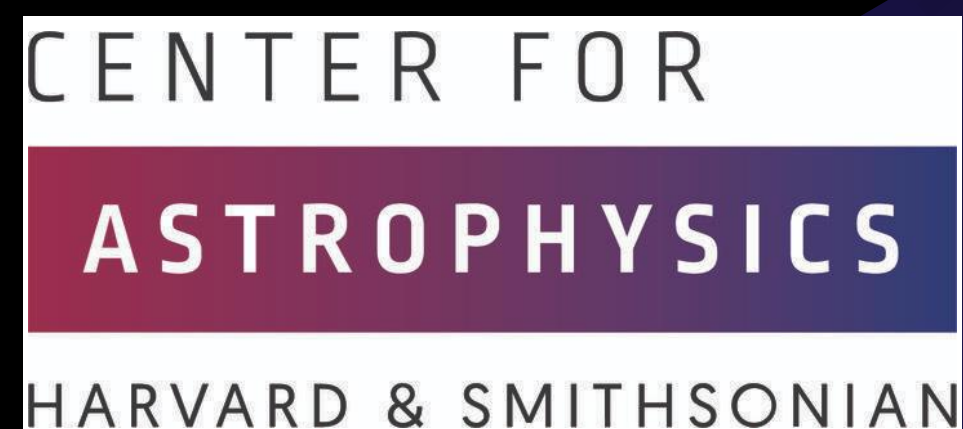


The DREAMS Project

[*Machine*] Learning the Galaxy Halo Connection

Alex Garcia

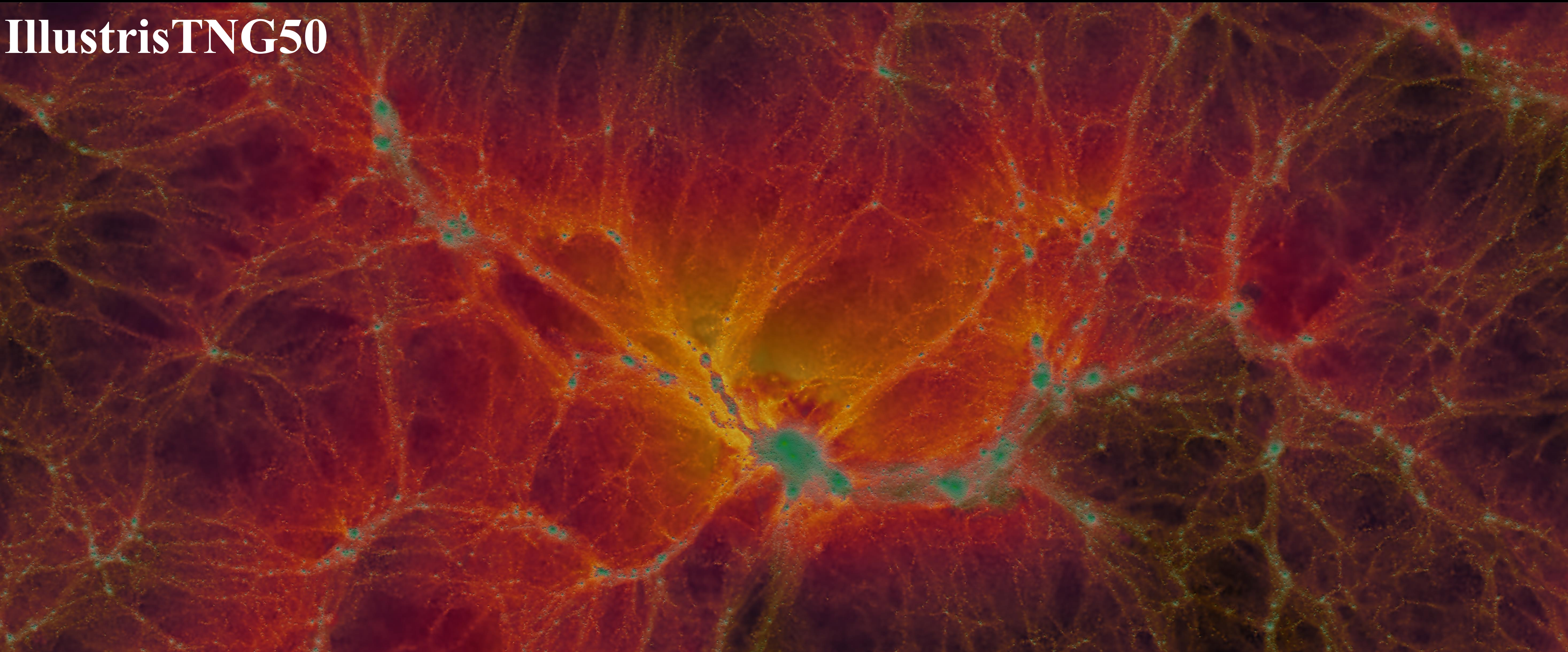


Uncertainty

Uncertainty (or the lack thereof)

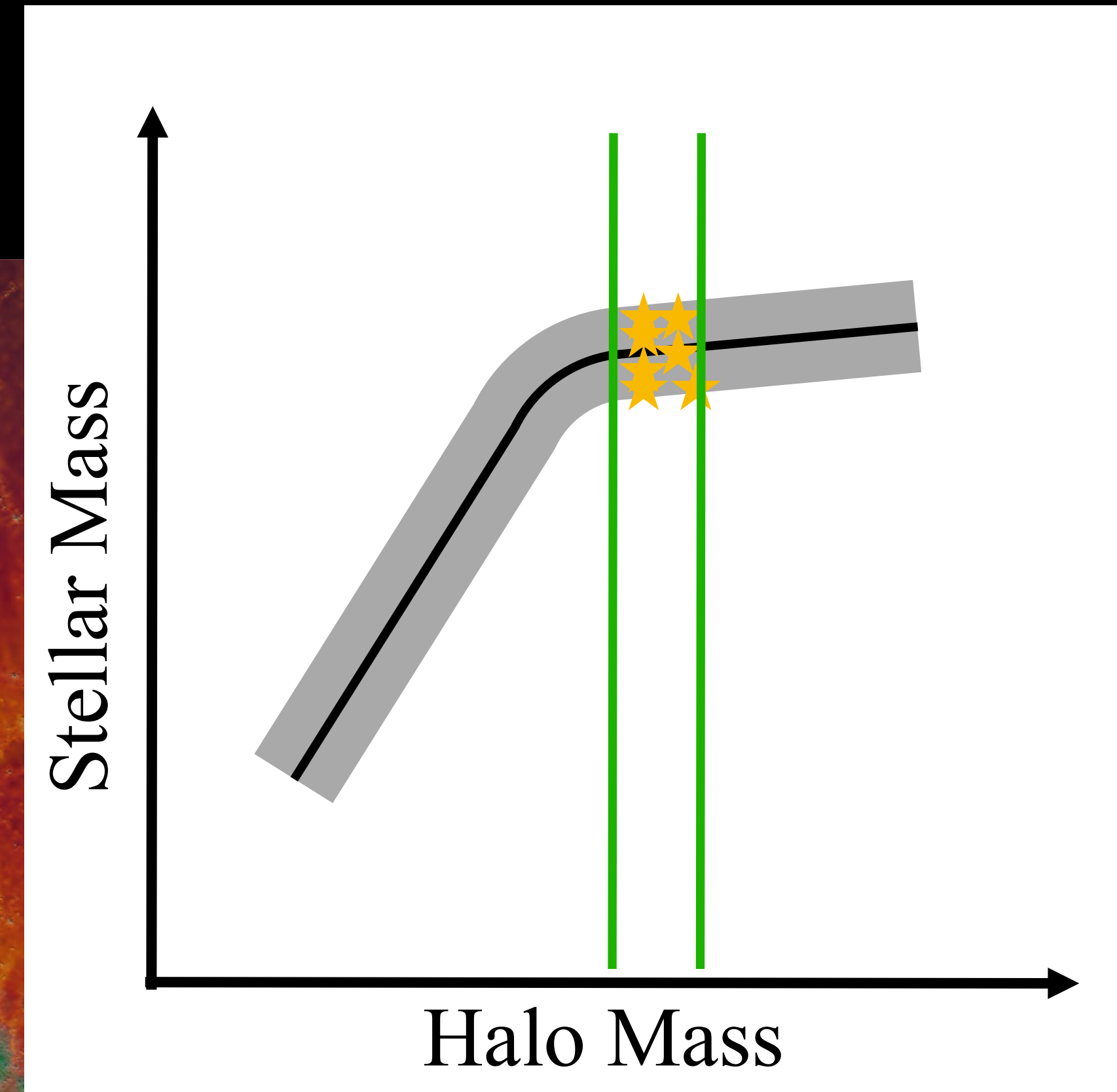
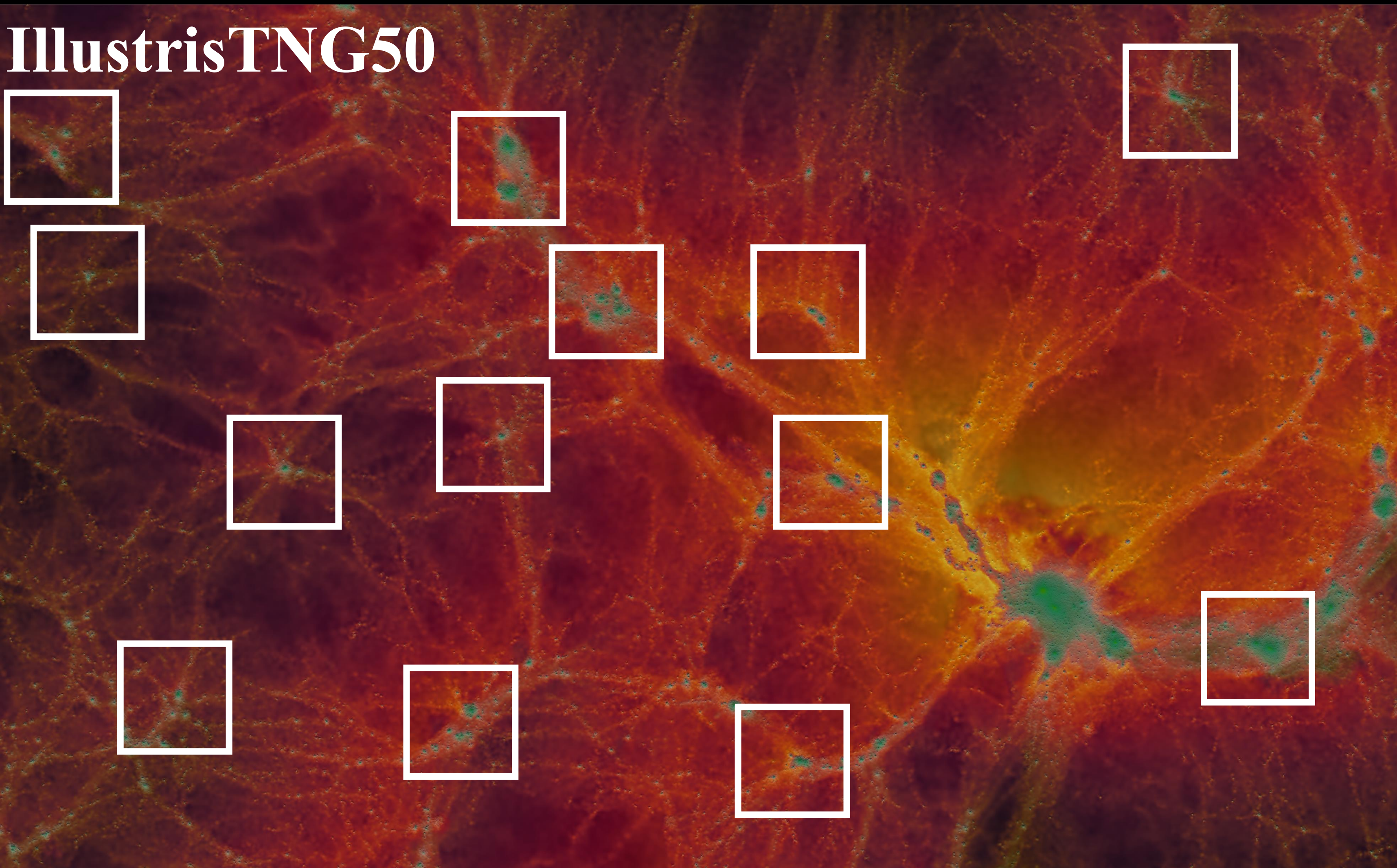
A Modern Cosmological Simulation

