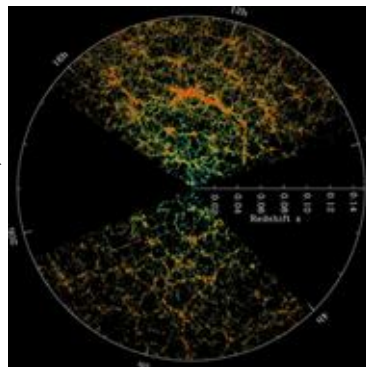
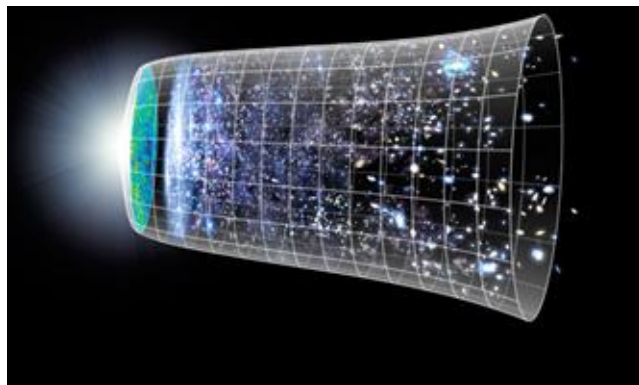


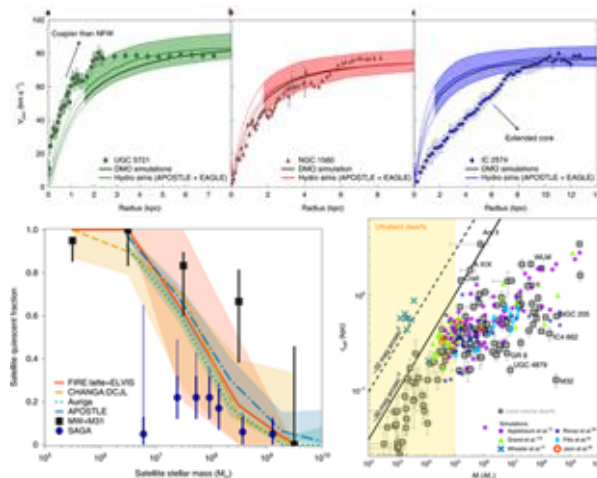
# DREAMS Dwarf Suites: A Multi-Code Foundation for AI-Driven Cosmology

Jonah Rose  
7/15/2026

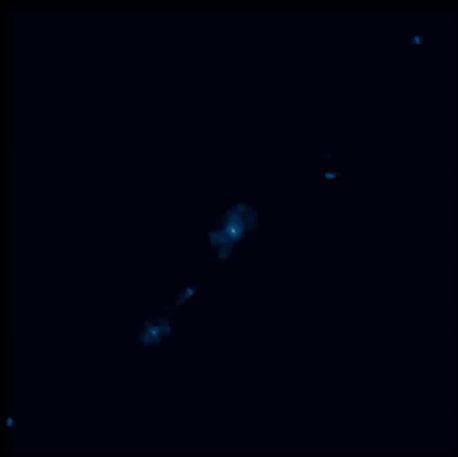




?



Dark Matter

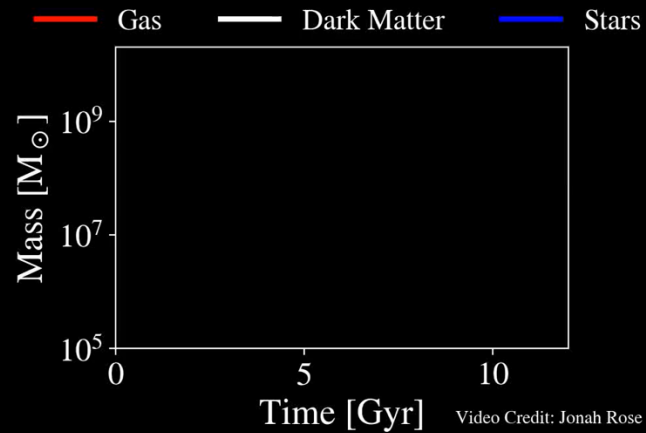
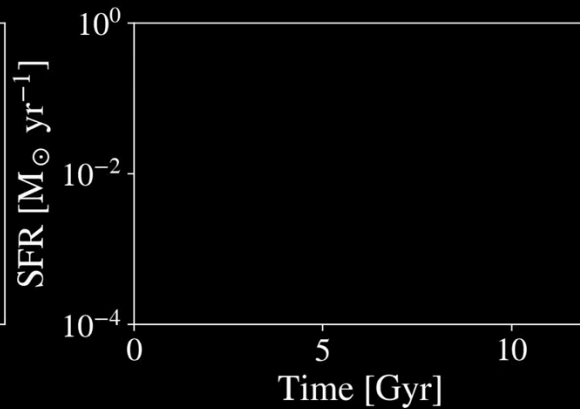
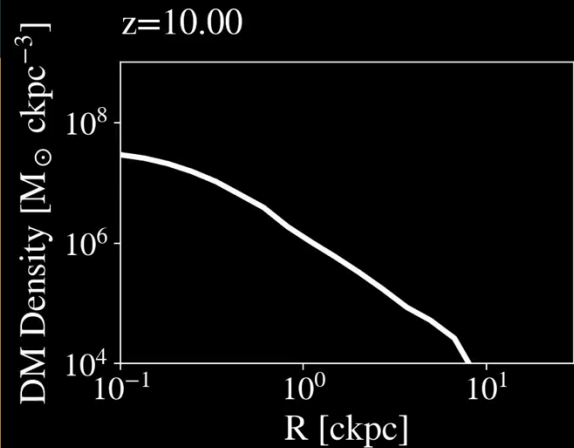


