

Continuous Representation of Hydrodynamic Simulations for Robust SBI

Ming-Shau Liu, Harvard CfA

Carolina Cuesta-Lazaro, Flatiron CCA

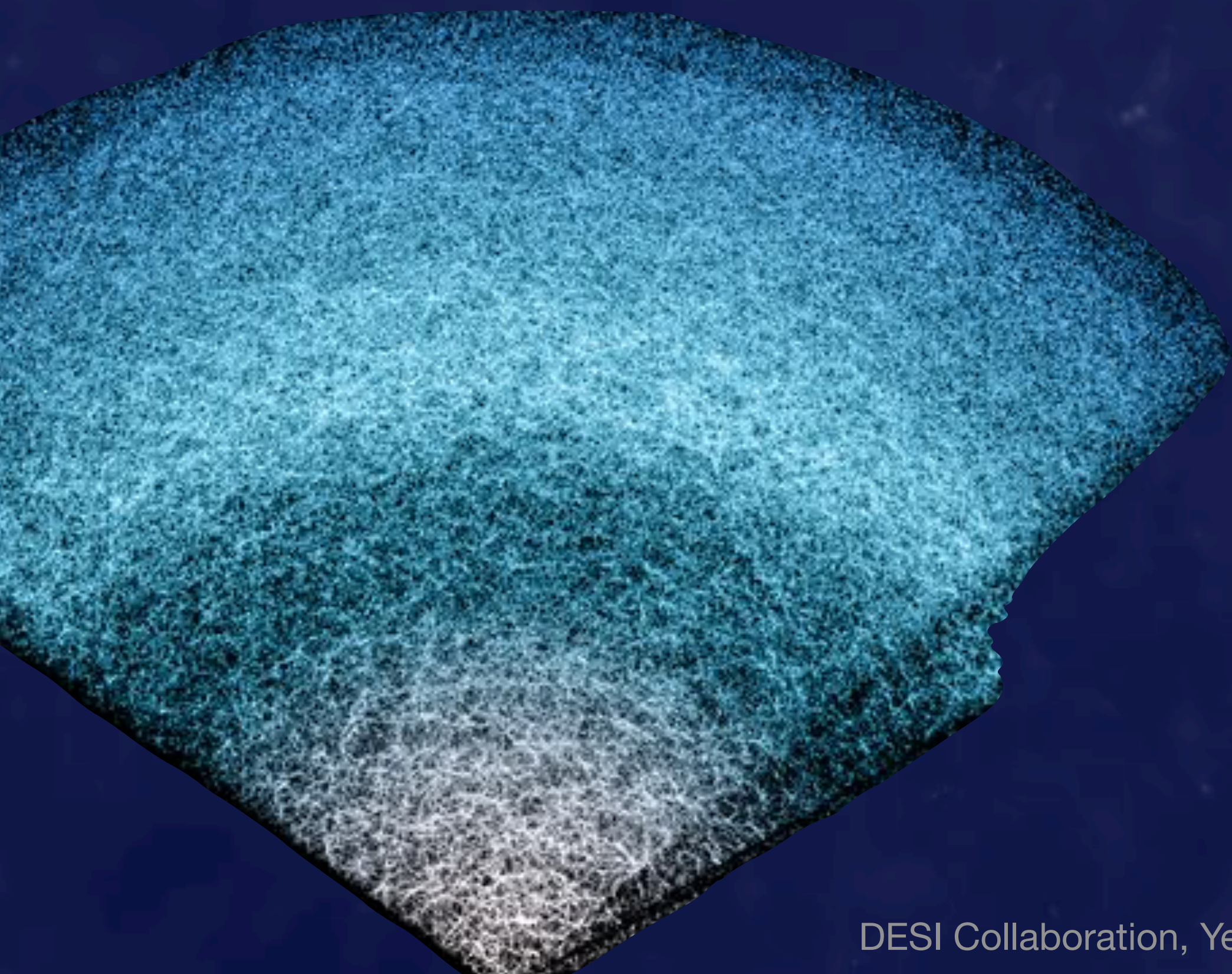
The EAGLE Simulation

icc.dur.ac.uk/Eagle

Gas Density
Dark Matter Density

The EAGLE Simulation

icc.dur.ac.uk/Eagle



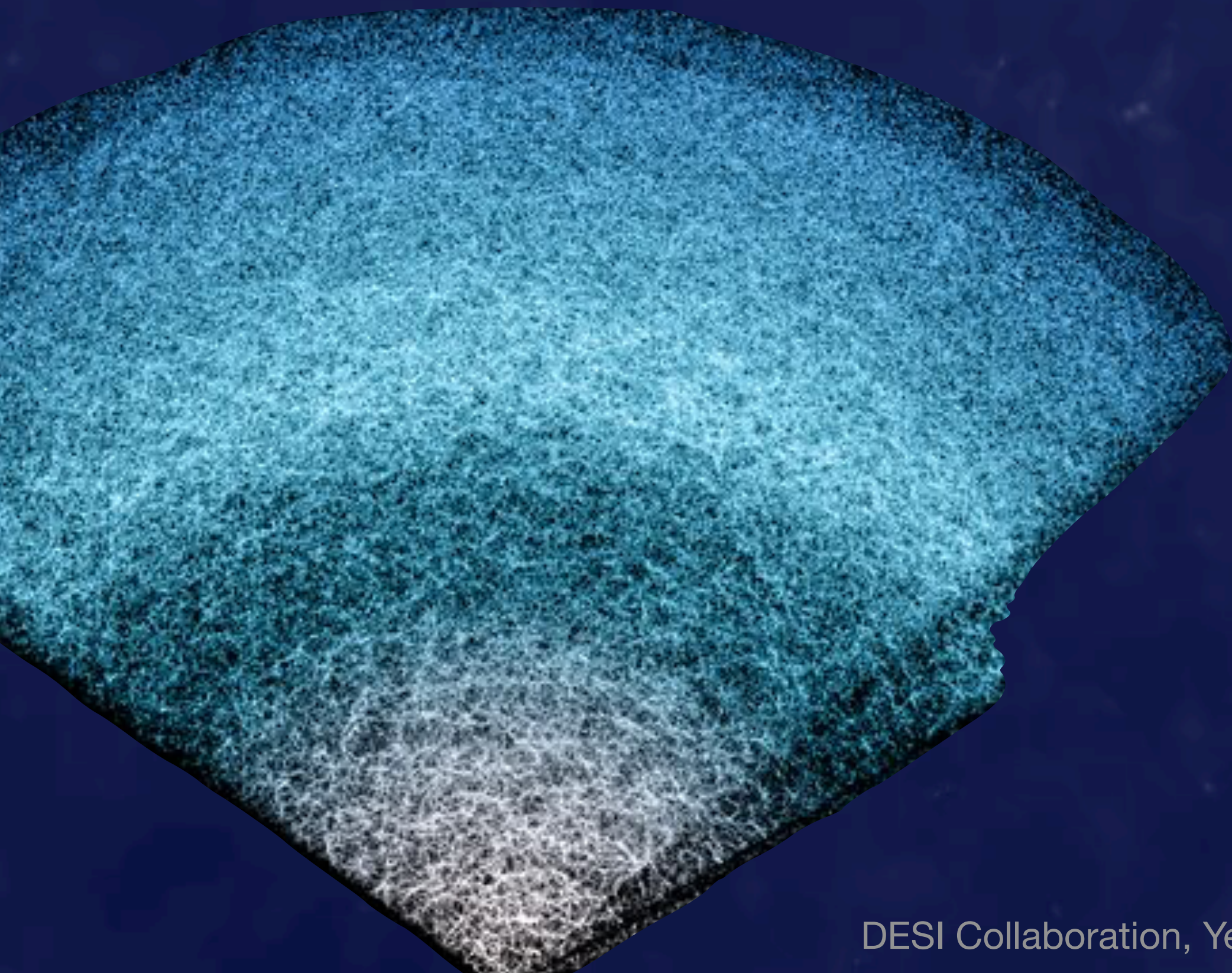
DESI Collaboration, Year 3 Data slice

Gas Density
Dark Matter Density

The EAGLE Simulation



Hubble Space Telescope, NASA/ESA



DESI Collaboration, Year 3 Data slice

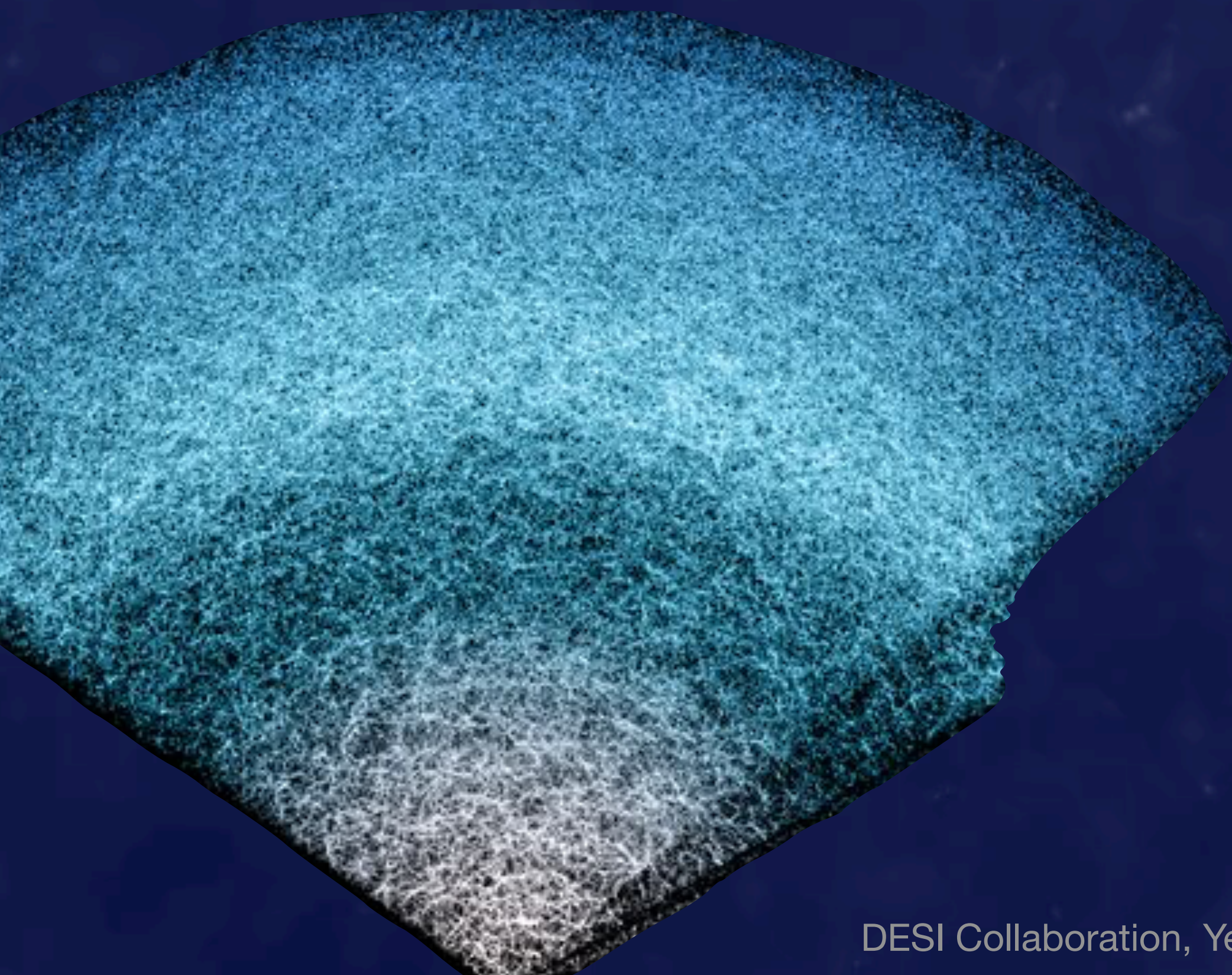
Gas Density
Dark Matter Density

The EAGLE Simulation

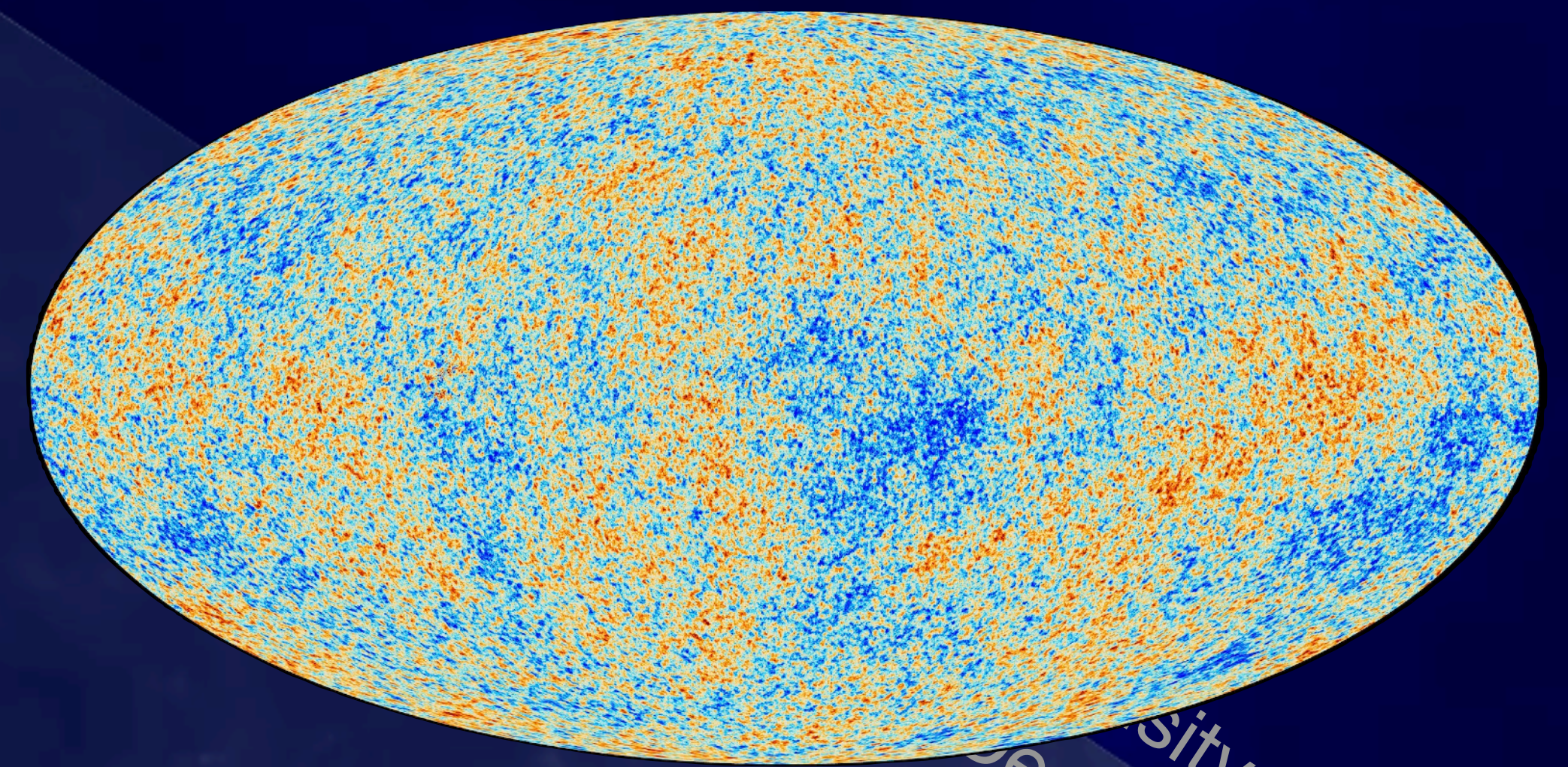


Hubble Space Telescope, NASA/ESA

ESA/Planck Collaboration



DESI Collaboration, Year 3 Data slice



density
density

The EAGLE Simulation

icc.dur.ac.uk/Eagle

Gas Density
Dark Matter Density

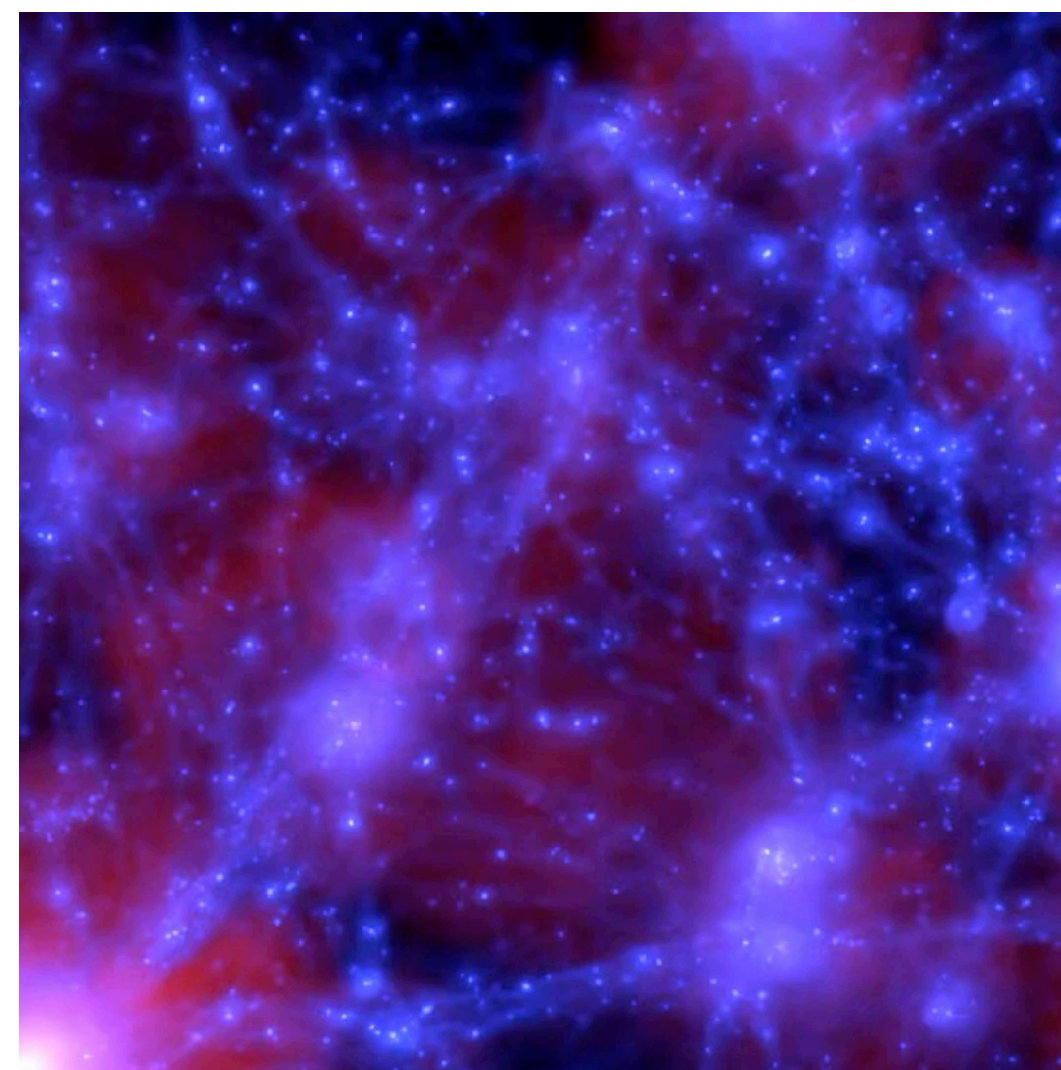


Observation

Simulate (forward)



Observation



Simulation

$$+ \begin{matrix} \Omega_m \\ \sigma_8 \end{matrix}$$

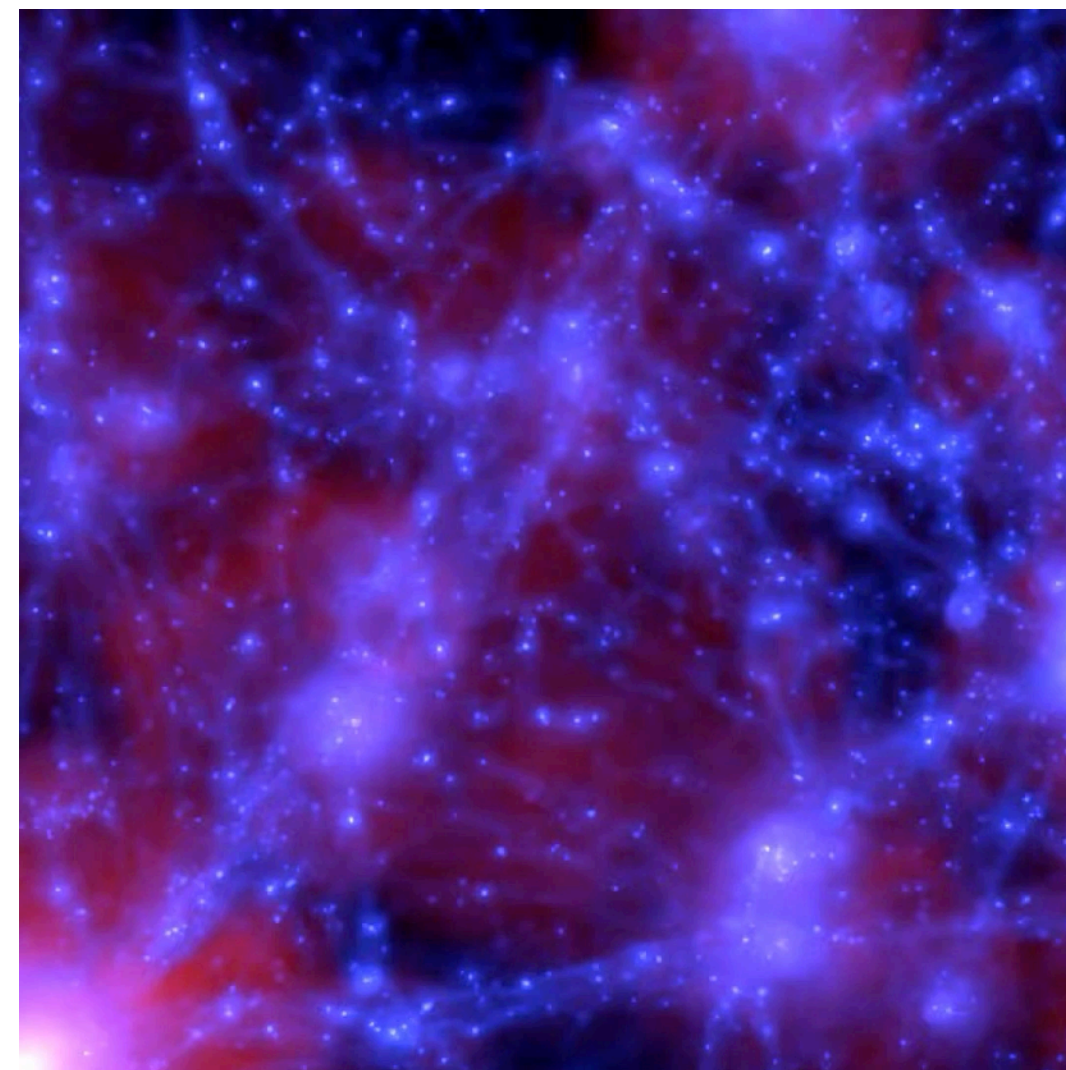
How much stuff is there

How spread out the stuff is

Infer cosmological parameters



Observation



Simulation

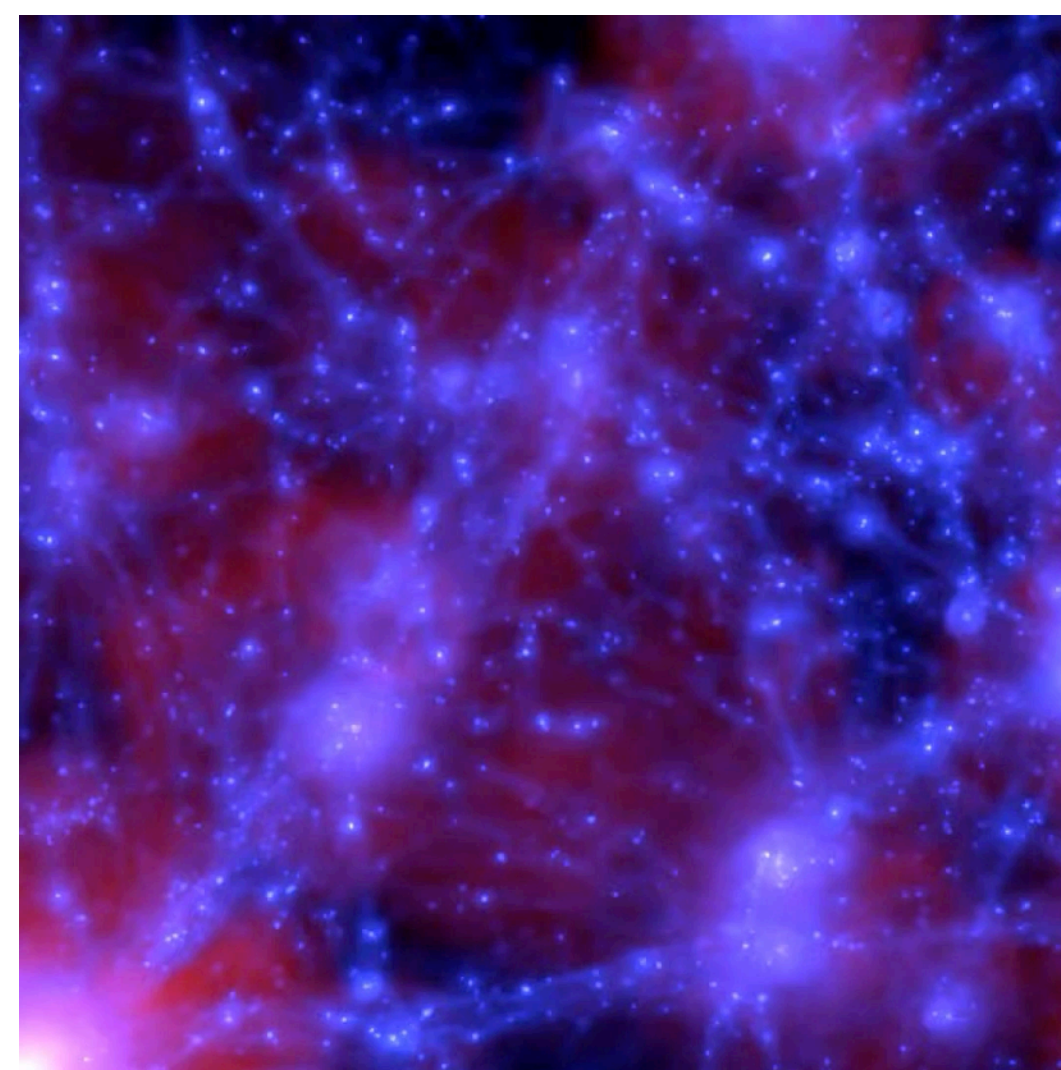
$$+ \begin{matrix} \Omega_m \\ \sigma_8 \end{matrix}$$

How much stuff is there

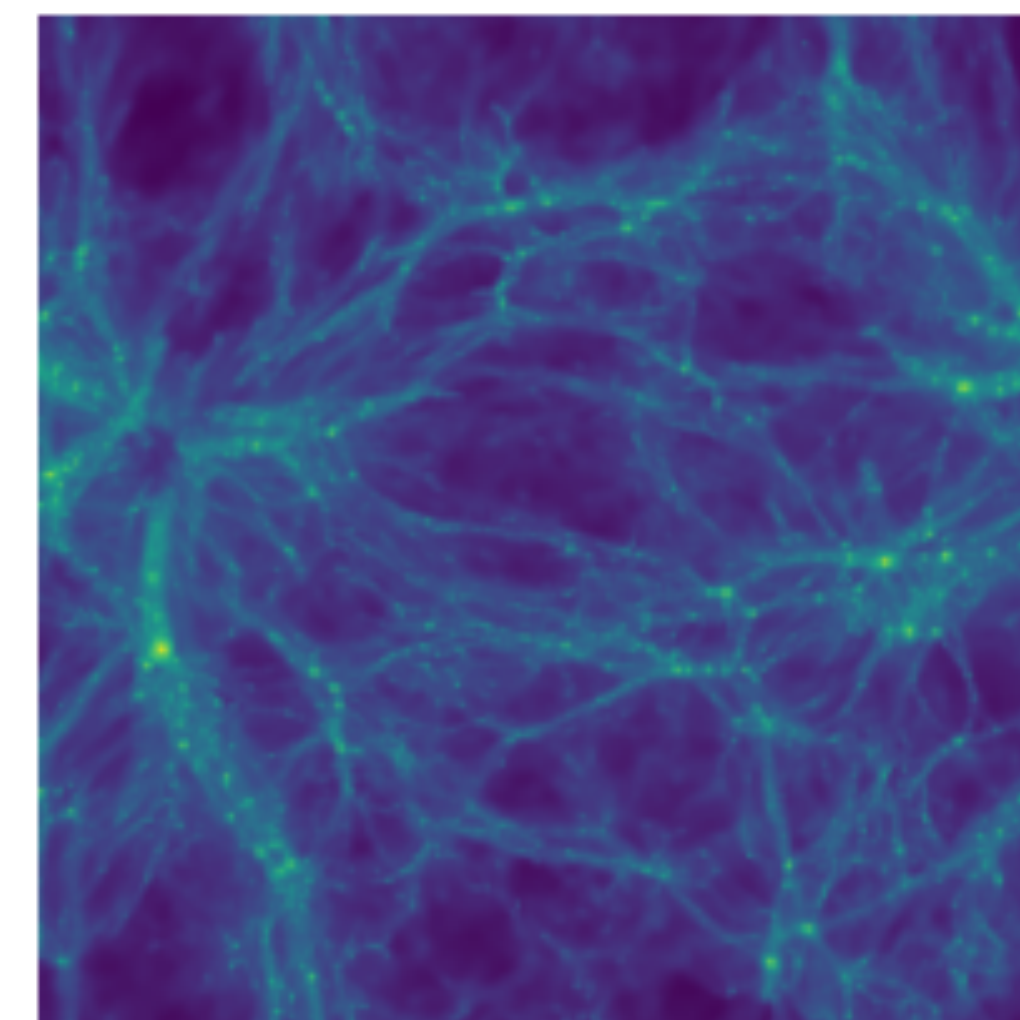
How spread out the stuff is



Observation



Hydro-Simulation
stars, gas, black holes...