IllustrisTNG50

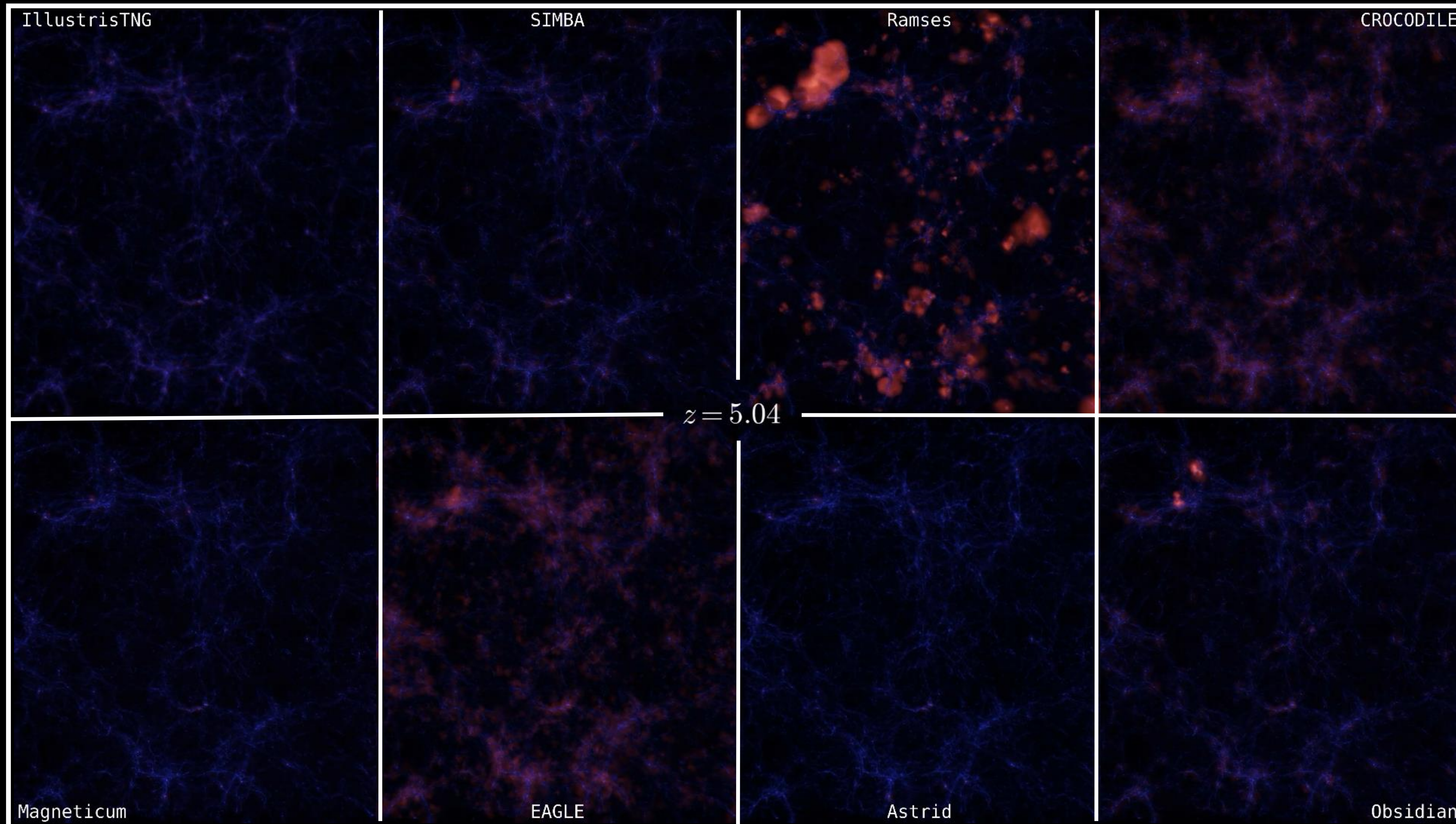


**Halo-to-halo variation, assembly
history, environment, etc...**

IllustrisTNG50



Modern Cosmological Simulations

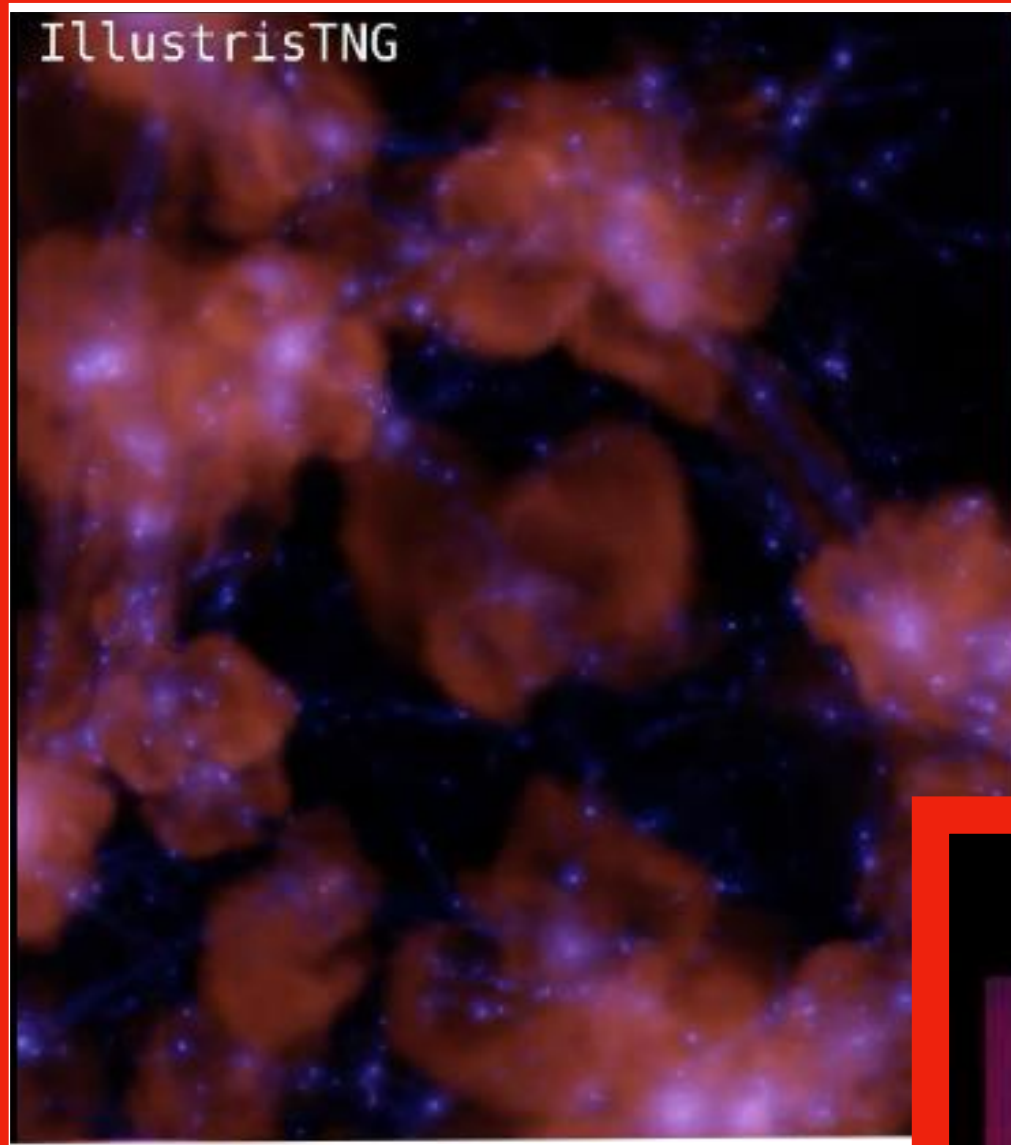


Gas Density
Gas Temperature

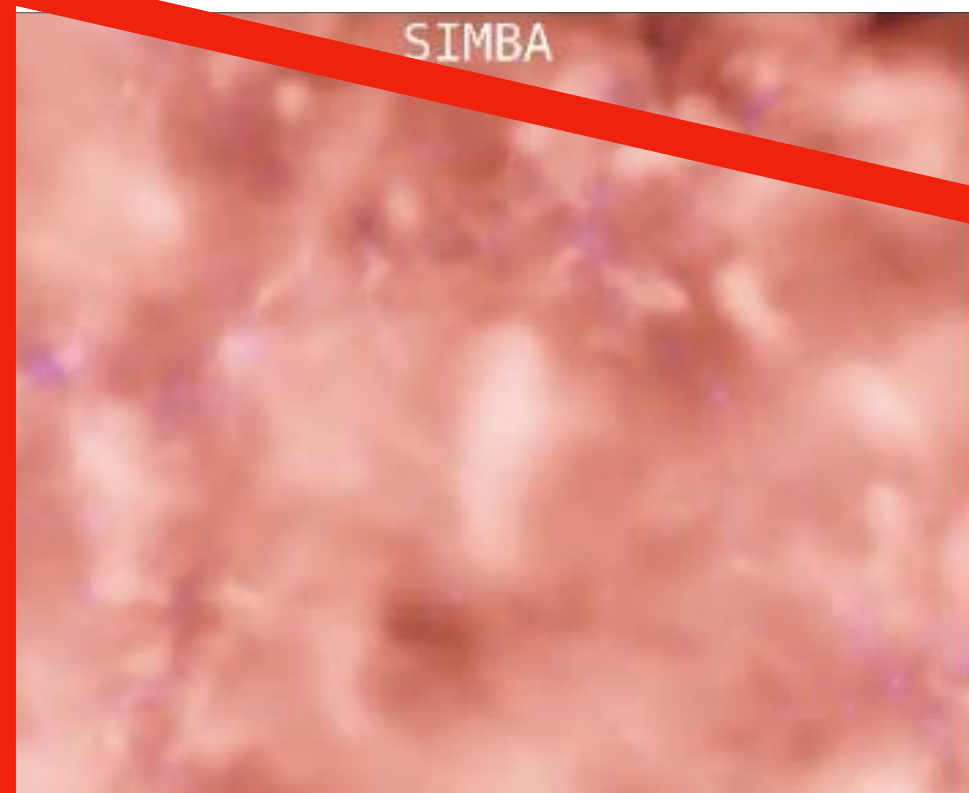
Video:
CAMELS
Collaboration

Modern Cosmological Simulations

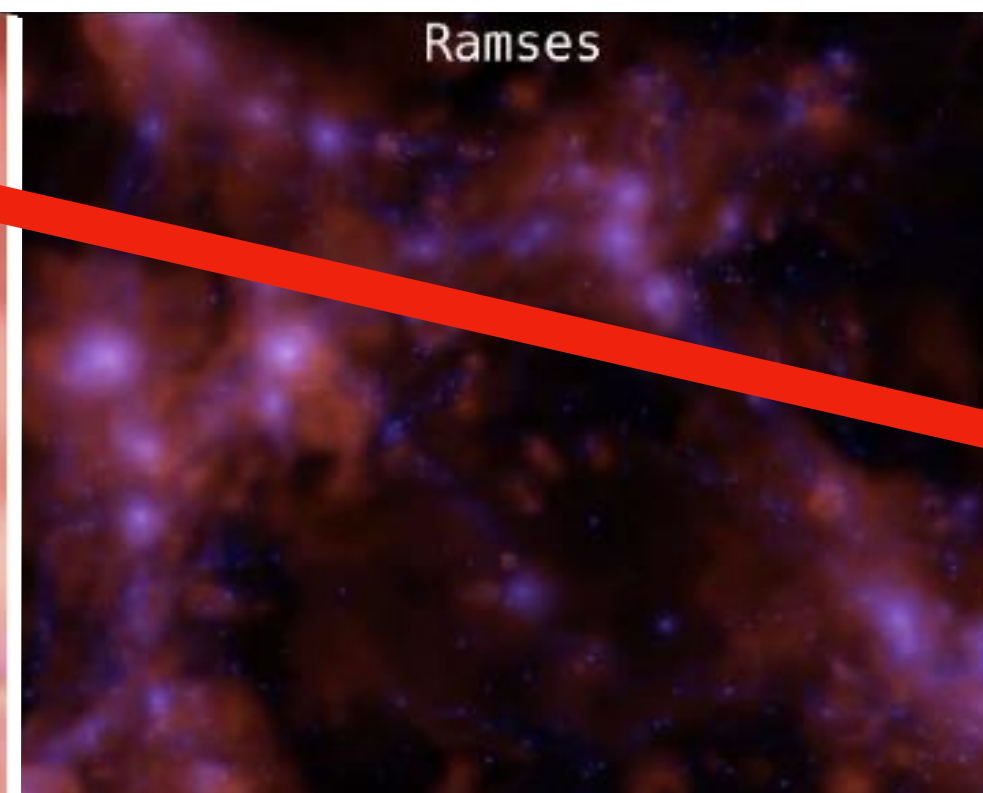
IllustrisTNG



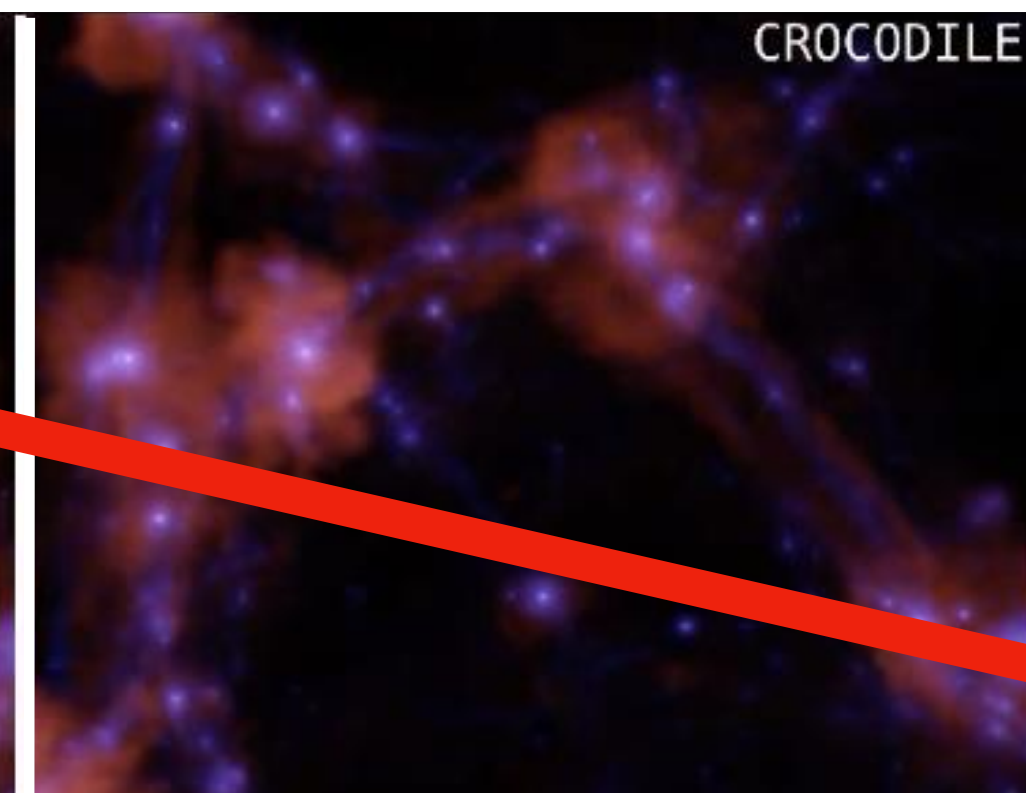
SIMBA



Ramses

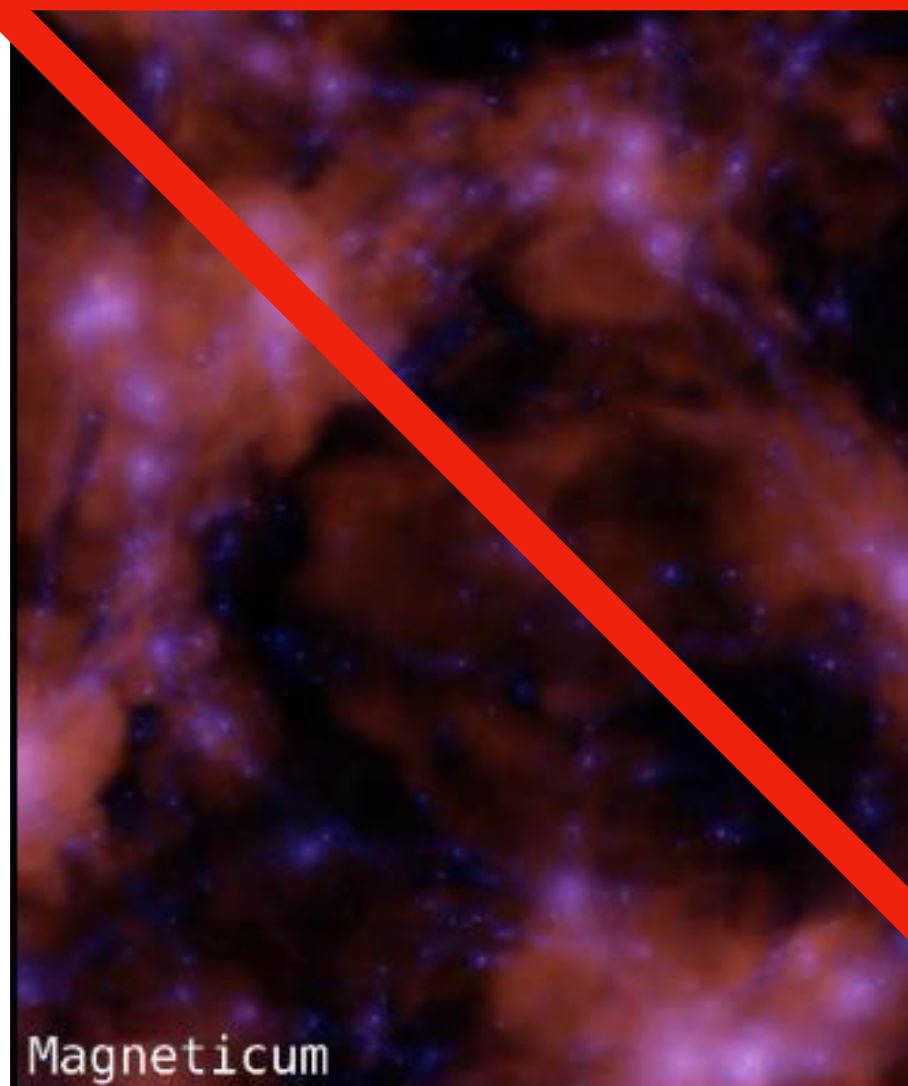


CROCODILE

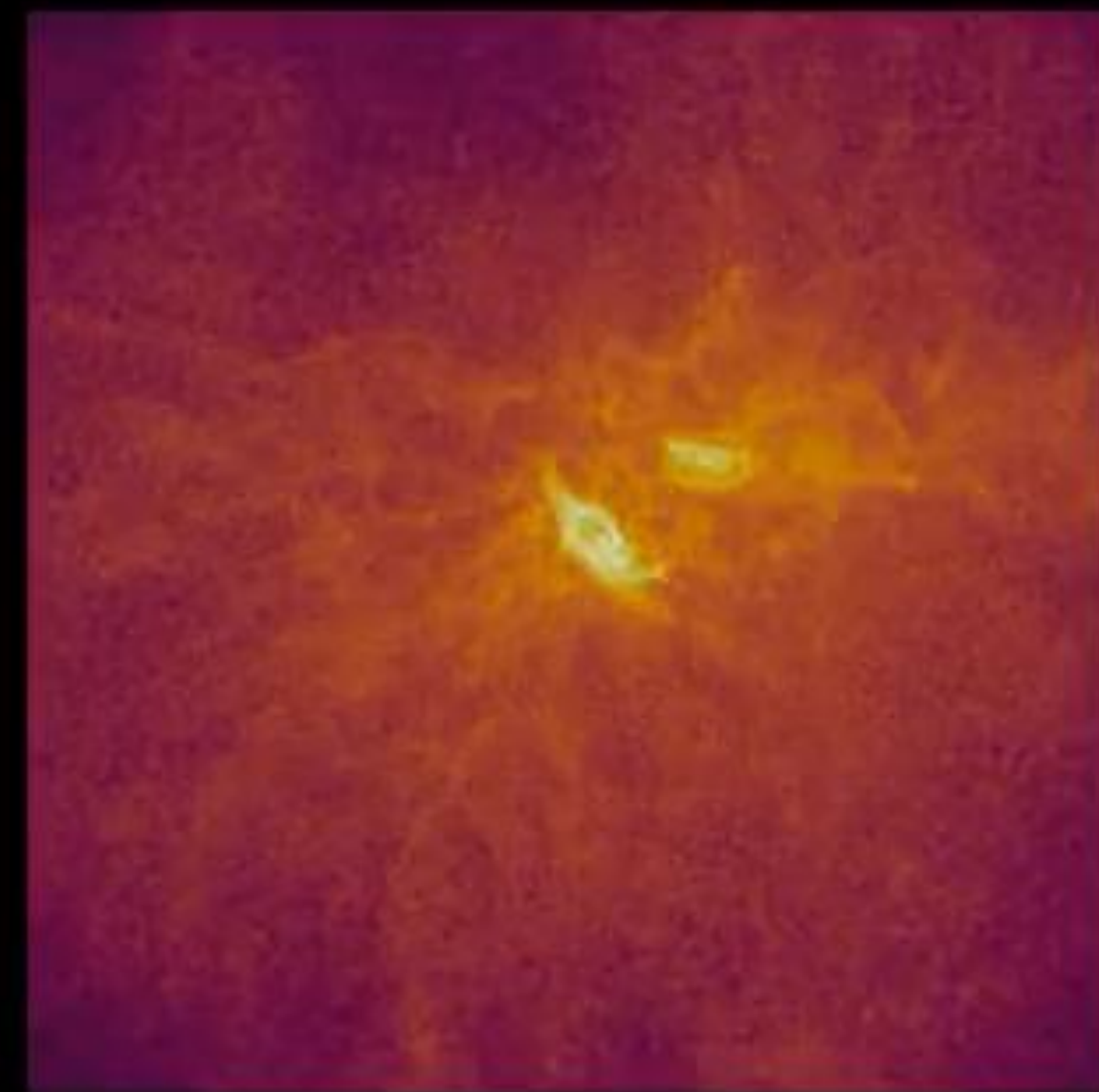


Gas Density
Gas Temperature