Gas



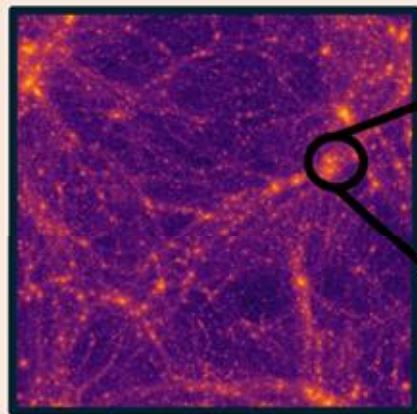
Stars

30 kpc

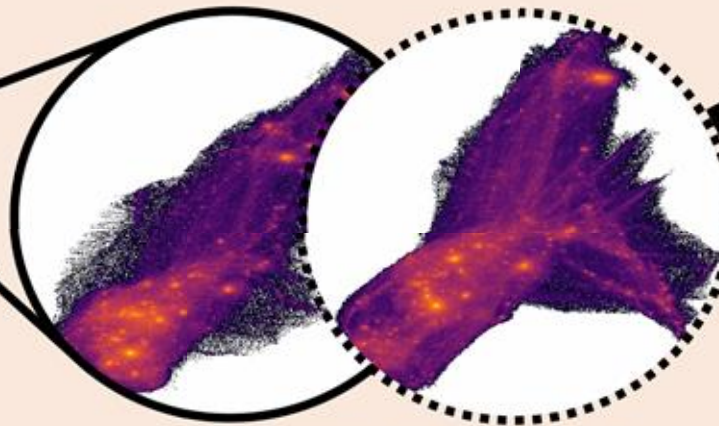


Video Credit: Jonah Rose

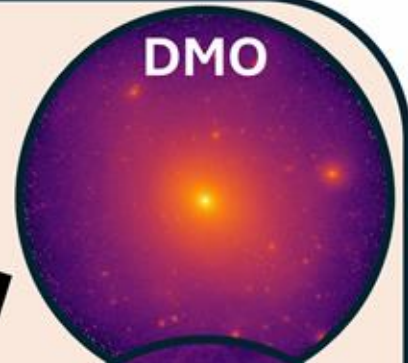
# The DREAMS Pipeline



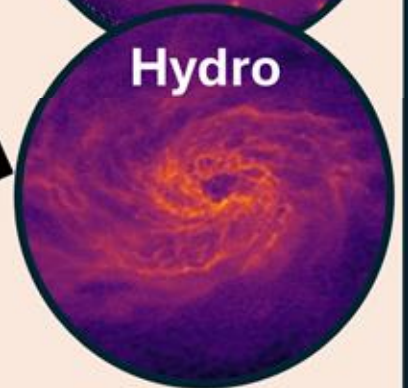
Uniform Box



Intermediate DMO



DMO

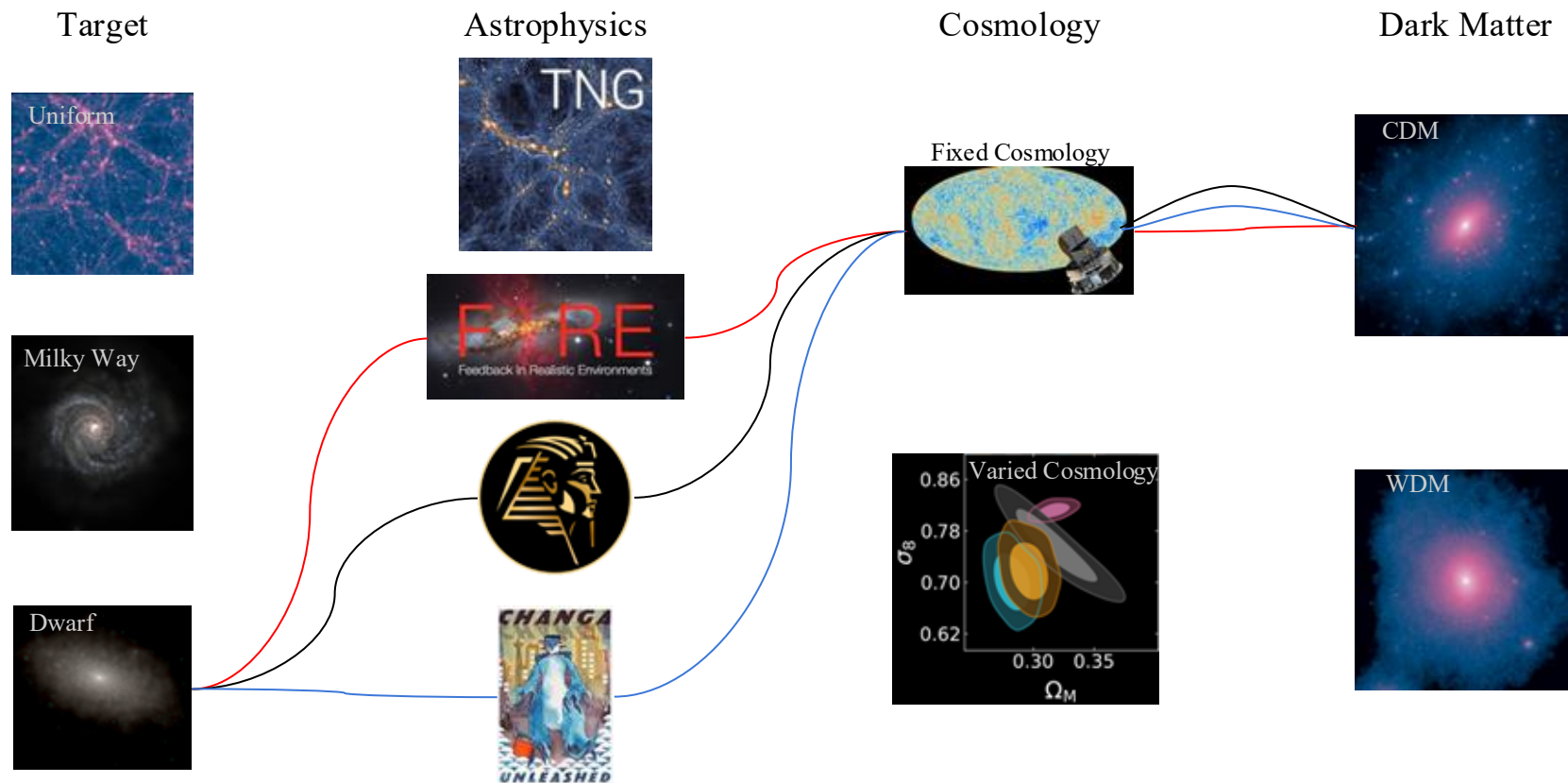


Hydro

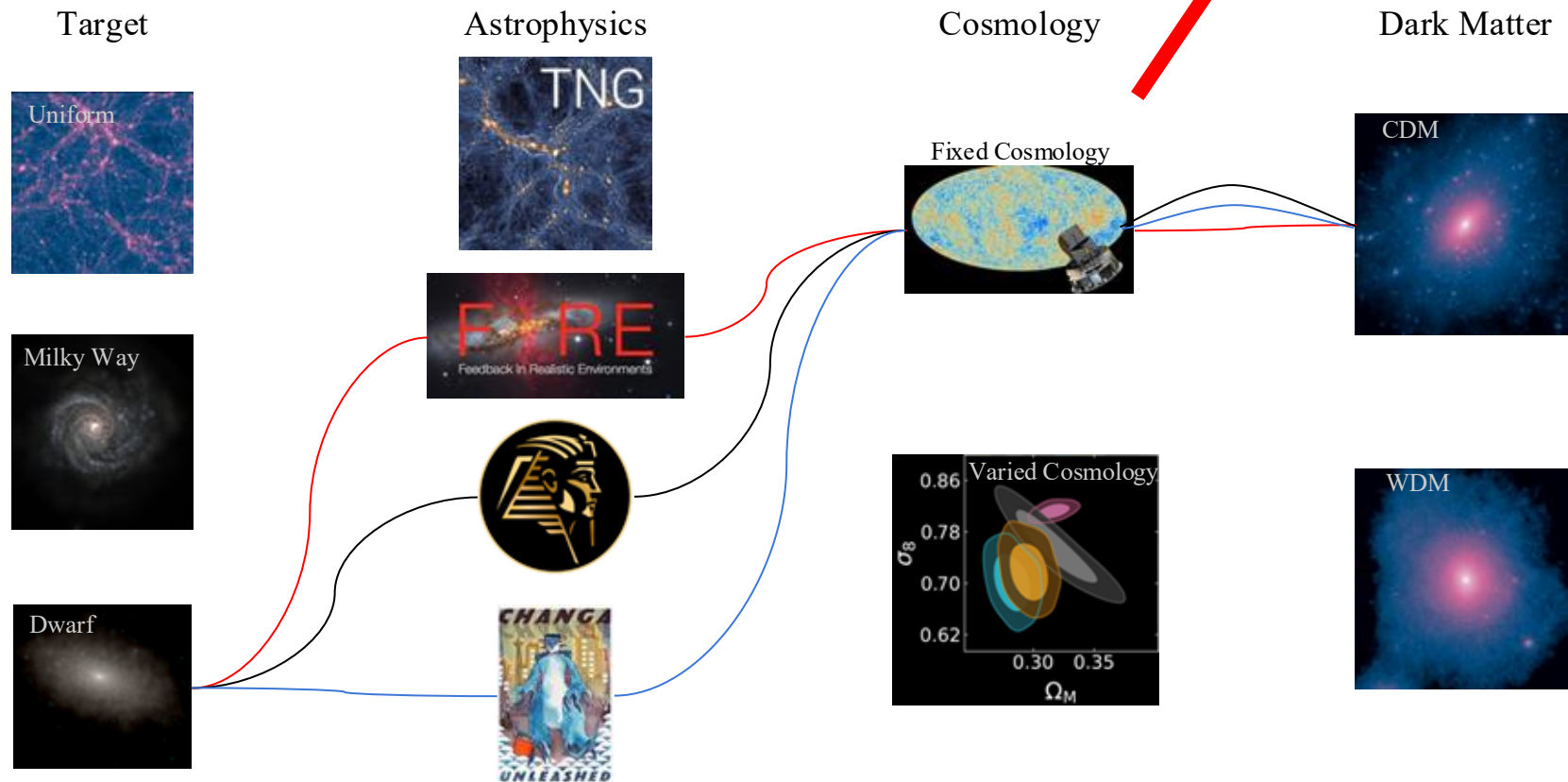