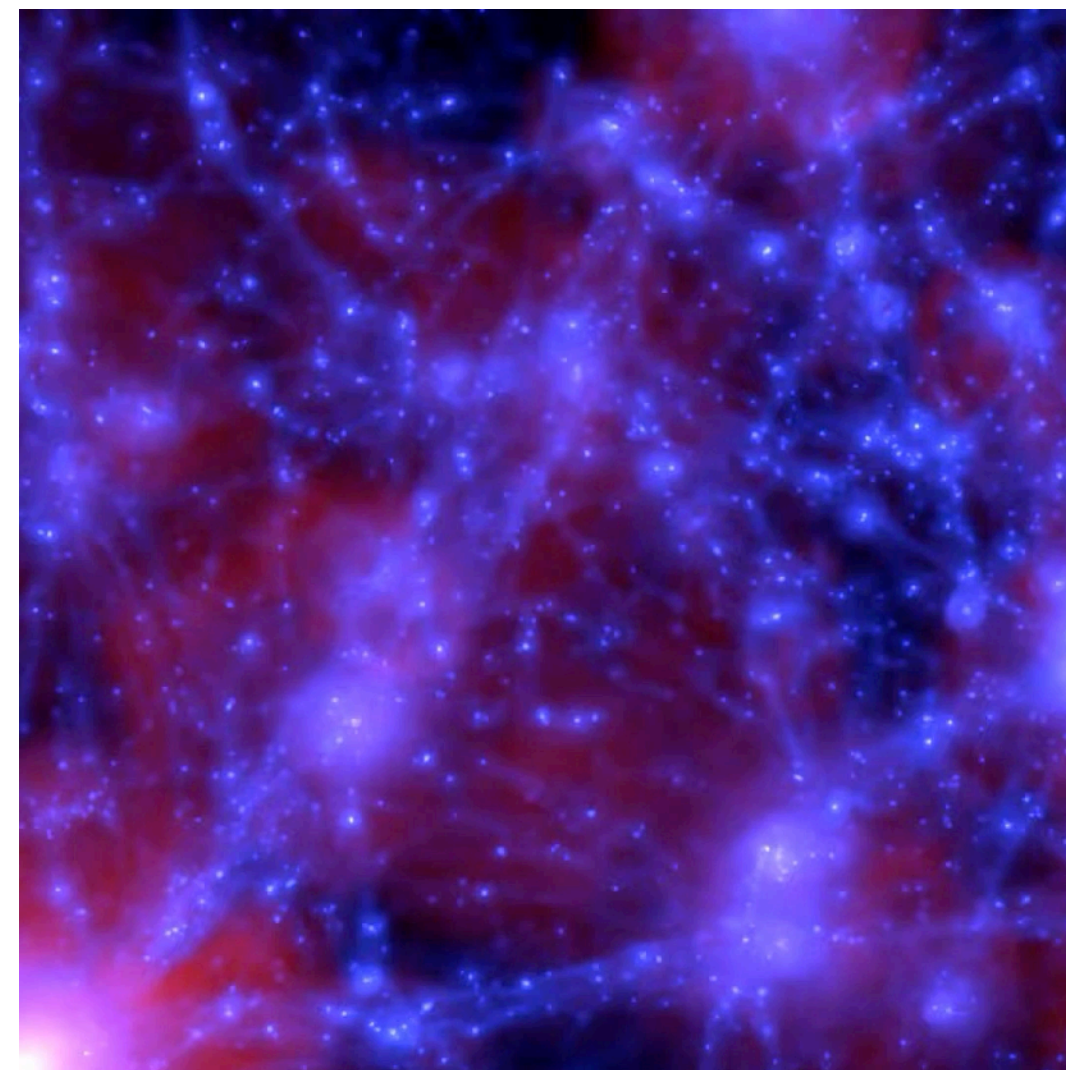
Gravity-only simulation
Dark Matter

Infer cosmology parameters

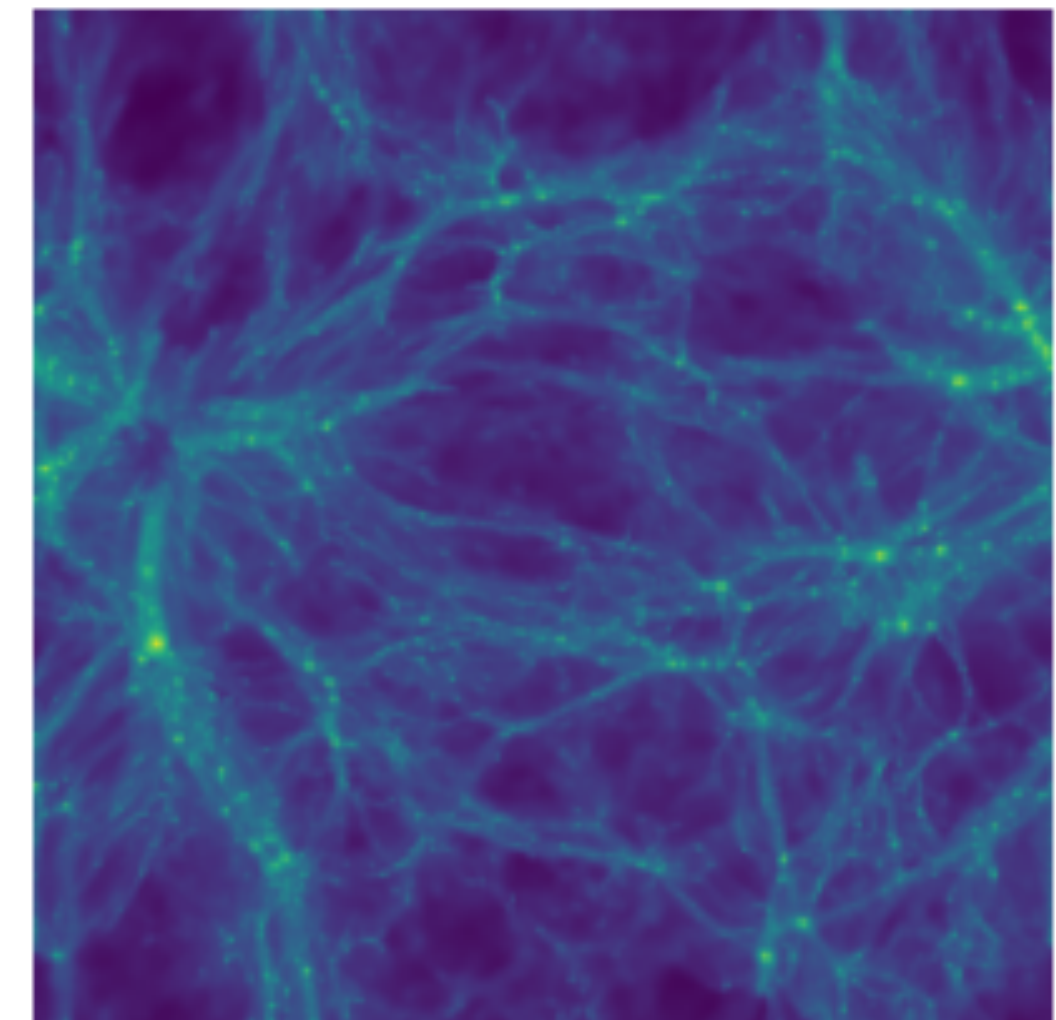
Baryonic feedback



Observation



Hydro-Simulation
stars, gas, black holes...



Gravity-only simulation
Dark Matter

Learn about baryonic feedback

IllustrisTNG

SIMBA

Ramses

CROCODILE

$z = 10.00$

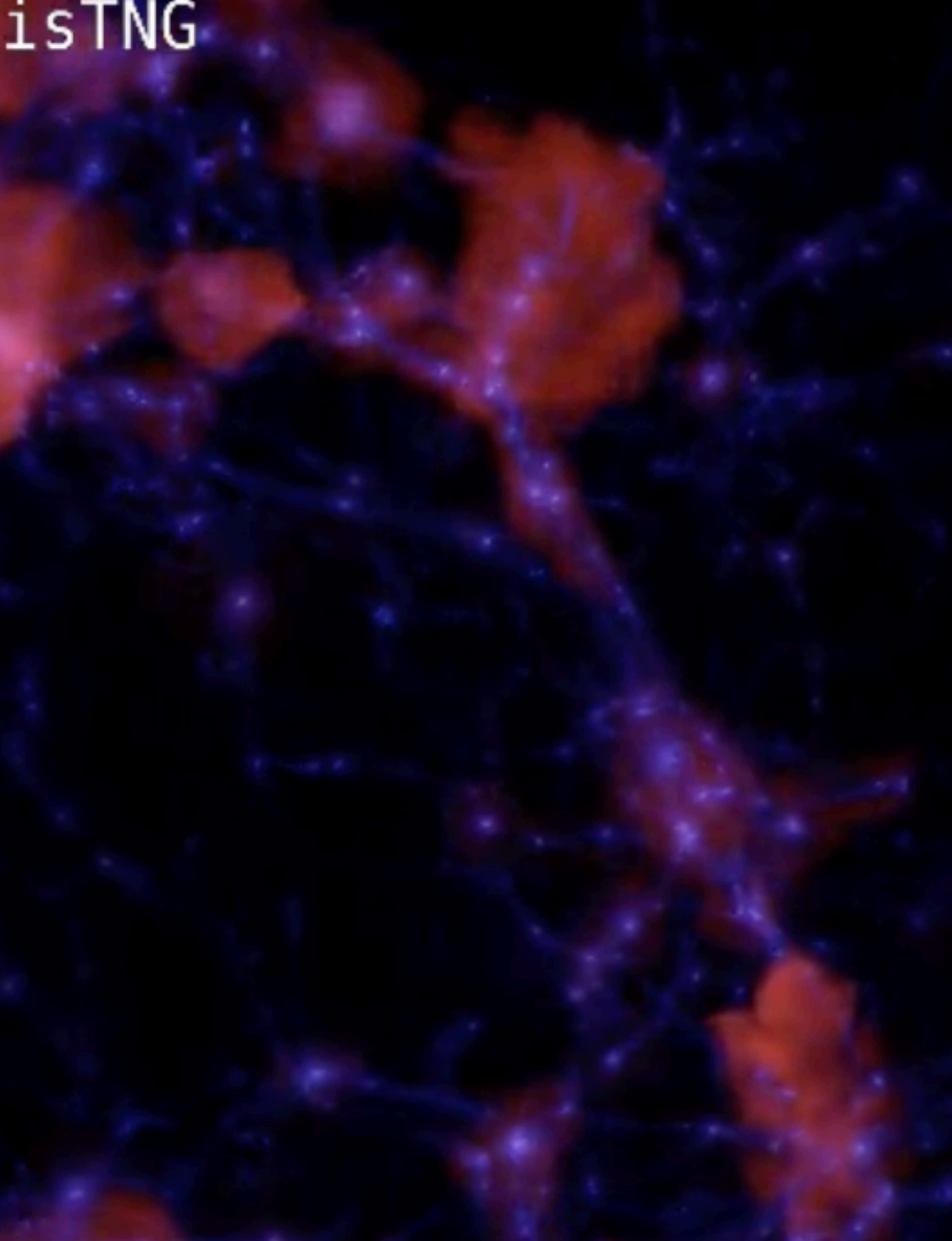
Magneticum

EAGLE

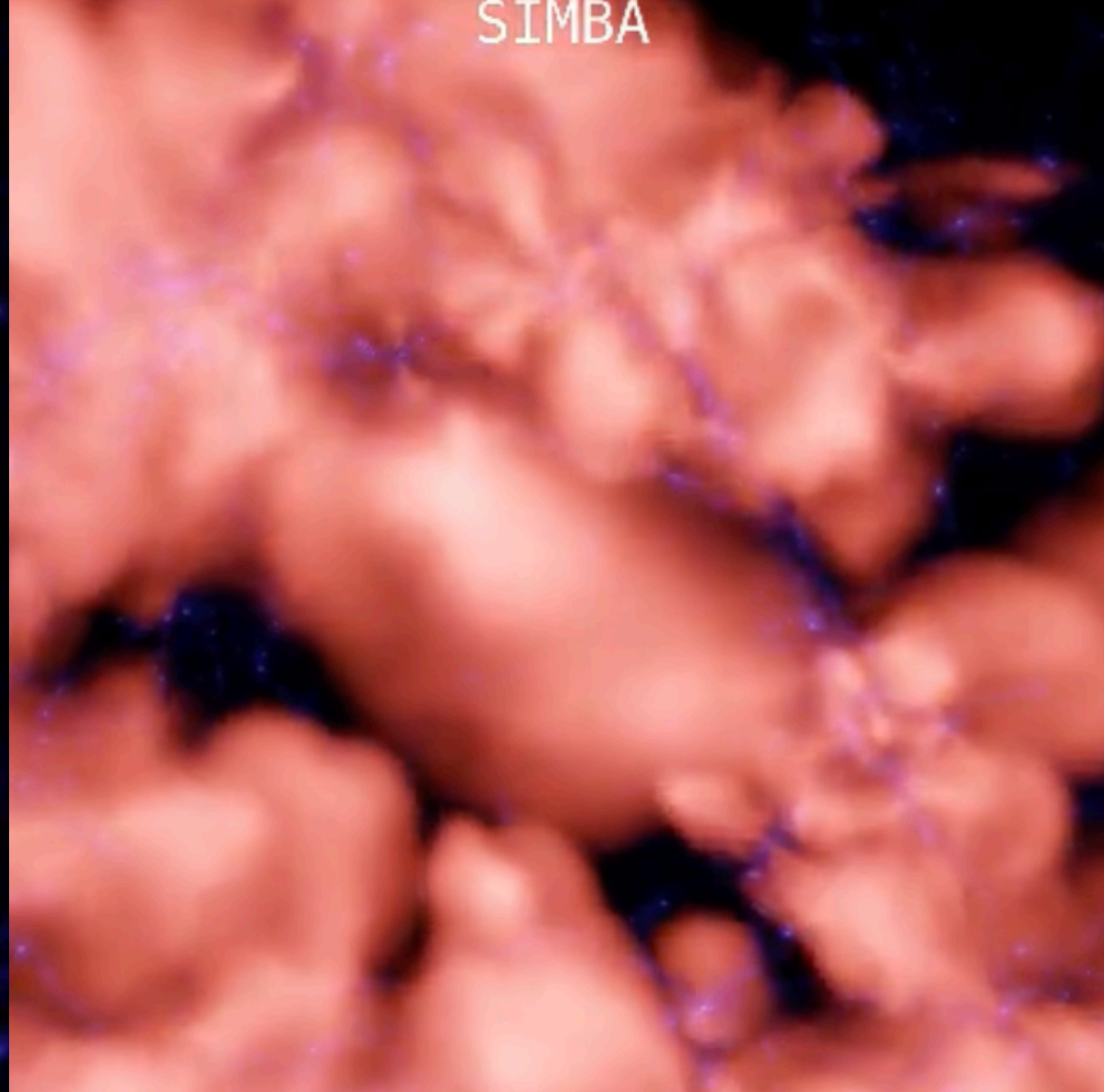
Astrid

Obsidian

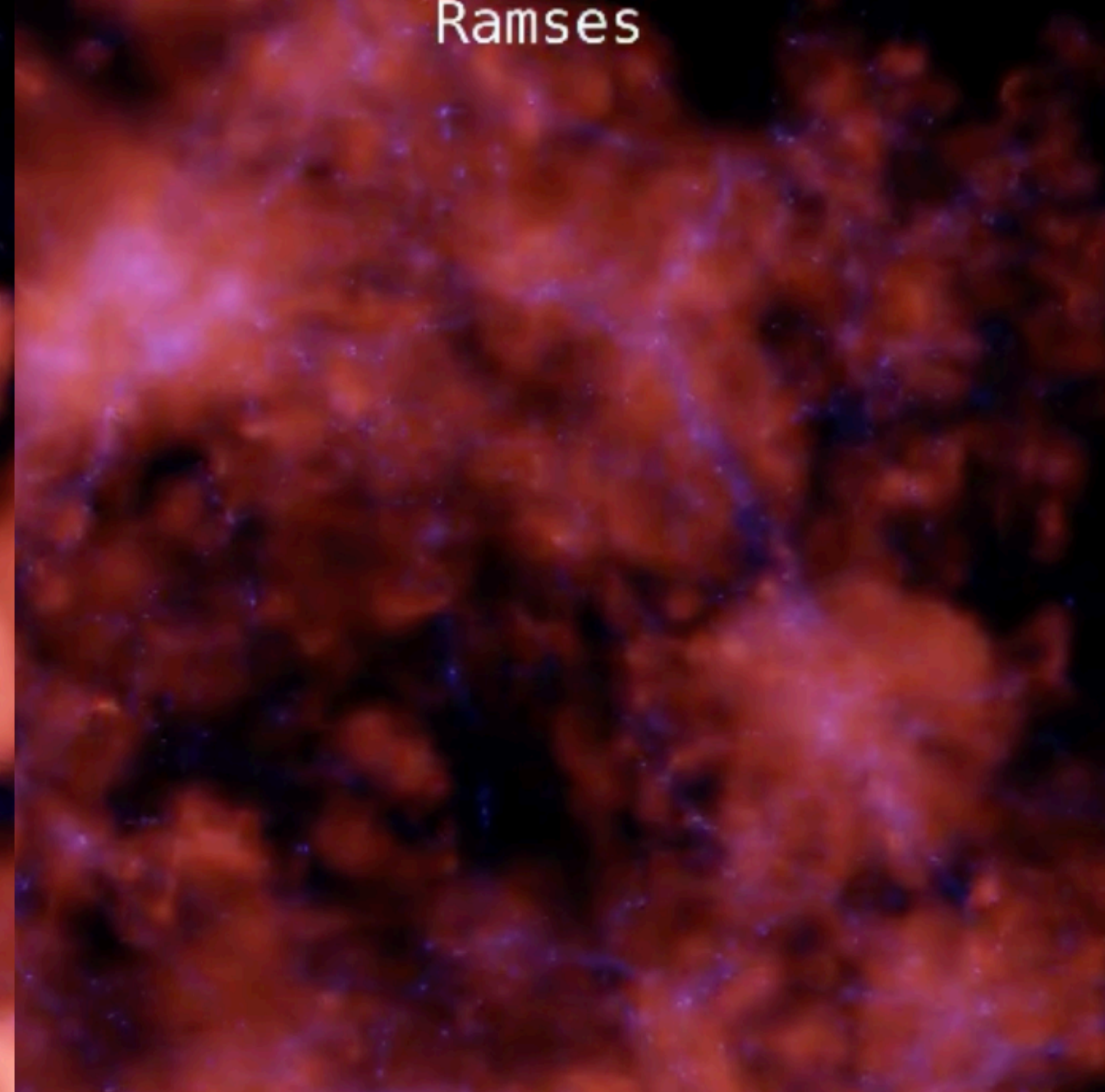
1STNG



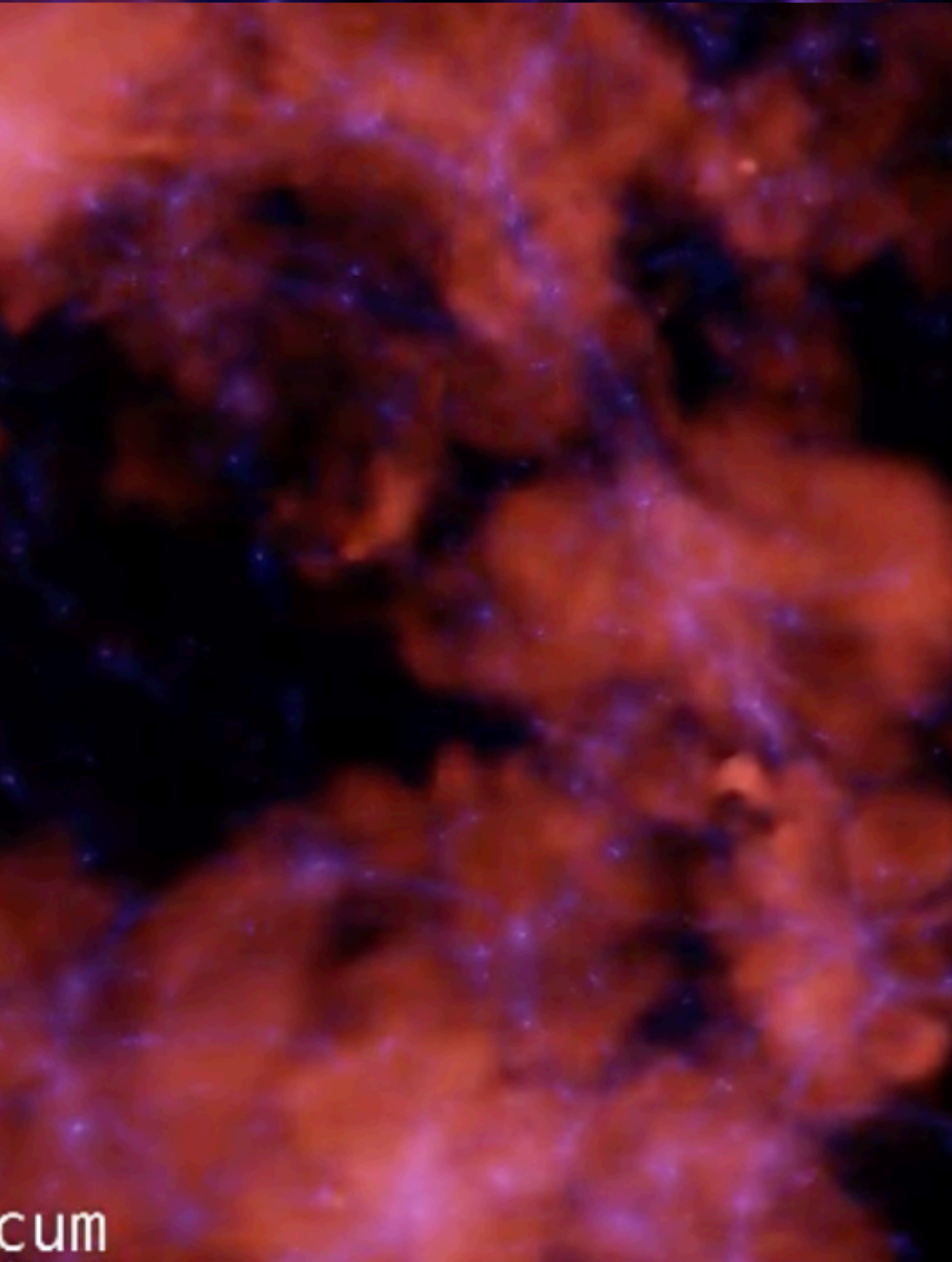
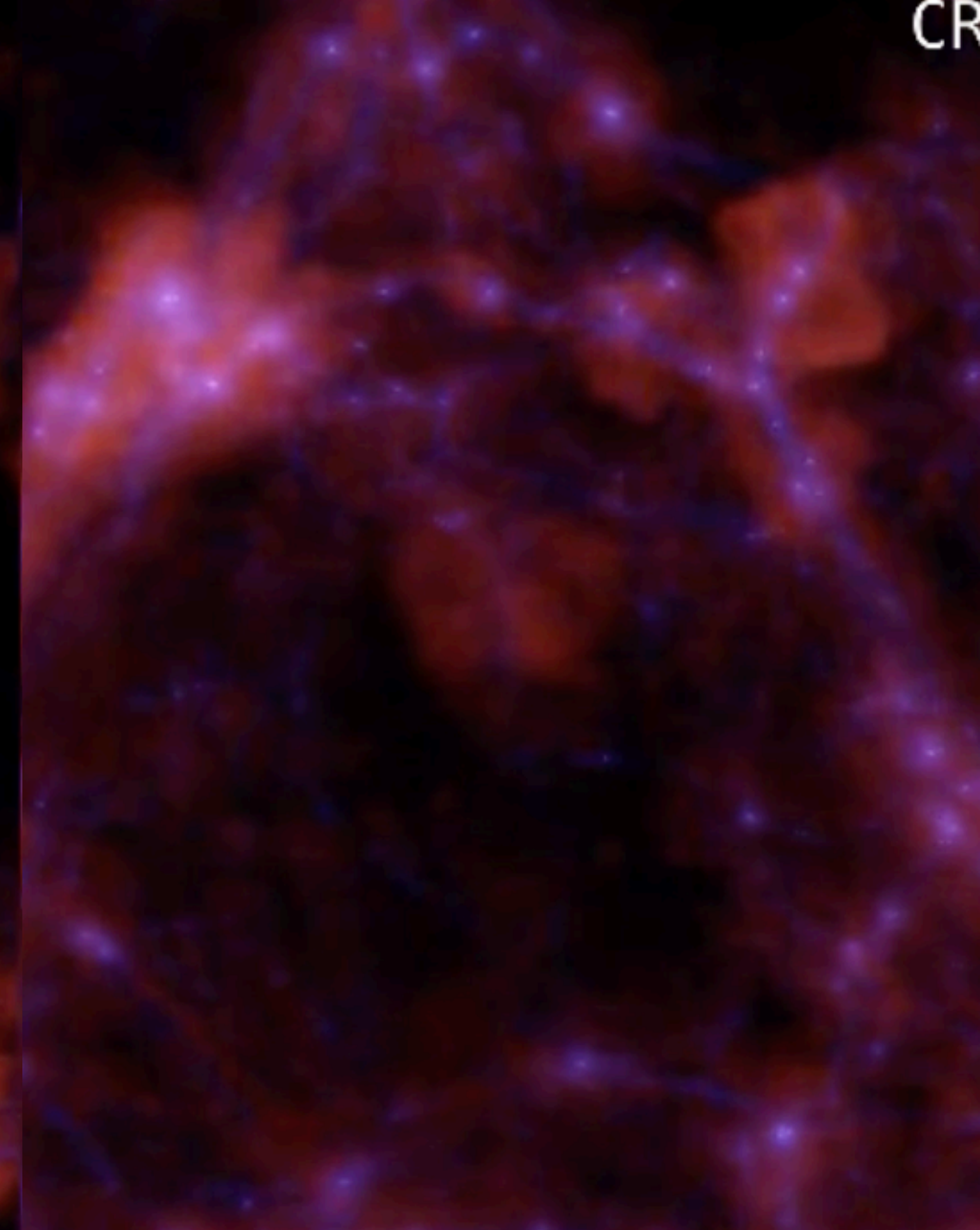
SIMBA