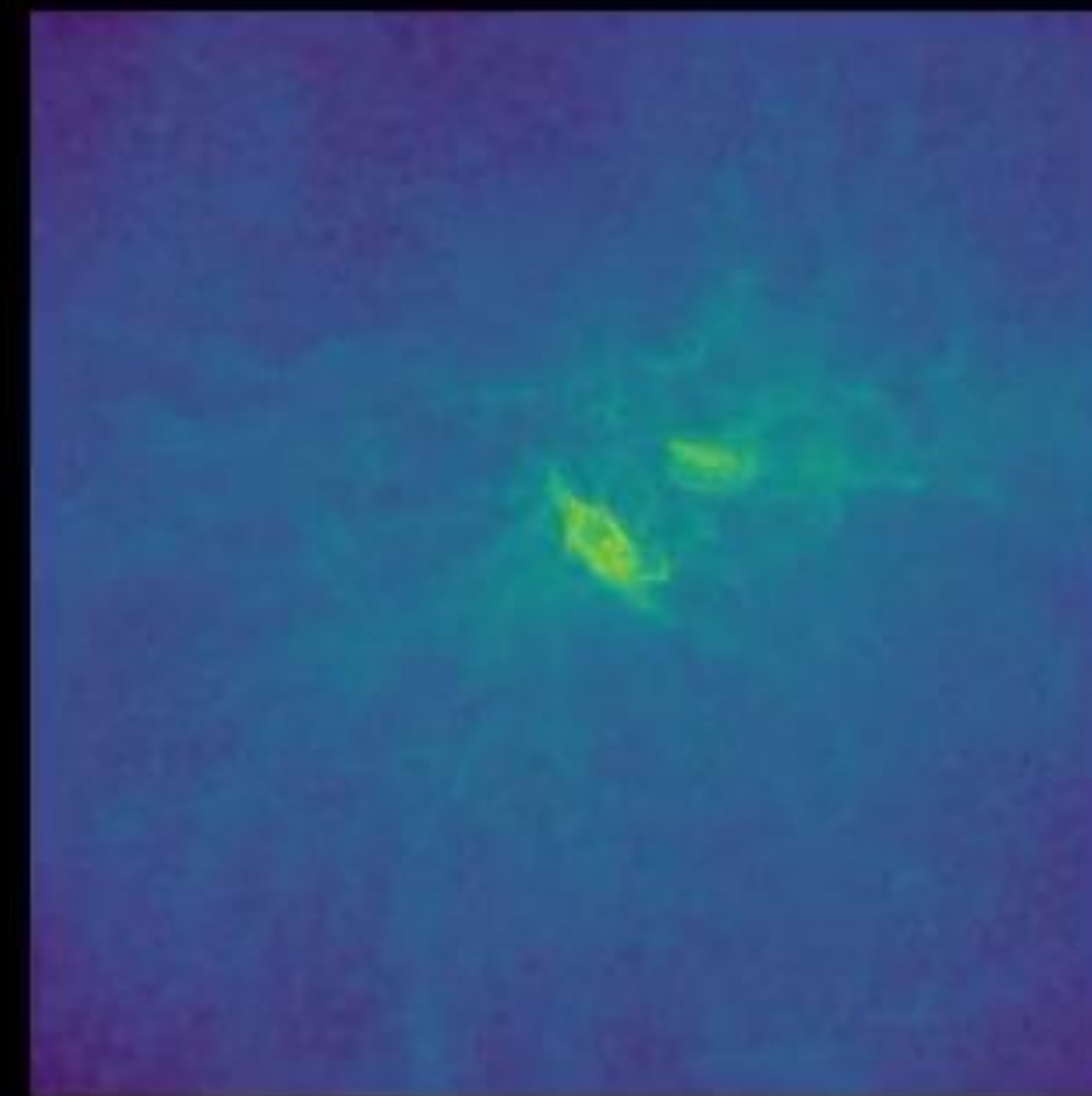
$z = 1.000$



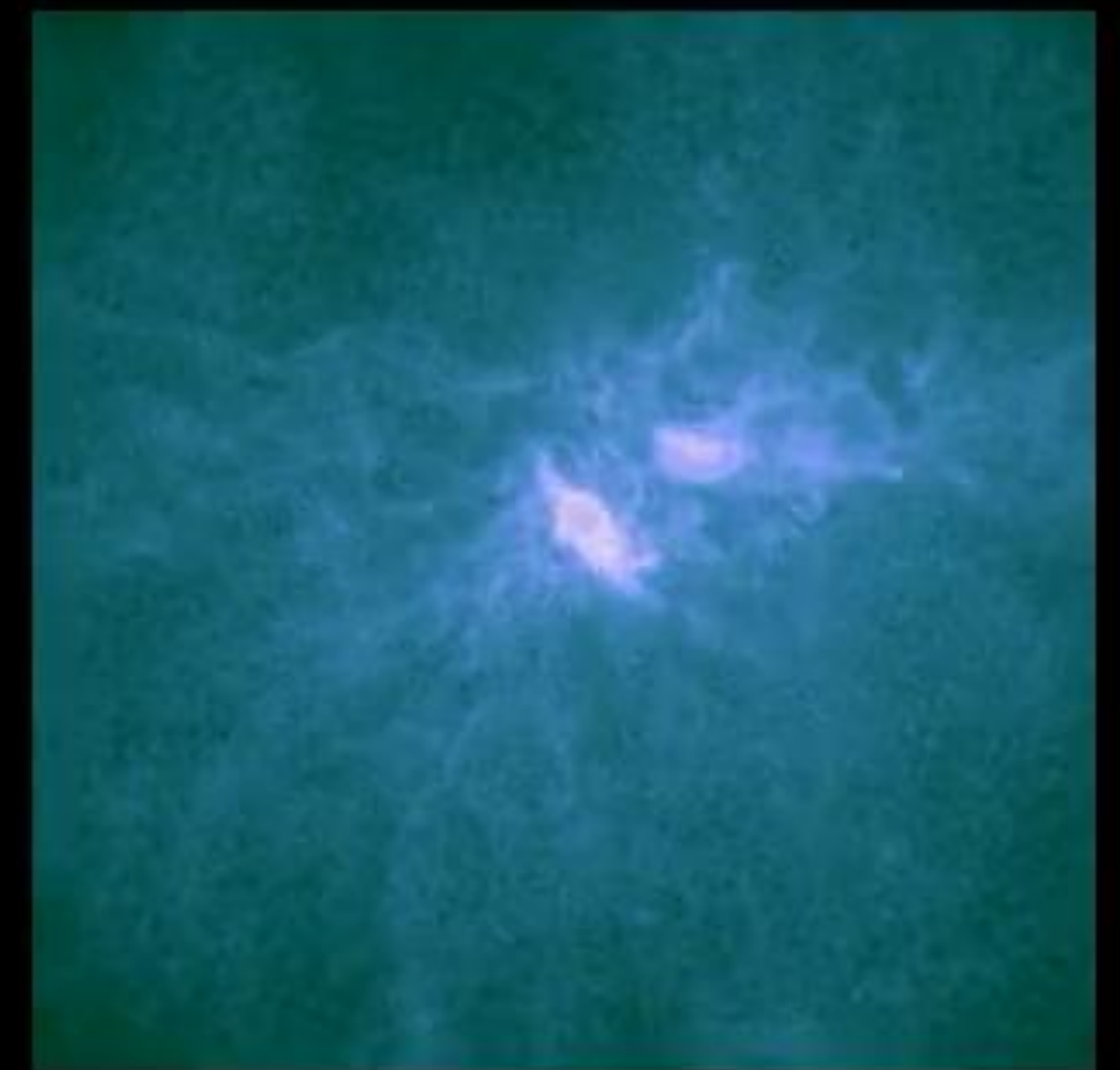
Magneticum



EAGLE



Astrid



Obsidian

Collaboration

Modern Cosmological Simulations

IllustrisTNG

SIMBA

Ramses

CROCODILE

Gas Density
Gas Temperature

Weaker Stellar Feedback

$z = 1.000$
Fiducial Feedback

Stronger Feedback

Magneticum

EAGLE

Astrid

Obsidian

Collaboration

Uncertainty

Aleatoric

← Intrinsic, irreducible variation

Halo-to-halo variation, assembly history, environment, etc...

Epistemic

← Variation associated with construction of model

Epistemic uncertainty in cosmo sims

Sources