Production  
Runs

Increasing Resolution

# DREAMS Simulation Suites



# DREAMS Simulation Suites



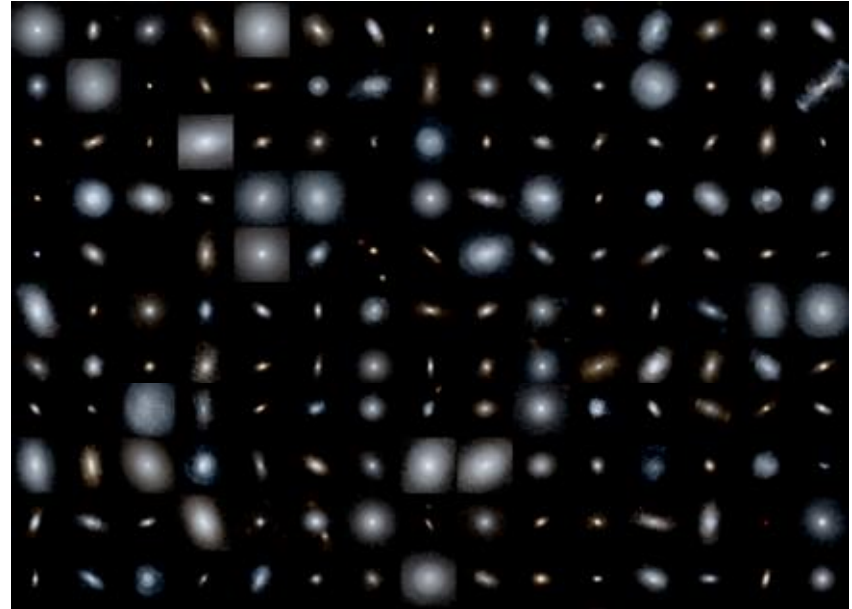
# Simulation Uncertainties



**RAMSES**



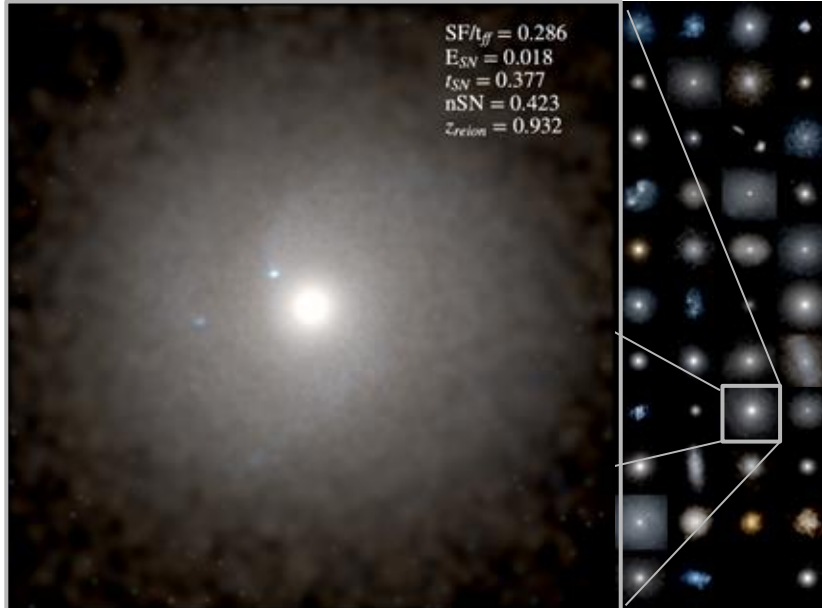
**FIRE**



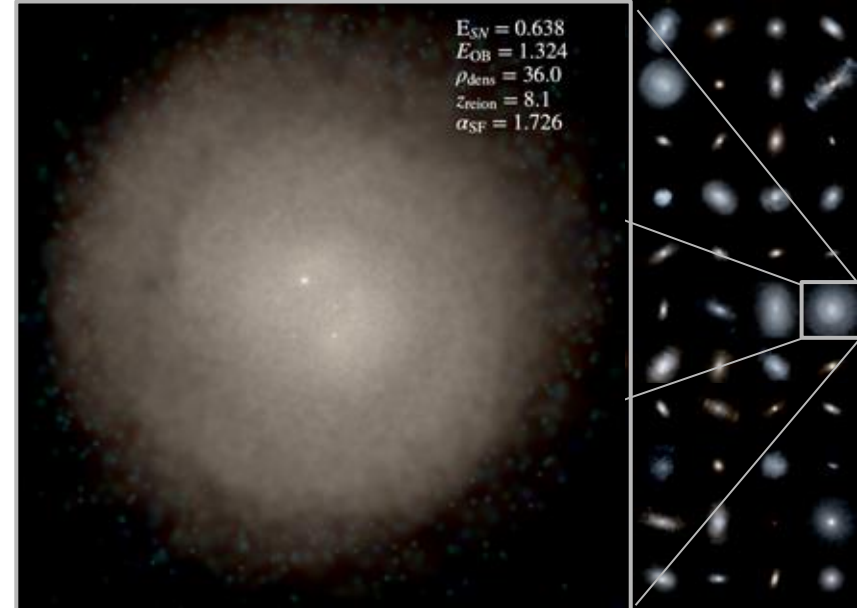
# Simulation Uncertainties



**RAMSES**



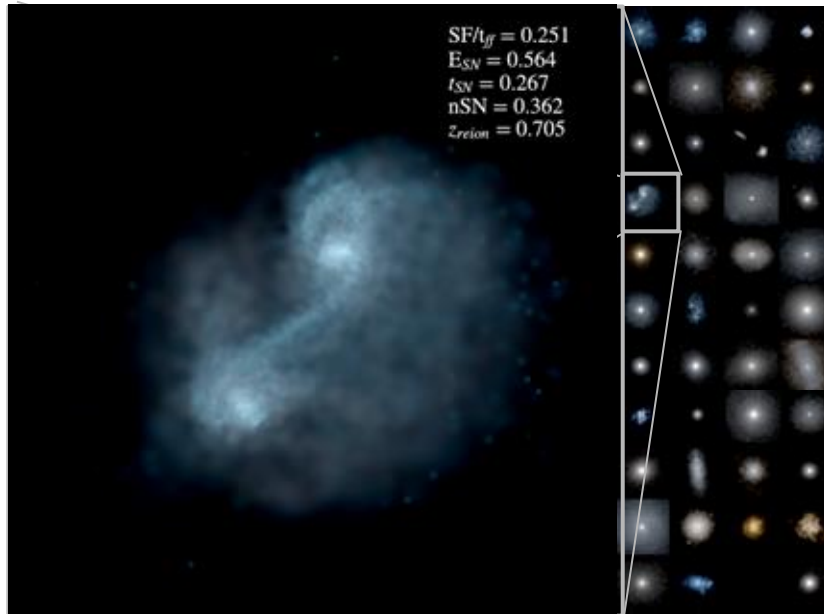