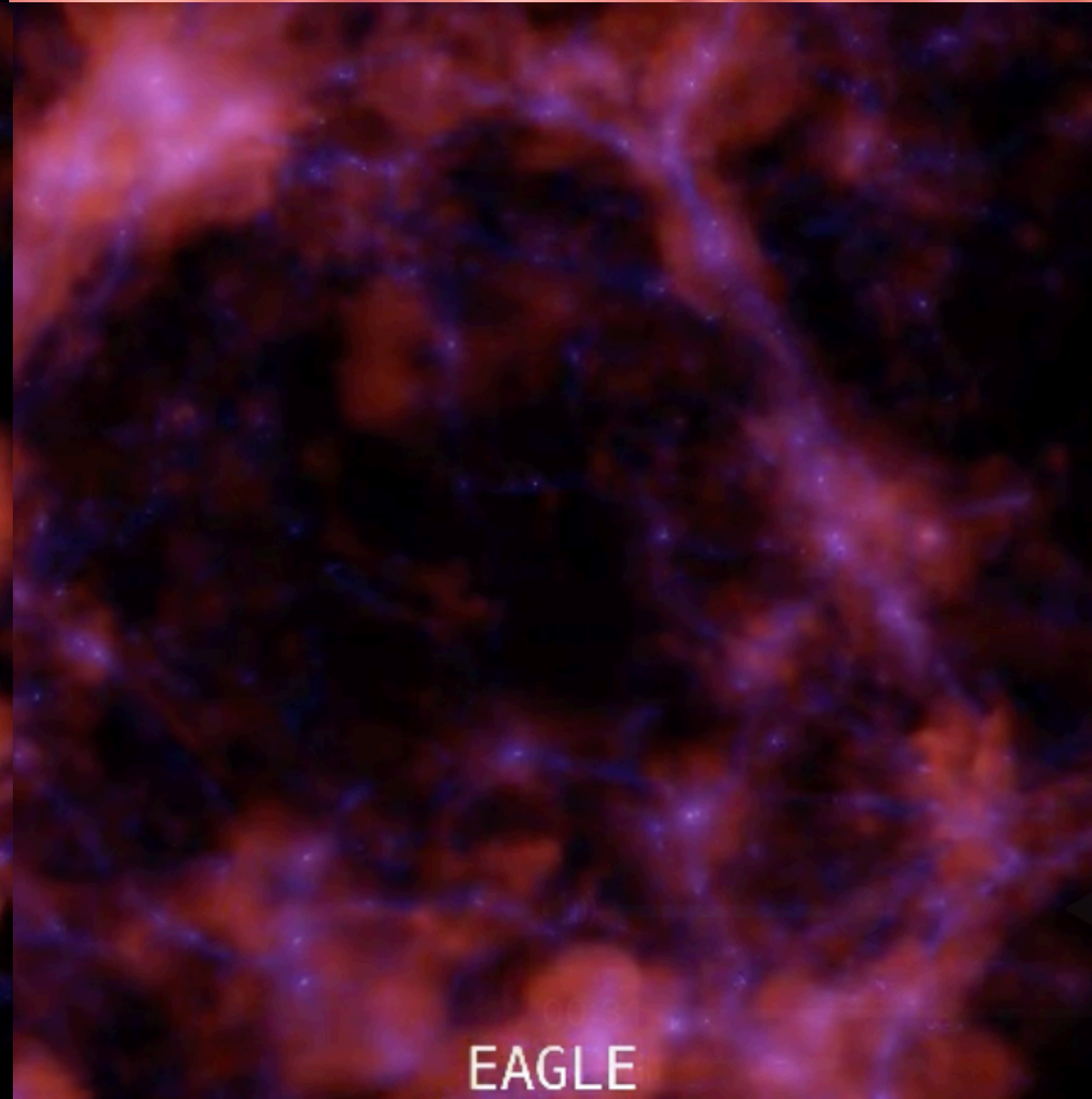
Ramses



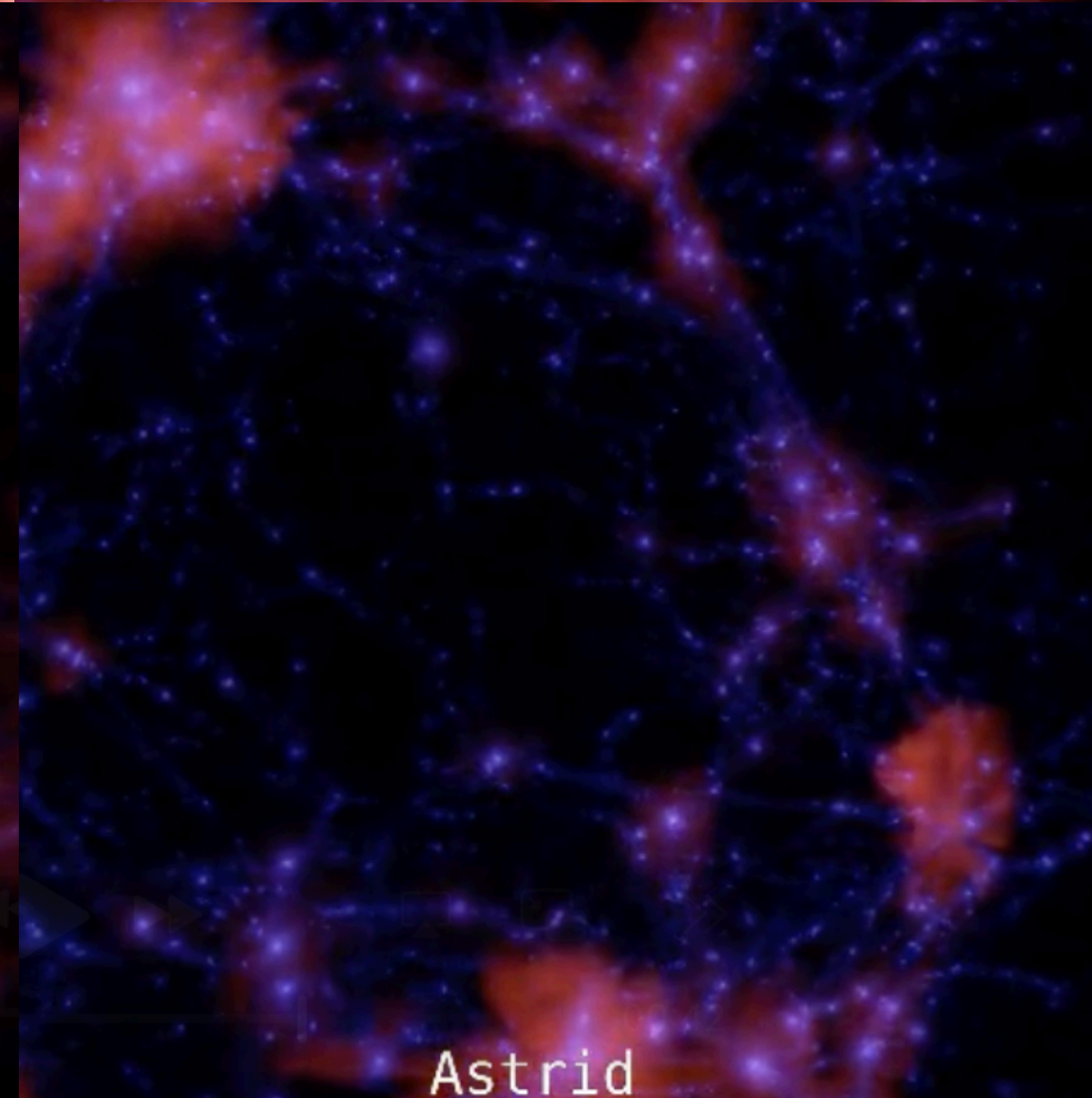
CR



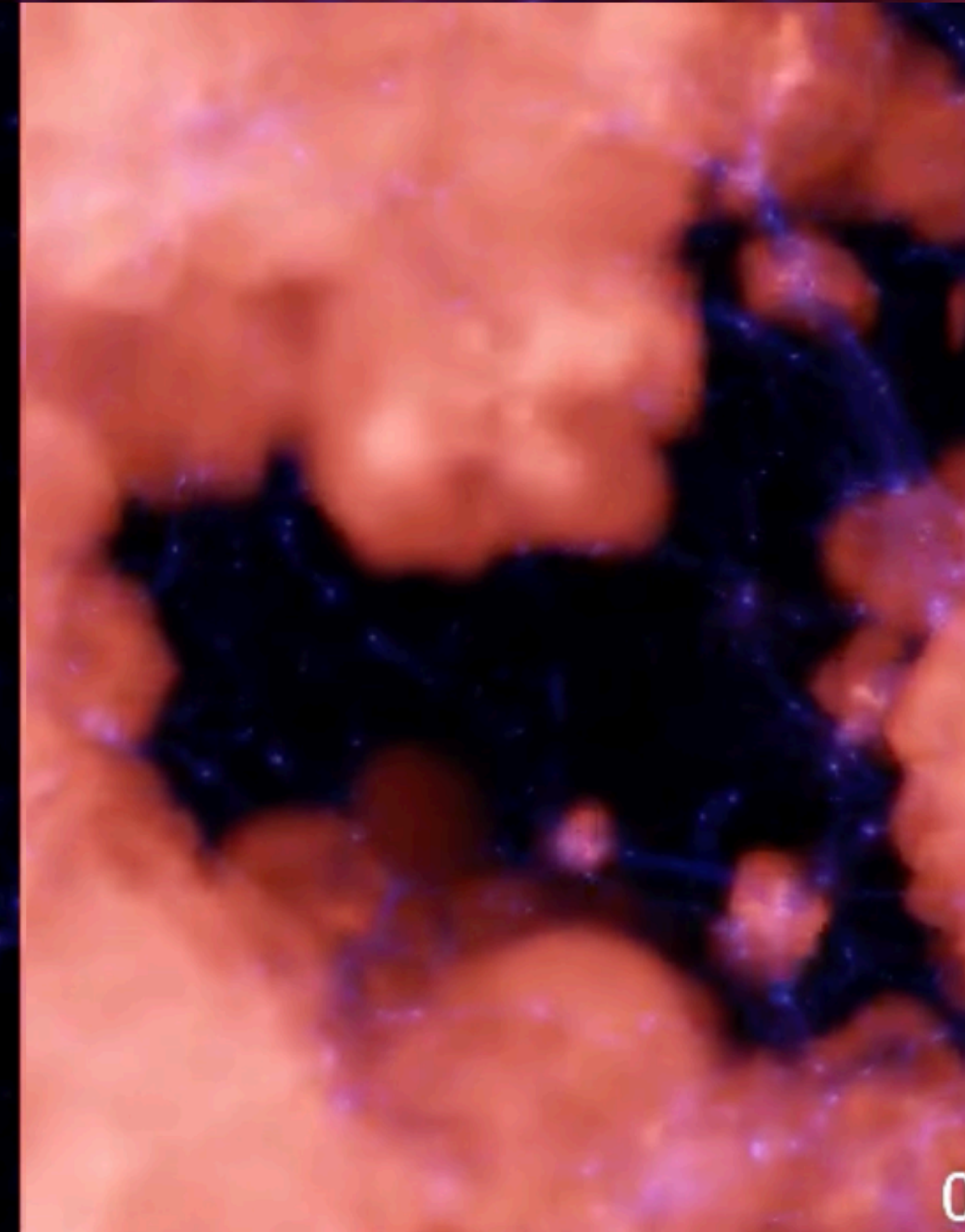
cum



EAGLE

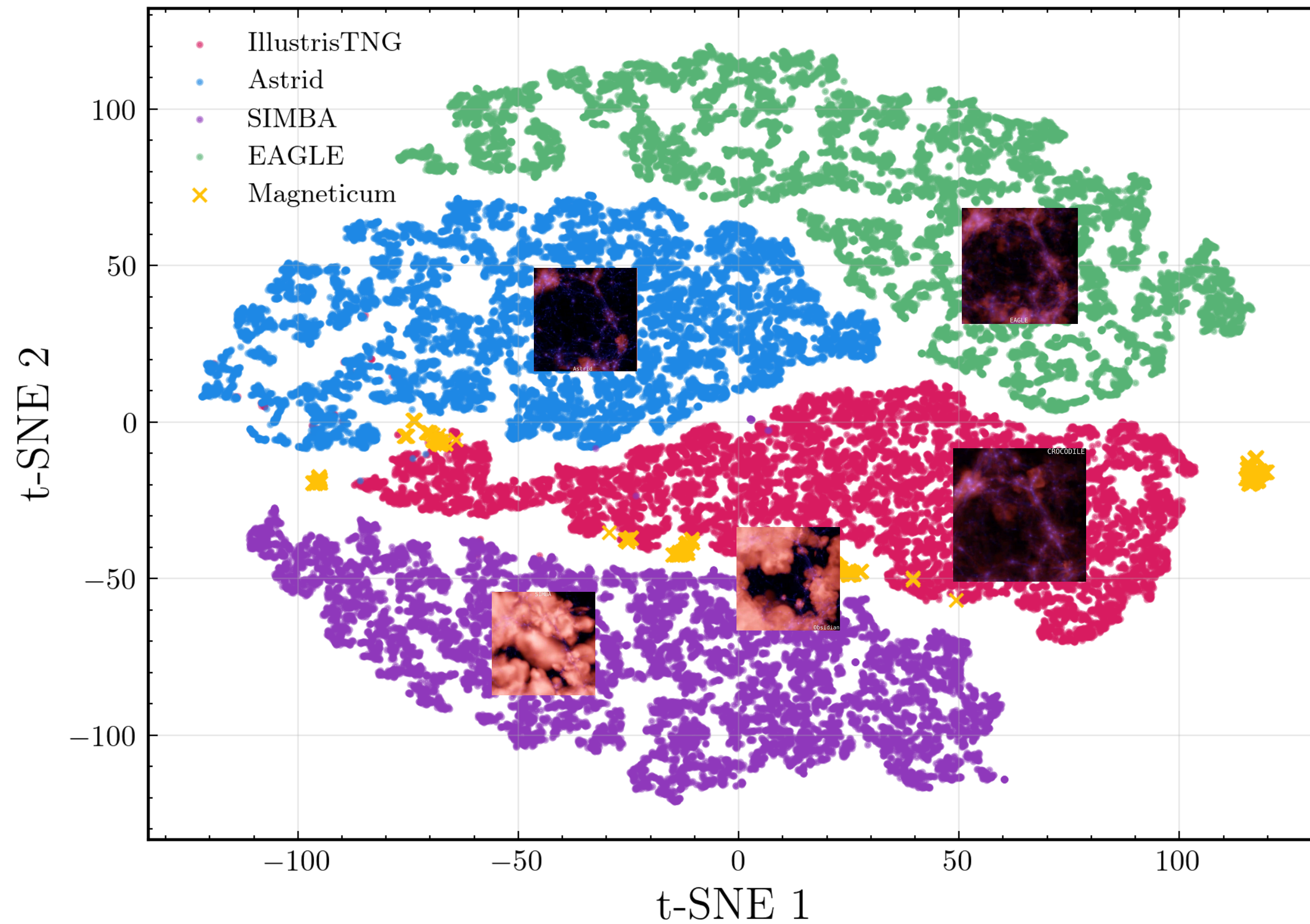


Astrid

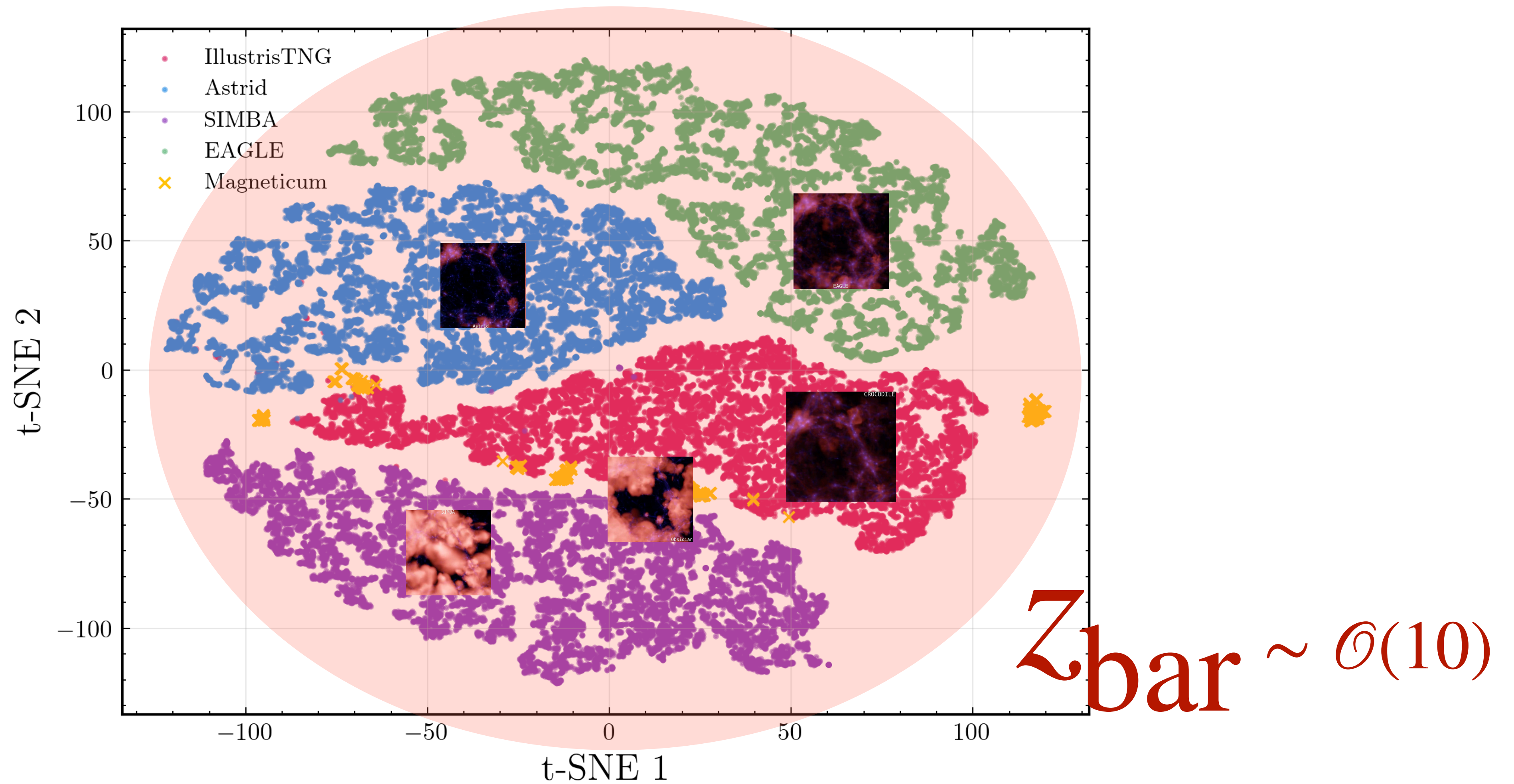


O

Baryonic feedback latent space

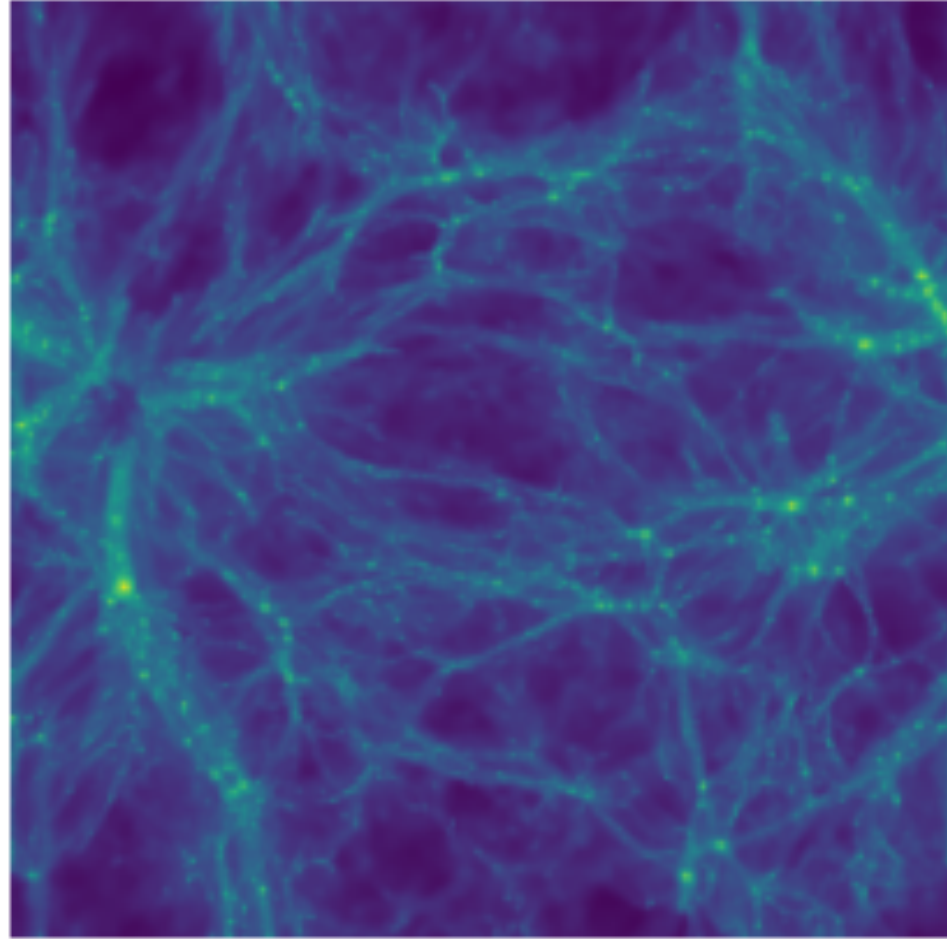


Baryonic feedback latent space



Gravity

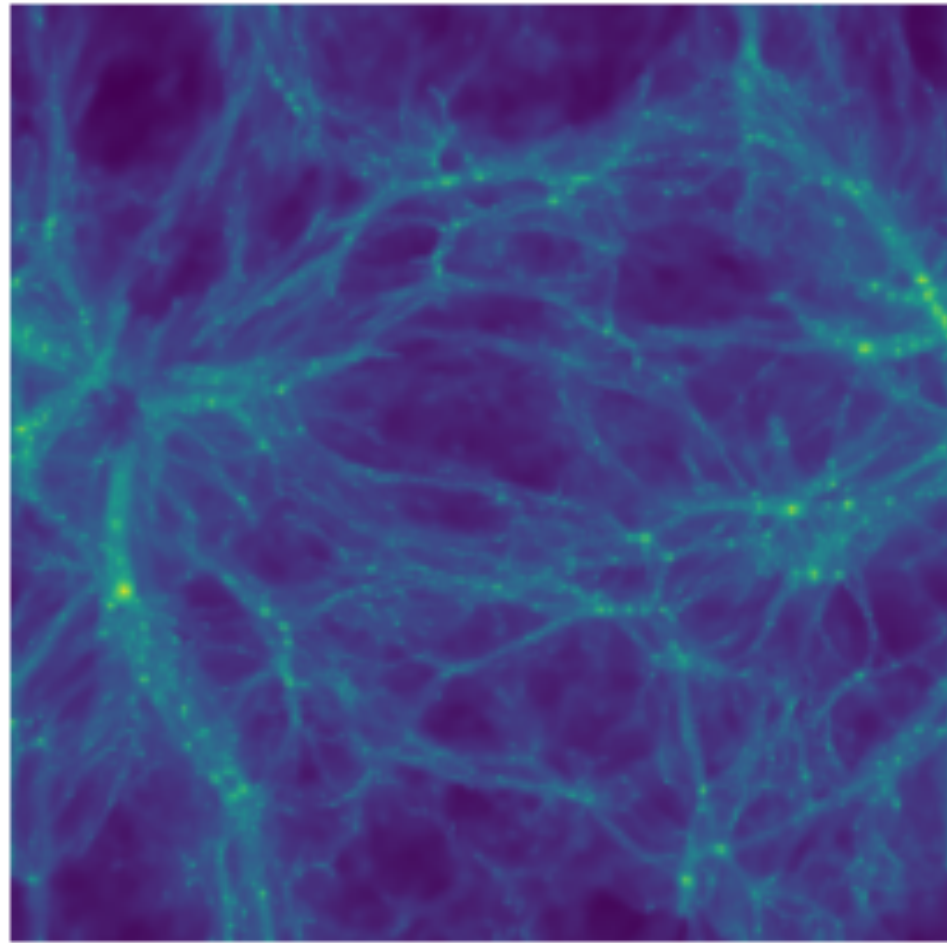
$\mathcal{E}$



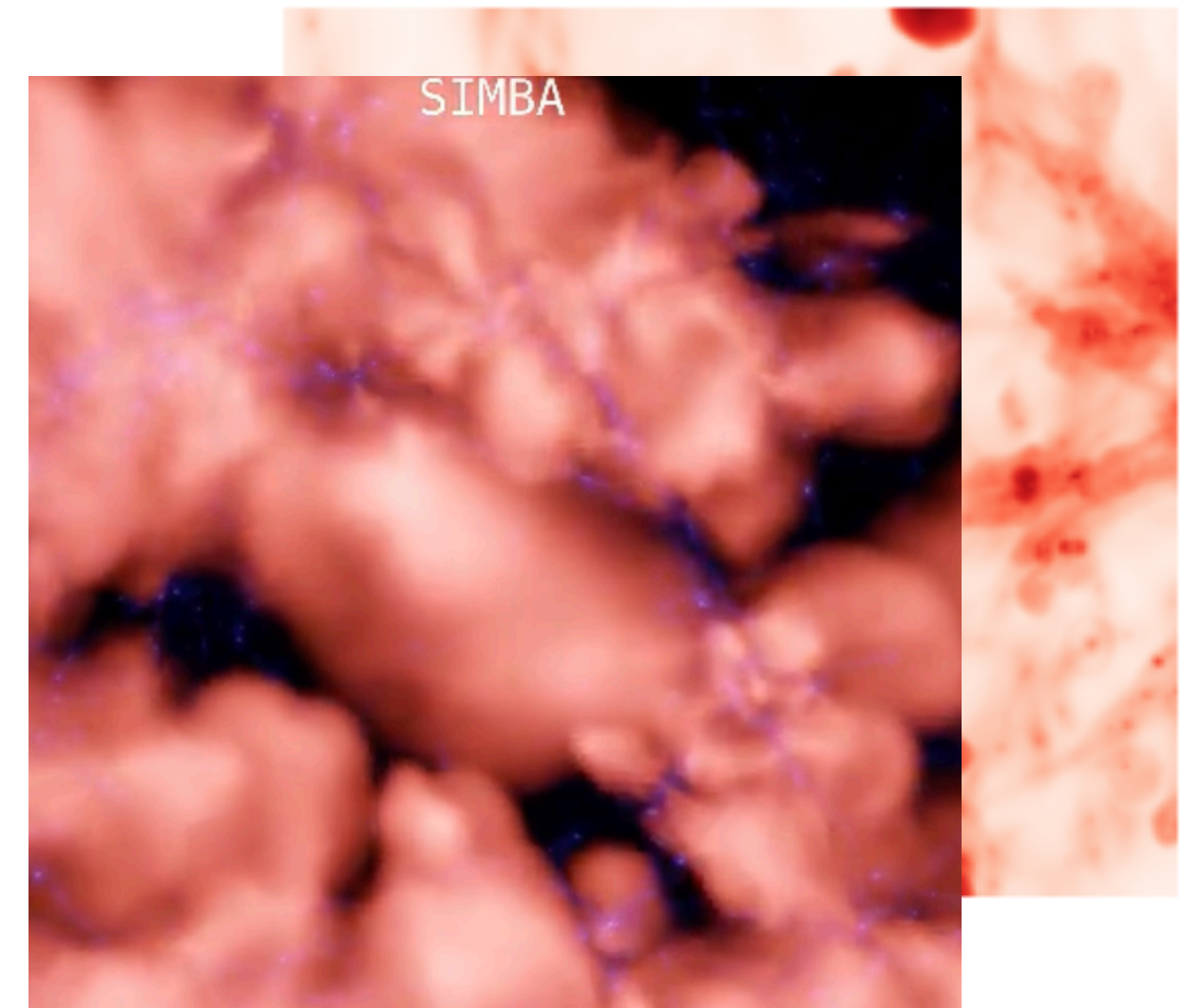
Gravity

Baryons

$\mathcal{C}$



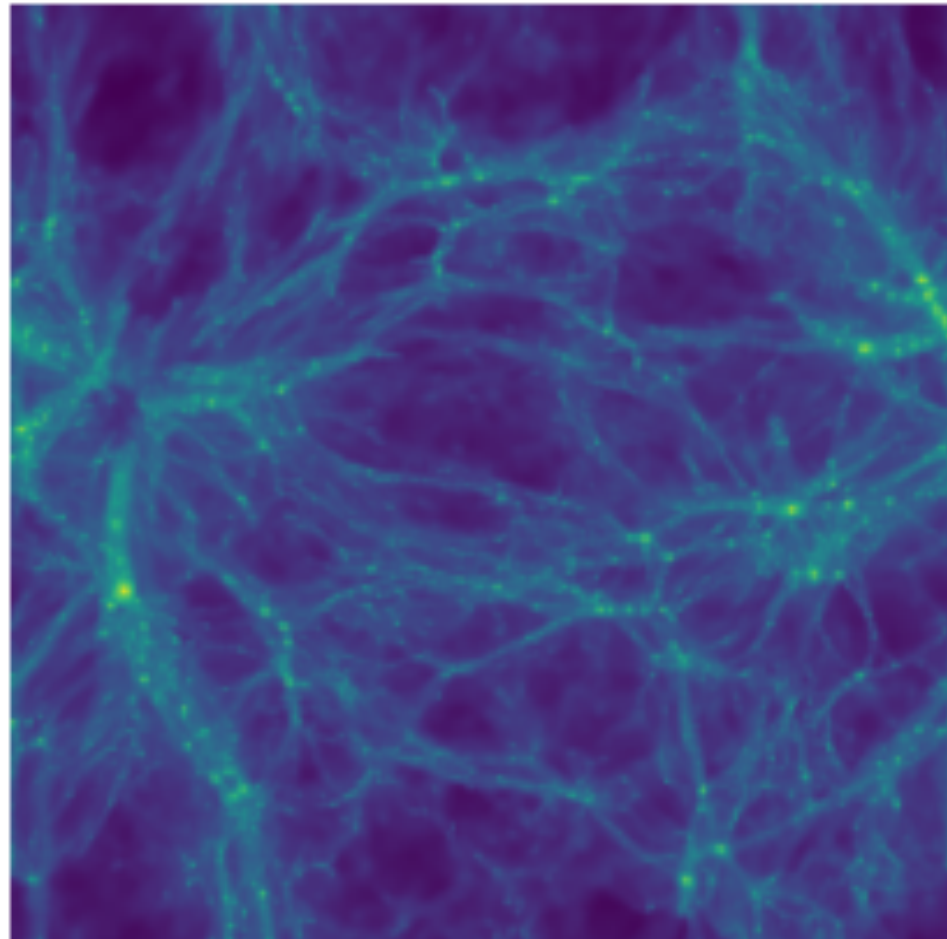
Generative model



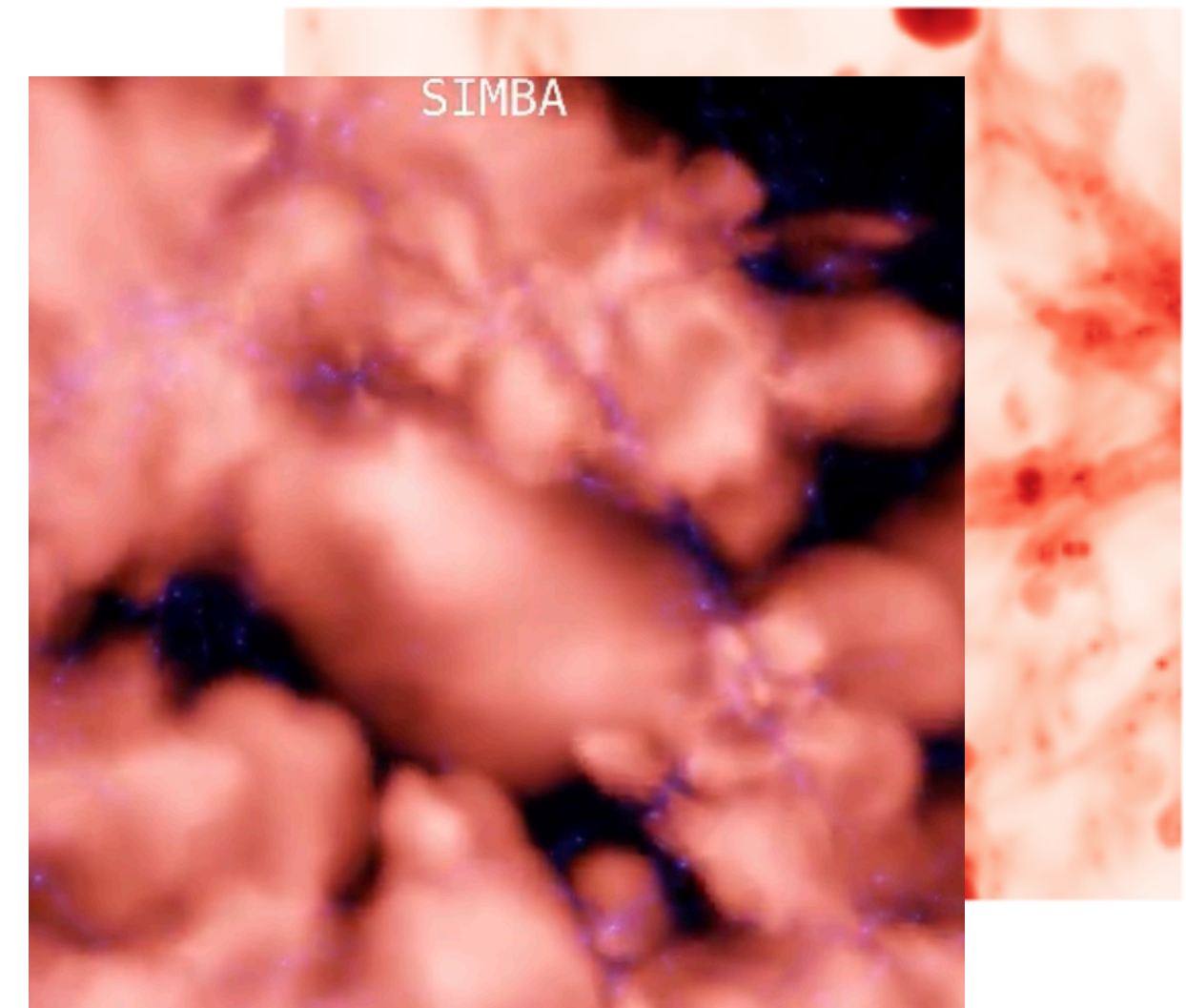
Gravity

Baryons

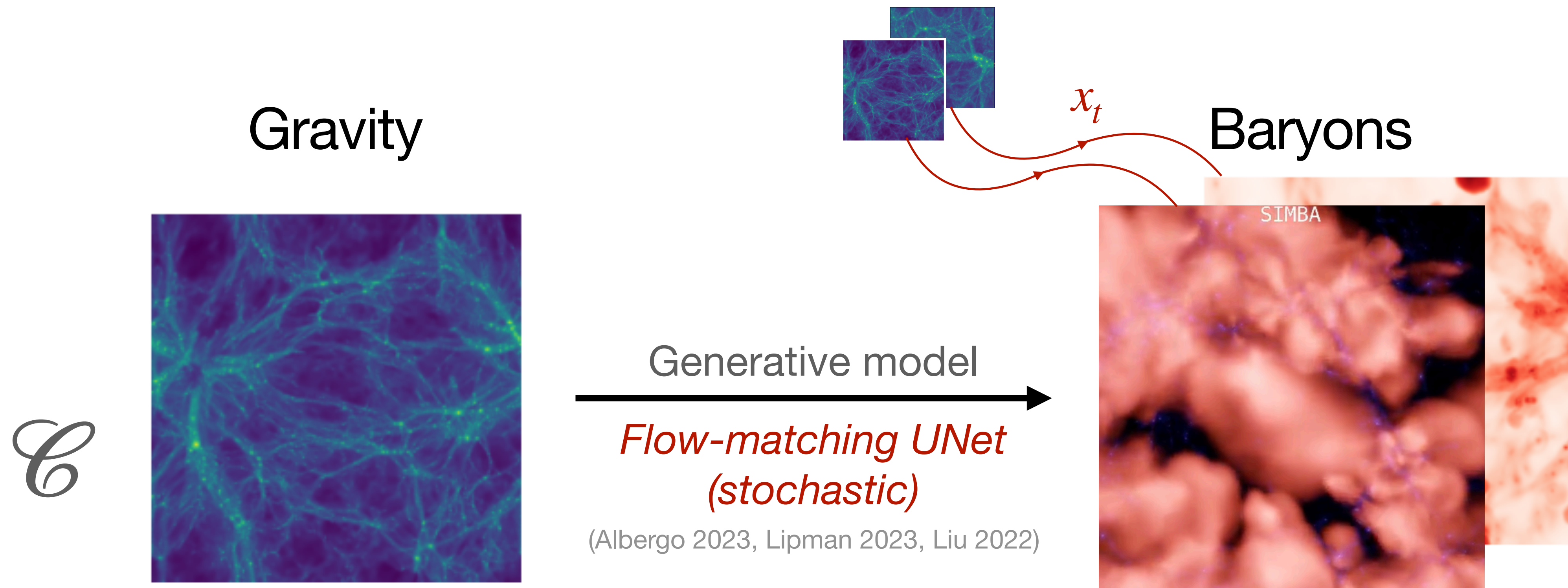
$\mathcal{C}$



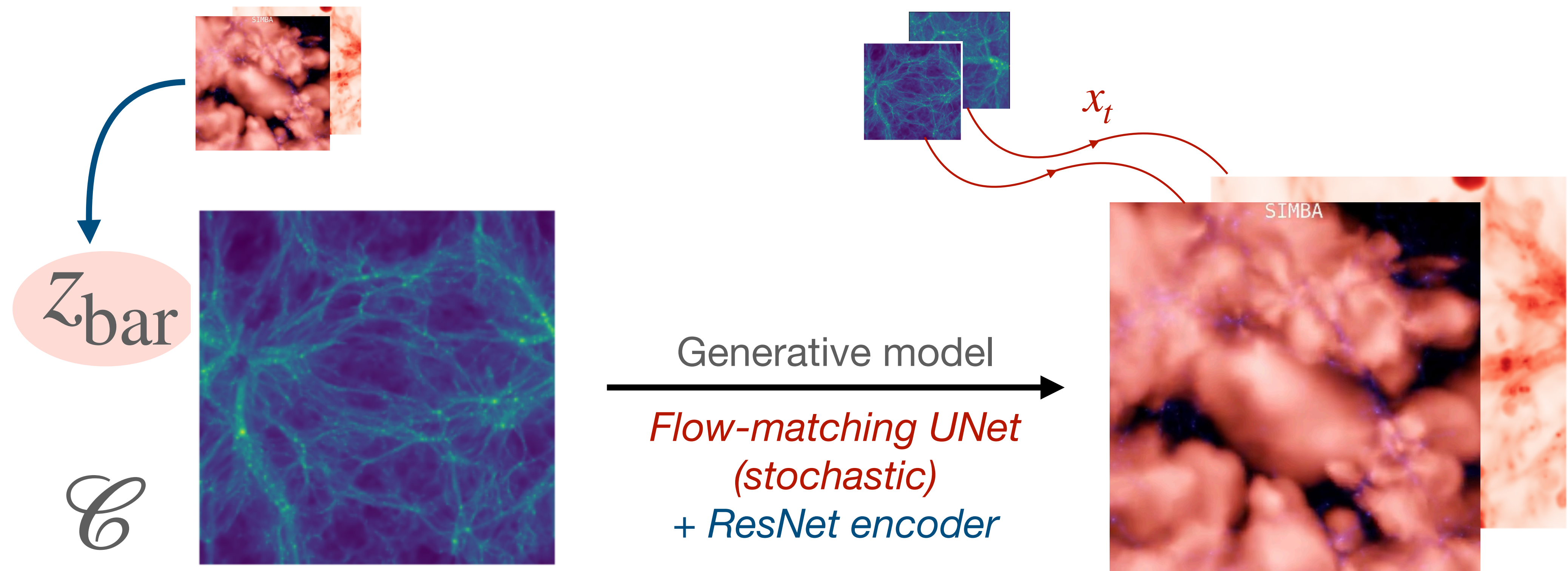
Generative model



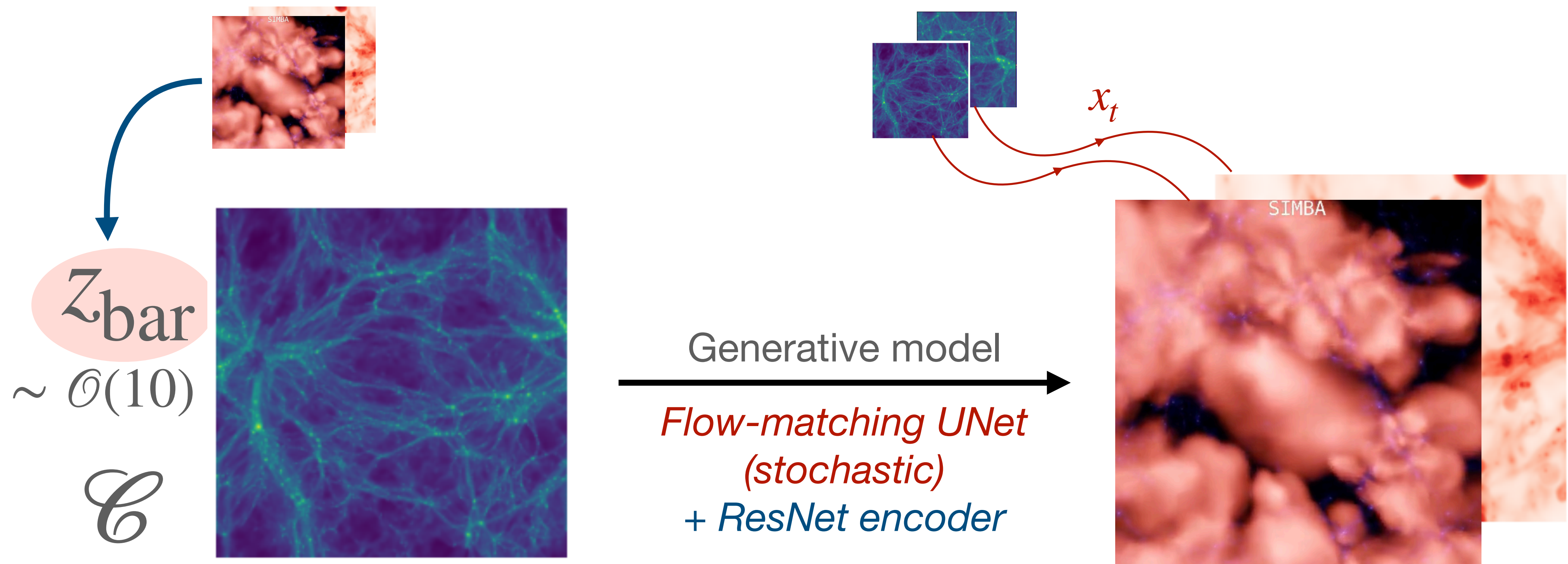
$$P_{\text{sim}}(\delta_{\text{baryons}} | \delta_{\text{dm}}, \mathcal{C})$$



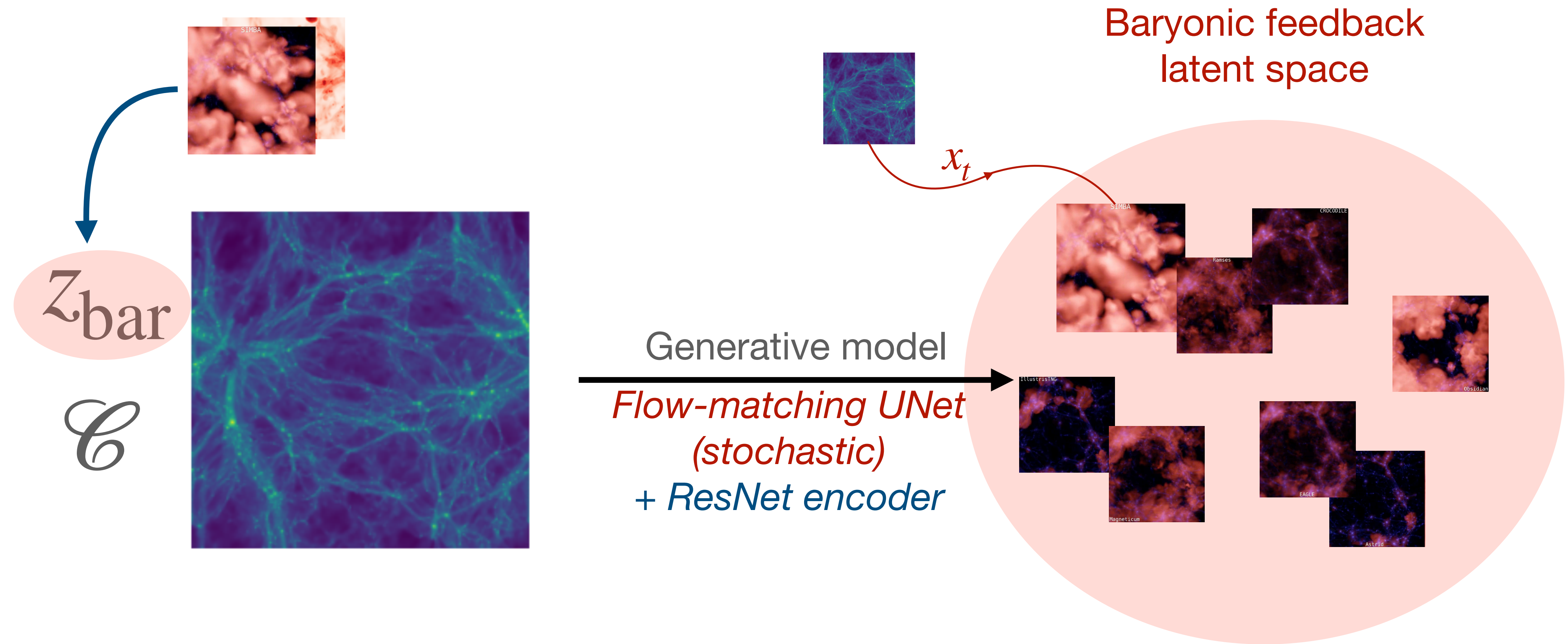
$$P_{\text{sim}}(\delta_{\text{baryons}} | \delta_{\text{dm}}, \mathcal{C})$$



$$P(\delta_{\text{baryons}} \mid \delta_{\text{dm}}, \mathcal{C}, z_{\text{bar}})$$