- **Physics Implementation**
 - Subgrid model choice (e.g., TNG, EAGLE, SIMBA, FIRE...)
 - Subgrid model implementation (e.g., feedback strength, star formation density...)
- **Numerical Implementation**
 - Resolution (e.g., mass resolution, force softening lengths ...)
 - Hydrodynamic Solver (e.g., MFM, MVM, SPH, ...)
 - Structure Finder (e.g., SubFind, Rockstar, Amiga, ...)
- **Cosmology**
 - Matter Density and distribution of universe (e.g., Ω_M , σ_8 ...)
 - Dark matter properties (e.g., CDM, WDM, SIDM, ...)

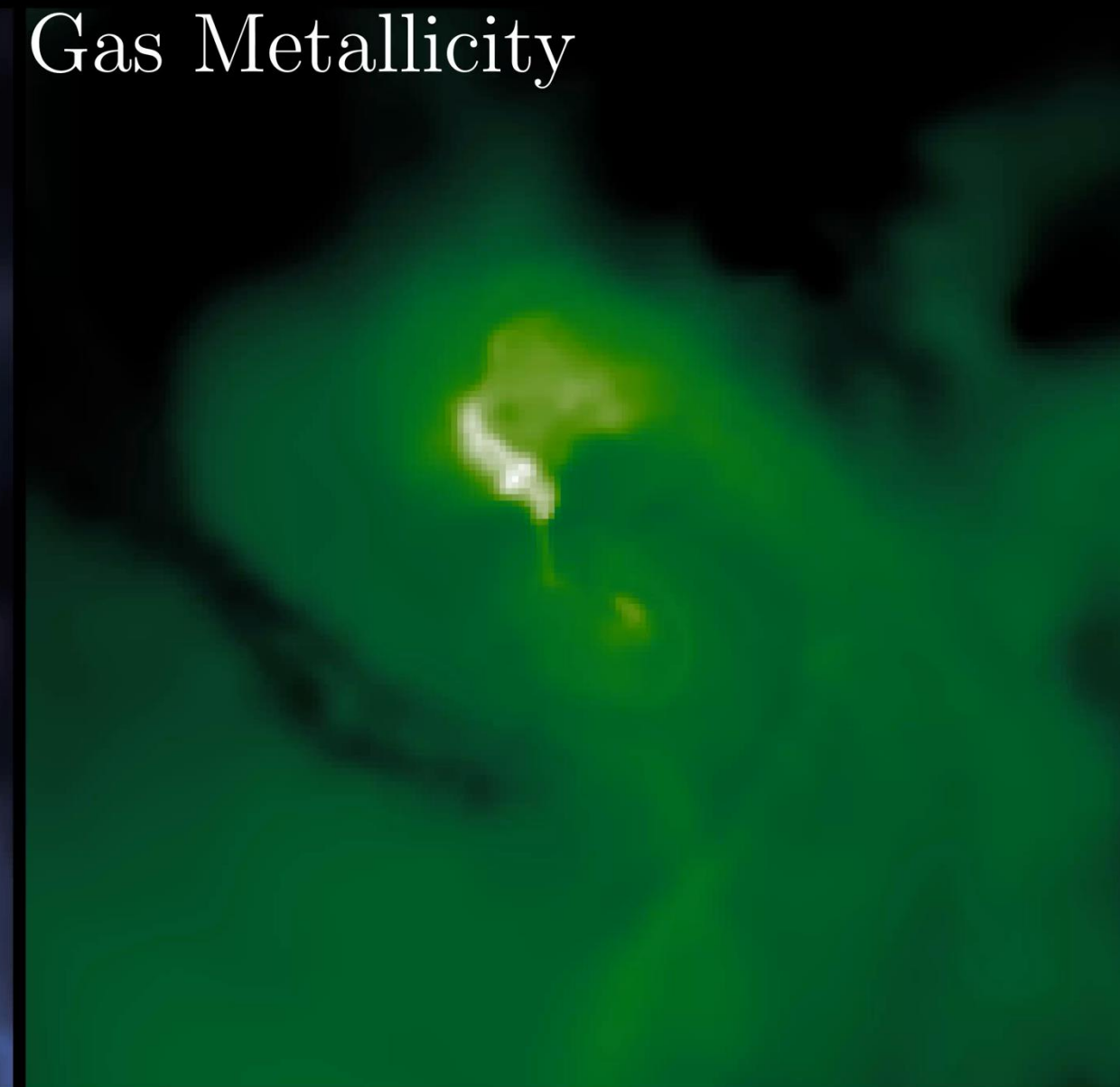
How do we quantify our “epistemic”
uncertainties?