**FIRE**



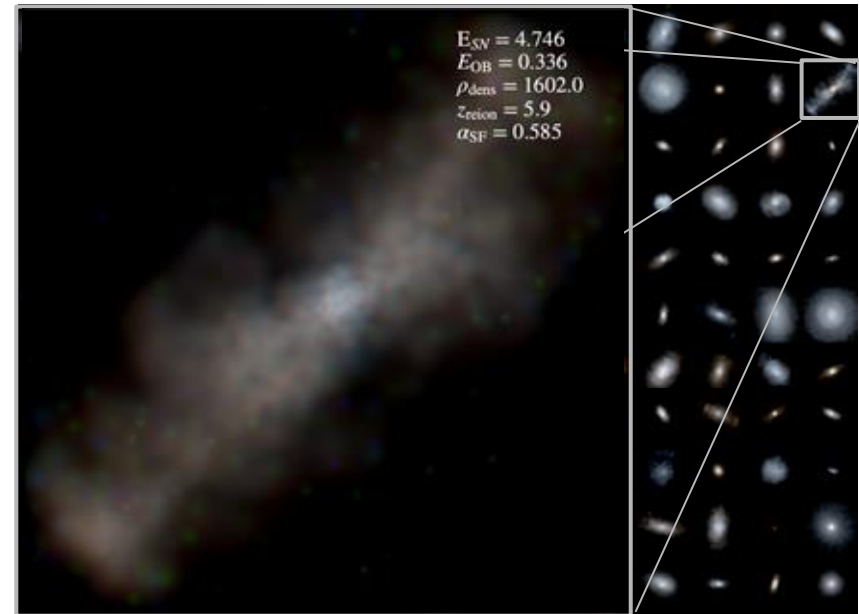
# Simulation Uncertainties



**RAMSES**



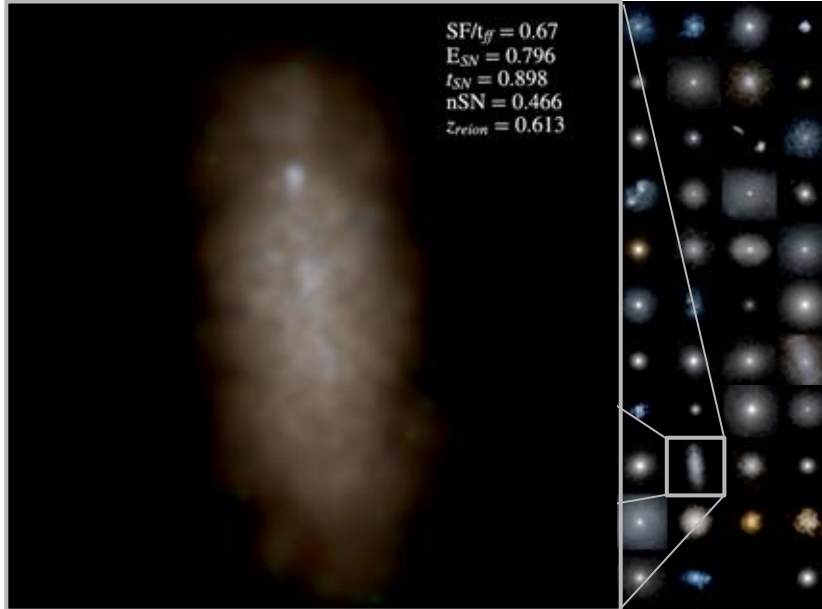
**FIRE**



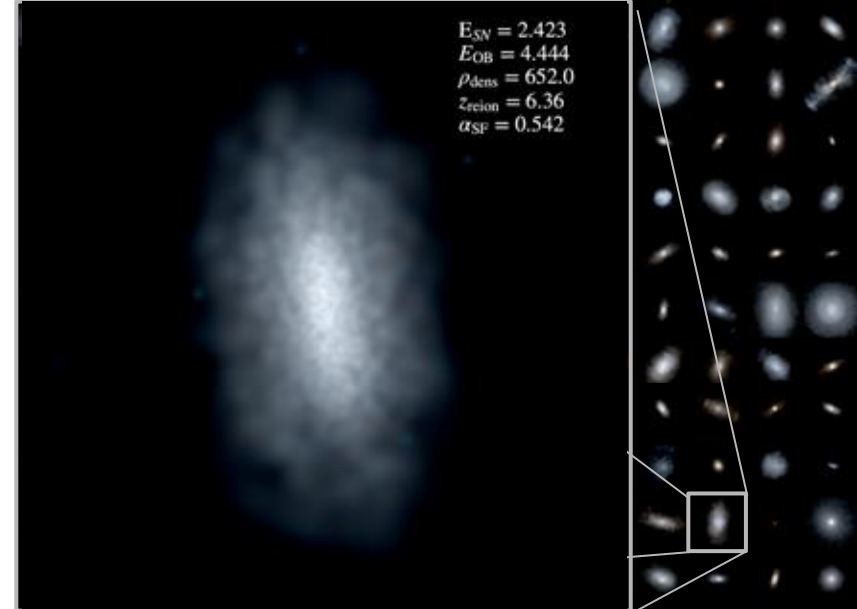
# Simulation Uncertainties



**RAMSES**



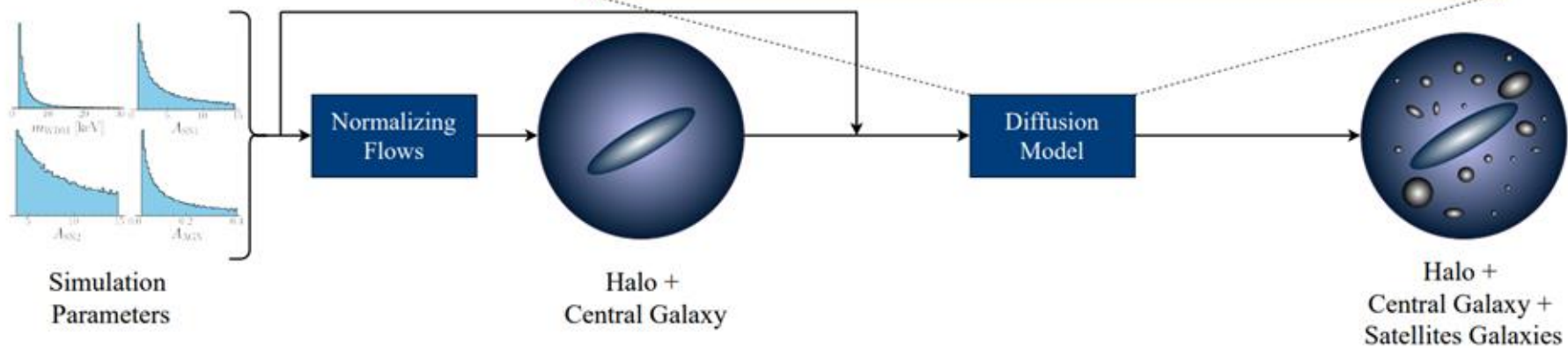
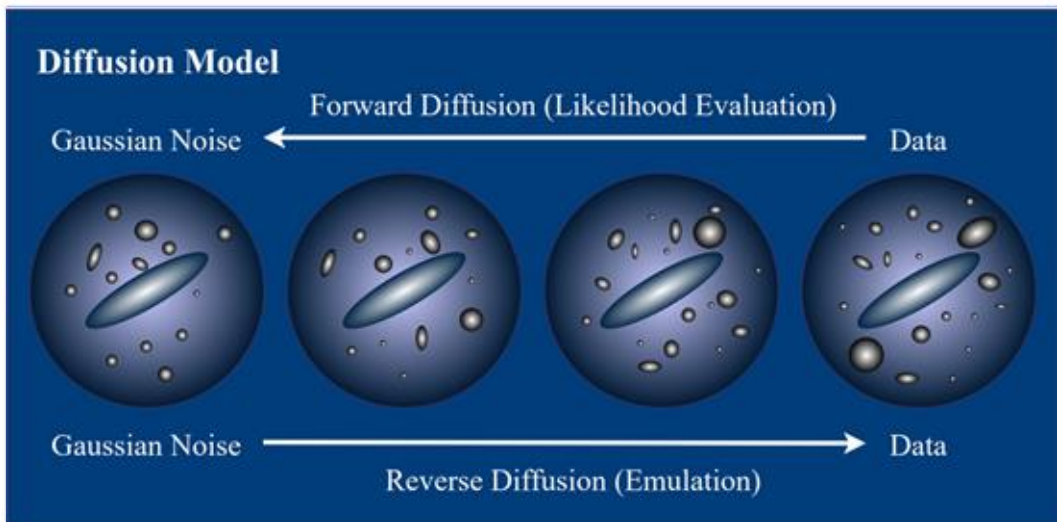
**FIRE**