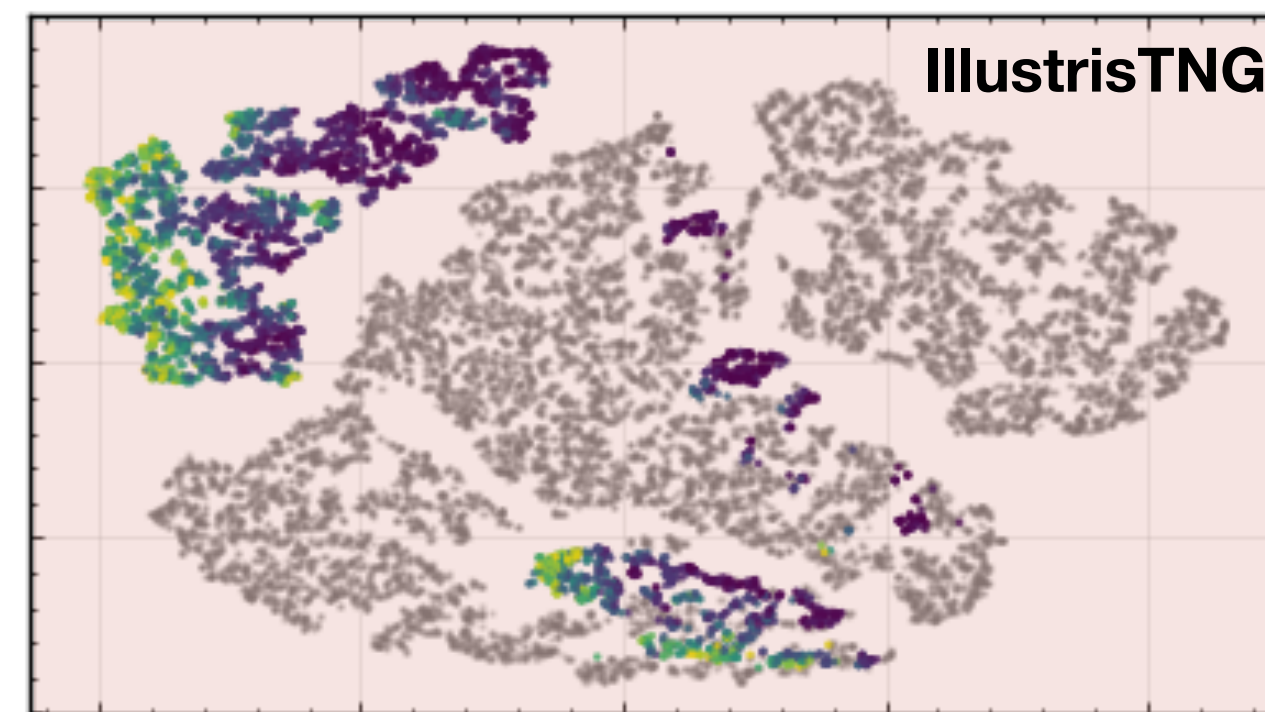
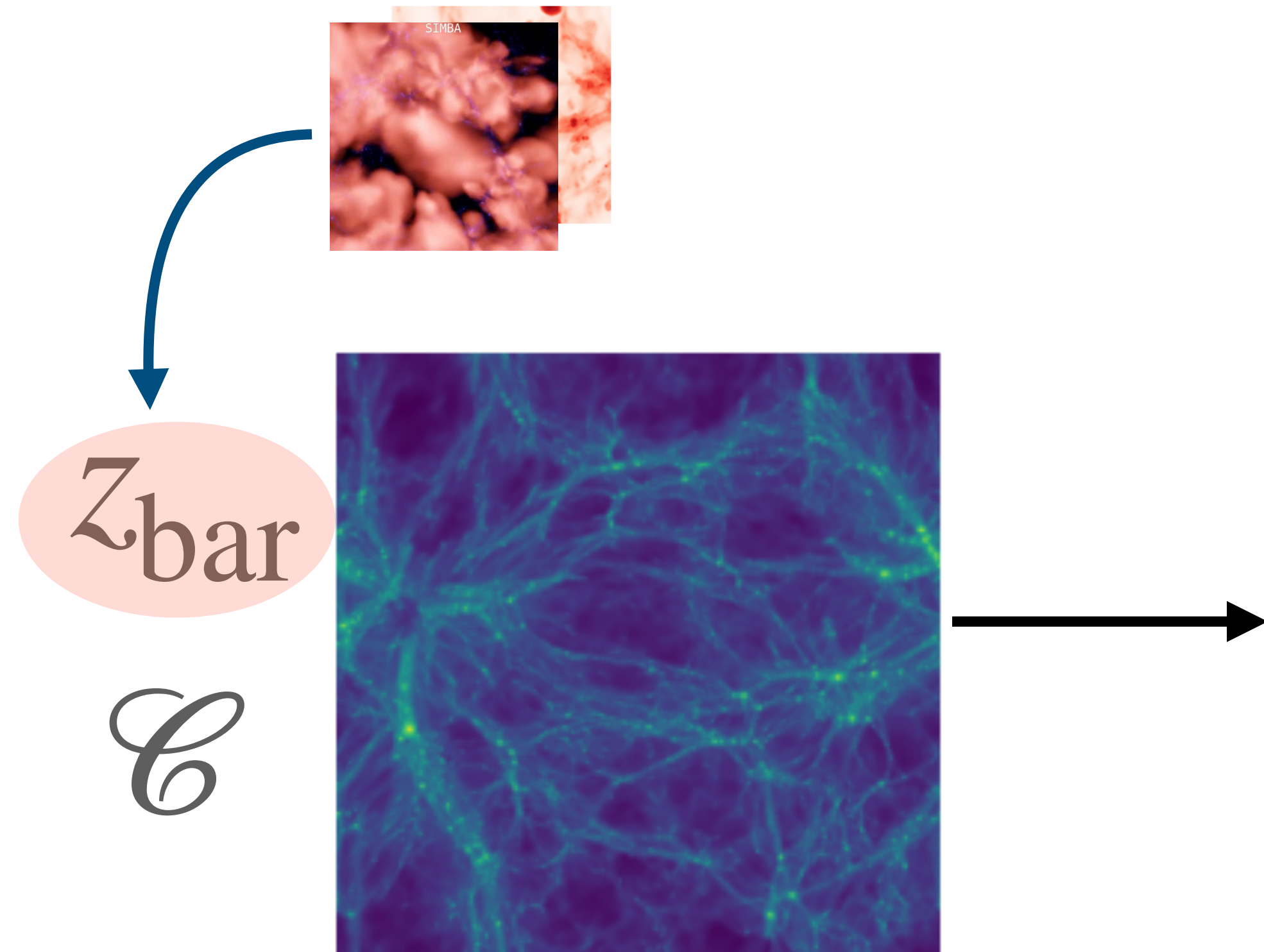


$$P(\delta_{\text{baryons}} \mid \delta_{\text{dm}}, \mathcal{C}, z_{\text{bar}})$$

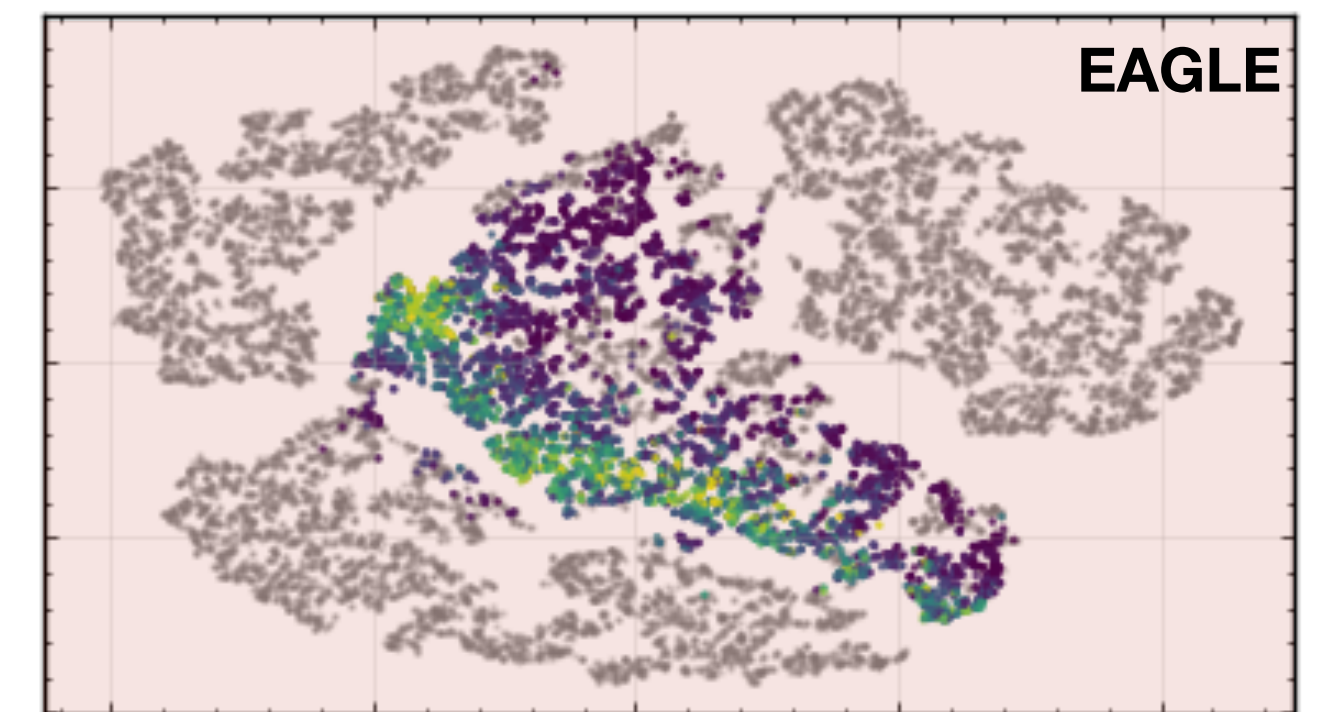


$$P(\delta_{\text{baryons}} \mid \delta_{\text{dm}}, \mathcal{C}, z_{\text{bar}})$$

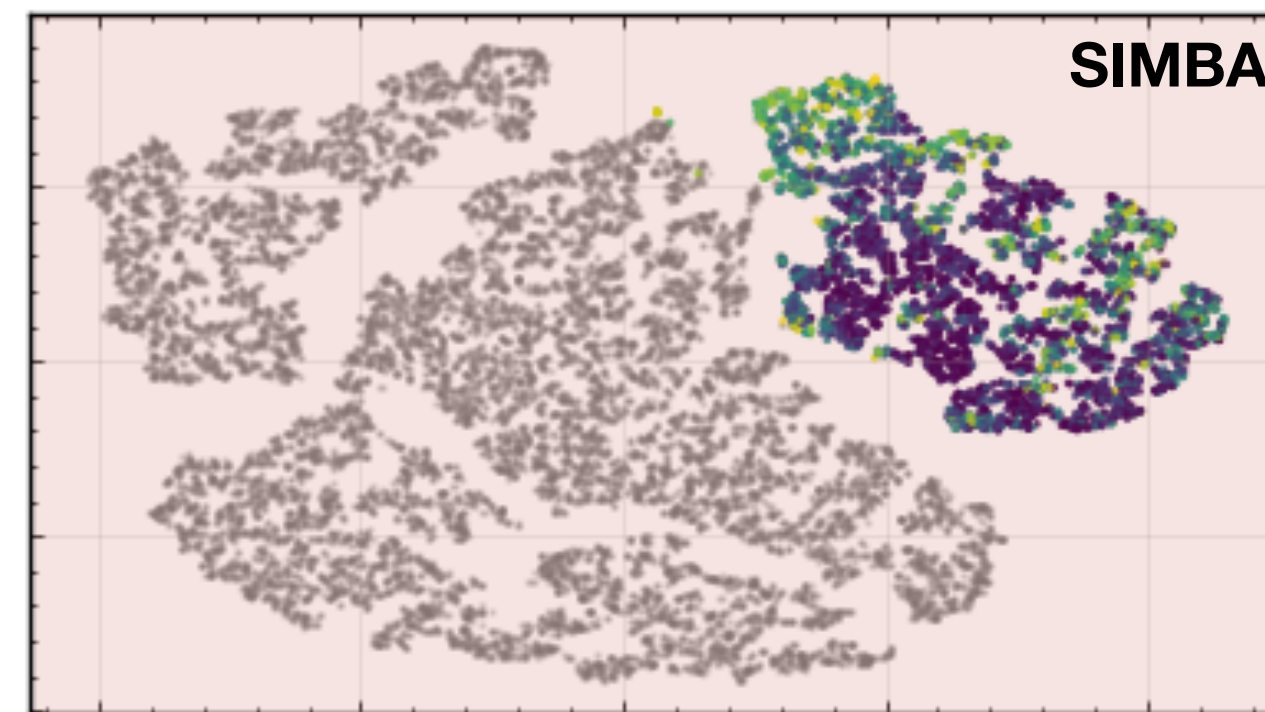
Latent Space z_{bar} , coloured by “ A_{SN1} ”



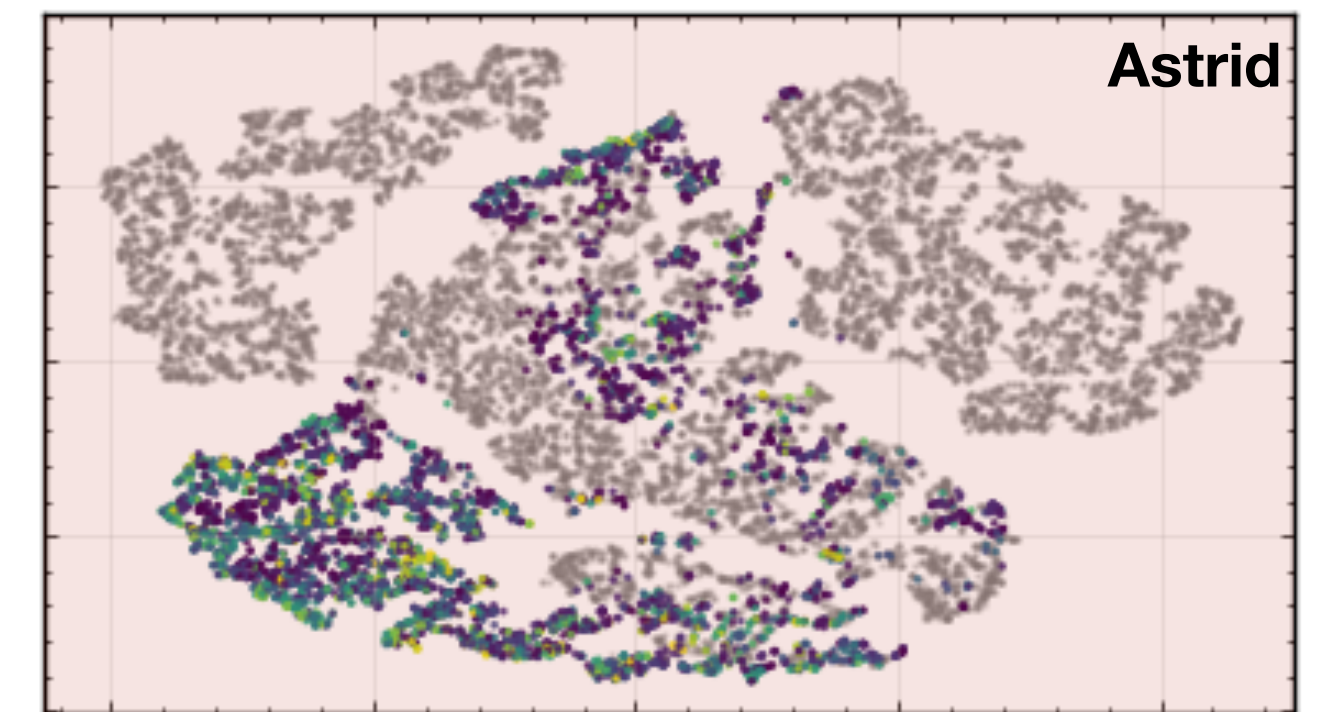
Winds energy



Thermal Energy per SNII



Mass loading of the galactic winds



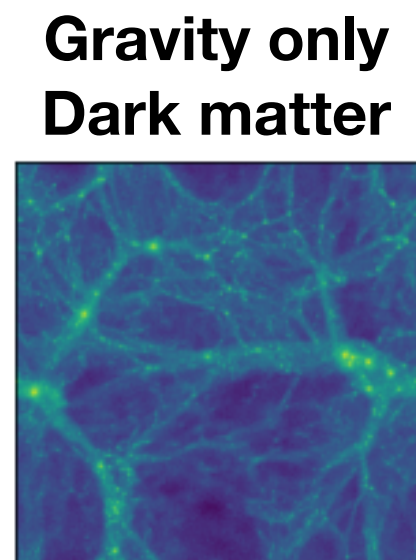
Energy per Star Formation Rate (SFR)

$$P(\delta_{\text{baryons}} | \delta_{\text{dm}}, \mathcal{C}, z_{\text{bar}})$$

Reconstruction • Interpolation • Emulation

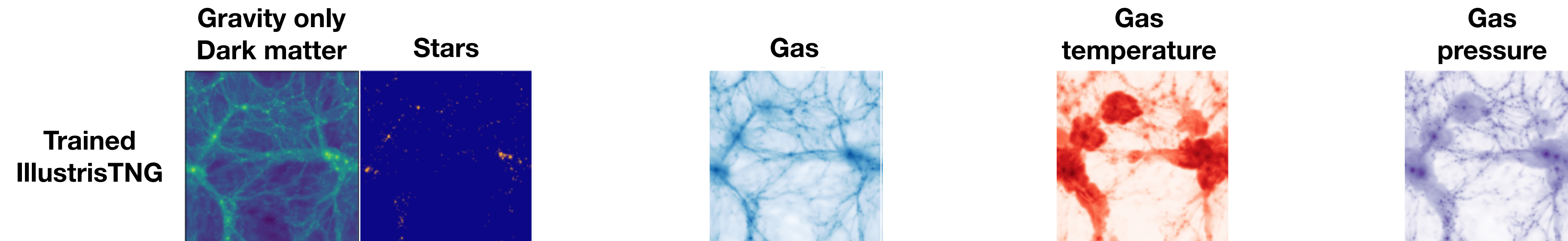
Reconstructs unseen Magneticum maps

Trained
IllustrisTNG



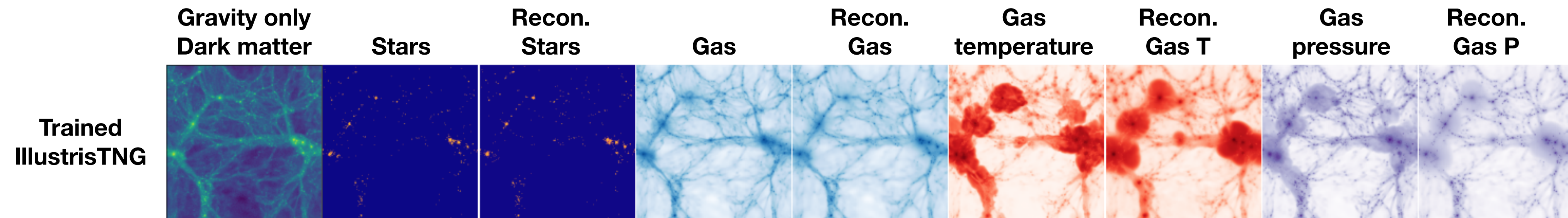
Reconstruction • Interpolation • Emulation

Reconstructs unseen Magneticum maps



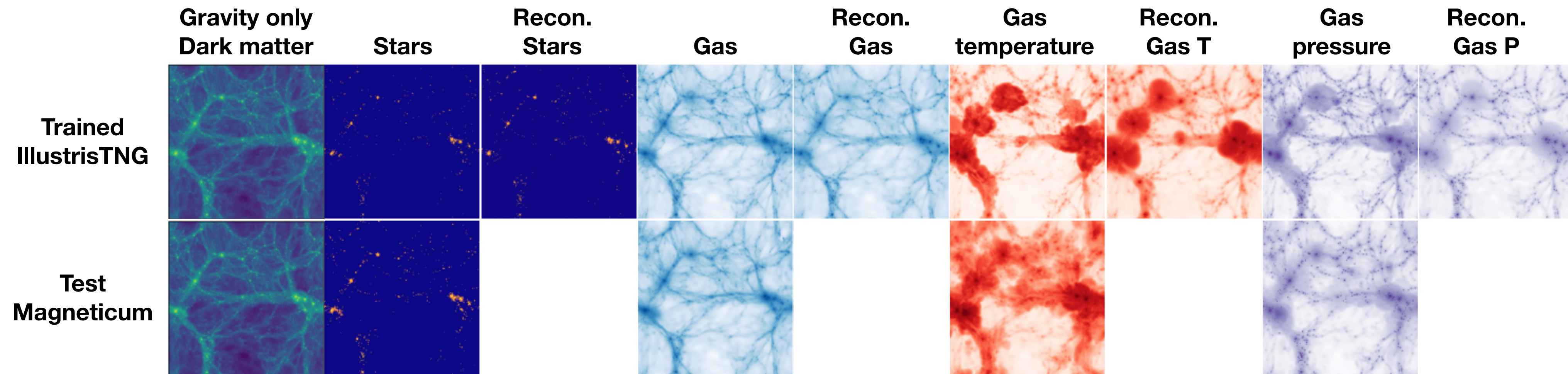
Reconstruction · Interpolation · Emulation

