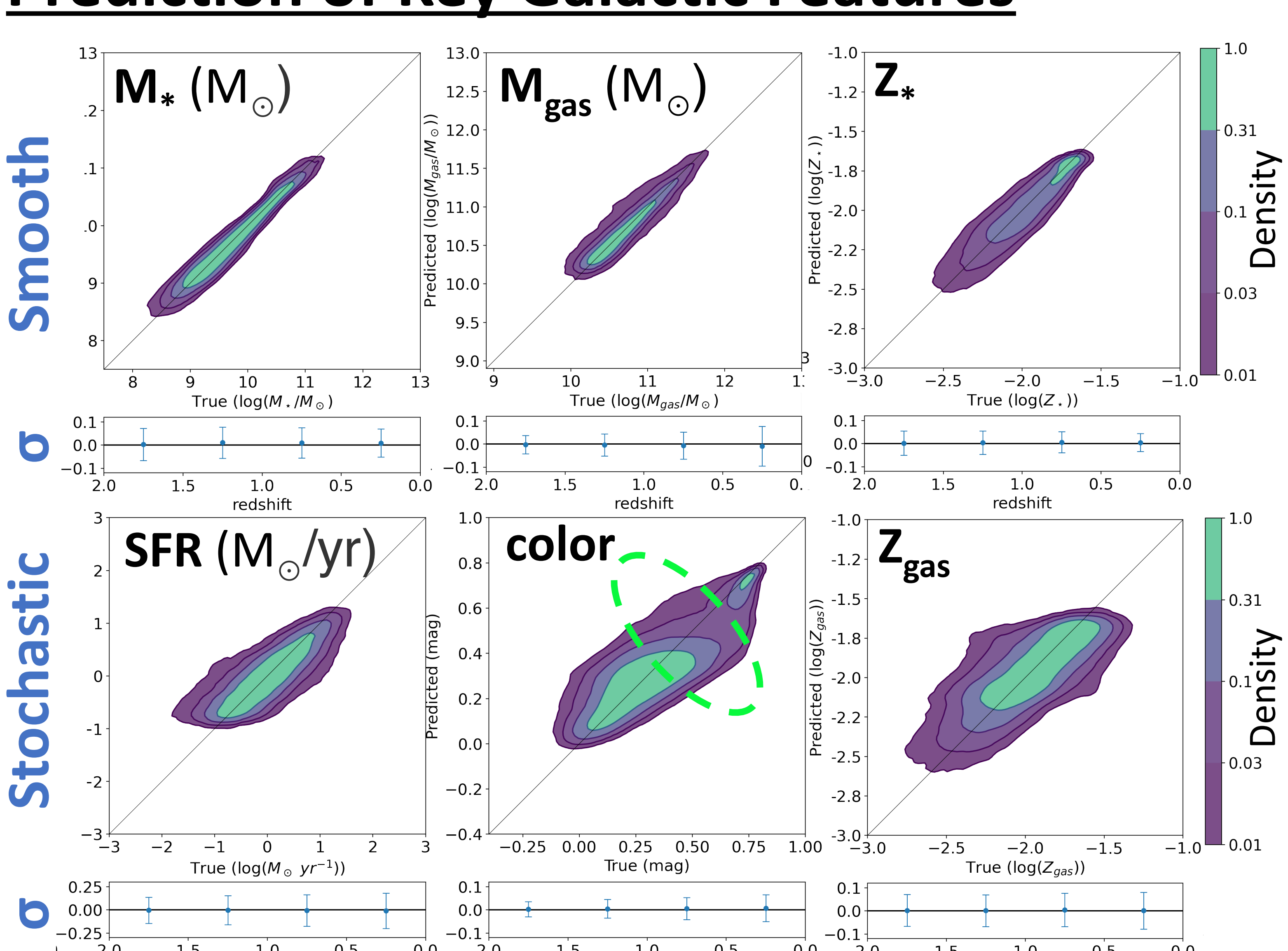
- 100000 merger trees from IllustrisTNG 300, the ratio of train, validation, and test set is 6:1:1
- Training time: 1000 epochs, 7 hr/run, 1 month for hyper-parameter search
- Validation range: redshift ≤ 2, dark matter mass ≥ 10^{11} $M_\odot$