# NeHOD

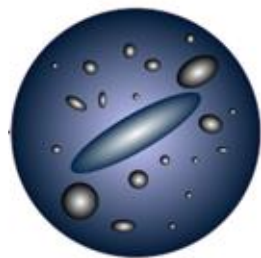
Emulating satellite populations  
with variational diffusion models

Work done by Tri Nguyen

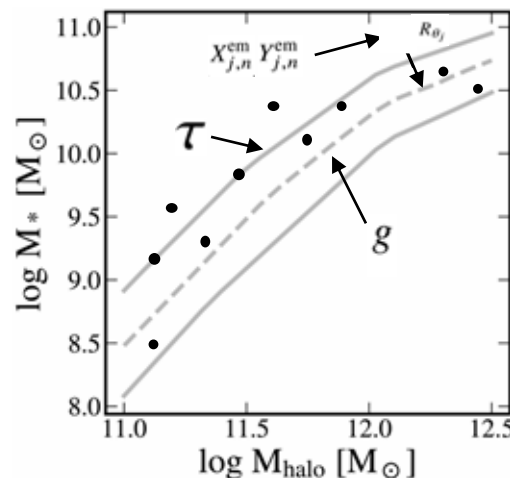


# Calculating Pseudo Posteriors

**Goal:** Calculate the likelihood for our parameter space based on how well galaxies with given parameters recreate observed scaling relations.



Halo +  
Central Galaxy +  
Satellites Galaxies



**Residuals**

$$R_{\theta_j} = \frac{1}{N_j} \sum_{n=1}^{N_j} (y_{j,n}^{\text{em}} - g(x_{j,n}^{\text{em}}))$$

**Parameters** **Stellar Mass** **Halo Mass**

**Observations**

$$\tilde{w}_j = \exp\left(-\frac{R_{\theta_j}^2}{2\tau^2}\right)$$

**Uncertainty**

**Final Weight**

$$w_j = \frac{\tilde{w}_j}{\sum_j \tilde{w}_j}$$

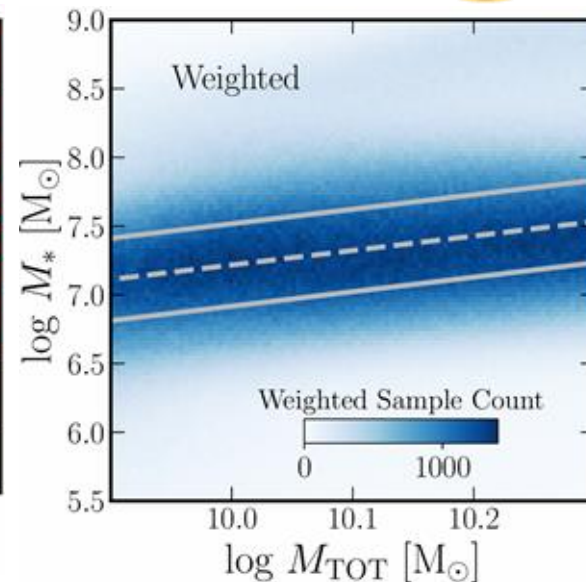
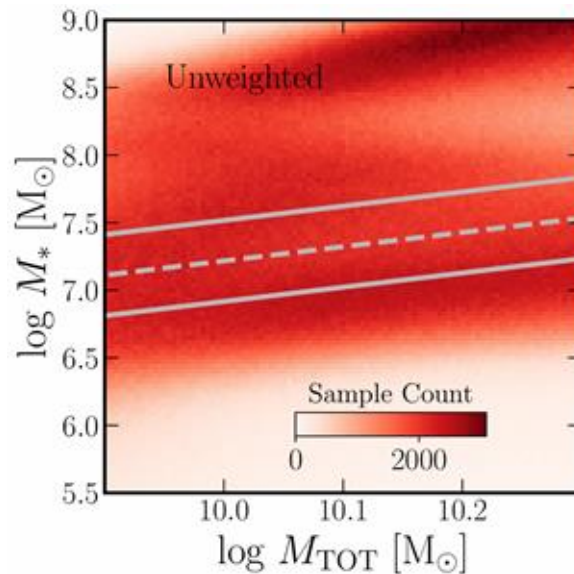


# Realistic Parameter Space Weighting



## Parameter Constraints:

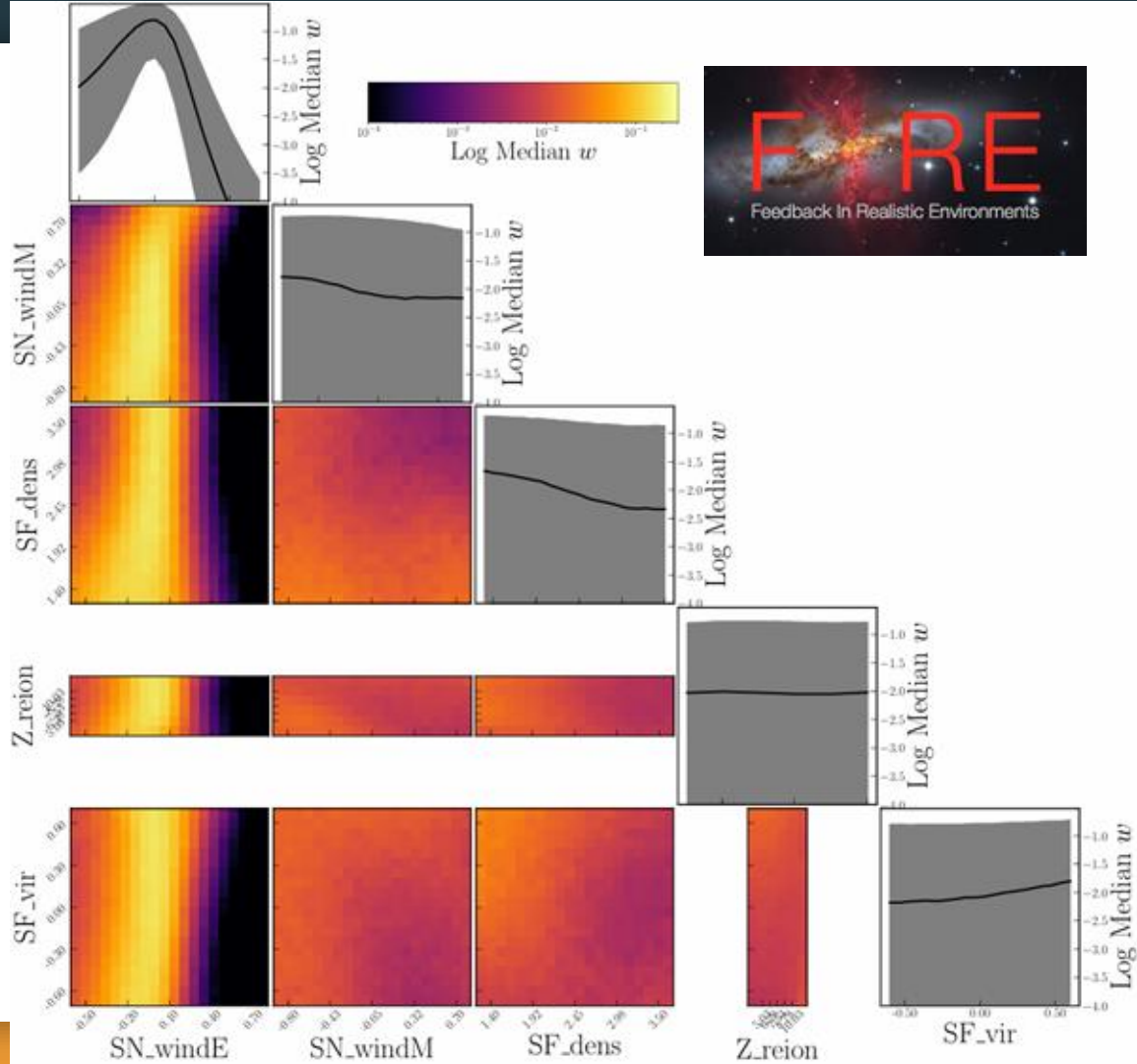
- Uniform priors produce unrealistic galaxies
- Weighting by our likelihood brings the simulated galaxies much closer to observations