Reconstructs unseen Magneticum maps



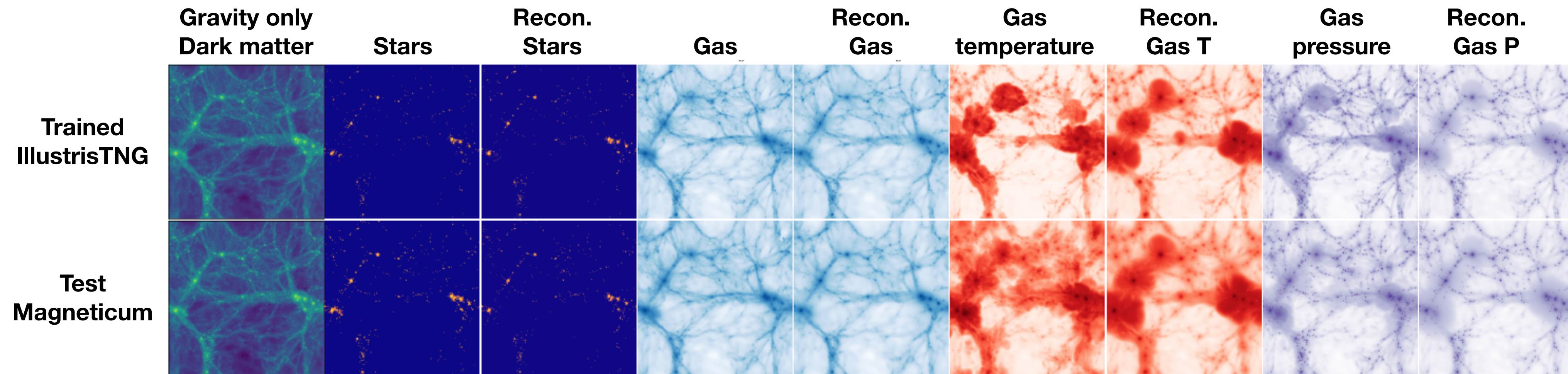
Reconstruction · Interpolation · Emulation

Reconstructs unseen Magneticum maps



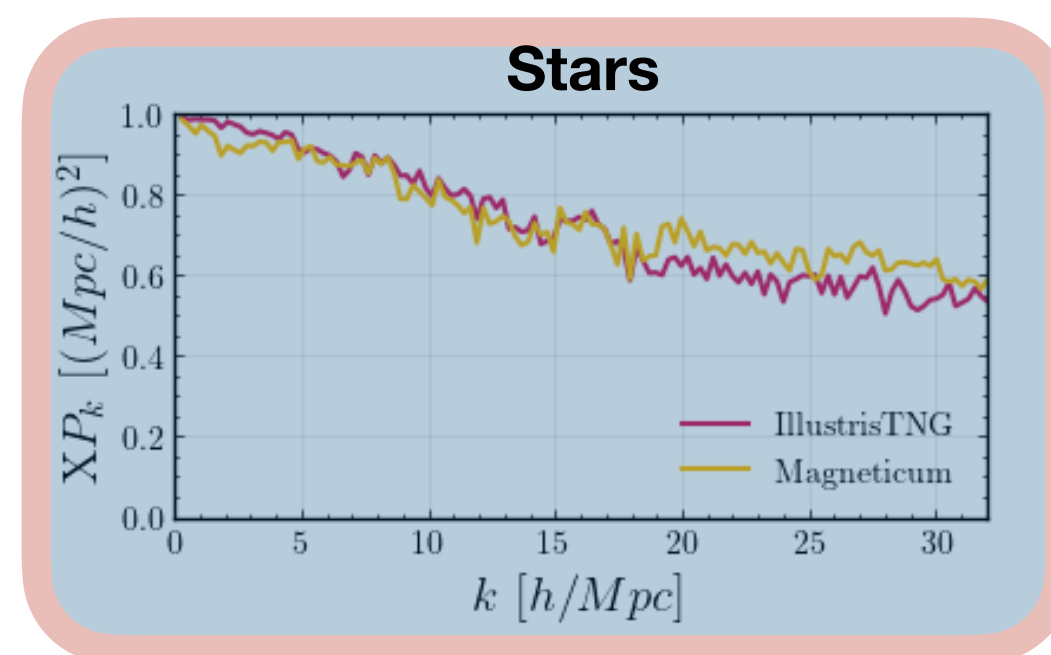
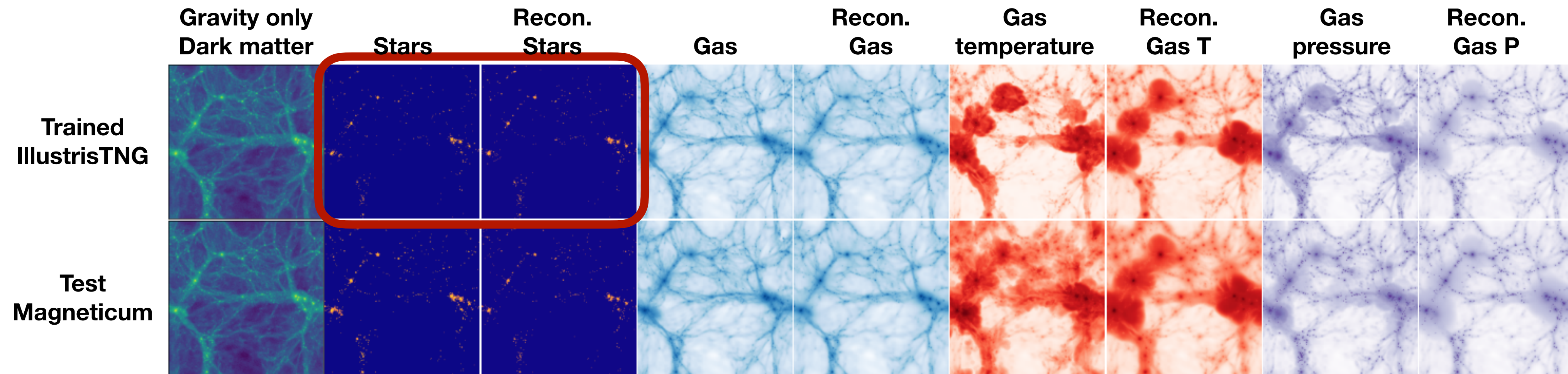
Reconstruction · Interpolation · Emulation

Reconstructs unseen Magneticum maps



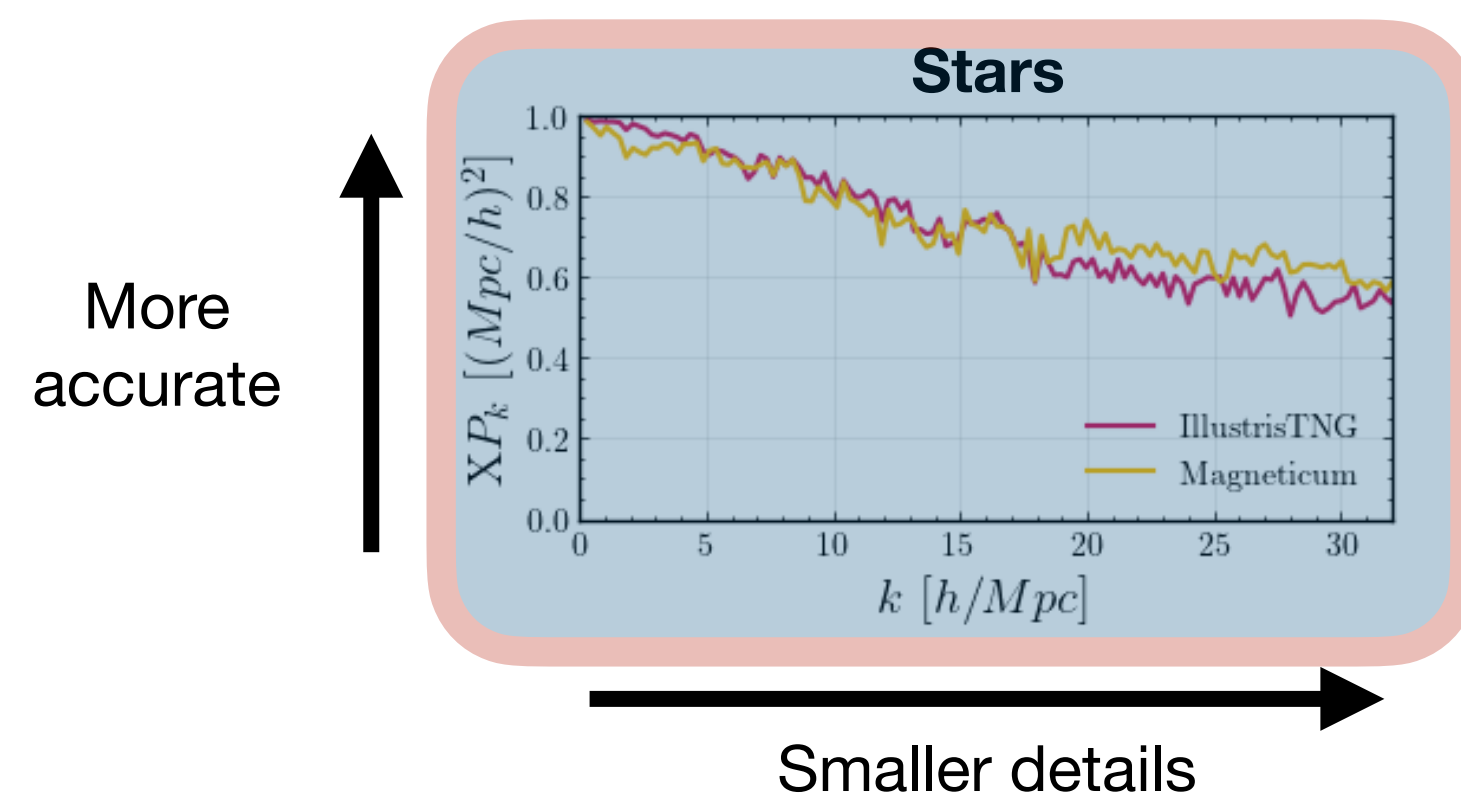
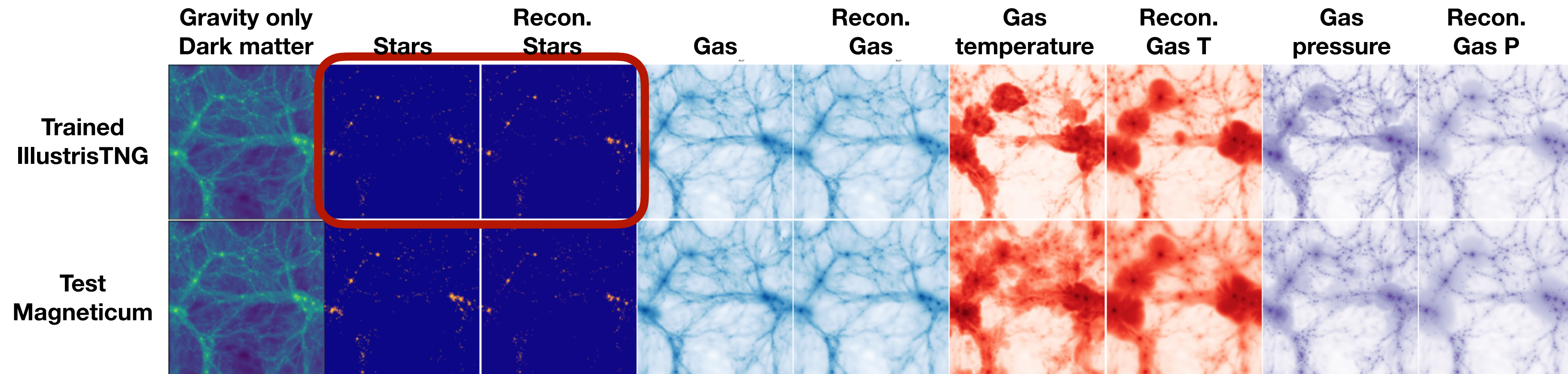
Reconstruction · Interpolation · Emulation

Reconstructs unseen Magneticum maps



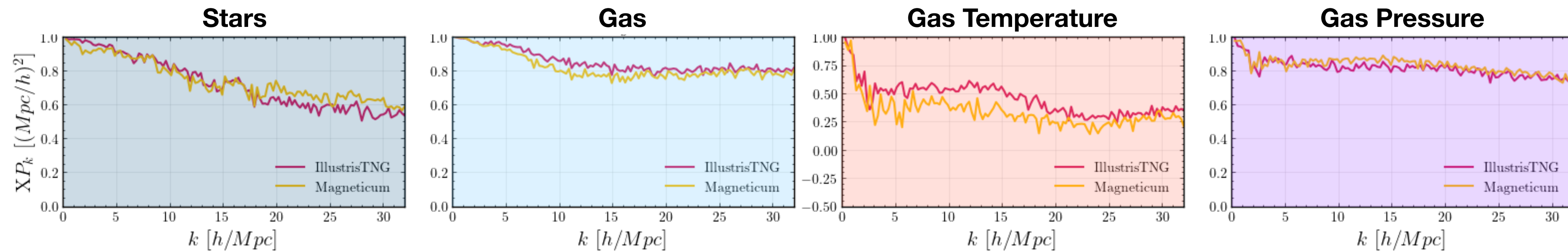
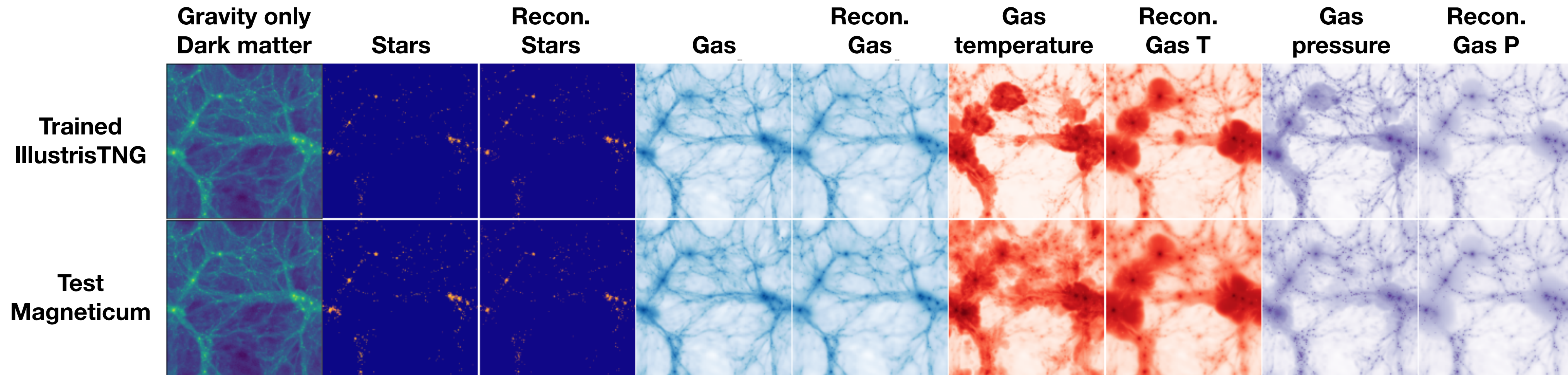
Reconstruction · Interpolation · Emulation

Reconstructs unseen Magneticum maps



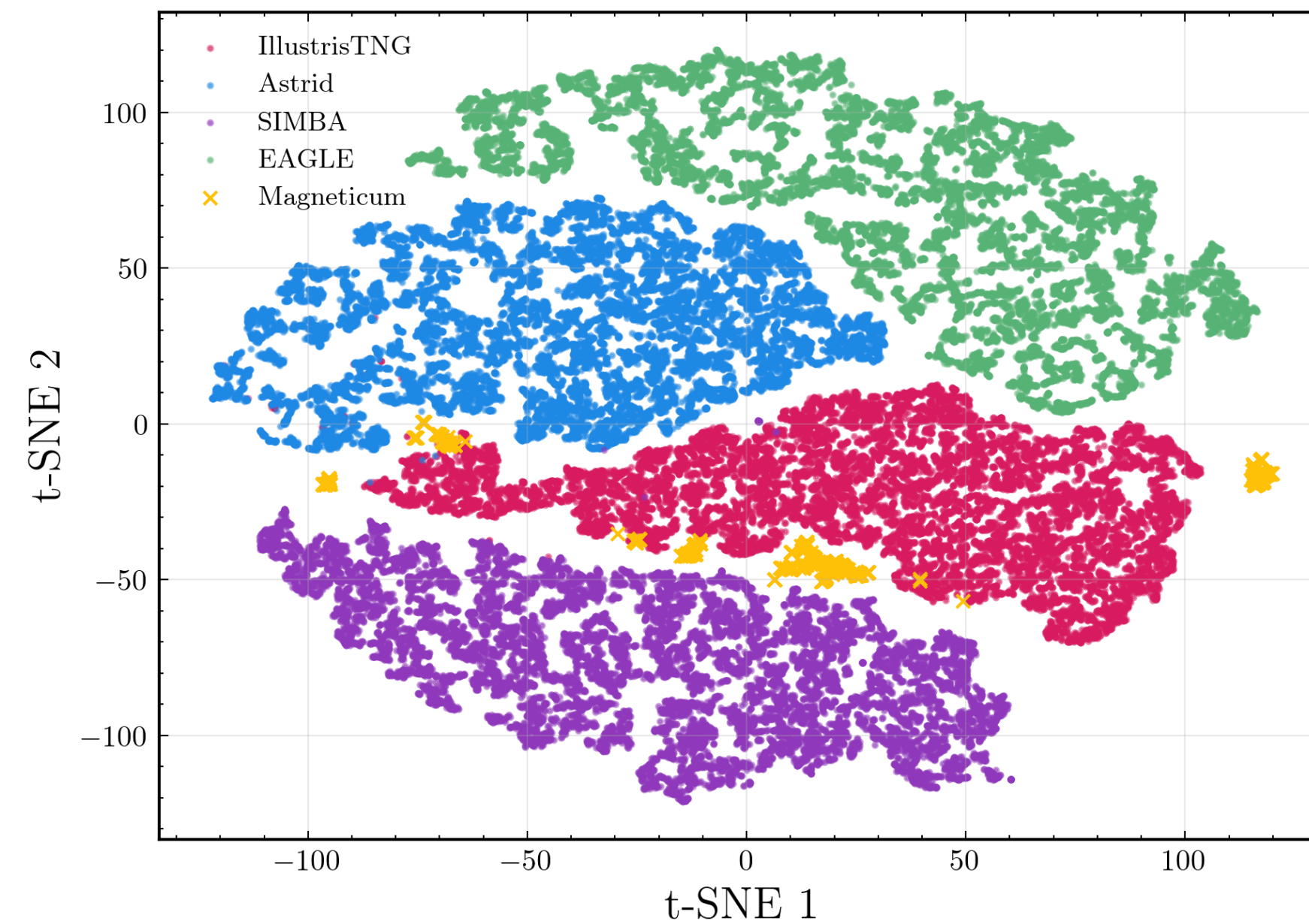
Reconstruction · Interpolation · Emulation

Reconstructs unseen Magneticum maps



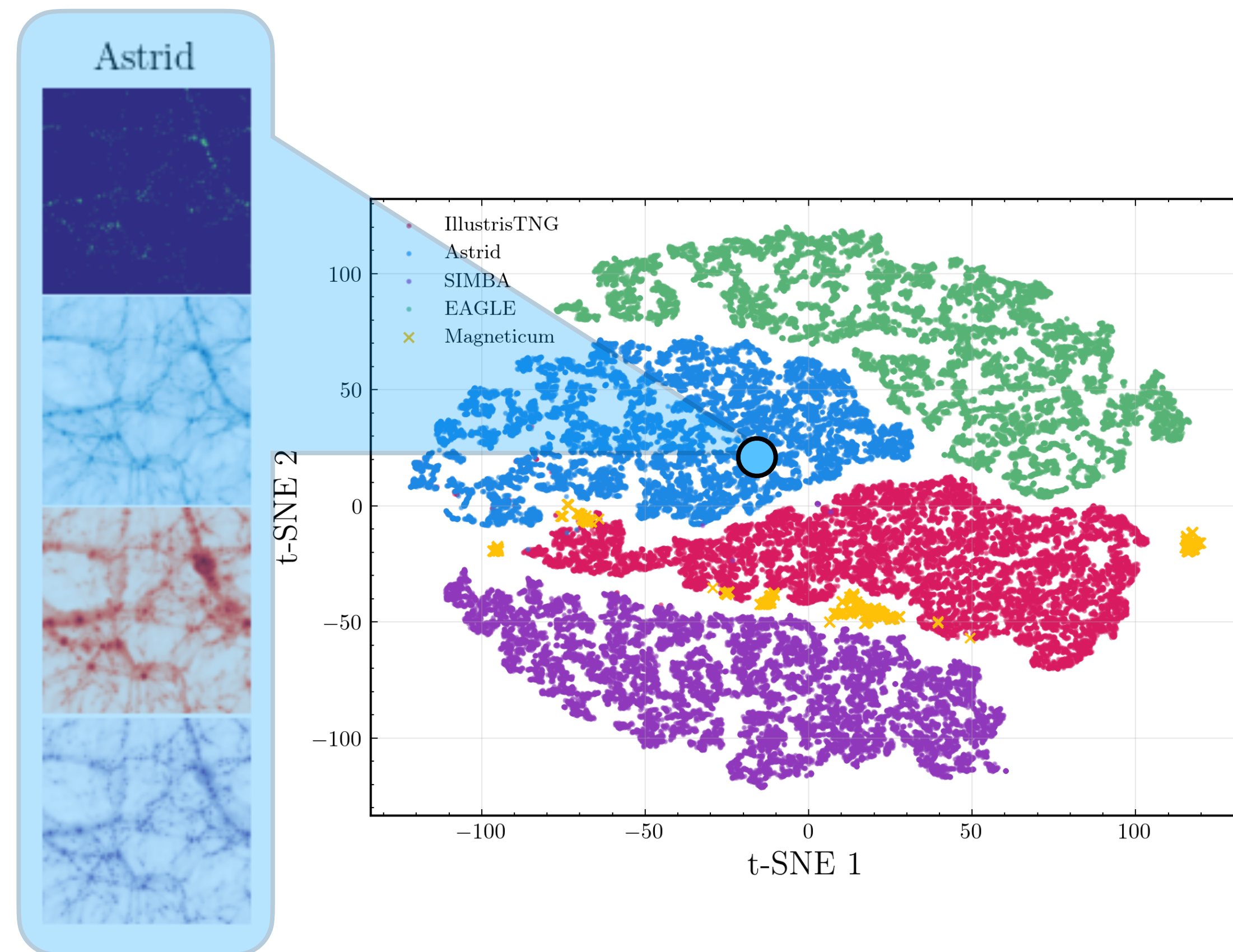
Reconstruction · **Interpolation** · Emulation

Interpolate across different simulations



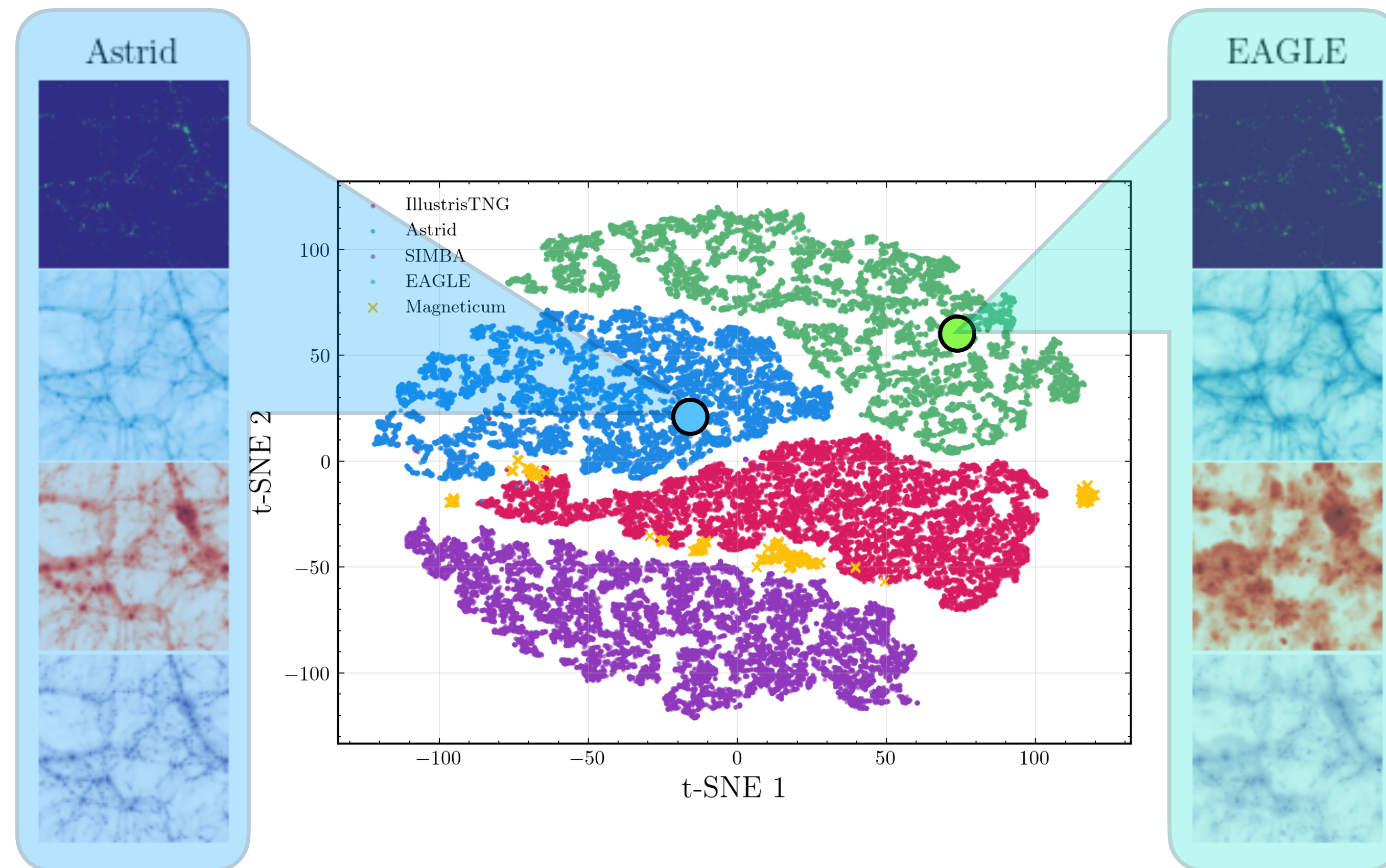
Reconstruction · **Interpolation** · Emulation

Interpolate across different simulations



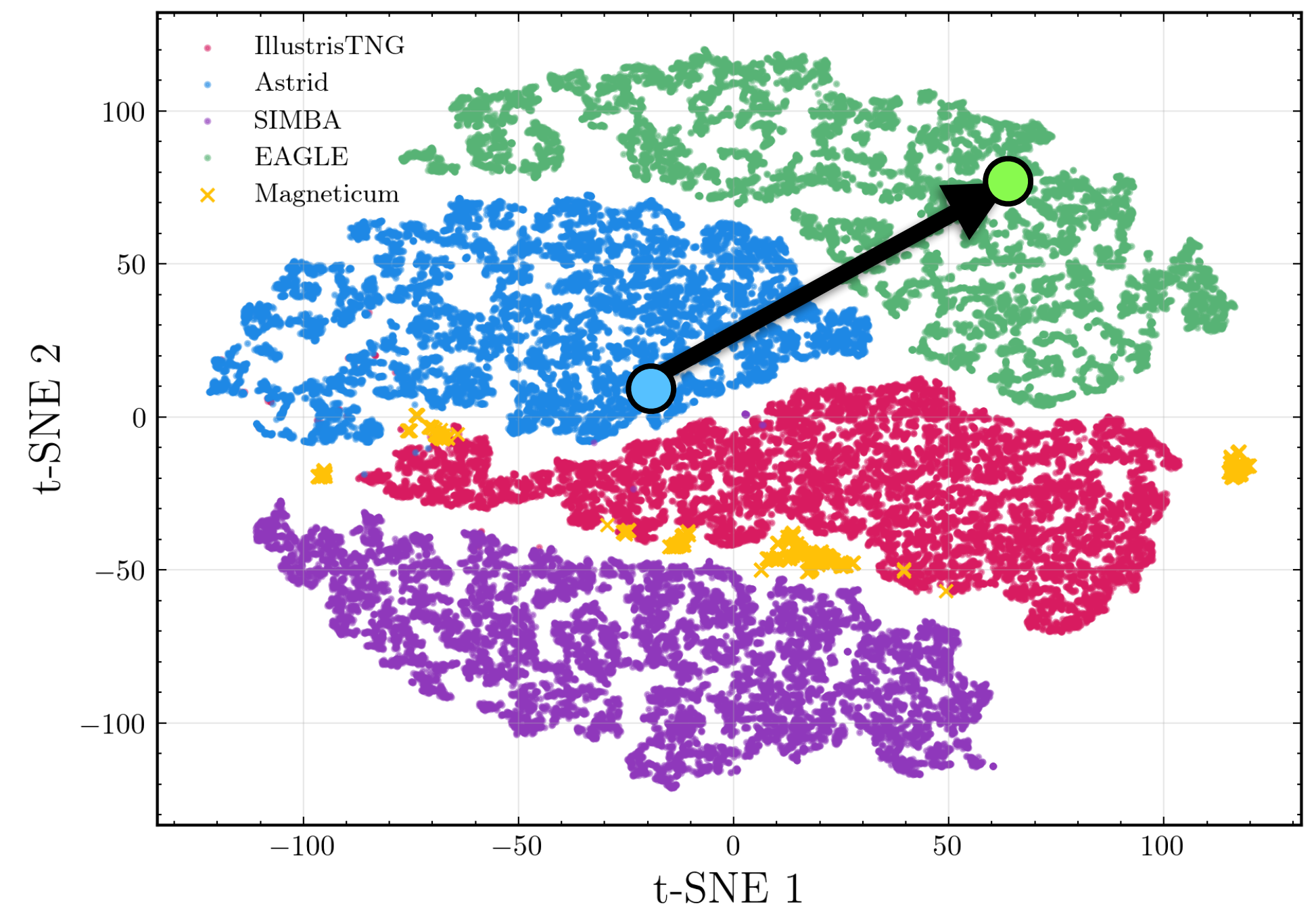
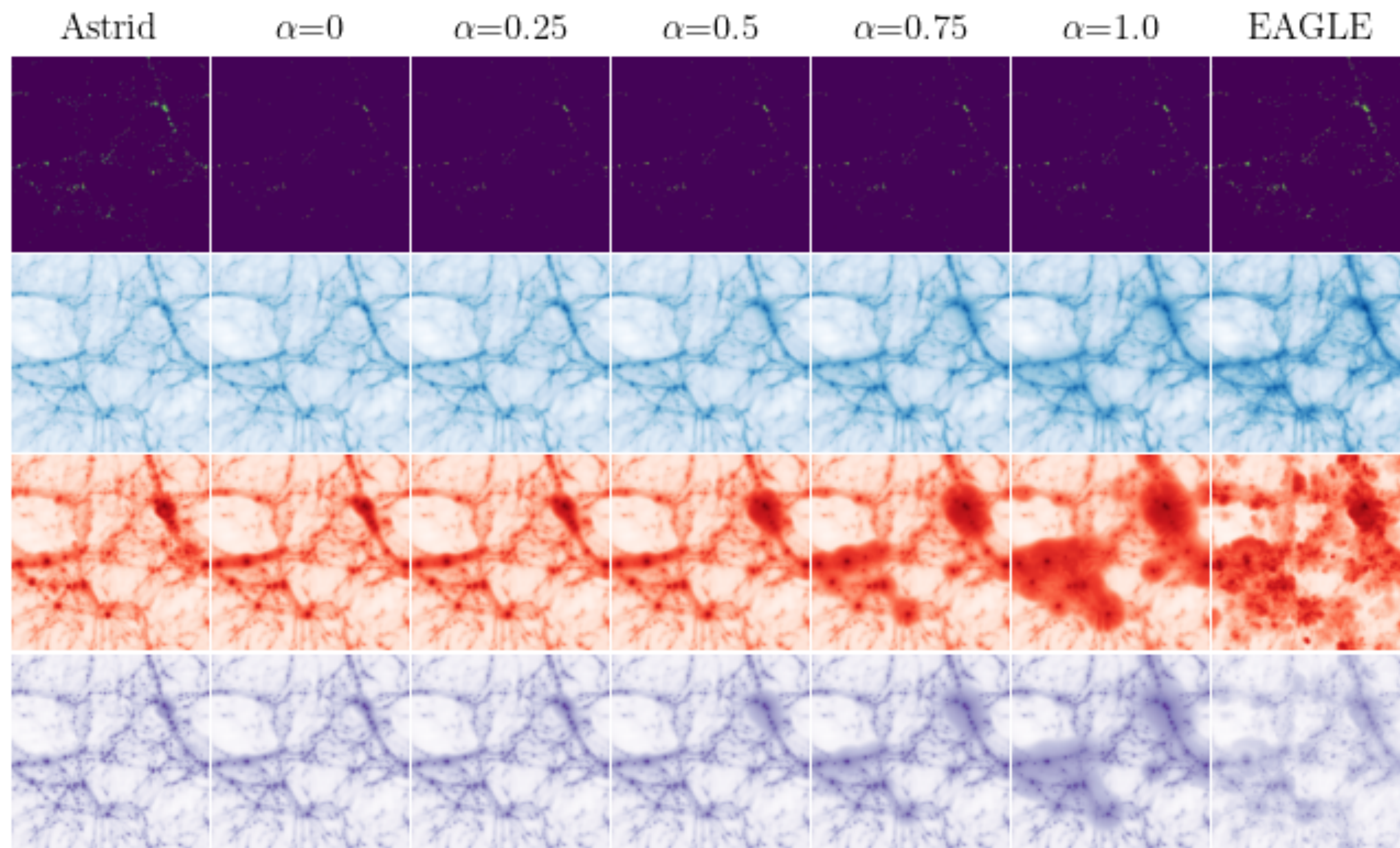
Reconstruction · **Interpolation** · Emulation