Simulations with parameter variations

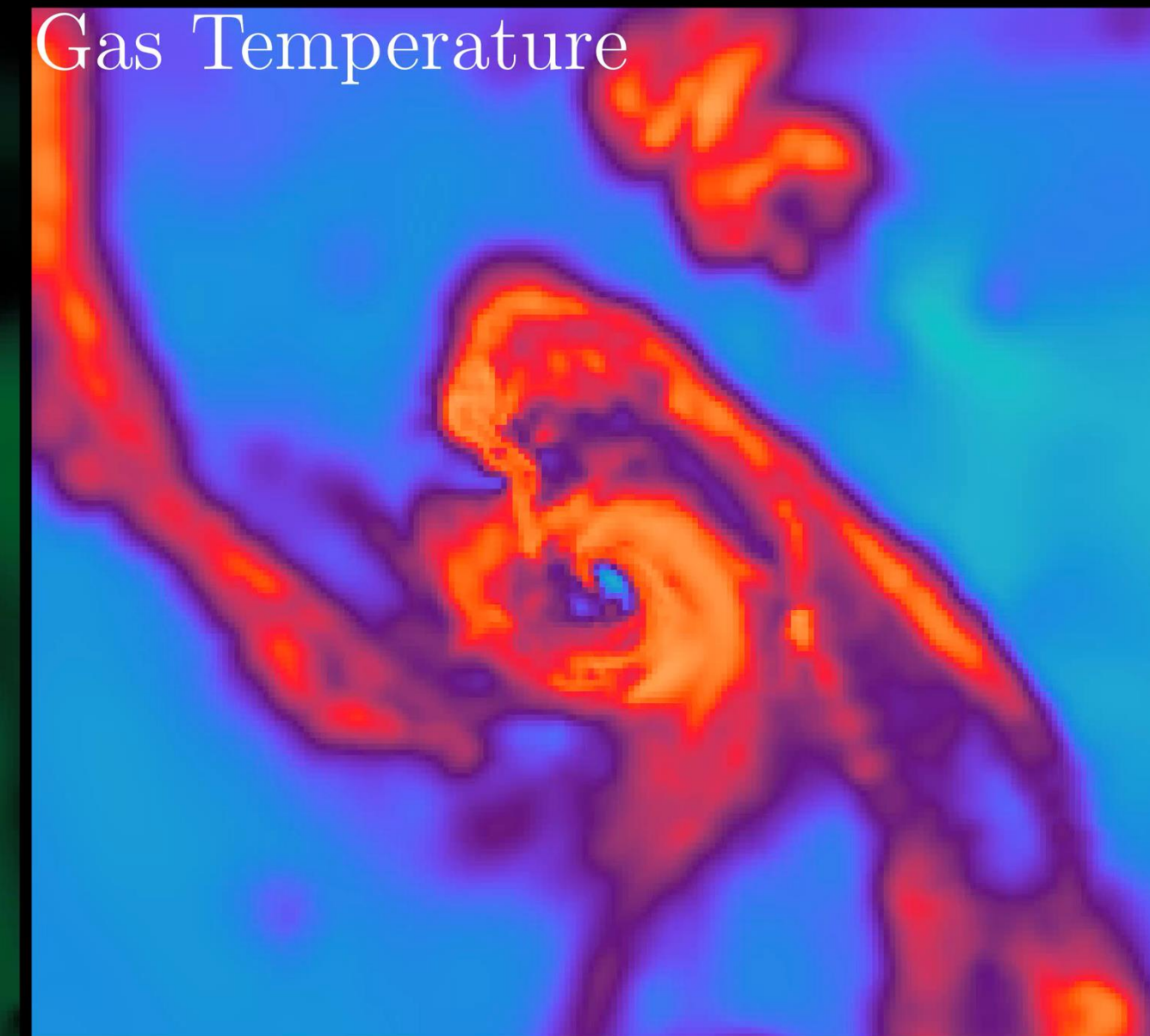
Gas Mass



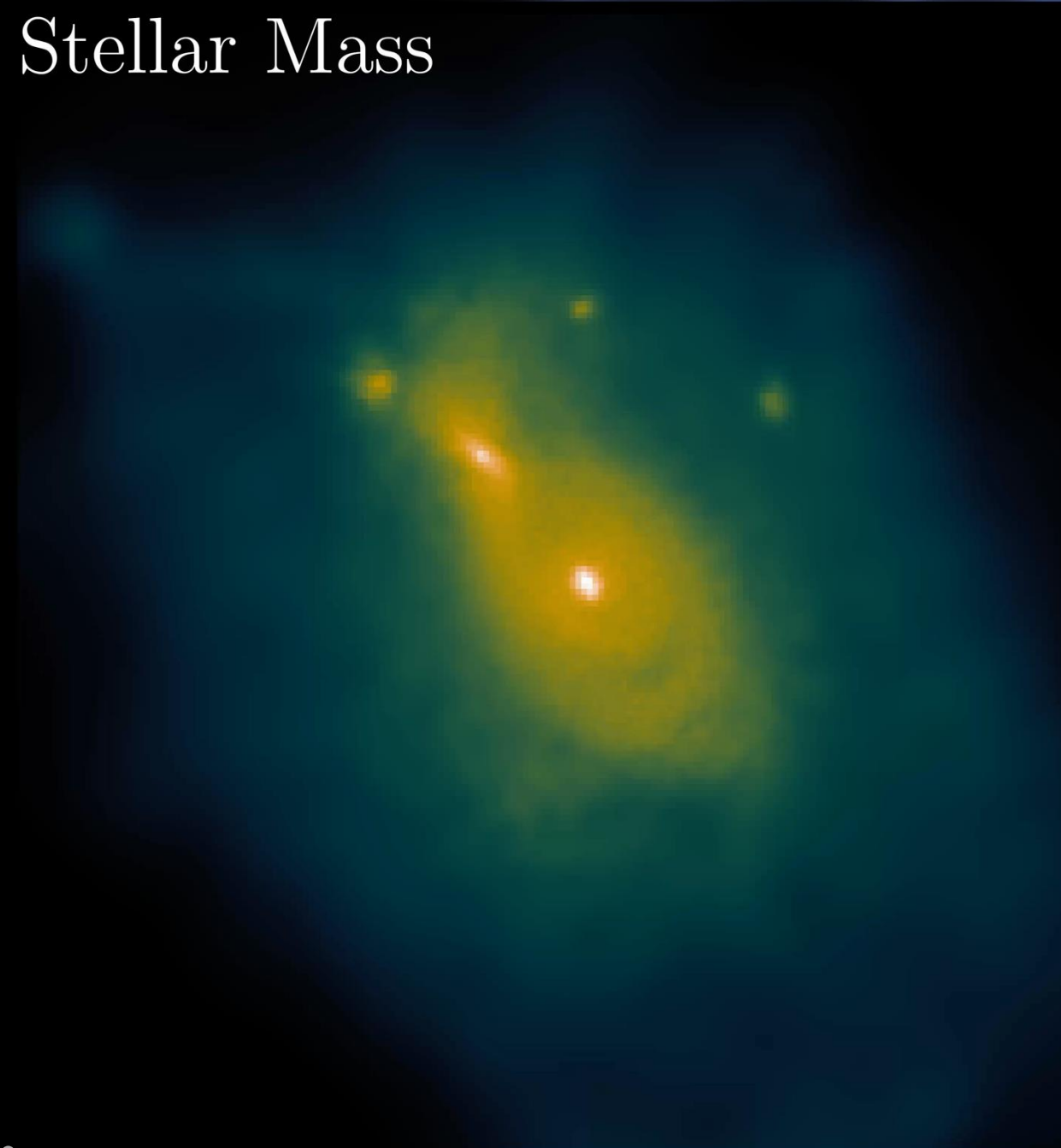
Gas Metallicity



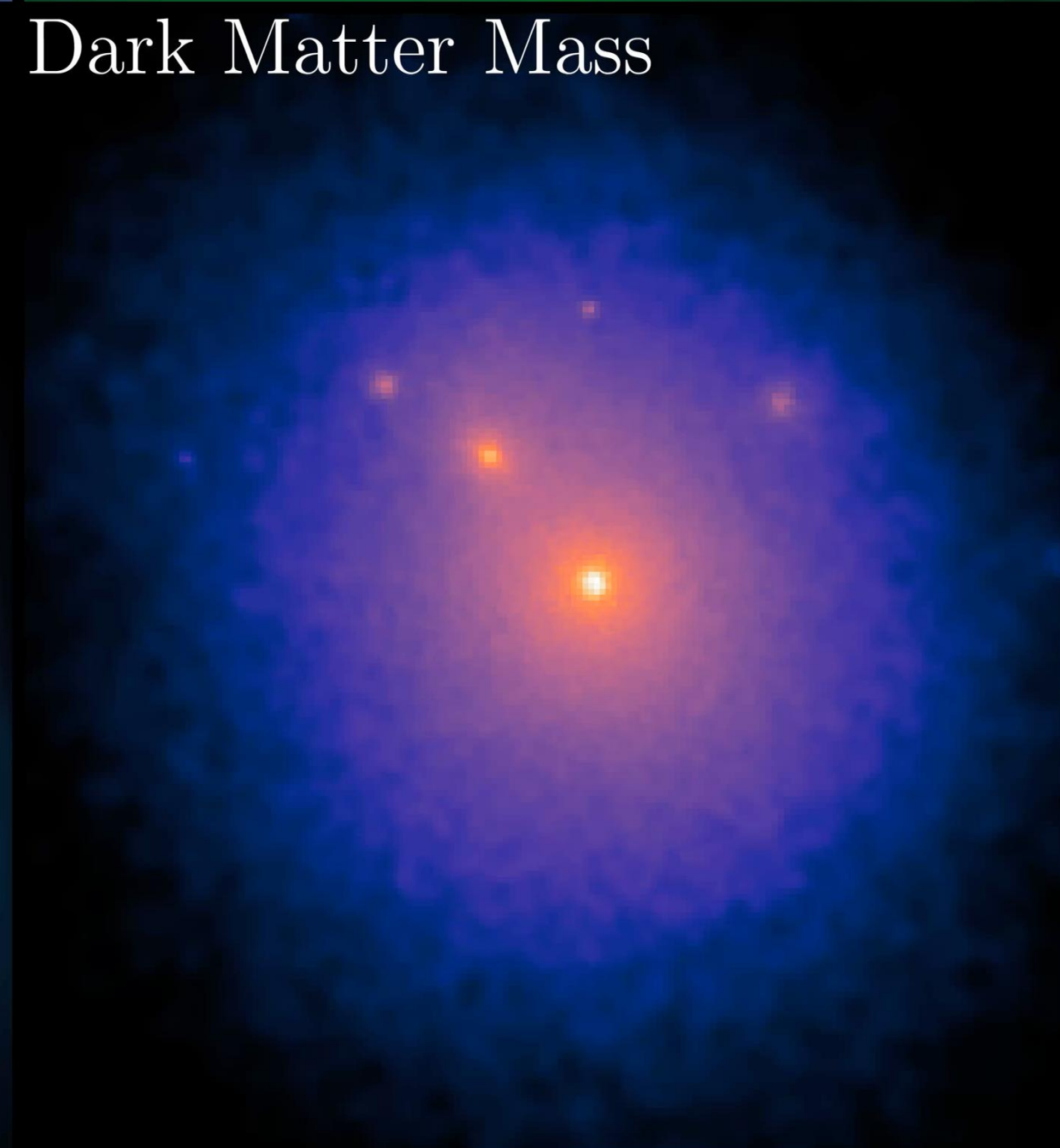
Gas Temperature



Stellar Mass



Dark Matter Mass



Box 0000

$\bar{e}_w$	= 3.281
κ_w	= 4.579
$\epsilon_{f, \text{high}}$	= 0.056
Ω_{M}	= 0.281
σ_8	= 0.802

$$\log(M_{\text{Halo}}) = 12.27$$

$$\log(M_{\star}) = 11.02$$

$$\log(M_{\text{gas}}) = 10.74$$

DREAMS

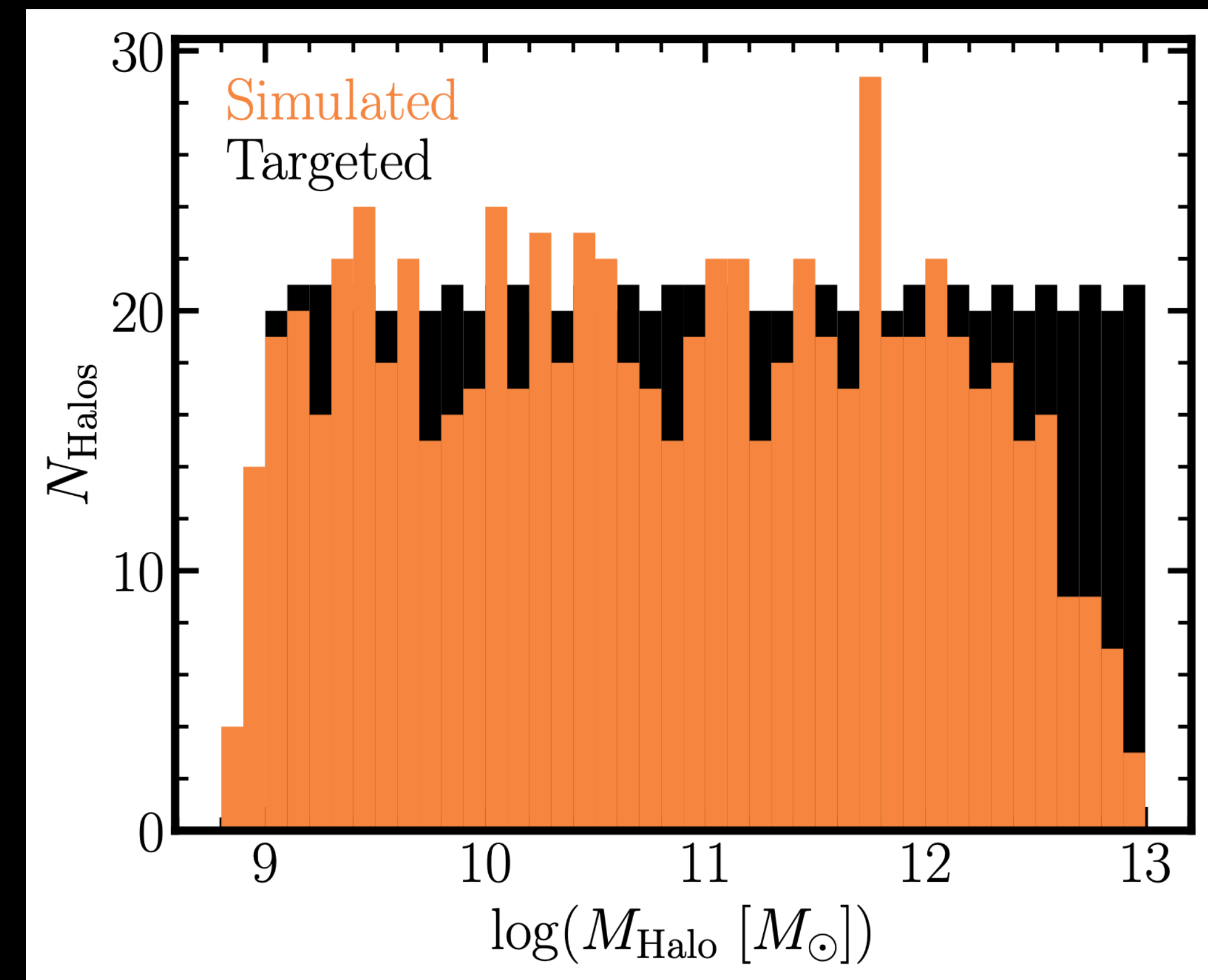
Rose+2025a,b,c,
Garcia+2026a, Lillie+2026,
Torrey+Prep, Garcia+Prep, ...

Alex Garcia

Mass Varied Suite (IllustrisTNG Physics)

> 700 Zoom-in Simulations

- $M_{\text{Halo}} \in [10^9, 10^{13}] M_{\odot}$
- 3 TNG Physics parameters
 - 2 supernova, 1 AGN
- 2 cosmological parameters
 - Ω_M and σ_8
- $\sim$ TNG50 mass resolution
- Every halo is a unique realization and unique formation history

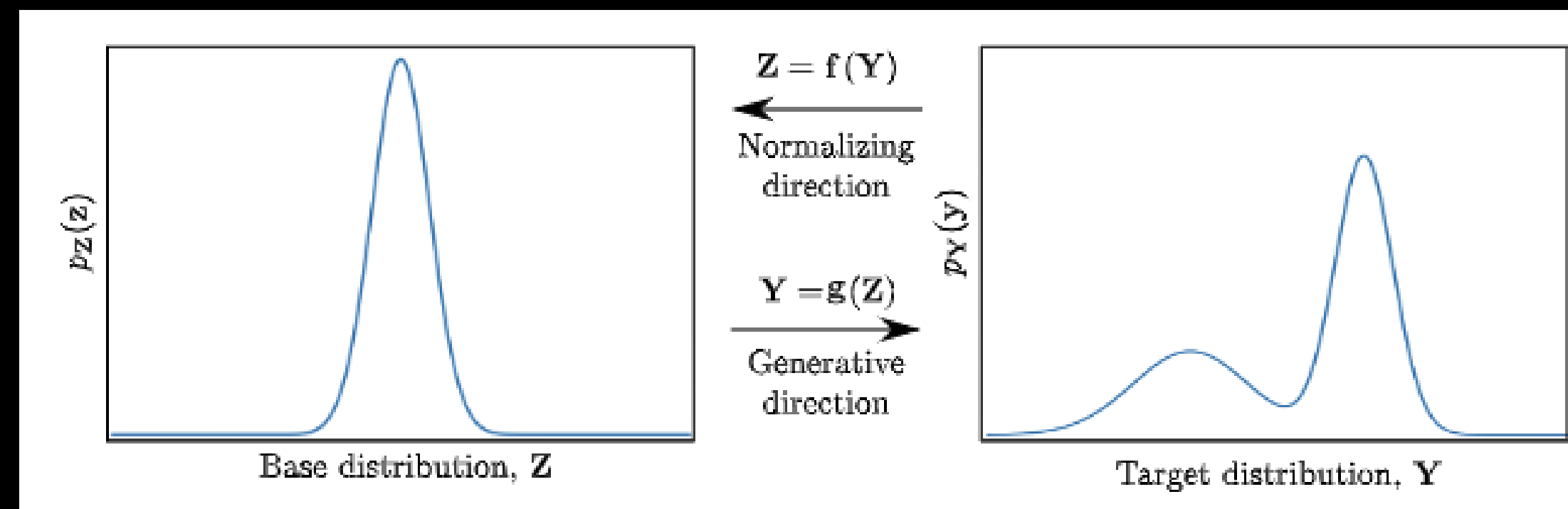


Torrey+Prep

The experiment

Learn the dependence of galaxy properties on simulation inputs

Normalizing Flows



θ

Simulation Features

NeHOD

Nguyen+(2026; incl. AMG)