# Realistic Parameter Space Weighting

### Parameter Constraints:

- Using the entire parameter space is overestimating the uncertainties.
- Large portions of parameter space are degenerate and produce reasonable galaxies
- This is a conservative estimate, additional constraints can be placed
- Similar to Ramses, SN energy is the most constrained parameter

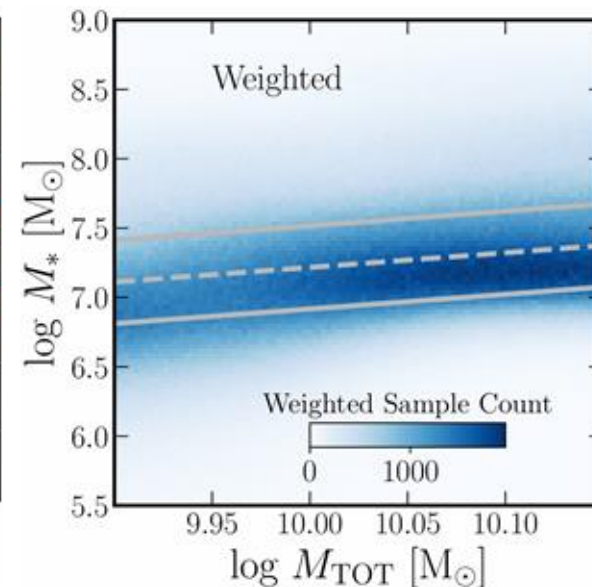
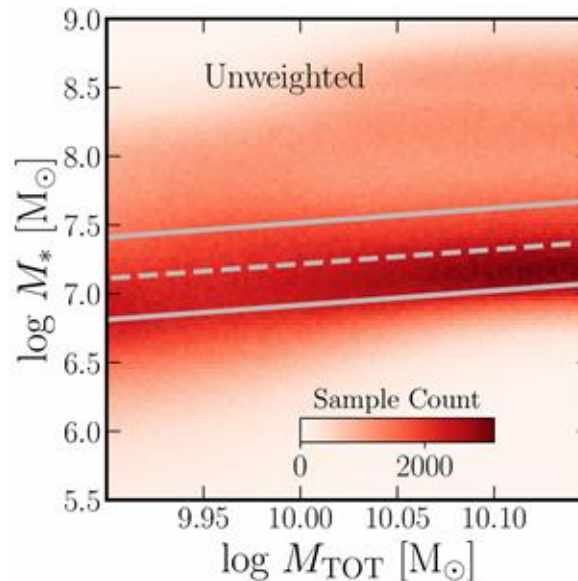


# Realistic Parameter Space Weighting



## Parameter Constraints:

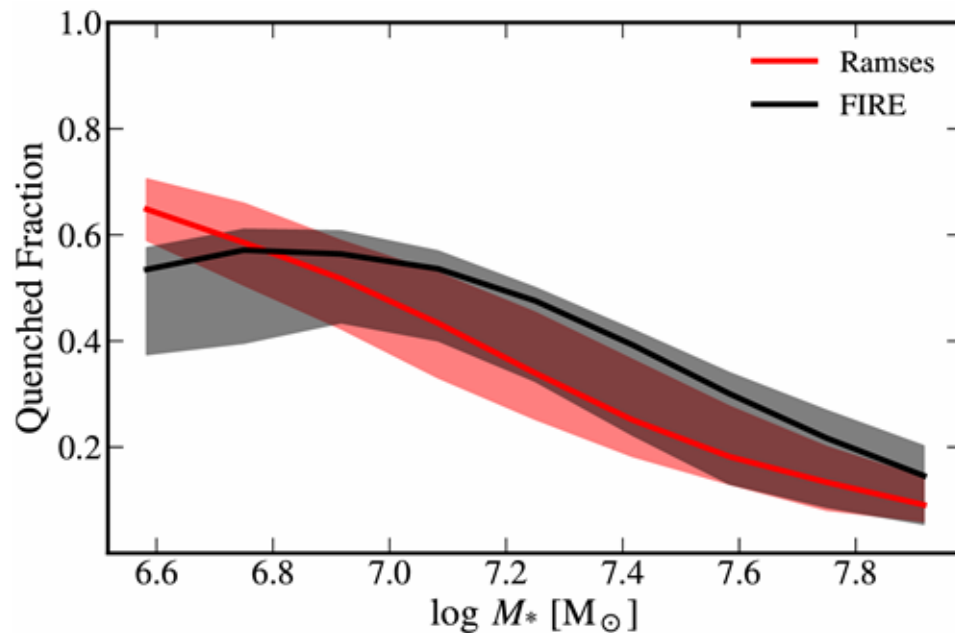
- Uniform priors produce unrealistic galaxies
- Weighting by our likelihood brings the simulated galaxies much closer to observations



# Dwarf Galaxy Predictions

Predictions from fiducial model + uncertainties  
from galaxy formation model.

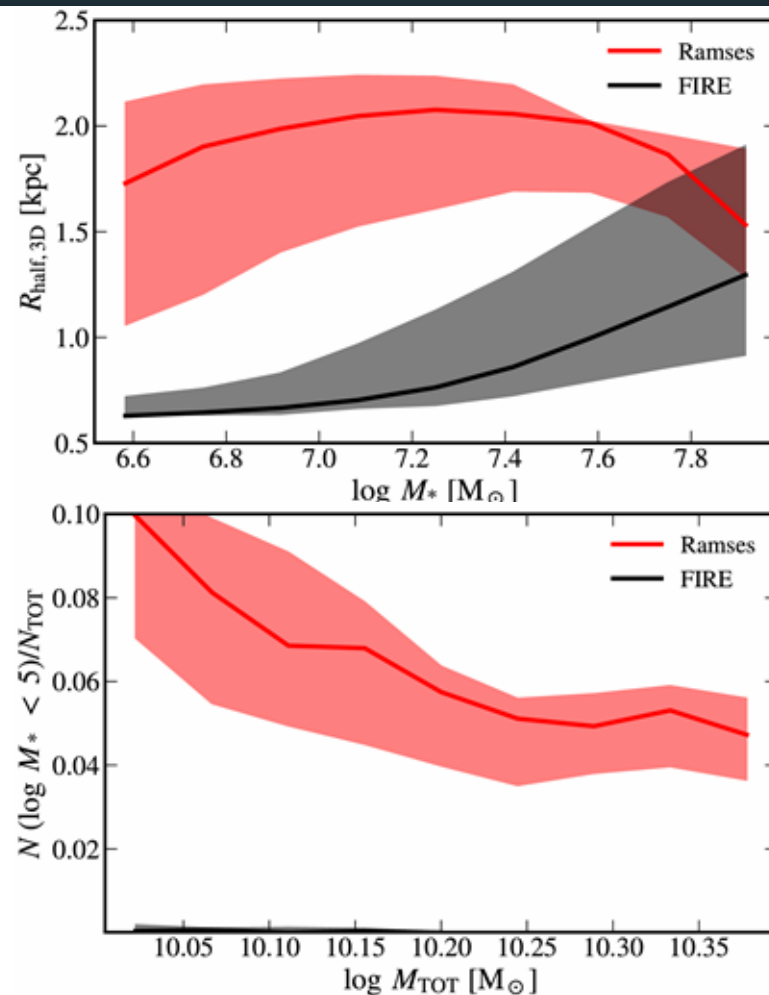
- Quenched Fractions
  - Star formation defined as no star particles form in last 500 Myr.
  - Agree that 20-60% of halos should be quenched within 10%.