Interpolate across different simulations



Reconstruction · Interpolation · Emulation

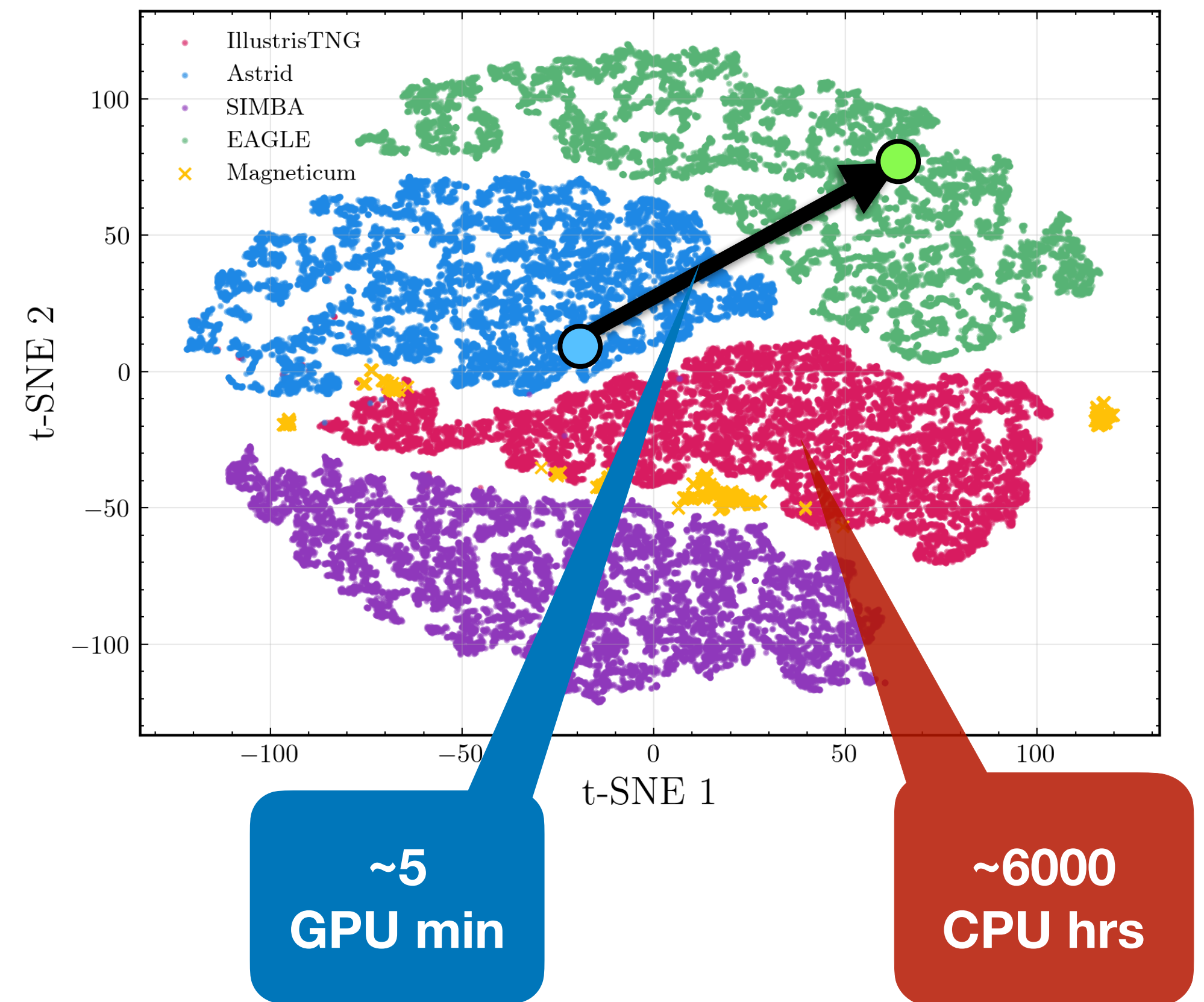
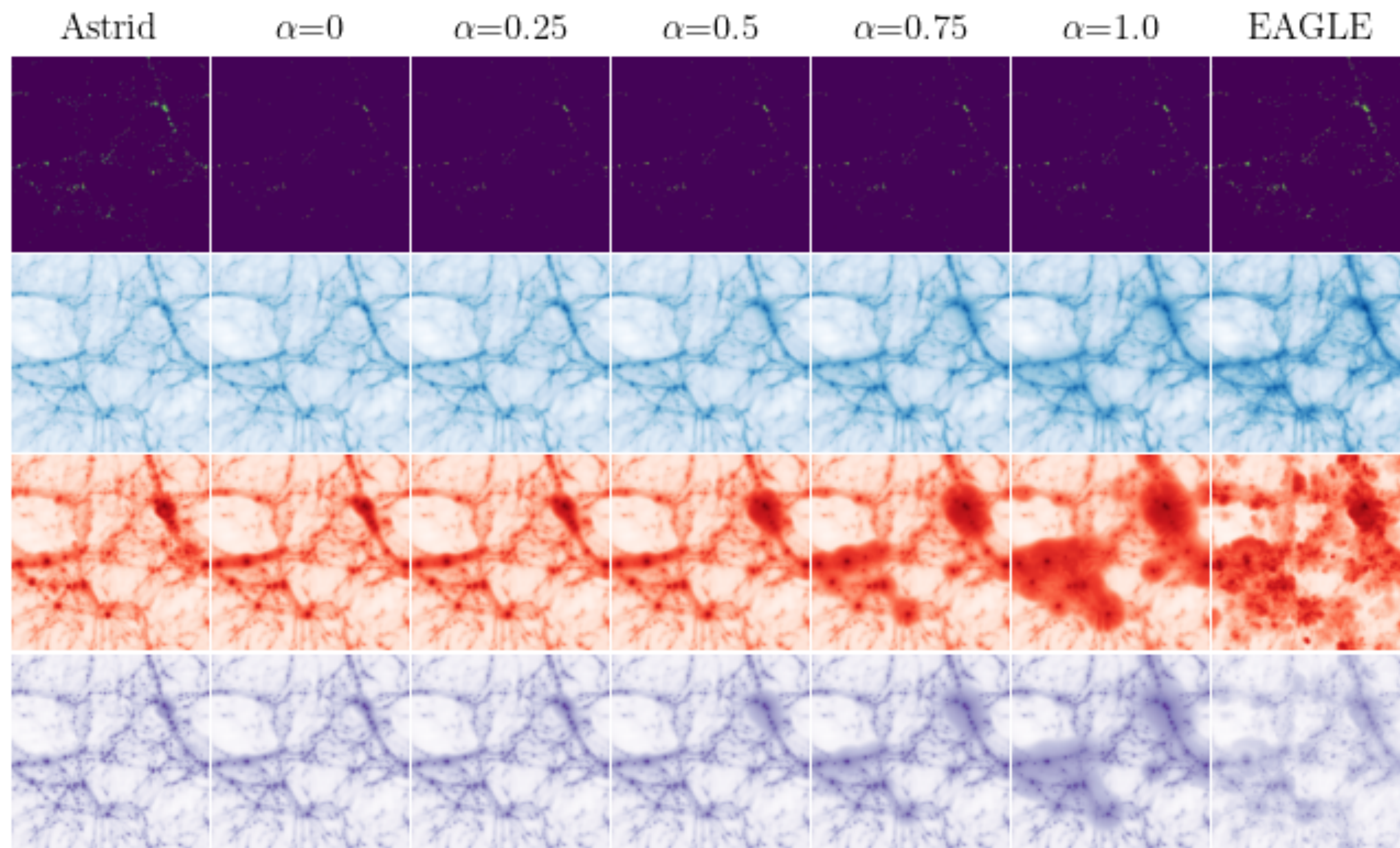
Interpolate across different simulations



Interpolate in **8 dimensional** z_{bar} space

Reconstruction · **Interpolation** · Emulation

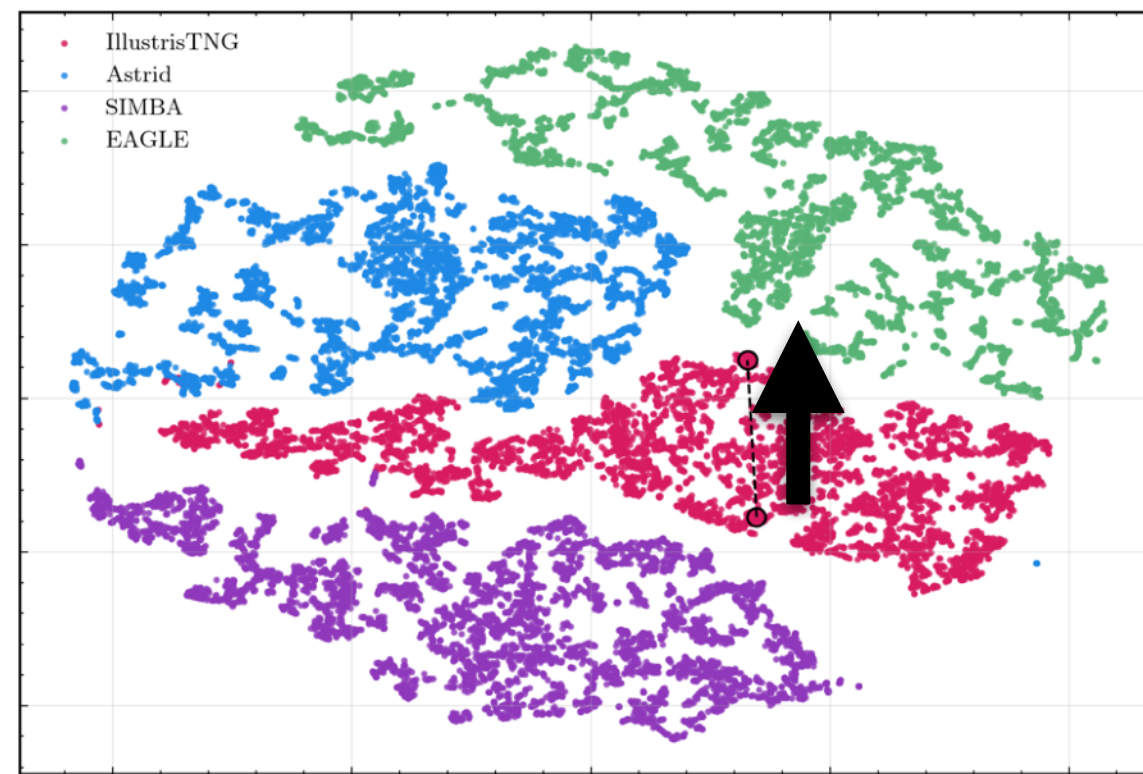
Interpolate across different simulations



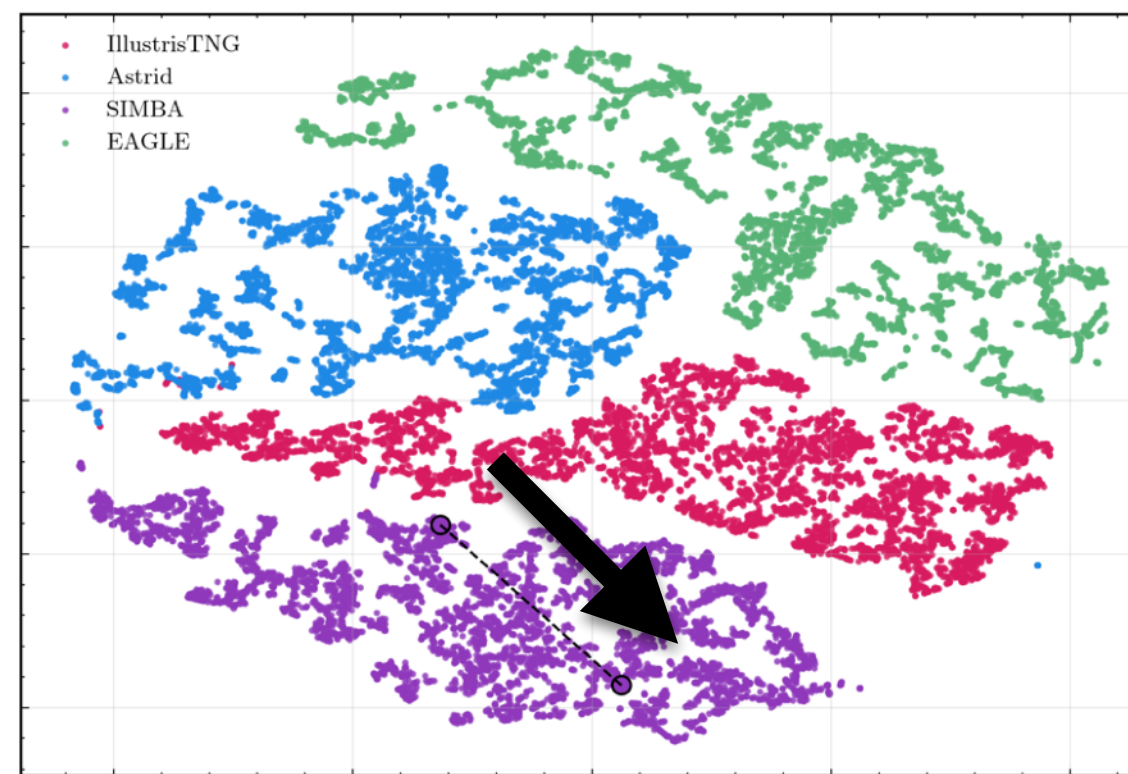
Reconstruction · Interpolation · Emulation