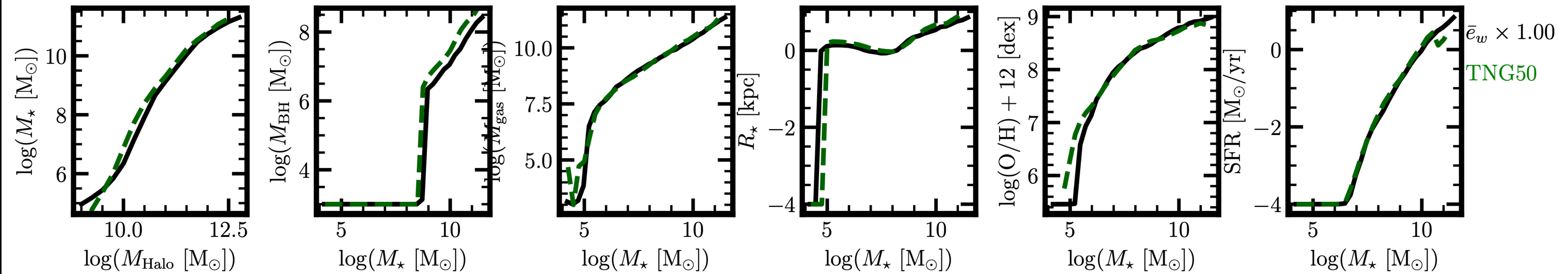


x

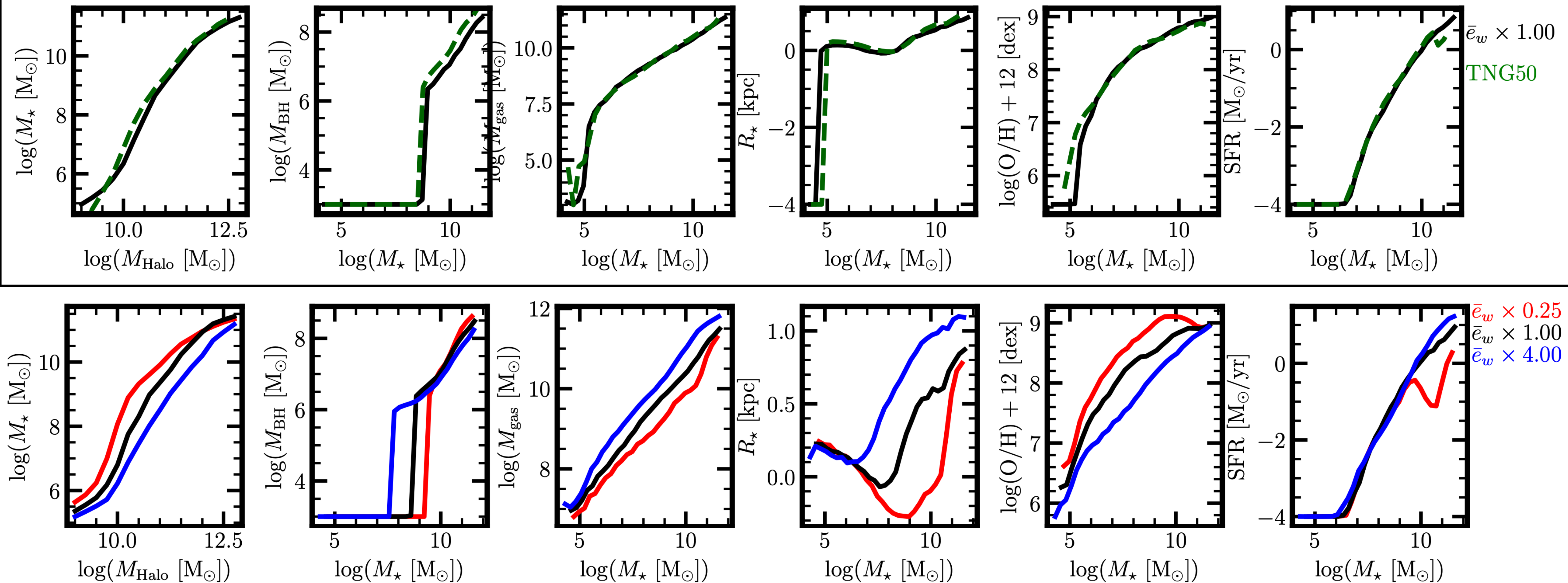
Simulation Outputs

Validate with existing full box simulations (TNG50)

Preliminary



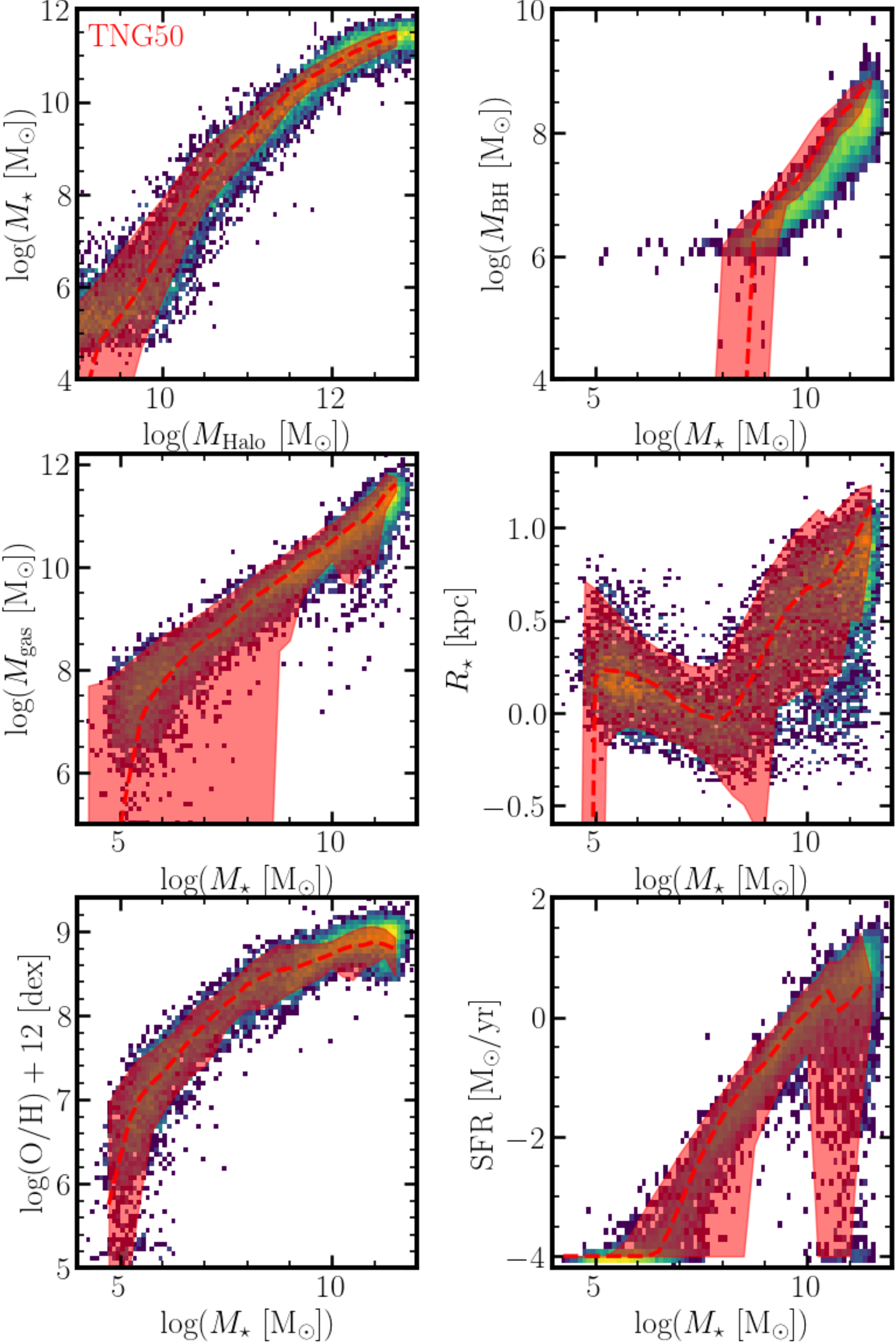
Preliminary



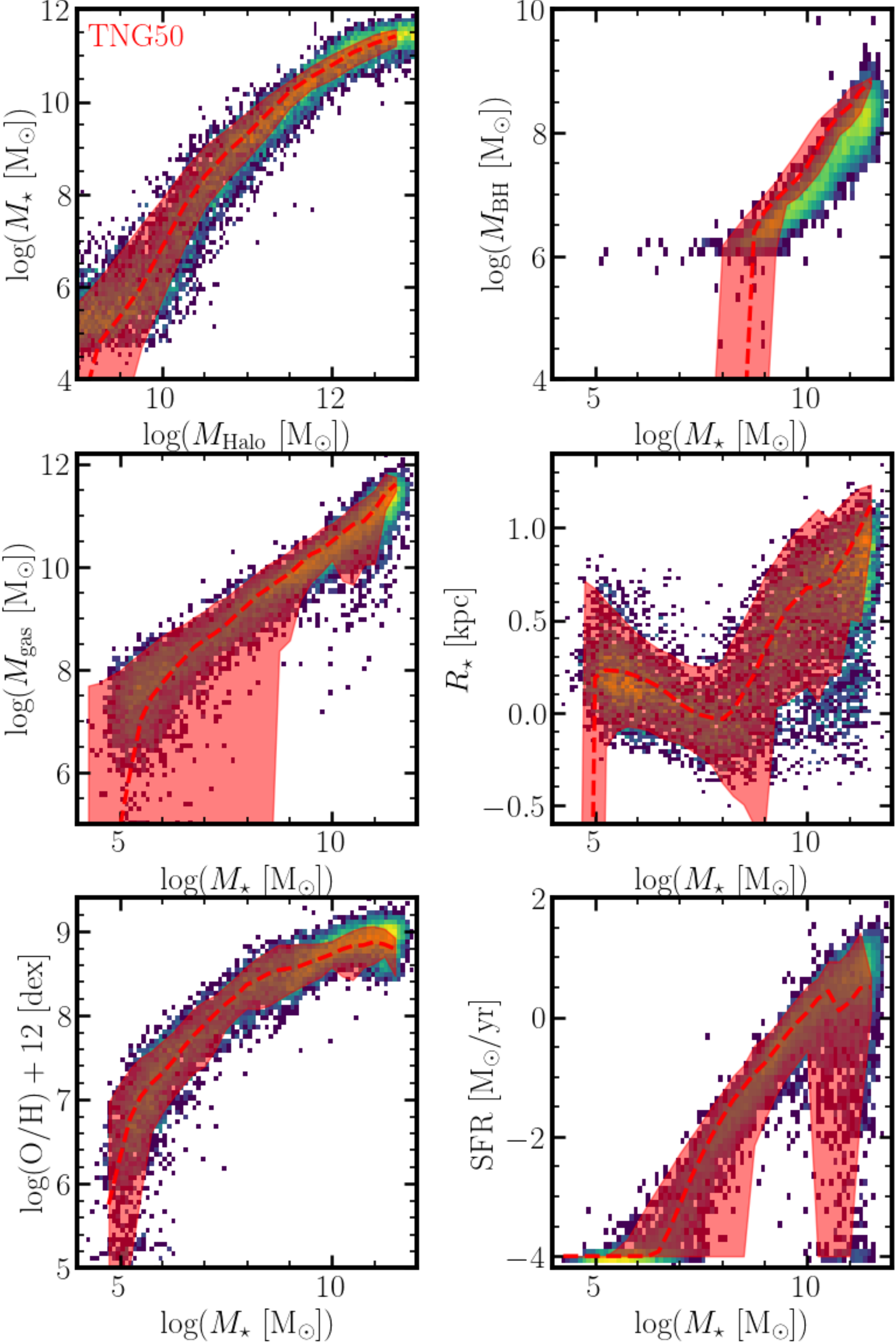
Epistemic uncertainty with respect to input parameters