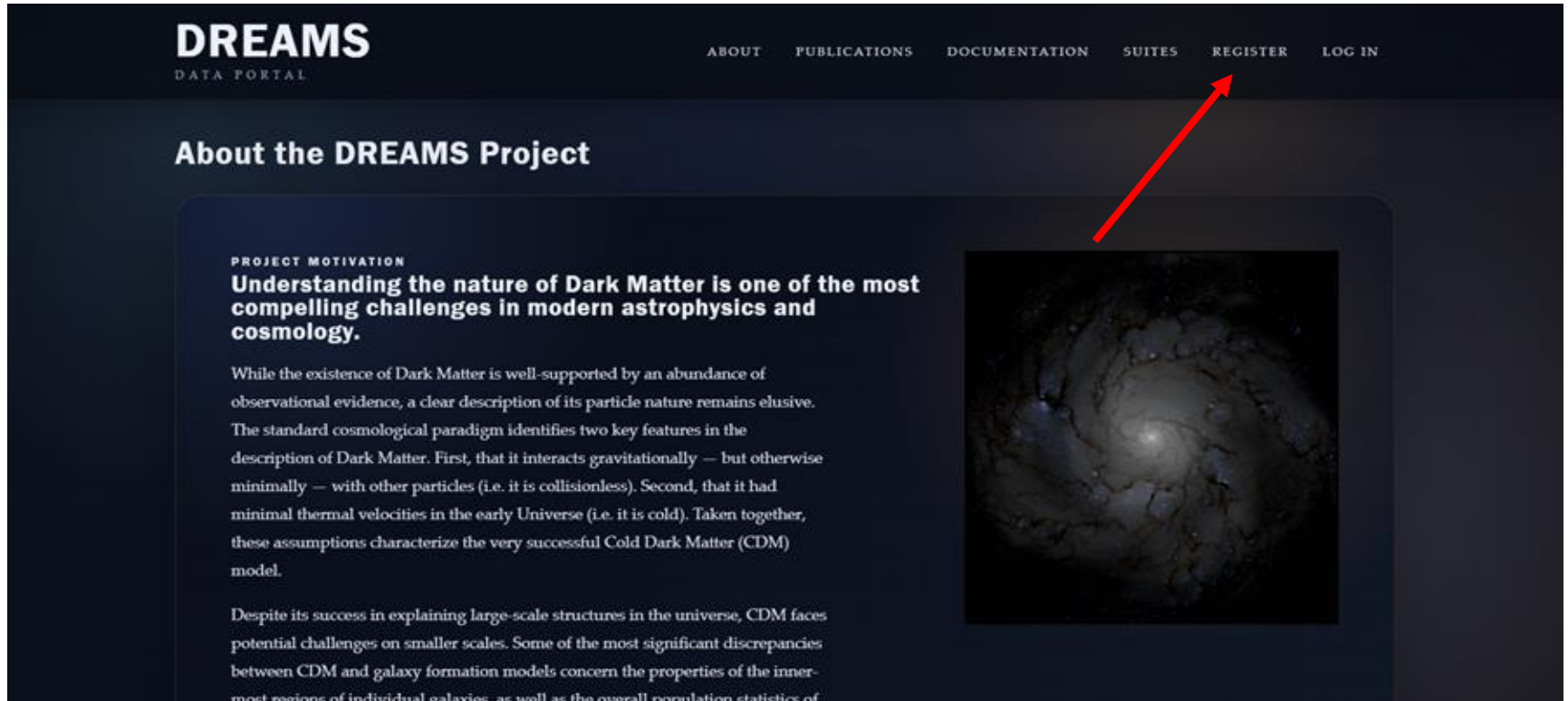
# Dwarf Galaxy Predictions

Predictions from fiducial model + uncertainties from galaxy formation model.

- Quenched Fractions
  - Star formation defined as no star particles form in last 500 Myr.
  - Agree that 20-60% of halos should be quenched within 10%.
- Size-Mass Relation
  - FIRE predicts much more concentrated satellites at all masses
- ‘Dark Halos’
  - Defined as a stellar mass below  $10^5$
  - Ramses predicts a significant population whereas FIRE does not



Updates to DREAMS Website: <https://www.dreams-project.org/>



Updates to DREAMS Website: <https://www.dreams-project.org/>

**DREAMS**  
DATA PORTAL  
REGISTRATION

ABOUT PUBLICATIONS DOCUMENTATION SUITES REGISTER LOG IN

## Request an account.

All public DREAMS data is downloadable with an approved account. Register here.

**BEFORE YOU BEGIN**

Registration creates the account, but access remains inactive until a site administrator approves it. Please be patient with us, we should be able to review your account quickly.

**CREATE ACCOUNT**

### Registration form

USERNAME:

Required. 150 characters or fewer. Letters, digits and @/./+/-/\_ only.

EMAIL:

Updates to DREAMS Website: <https://www.dreams-project.org/>

The screenshot displays the DREAMS Data Portal website. At the top, the 'DREAMS DATA PORTAL' logo is on the left, and navigation links for 'ABOUT', 'PUBLICATIONS', 'DOCUMENTATION', 'SUITES', 'REGISTER', and 'LOG IN' are on the right. The main content area is divided into two sections. The upper section, titled 'USER ACCESS', features the heading 'Log in for easy access.' and a subtext: 'Approved users can sign in here to view their account status and generate or rotate an API key.' To the right of this is a box labeled 'APPROVAL REQUIRED' stating: 'Newly registered accounts cannot log in until an administrator approves access in the DREAMS admin portal.' The lower section, titled 'SIGN IN', has the heading 'Approved user login' and contains input fields for 'USERNAME:' and 'PASSWORD:'.

**DREAMS**  
DATA PORTAL

ABOUT PUBLICATIONS DOCUMENTATION SUITES REGISTER LOG IN

**USER ACCESS**

**Log in for easy access.**

Approved users can sign in here to view their account status and generate or rotate an API key.