Emulate feedback within simulations

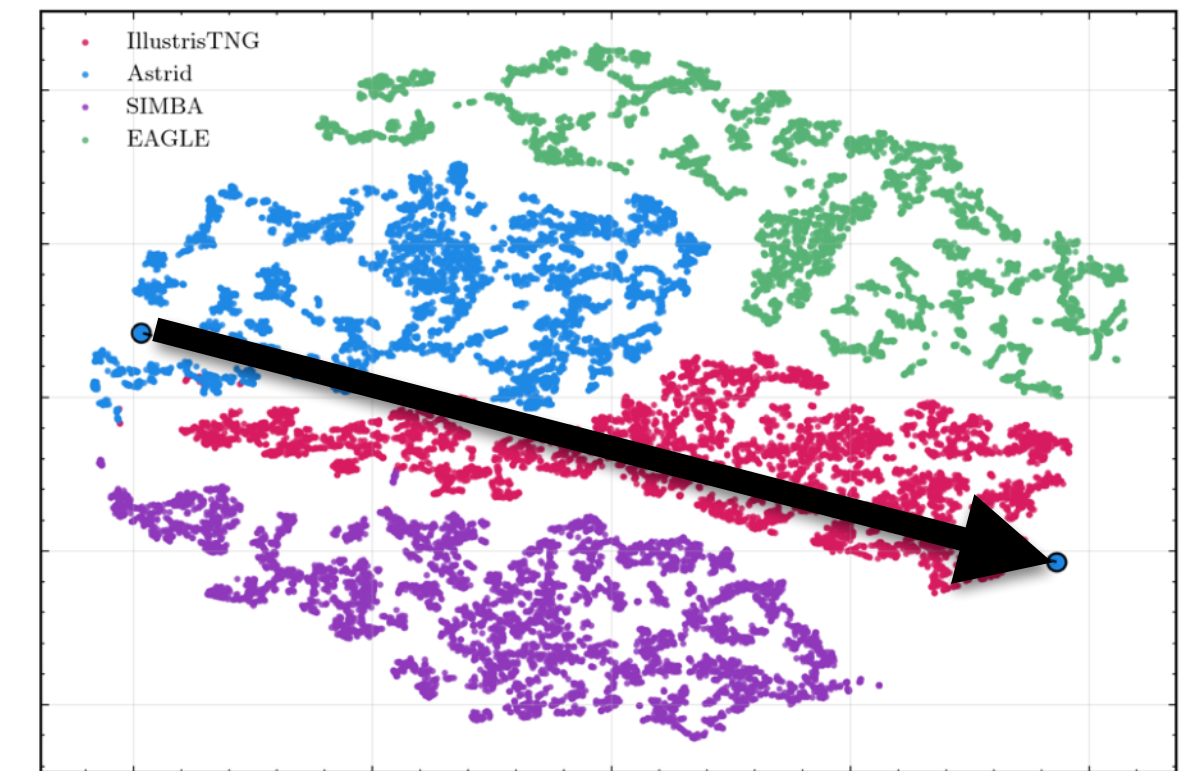
IllustrisTNG



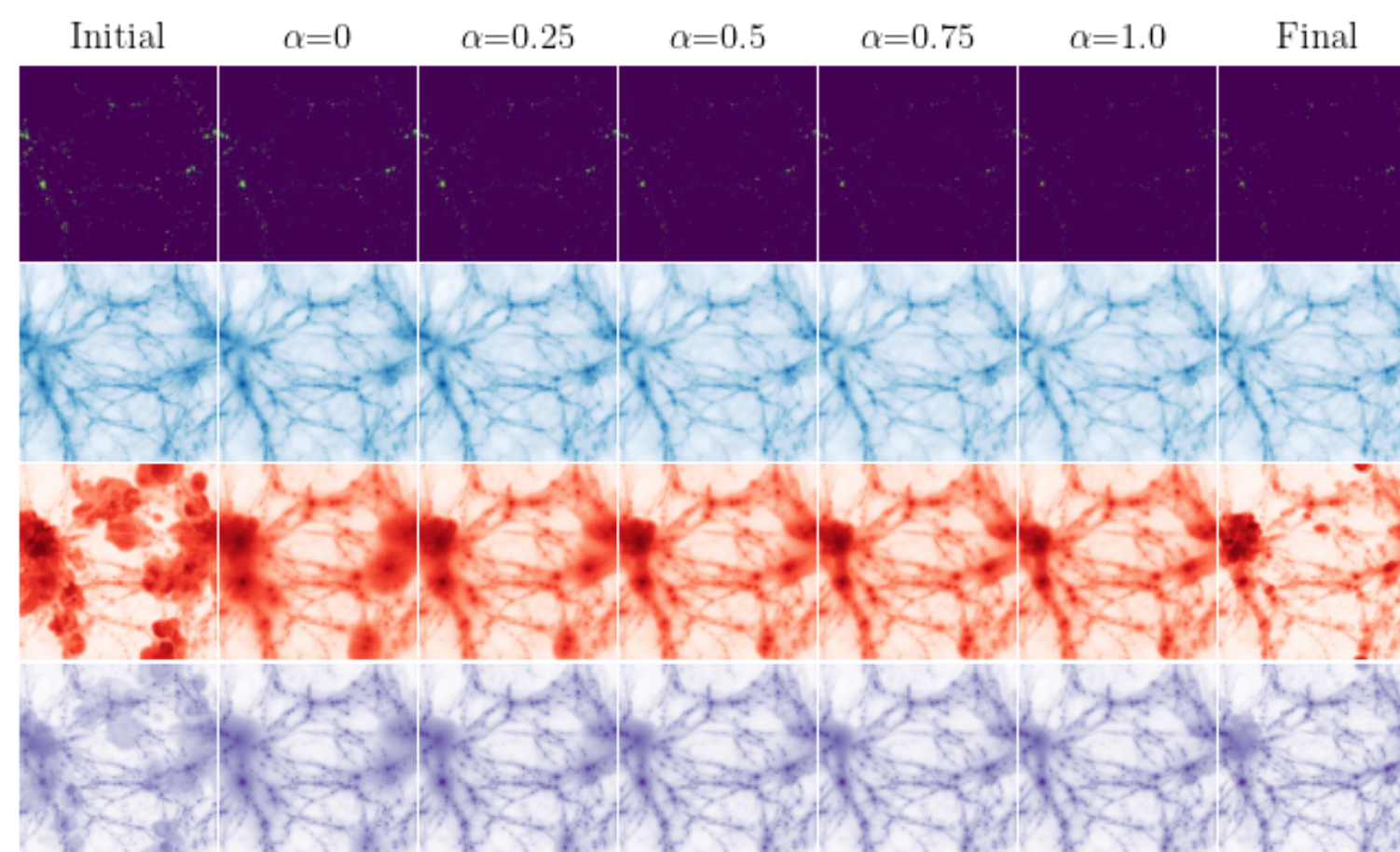
SIMBA



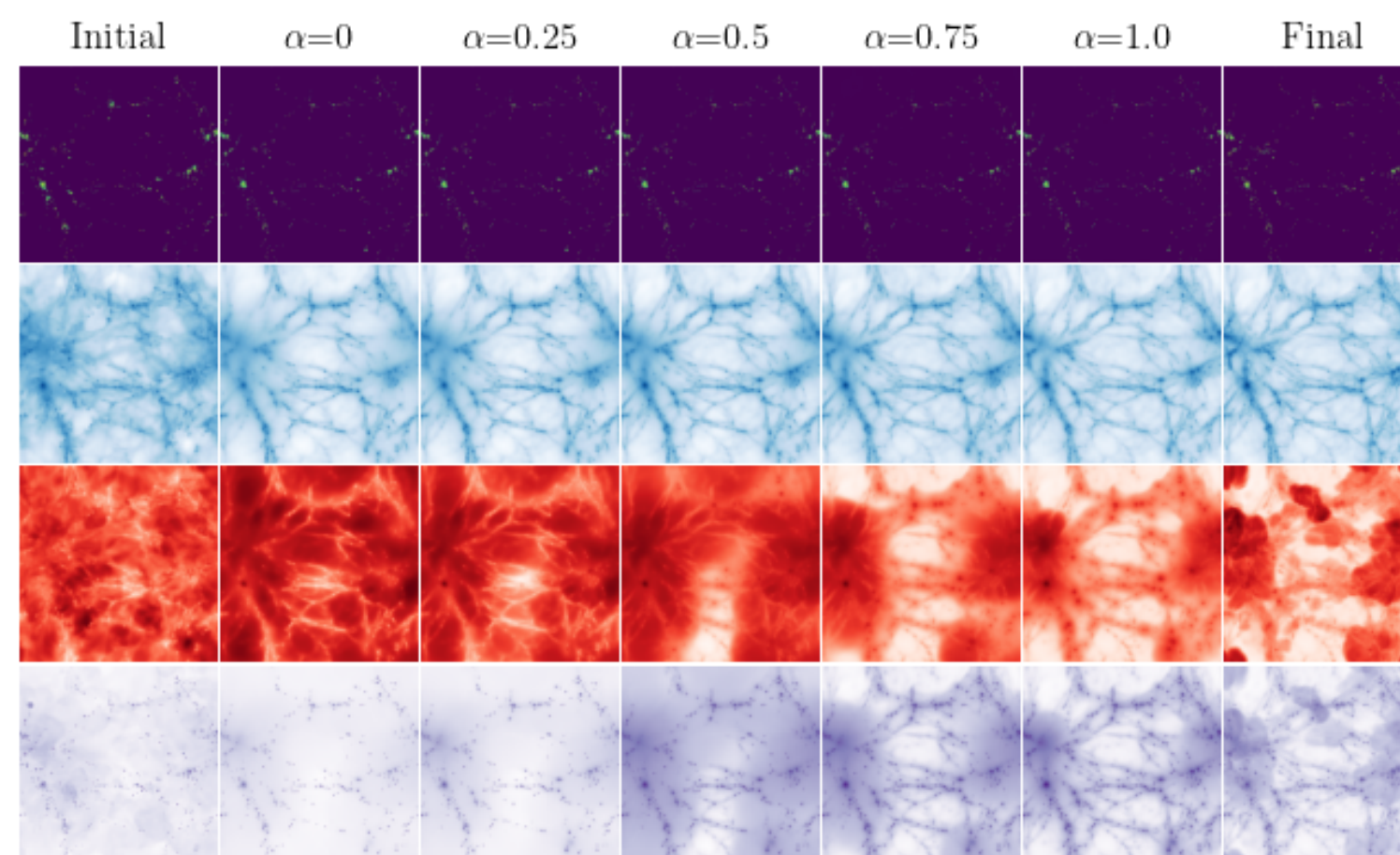
Astrid



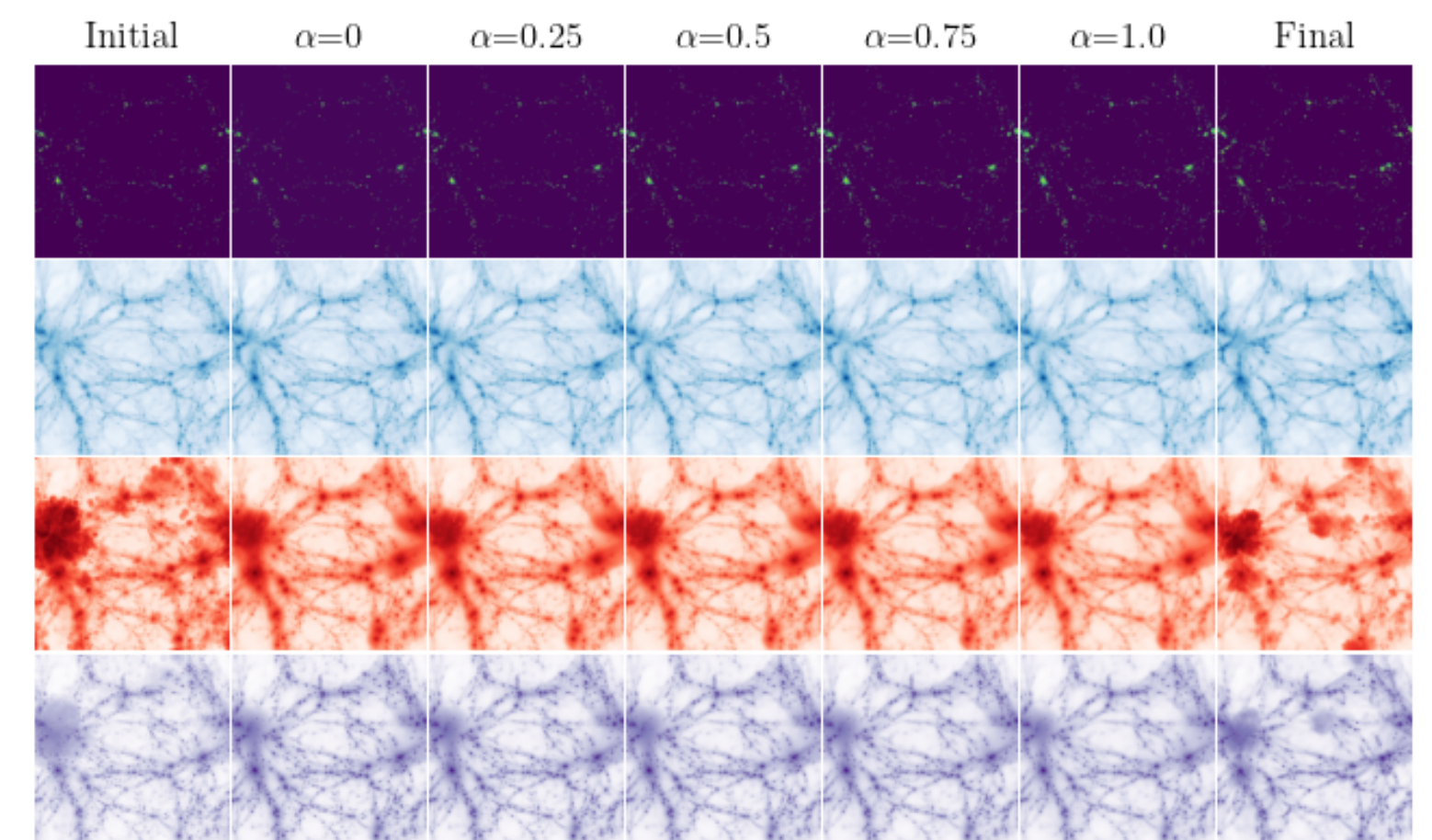
Wind Energy 0.9-14.4 e15 erg



Supernovae Speed 0.8-3.2

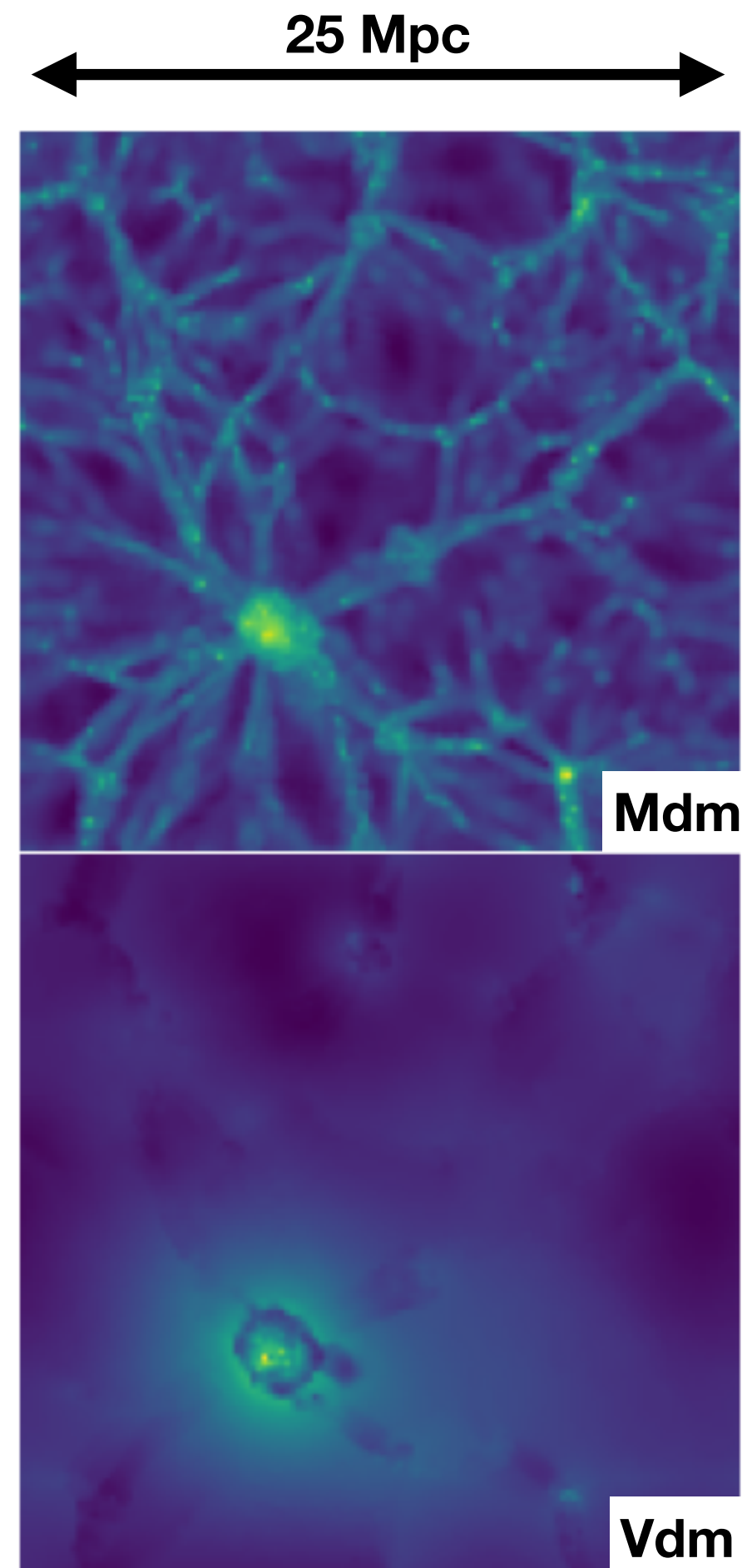


Baryon density 0.01 – 0.09

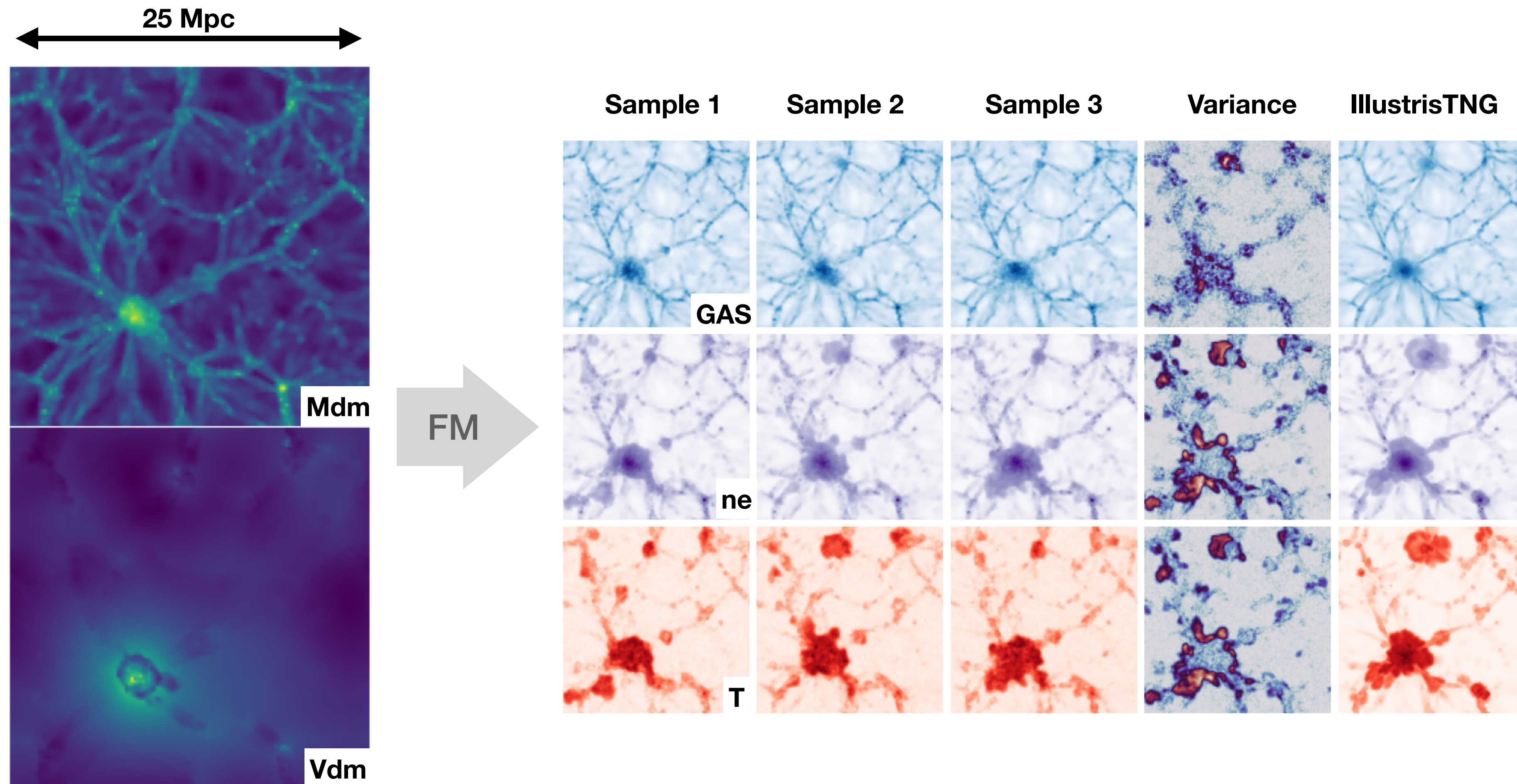


FUTURE

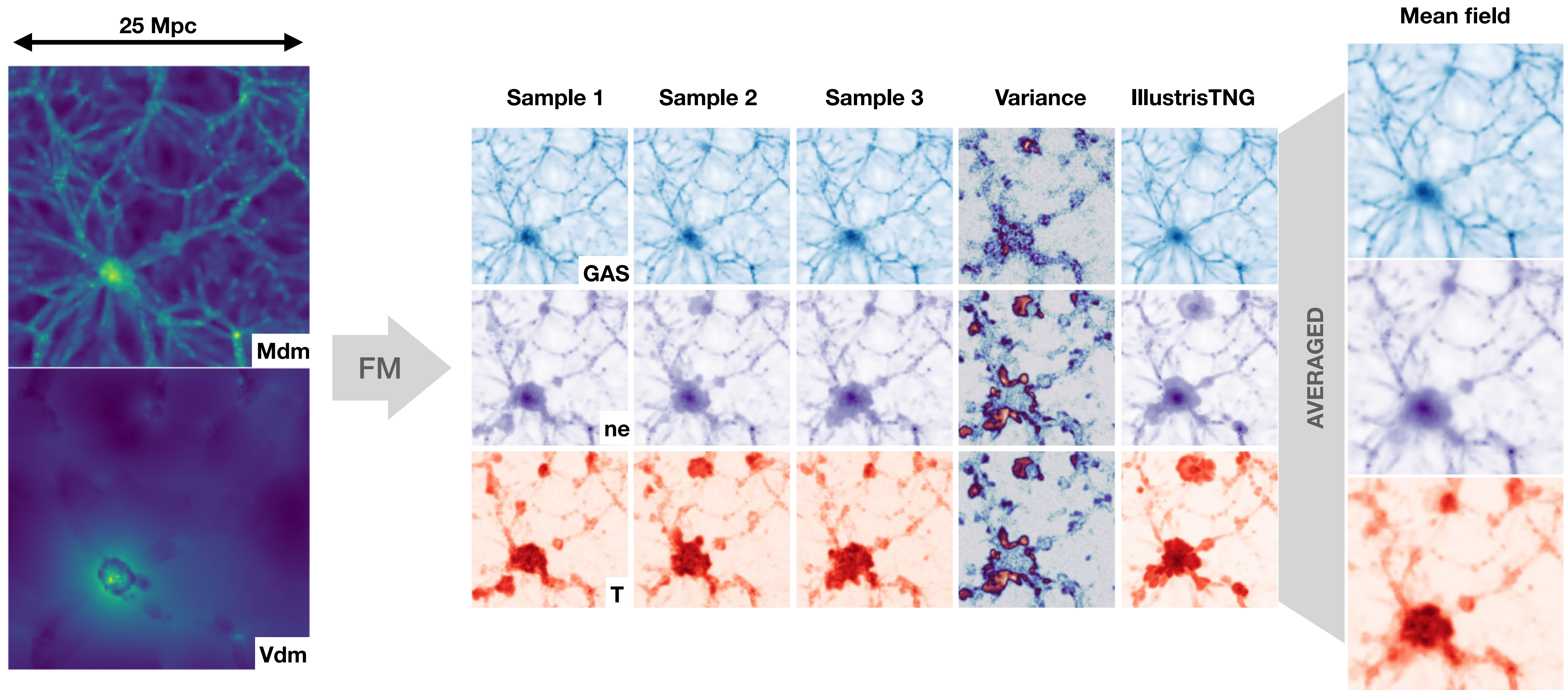
Observation mocks • Up-Scale Sampling



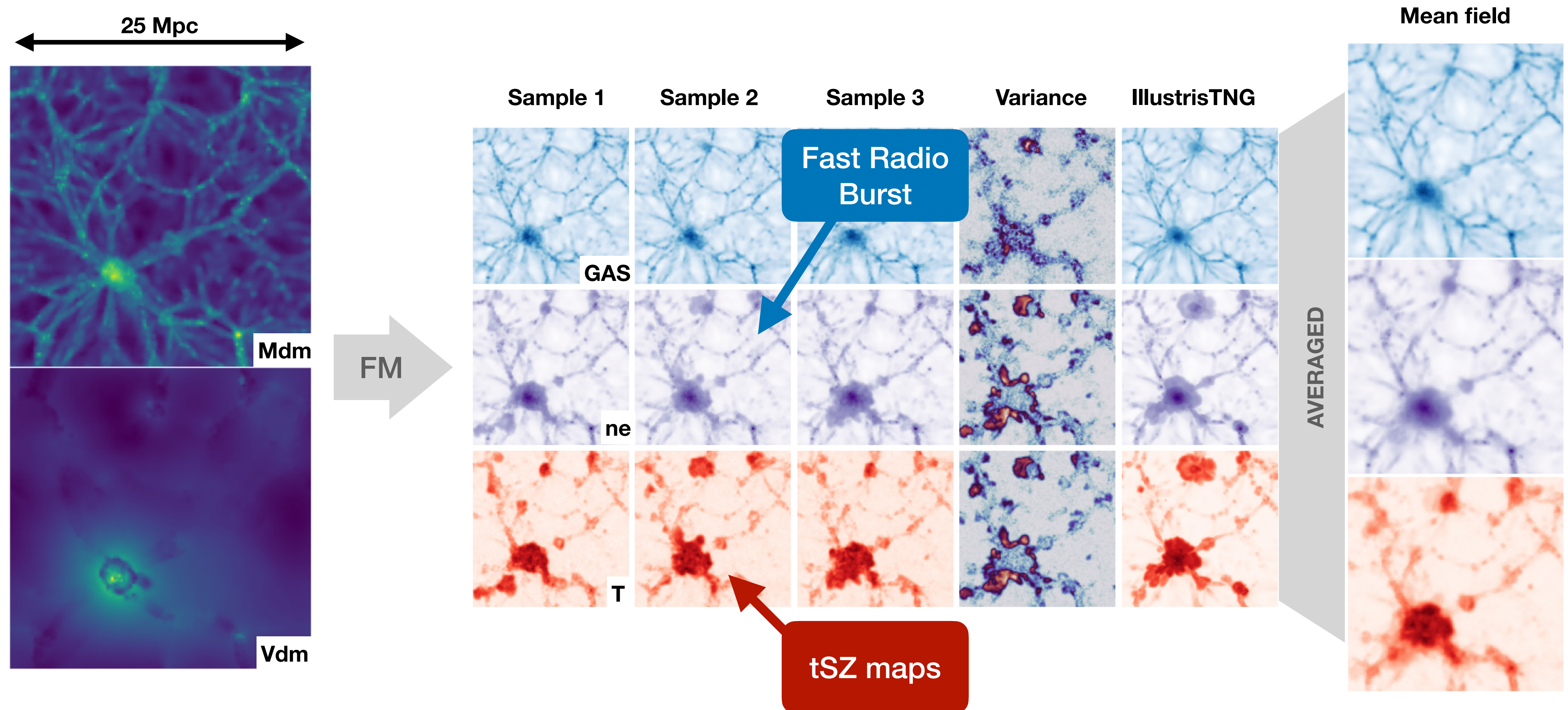
FUTURE Observation mocks · Up-Scale Sampling



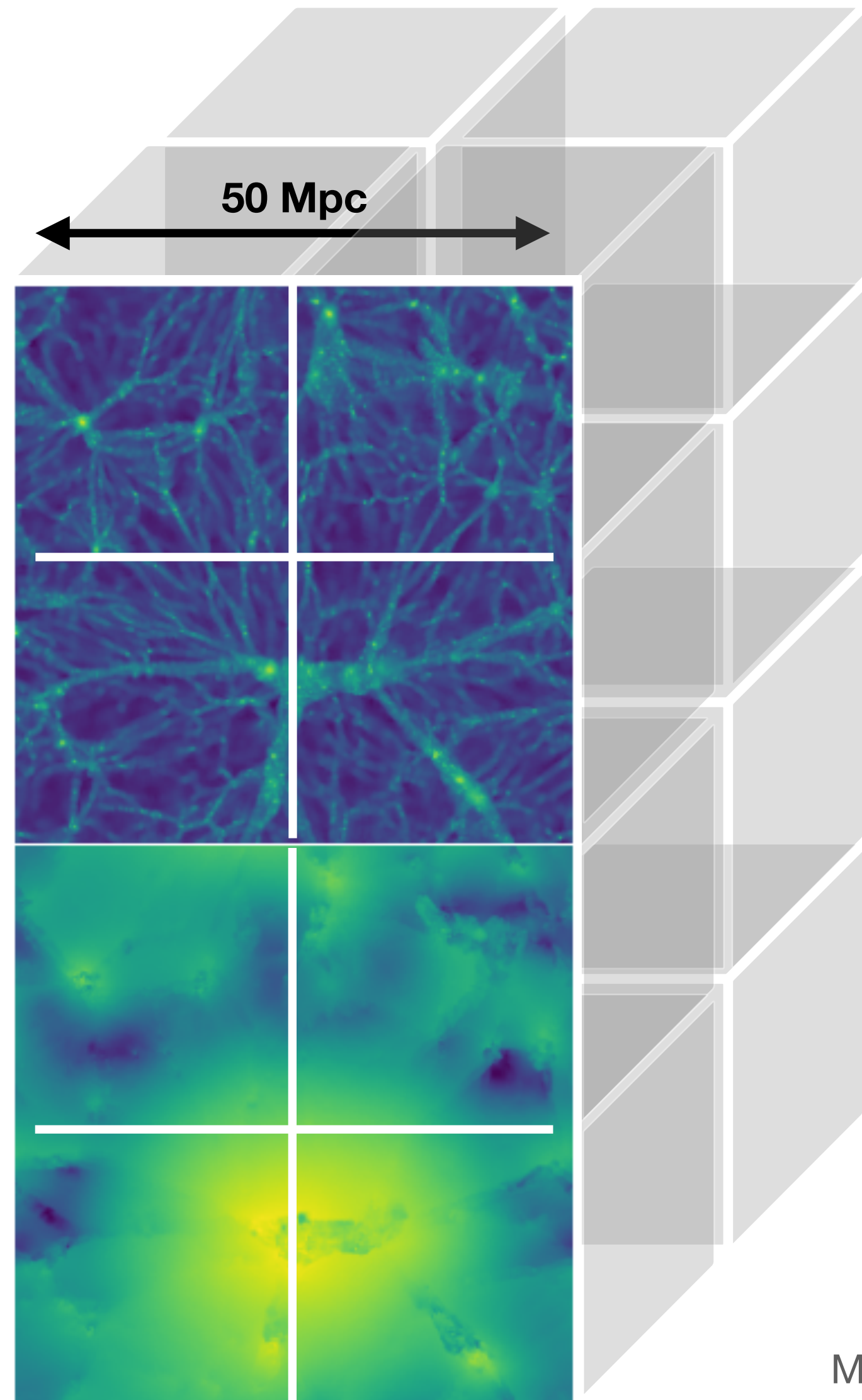
FUTURE Observation mocks · Up-Scale Sampling



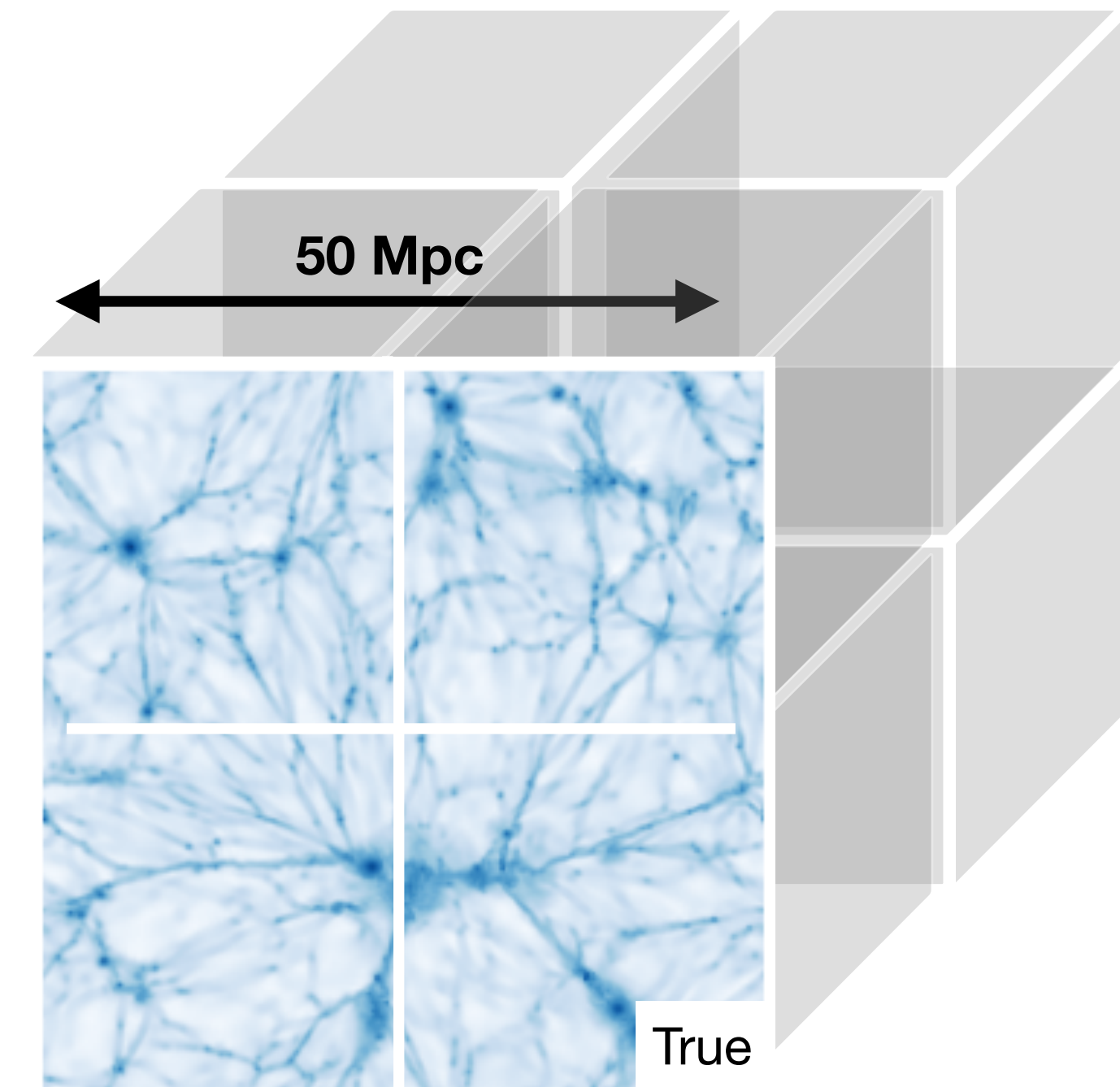
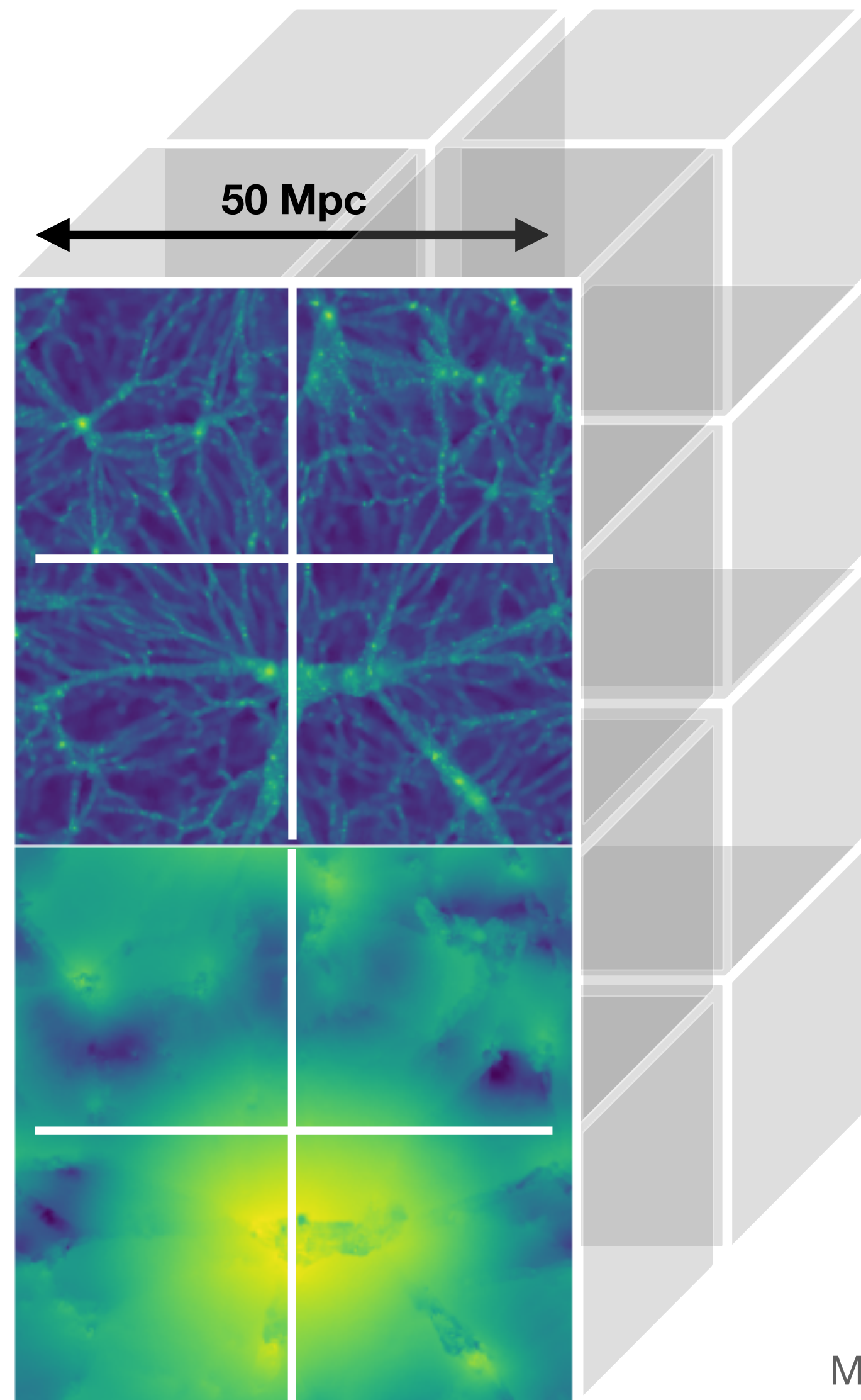
FUTURE Observation mocks • Up-Scale Sampling



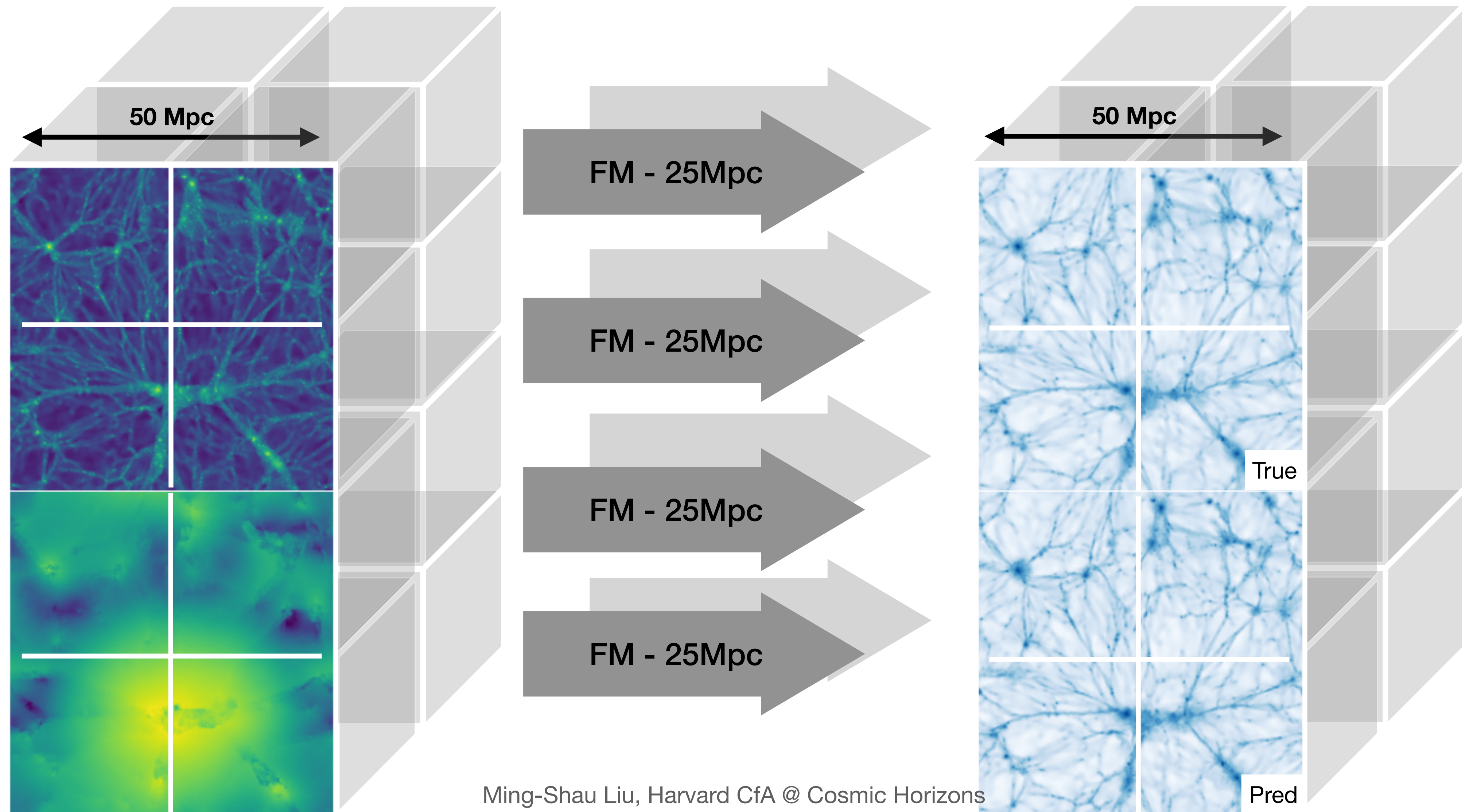
FUTURE Observation mocks • Up-Scale Sampling