Preliminary

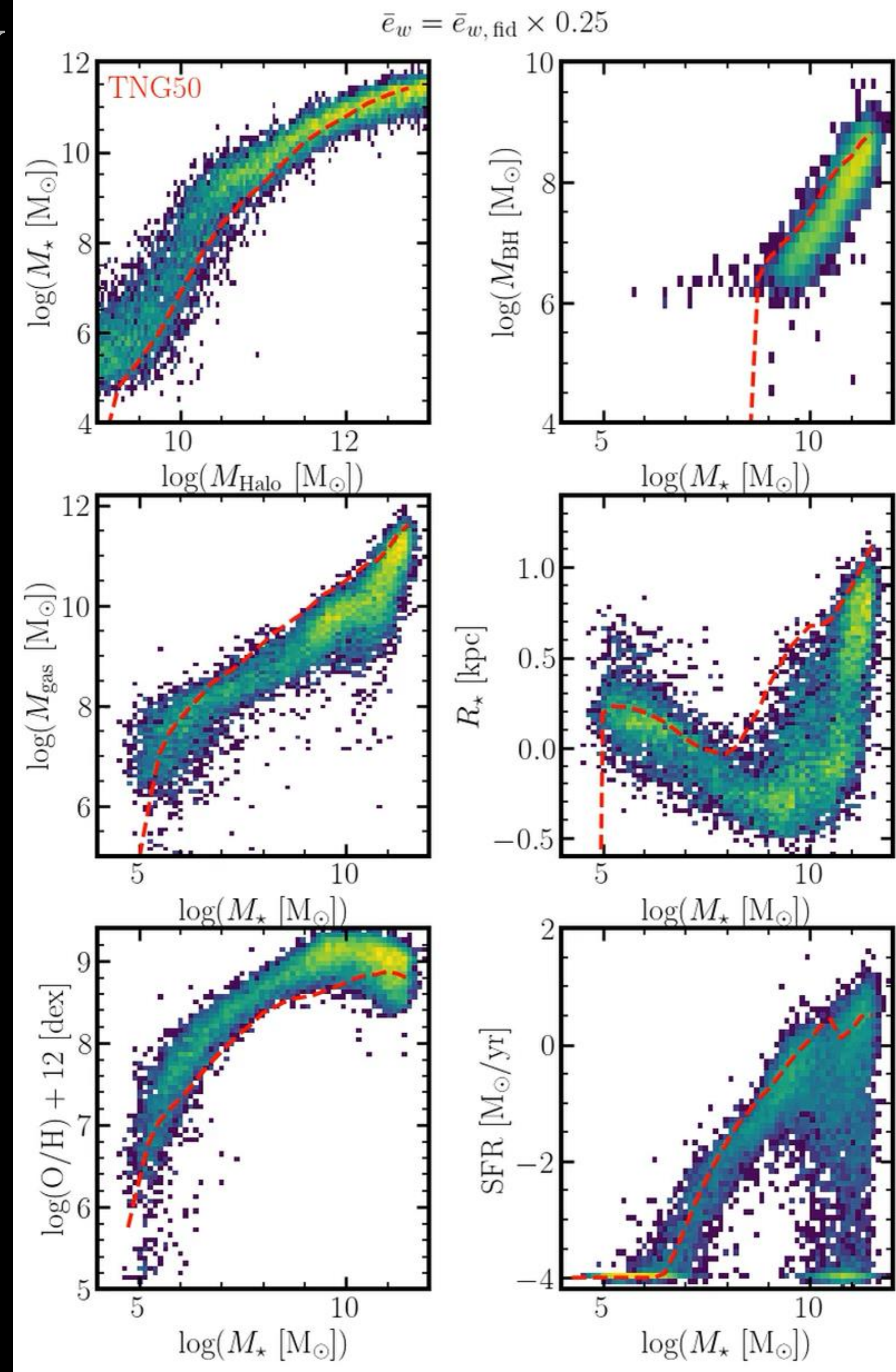


Aleatoric uncertainty at fixed input parameters ✓



Preliminary

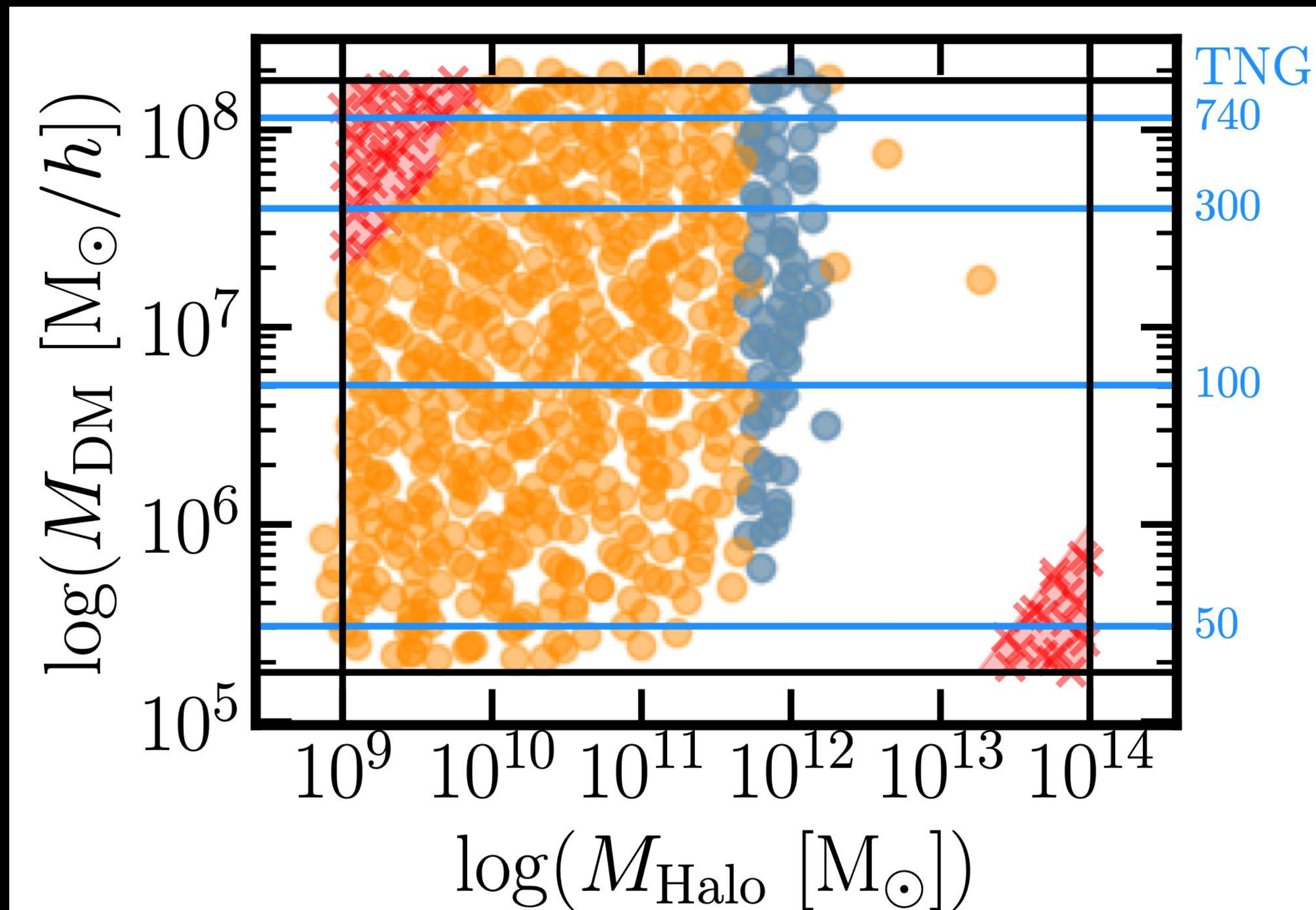
Increasing Supernova Wind Energy



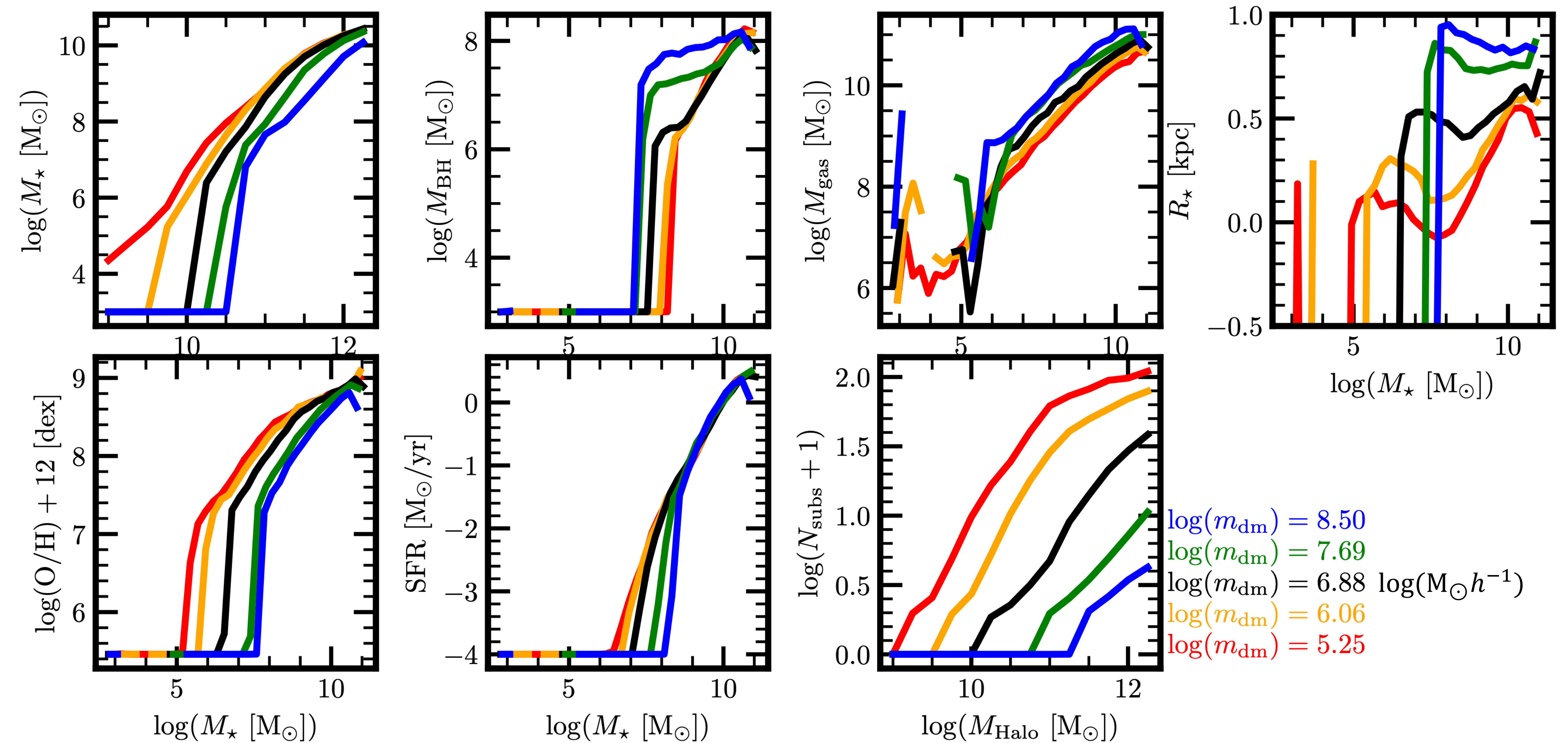
Resolution Varied Suite (IllustrisTNG Physics)

SB9 — Approx. 550 Simulations Done (~55%)

- $M_{\text{Halo}} \in [10^9, 10^{14}] M_{\odot}$
- 4 TNG Physics parameters
 - 2 supernova, 2 AGN
- 2 cosmological parameters Ω_M and σ_8
- Mass resolution ranging from $> \text{TNG50}$ to $< \text{TNG300}$
- Force softening length variations