Example



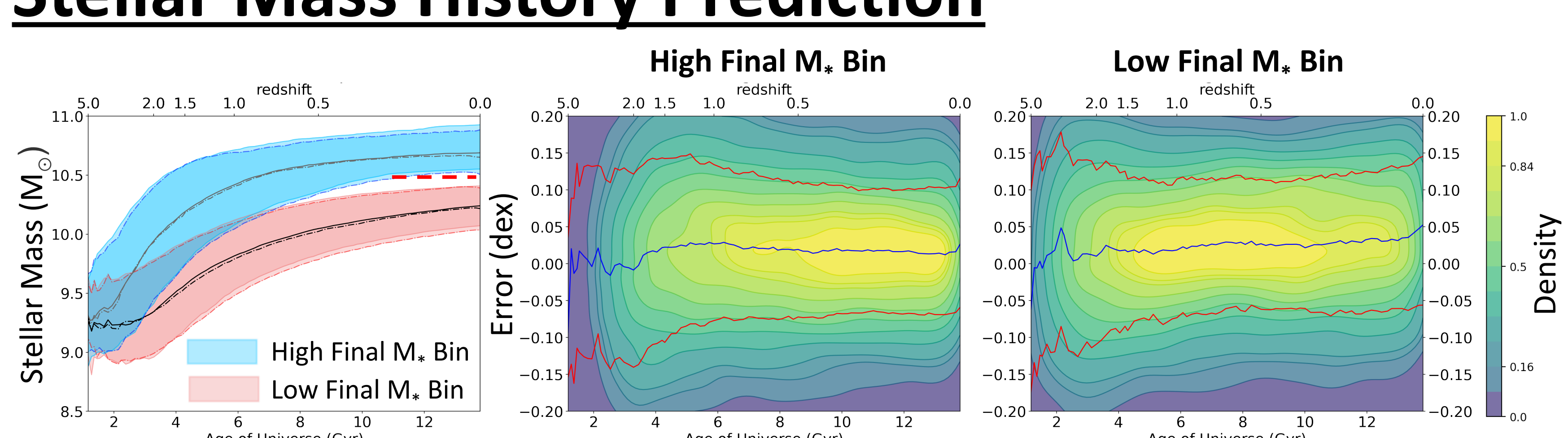
Results

Prediction of Key Galactic Features



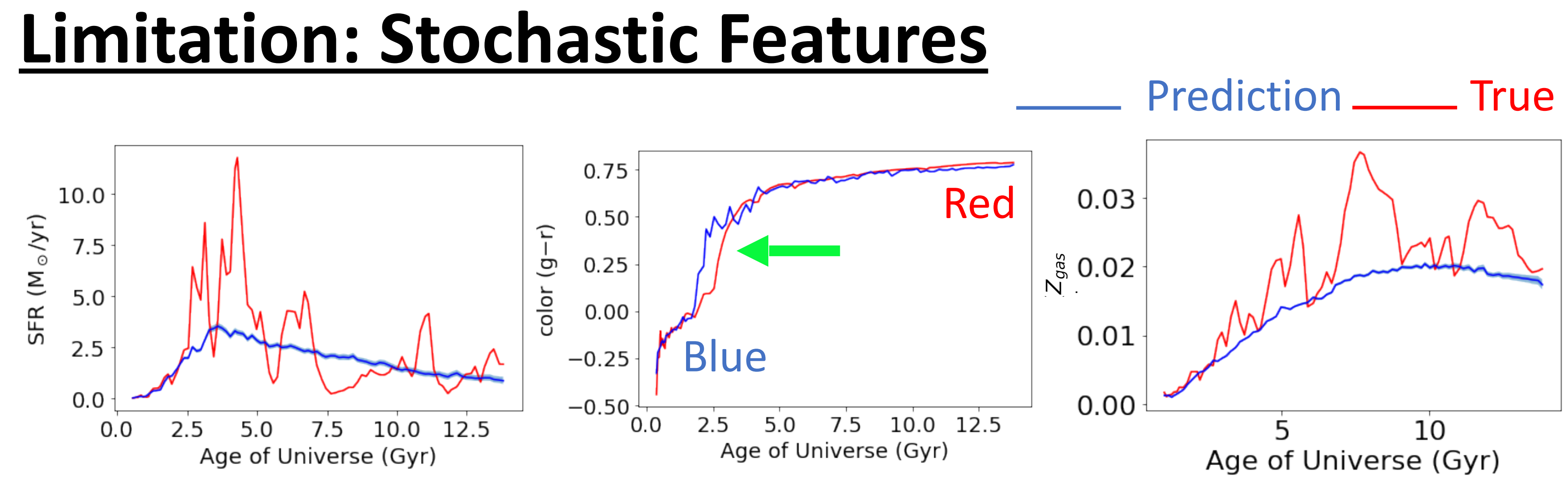
- M_*, M_{gas}, and Z_* are well predicted, while the predictions of SFR, color, and Z_{gas} are less accurate
- The color of green galaxies is not well predicted
- The prediction of gas mass, stellar metallicity, and color has redshift dependency

Stellar Mass History Prediction



- The predicted and the true mass history are consistent in both higher and lower mass populations up to redshift 5

Limitation: Stochastic Features



- GNN can overall reproduce the history of SFR, color, and Z_{gas}
- However, GNN cannot recover the stochastic part of SFR and Z_{gas}
- GNN cannot accurately predict when the transition of color from red to blue occurs in a galaxy, which explains the larger error for green galaxies