FUTURE Observation mocks • Up-Scale Sampling

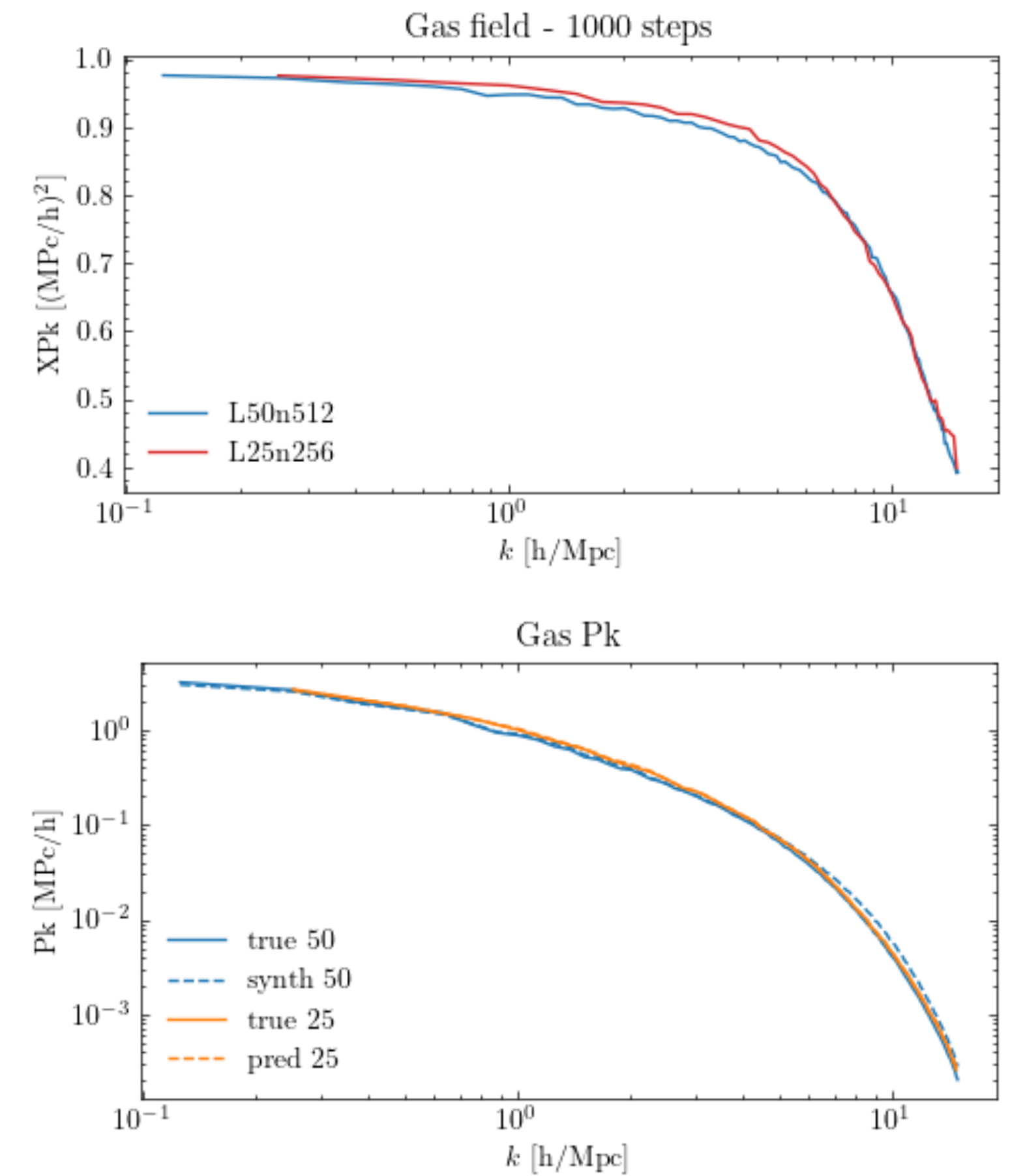
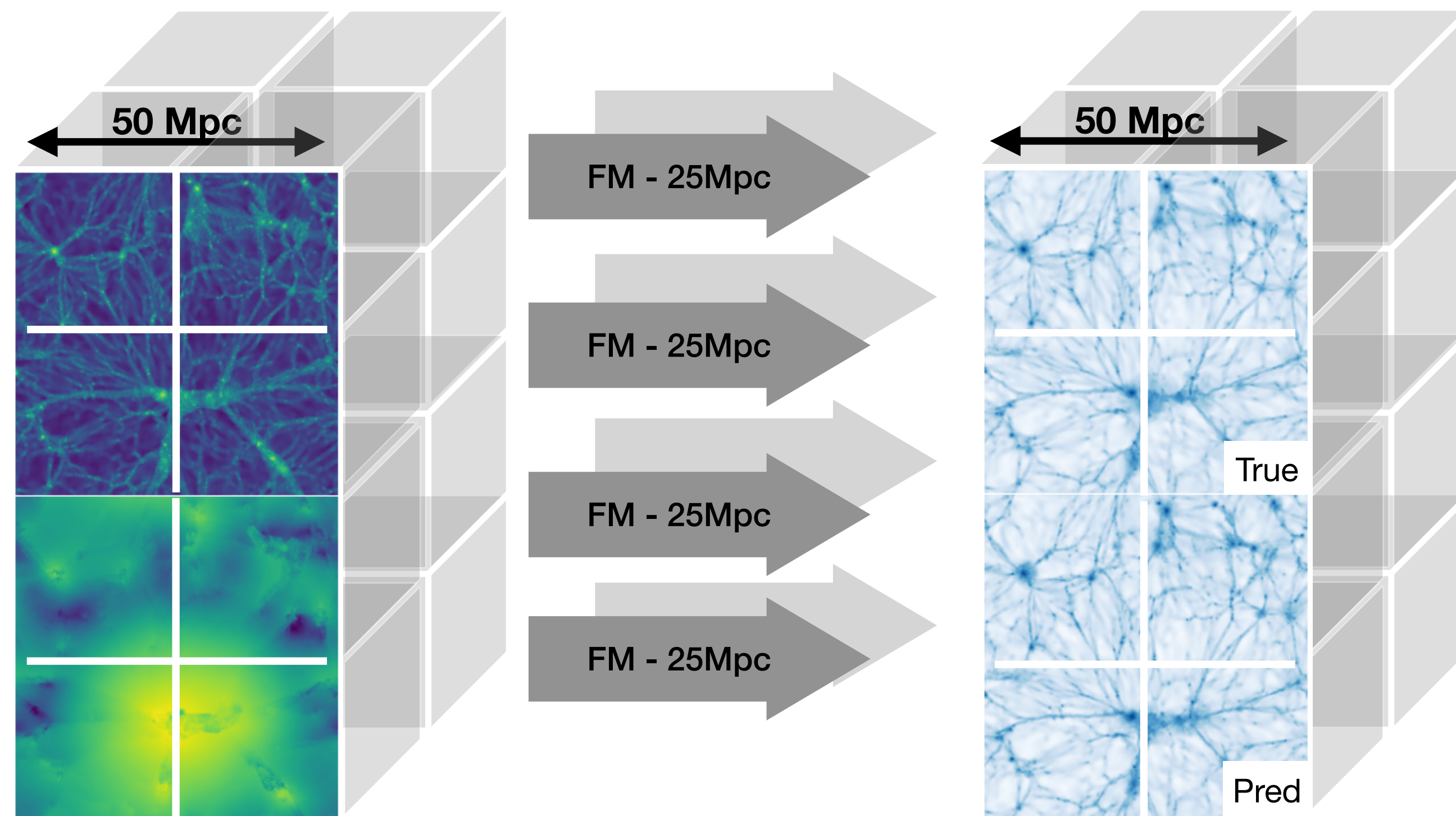


FUTURE Observation mocks • Up-Scale Sampling



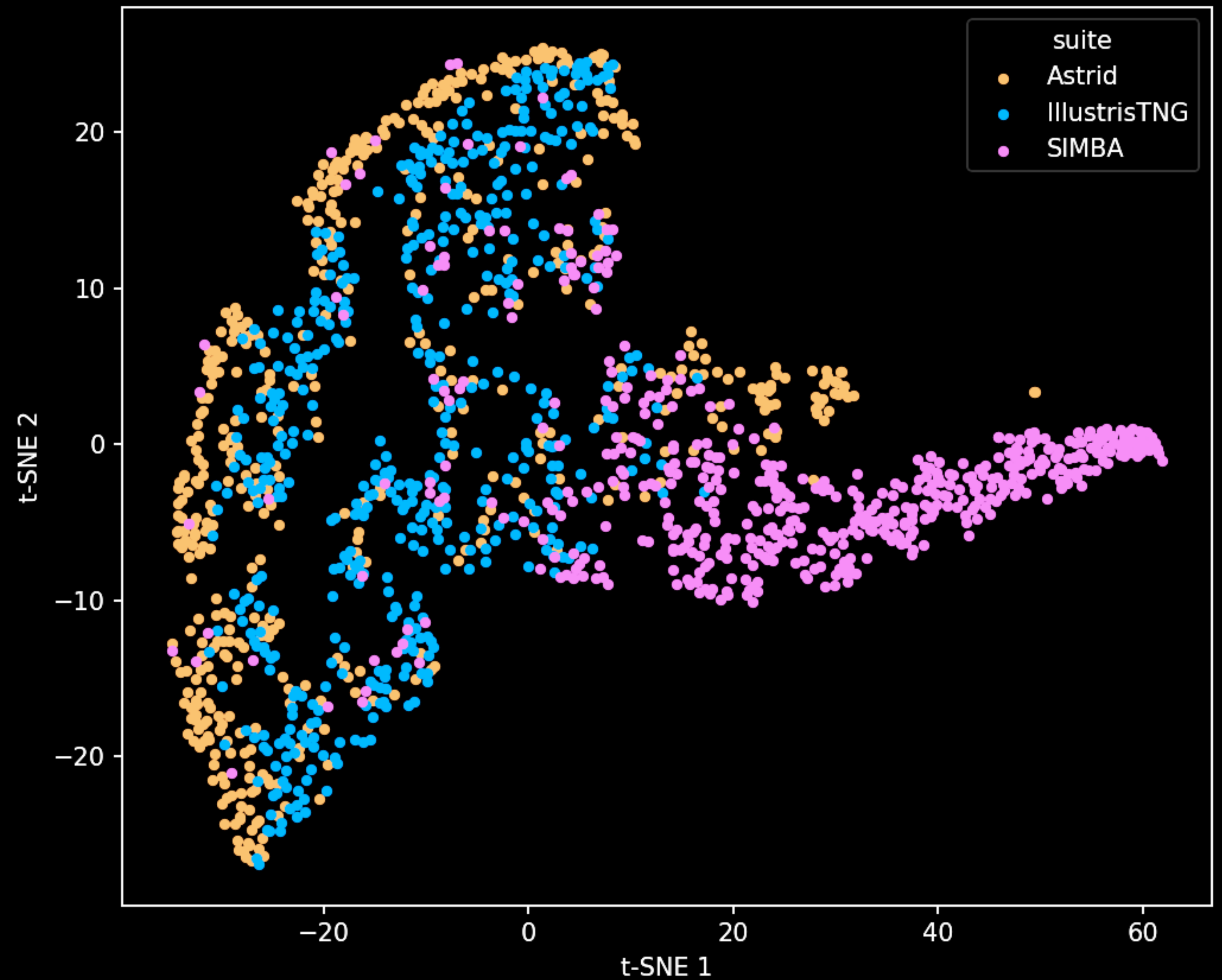
FUTURE

Observation mocks • Up-Scale Sampling



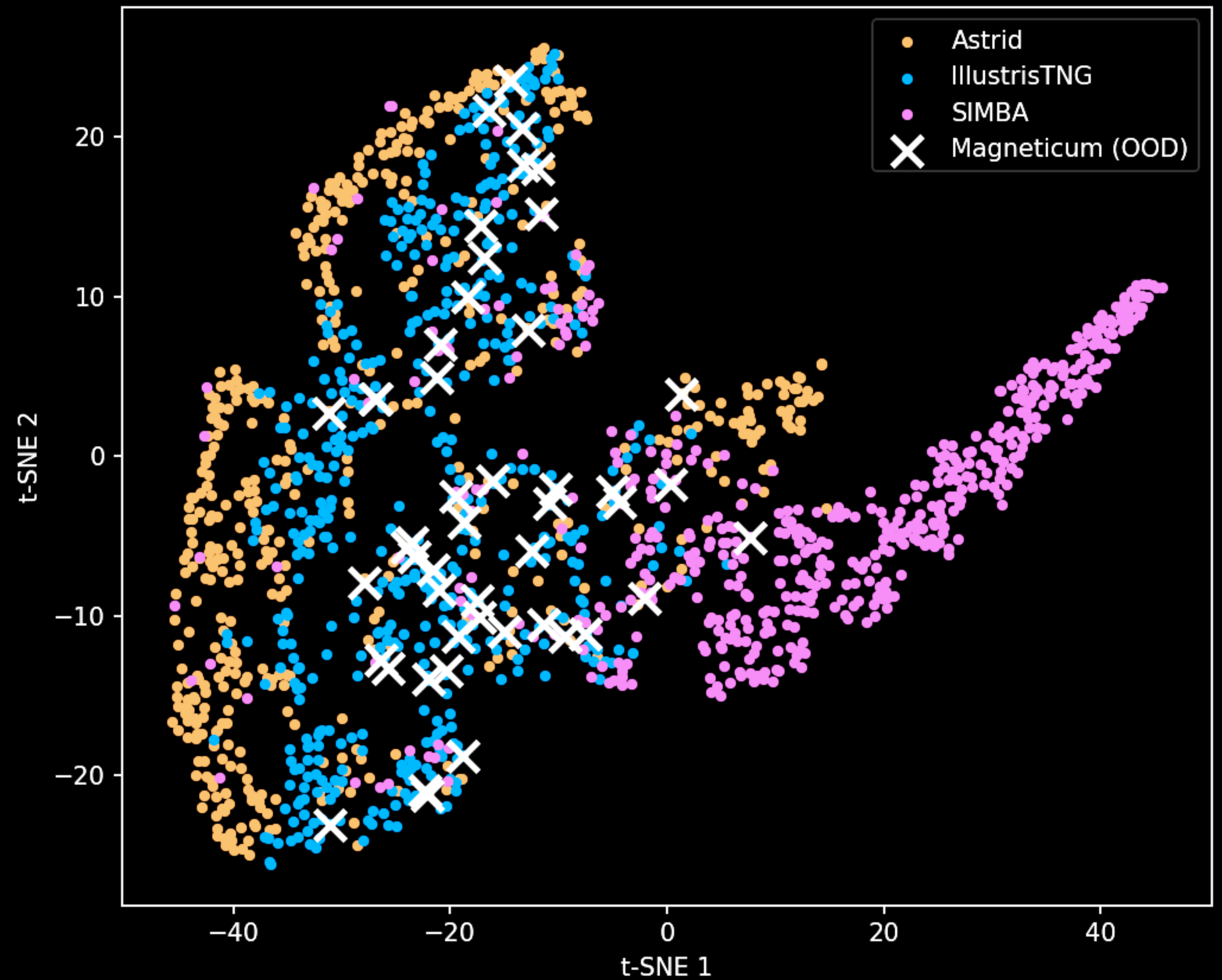
In Progress

1. 3D field model



In Progress

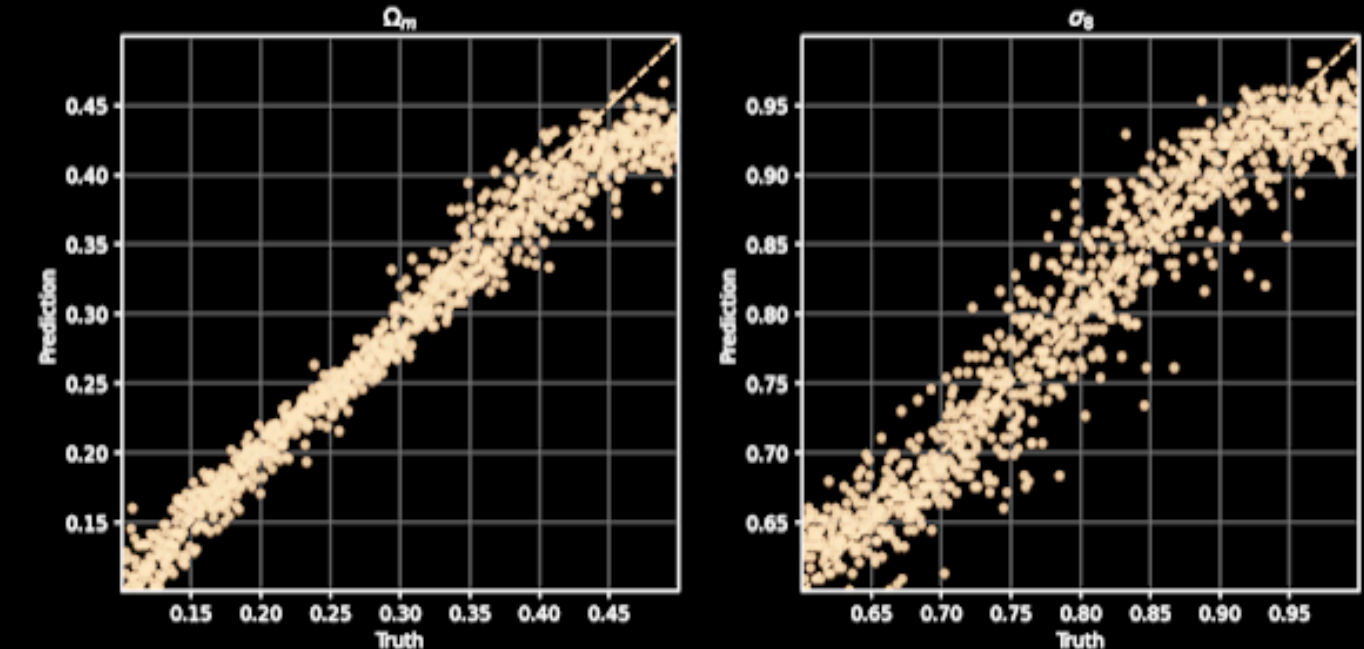
1. 3D field model



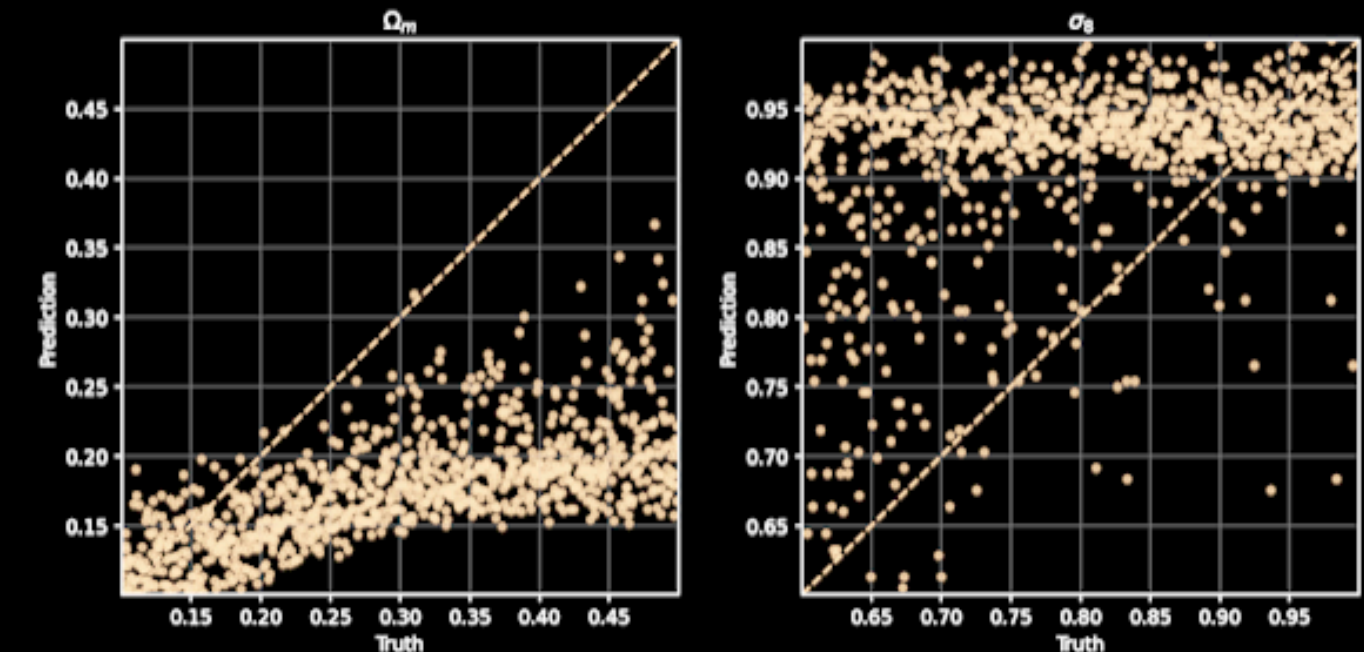
In Progress

1. 3D field model
2. Robustness test -
 - CAMELS showed simulation-robust inference model is difficult

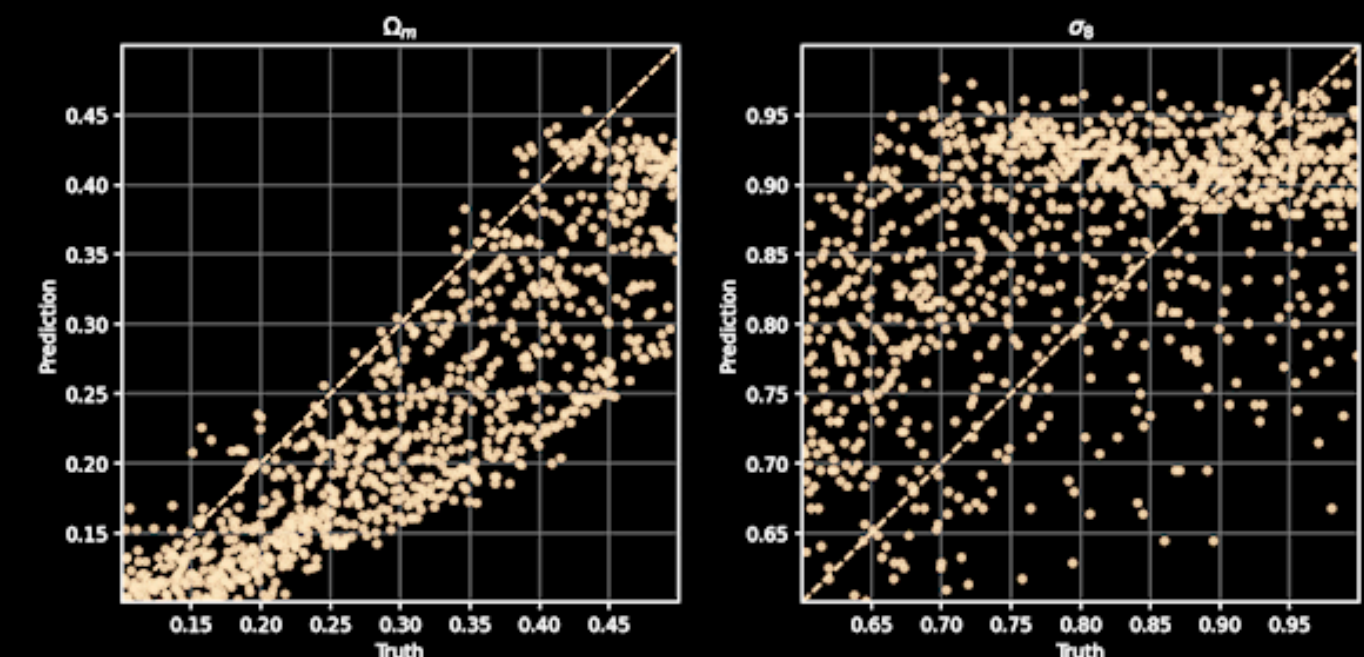
IllustrisTNG



SIMBA

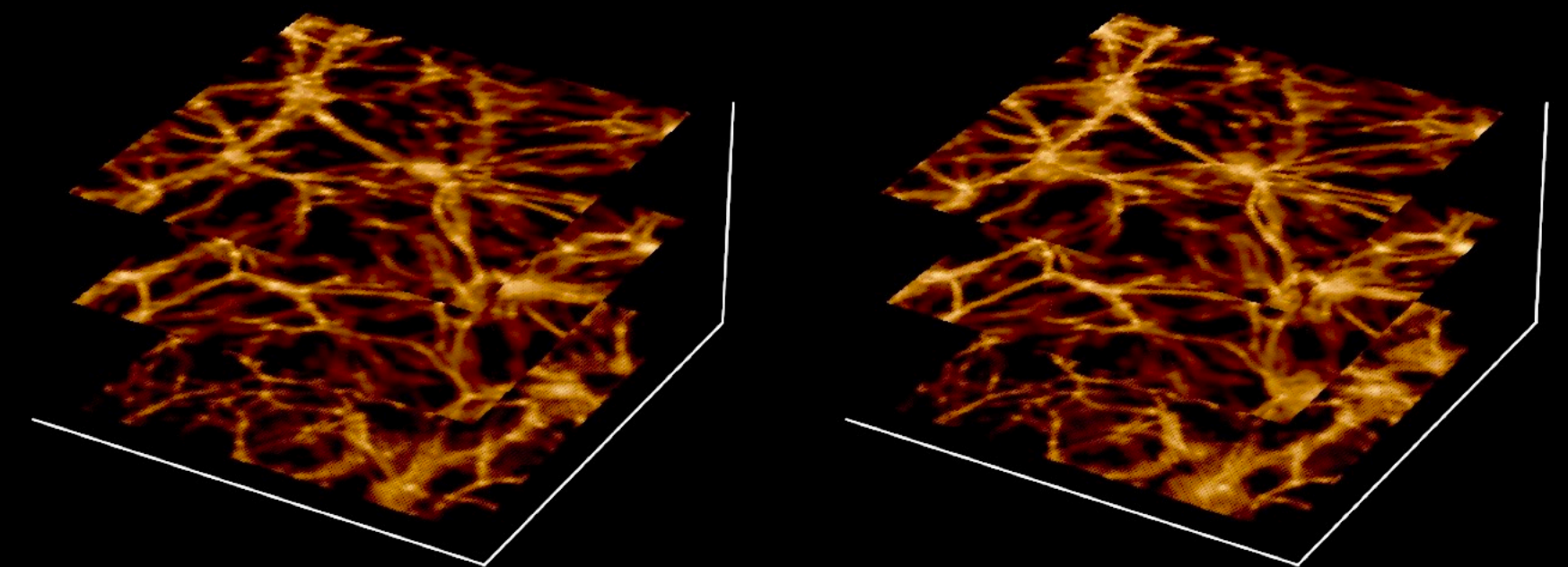
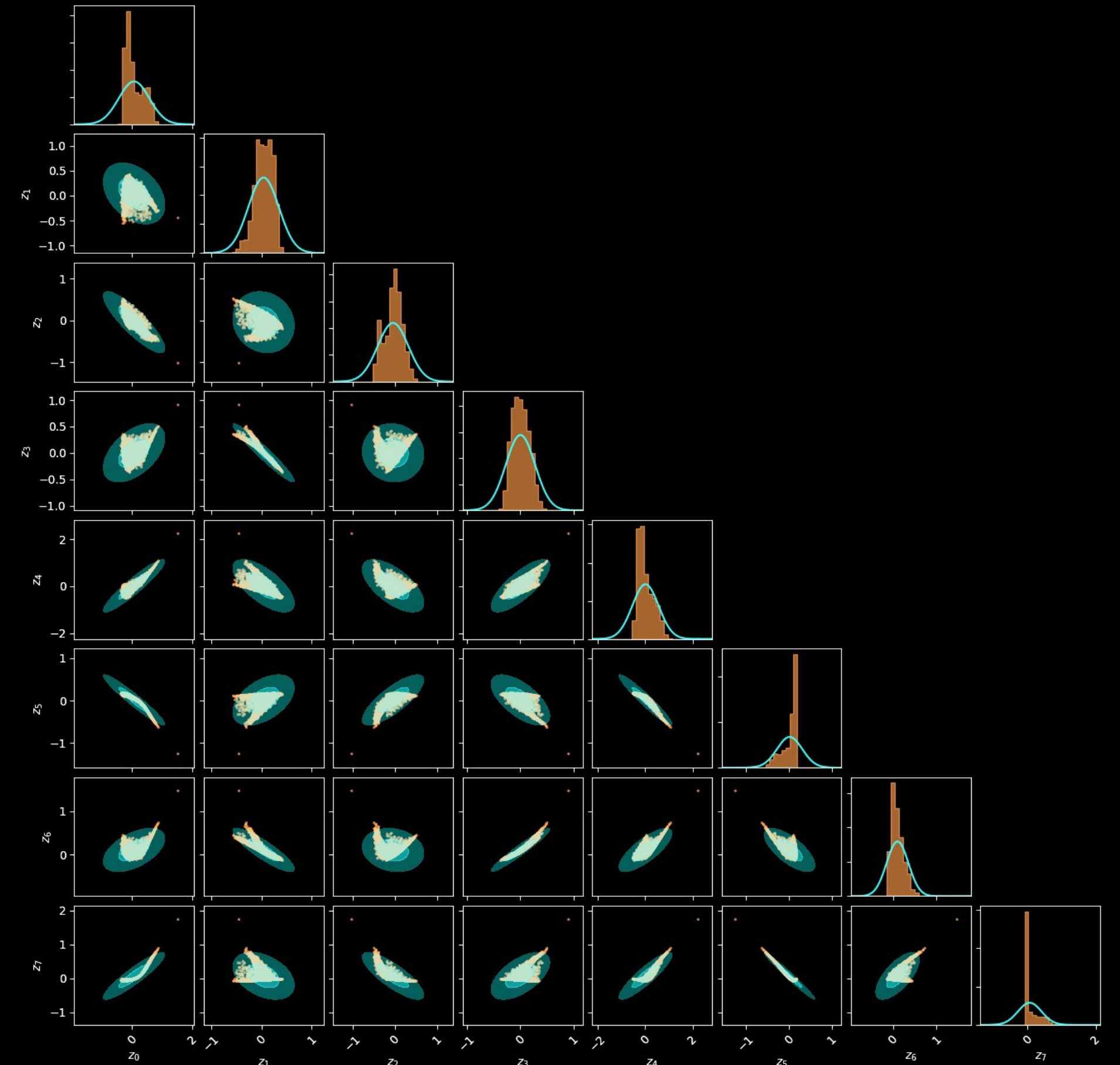


Astrid



In Progress

1. 3D field model
2. Robustness test -
 - CAMELS showed simulation-robust inference model is difficult
 - We can draw a prior on z_{bar}

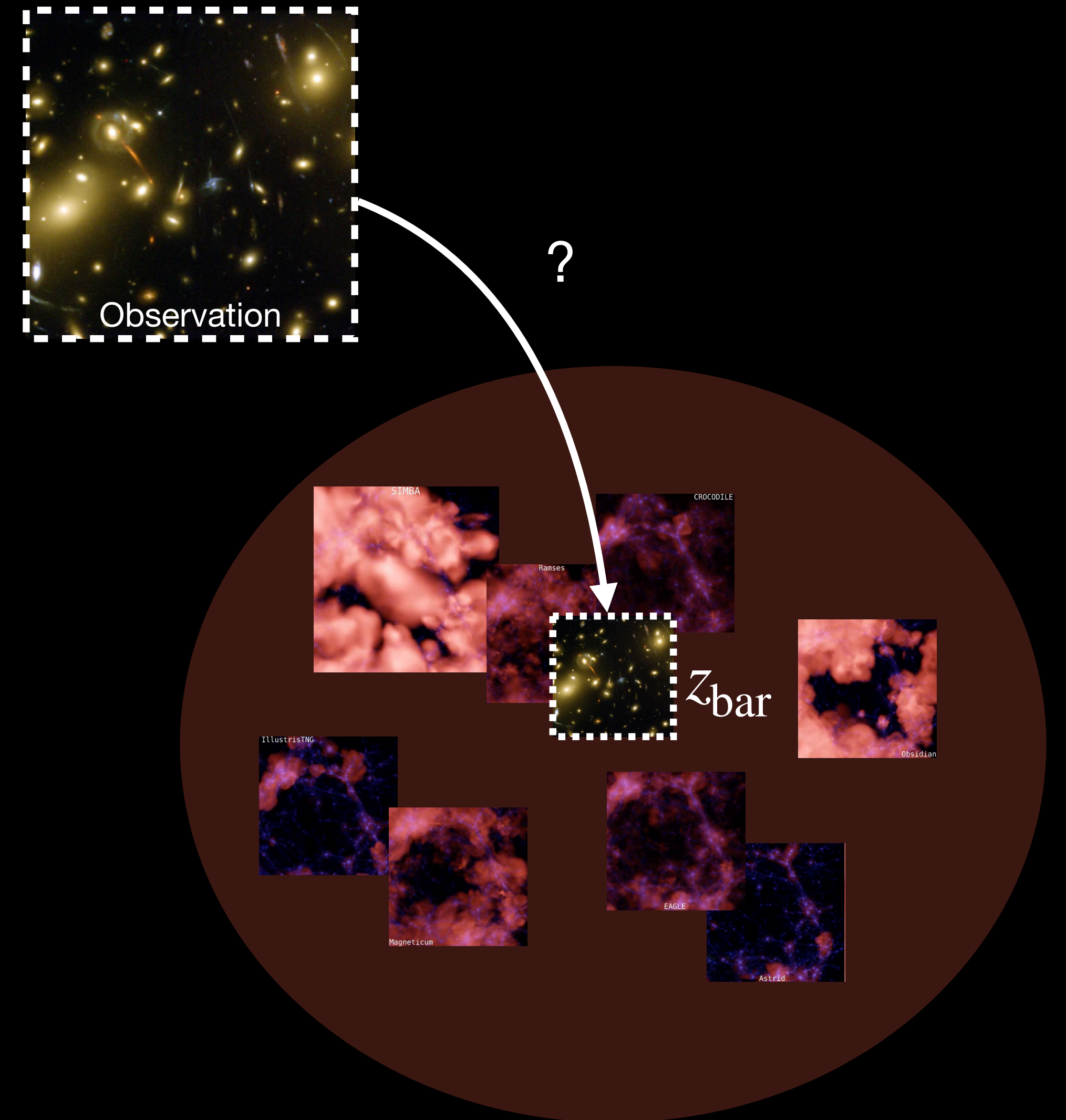


In Progress

1. 3D field model
2. Robustness test -
 - CAMELS showed simulation-robust inference model is difficult
 - We can draw a prior on z_{bar}
 - Train a simulation-robust inference

In Progress

1. 3D field model
2. Robustness test -
 - CAMELS showed simulation-robust inference model is difficult
 - We can draw a prior on z_{bar}
 - Train a simulation-robust inference
3. Learn about baryonic feedback
 - Infer z_{bar} from observation





Ming-Shau Liu
Harvard CfA
Johns Hopkins (soon)



Carolina Cuesta-Lazaro
Flatiron Institute
New York University

Summary

1. Field model mocks
2. Robust inference
3. Learn about baryonic feedback



The NSF Institute for
Artificial Intelligence and
Fundamental Interactions



FLATIRON
I N S T I T U T E