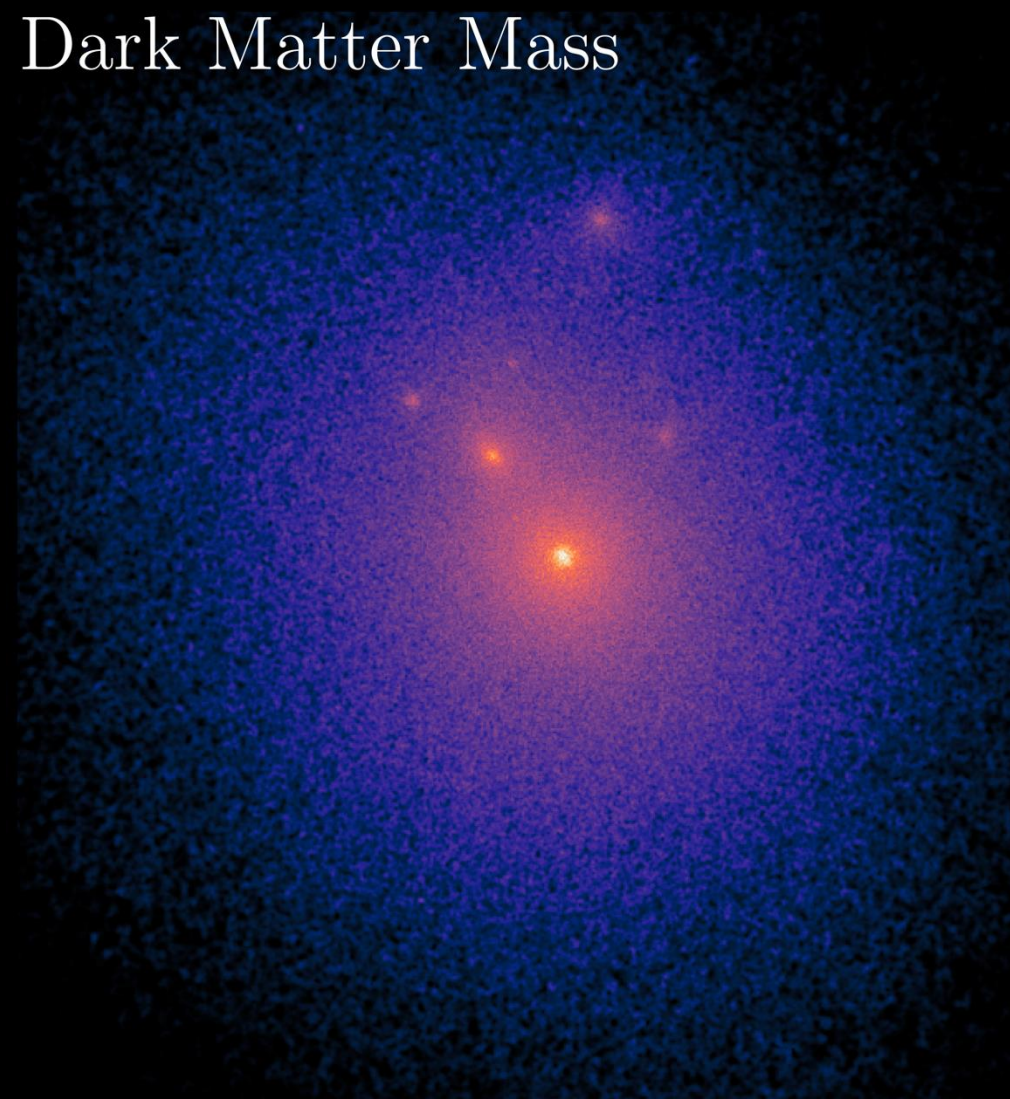


Preliminary

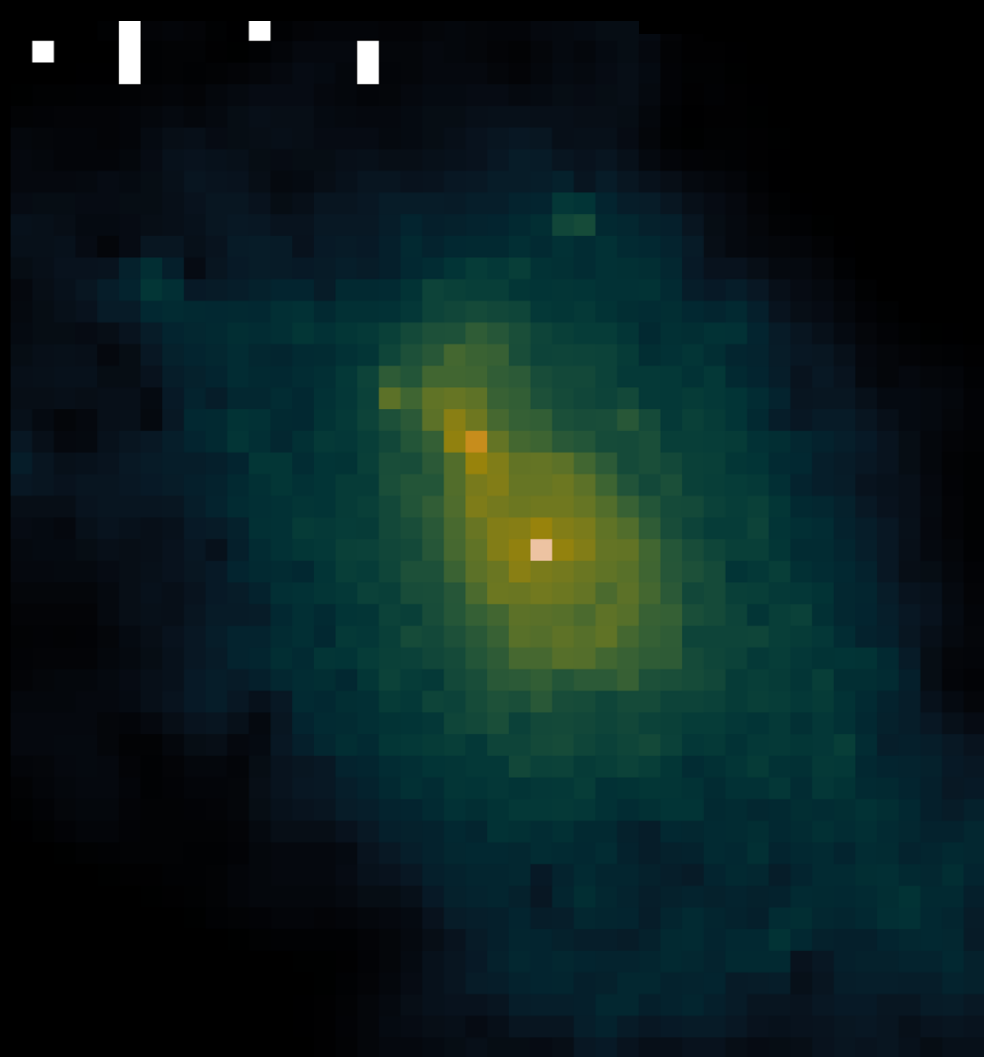
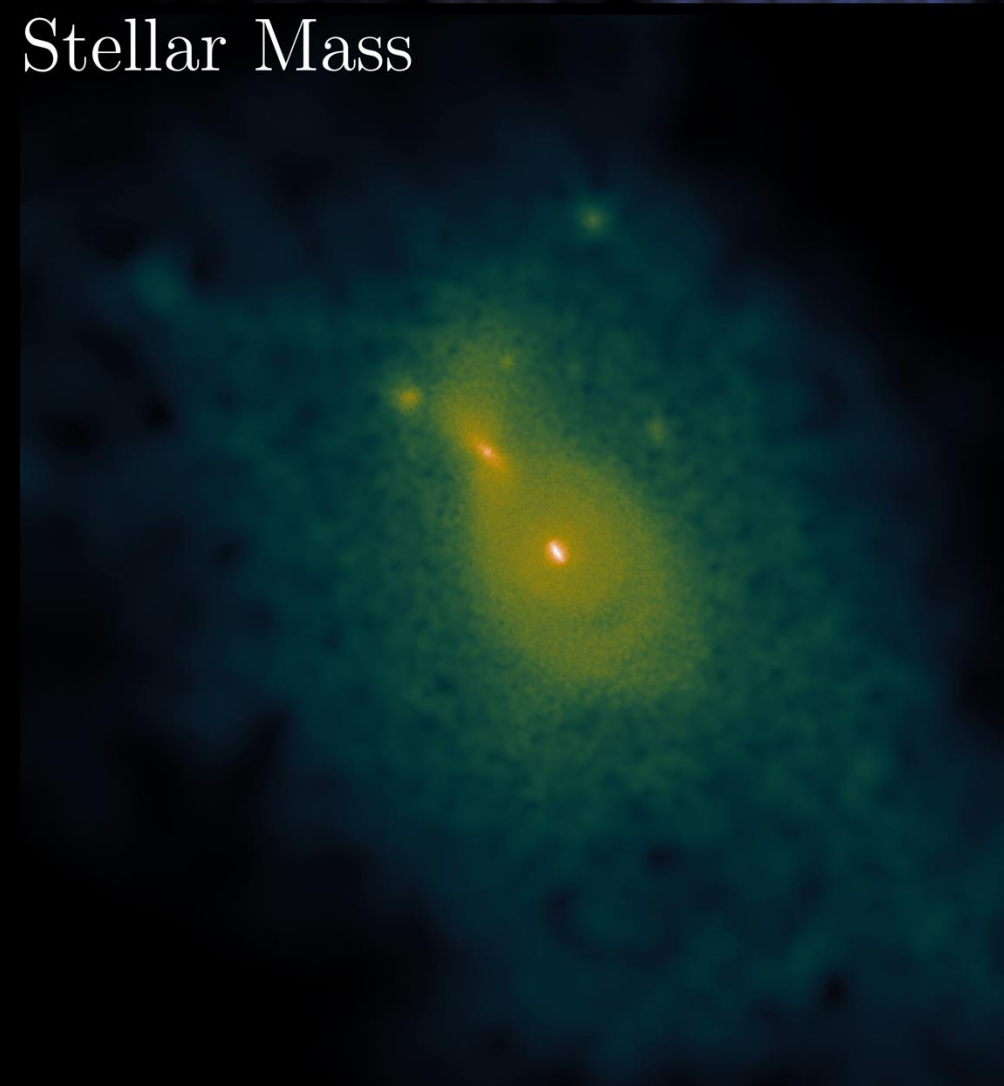


Baryonification? Super-resolution?

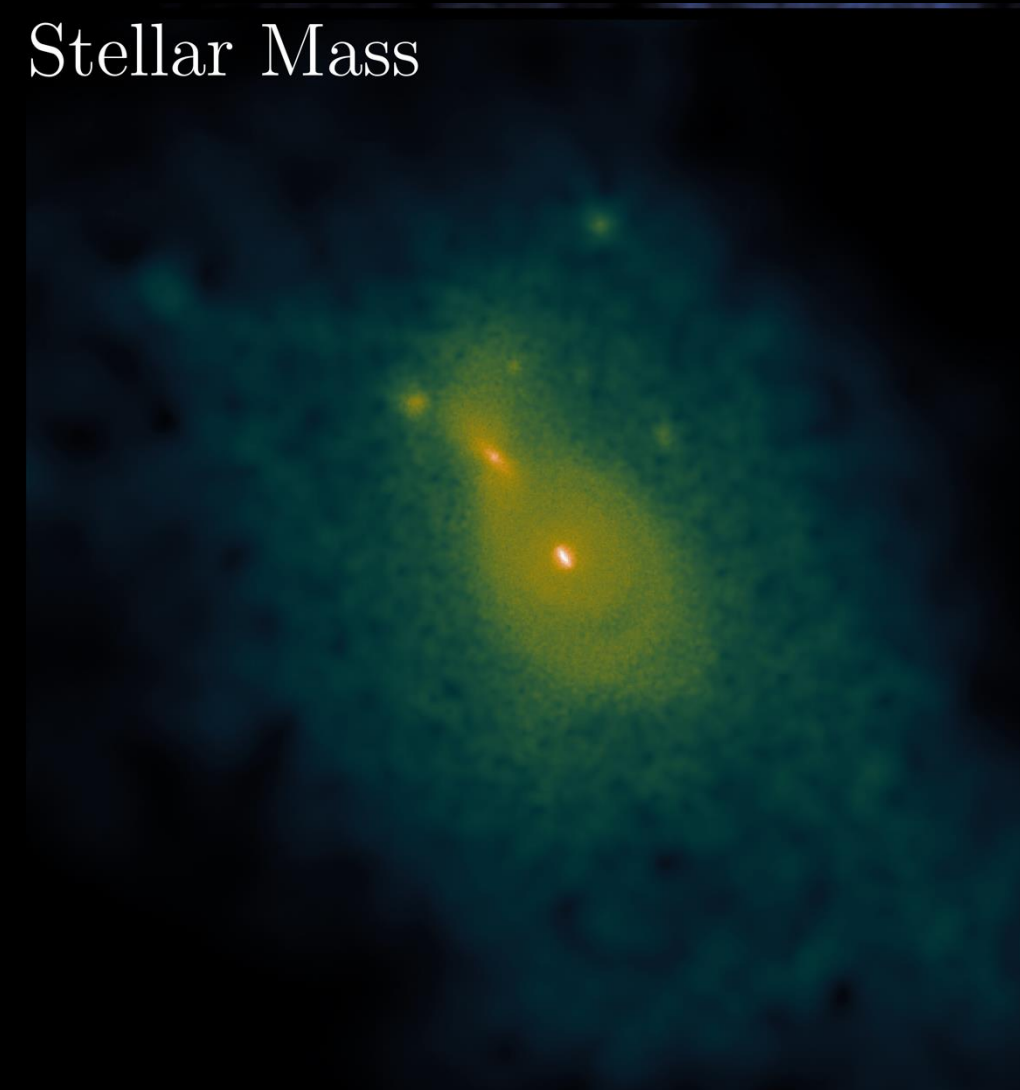
Dark Matter Mass



Stellar Mass



Stellar Mass



Conclusions

- Current galaxy simulation efforts under appreciate their *epistemic* uncertainties
- Curated **DREAMS** datasets of zoom-in simulations give us a sense of the role of uncertain astrophysics, cosmology parameters, and formation histories
- Machine learning emulators are able to reproduce full box scaling relations with just zoom-in simulations
 - Allows us to, for the first time, probe both the aleatoric and epistemic uncertainty of our cosmological simulations

Future Directions

- More galaxy formation models
- More dark matter models
- Emulation of full “group catalog” data — public facing data portal — coming soon!