**APPROVAL REQUIRED**

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**SIGN IN**

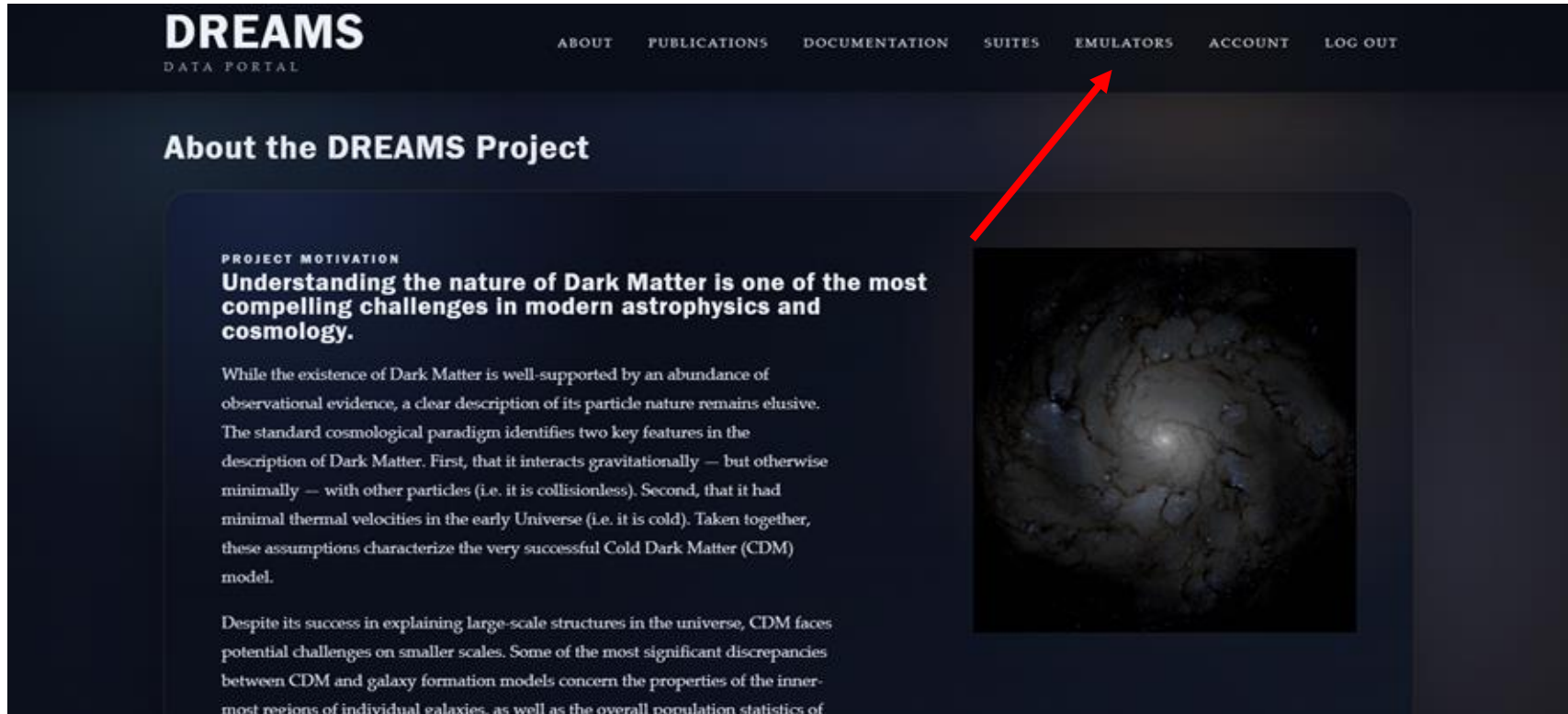
**Approved user login**

USERNAME:

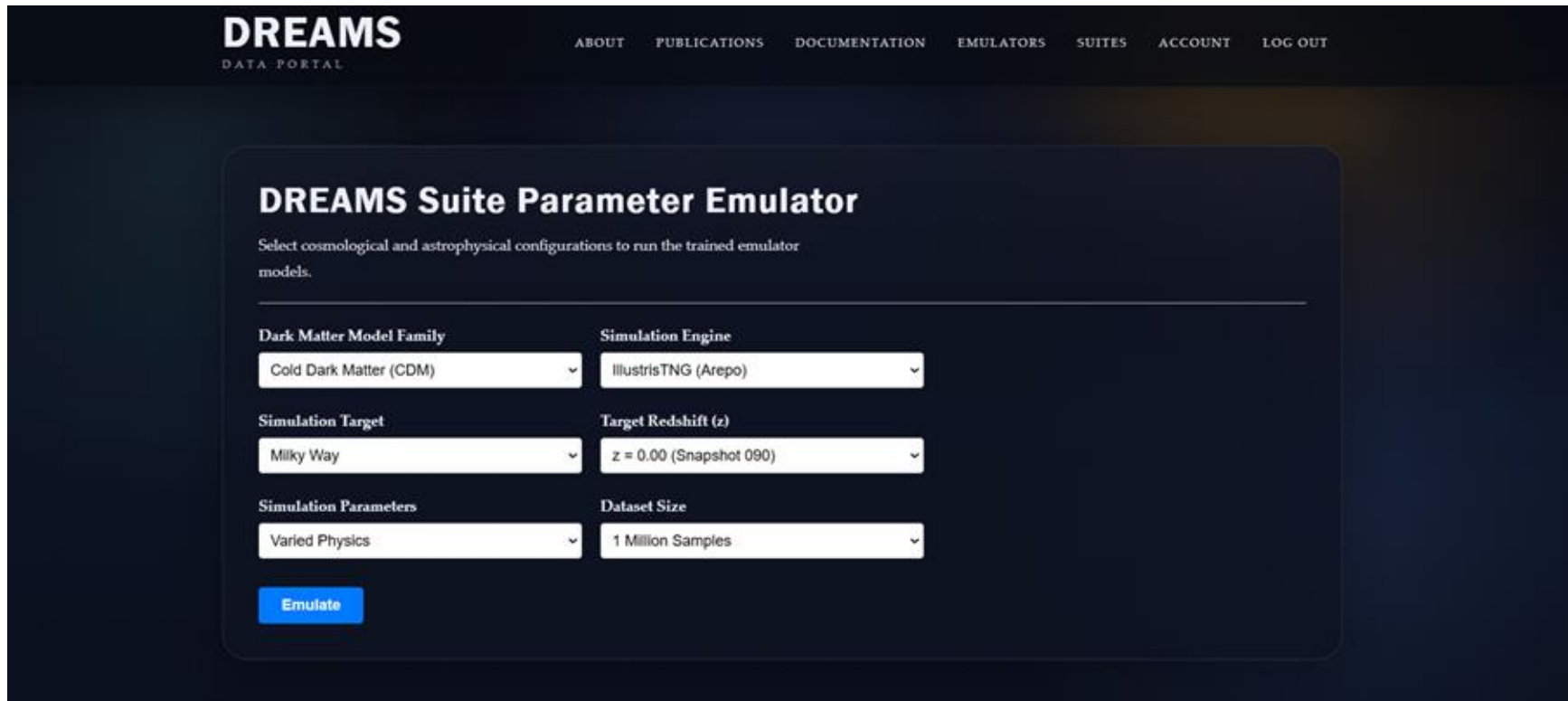
PASSWORD:

# Updates to DREAMS Website:

<https://www.dreams-project.org/>



Updates to DREAMS Website: <https://www.dreams-project.org/>



The screenshot shows the DREAMS Suite Parameter Emulator web interface. At the top, the DREAMS logo is on the left, and navigation links (ABOUT, PUBLICATIONS, DOCUMENTATION, EMULATORS, SUITES, ACCOUNT, LOG OUT) are on the right. The main content area is titled "DREAMS Suite Parameter Emulator" and includes a subtitle: "Select cosmological and astrophysical configurations to run the trained emulator models." Below this, there are six dropdown menus arranged in three rows and two columns. The first row contains "Dark Matter Model Family" (set to "Cold Dark Matter (CDM)") and "Simulation Engine" (set to "IllustrisTNG (Arepo)"). The second row contains "Simulation Target" (set to "Milky Way") and "Target Redshift (z)" (set to "z = 0.00 (Snapshot 090)"). The third row contains "Simulation Parameters" (set to "Varied Physics") and "Dataset Size" (set to "1 Million Samples"). A blue "Emulate" button is located at the bottom left of the form area.

**DREAMS**  
DATA PORTAL

ABOUT PUBLICATIONS DOCUMENTATION EMULATORS SUITES ACCOUNT LOG OUT

## DREAMS Suite Parameter Emulator

Select cosmological and astrophysical configurations to run the trained emulator models.

**Dark Matter Model Family**  
Cold Dark Matter (CDM) ▼

**Simulation Engine**  
IllustrisTNG (Arepo) ▼

**Simulation Target**  
Milky Way ▼

**Target Redshift (z)**  
z = 0.00 (Snapshot 090) ▼

**Simulation Parameters**  
Varied Physics ▼

**Dataset Size**  
1 Million Samples ▼

**Emulate**

# Summary

## Analysis Results

- Presented a light-weight and interpretable likelihood evaluation
- Found large degeneracies between astrophysical parameters

## Data Products

- 1024 low-resolution simulations, each with  $\sim 100,000$  galaxies
- 2048 high-resolution simulations, each with 1 Milky Way galaxy and  $\sim 10$  satellites
- 1536 ultra-high-res simulations of low-mass galaxies and their satellites
- (Upcoming) 1680 Mass-Varied Simulations

**See Cassidy's (previous)  
and Ethan's (tomorrow)  
talks**

**This Talk**

**Alex's Talk  
(tomorrow)**

## Tools

- Python tutorials for loading data and doing basic analysis
- Generative model: NeHOD
- Convolutional Neural Network Architecture and Training Scripts (CNNs)
- Graph Neural Network Architecture and Training Scripts (GNNs)



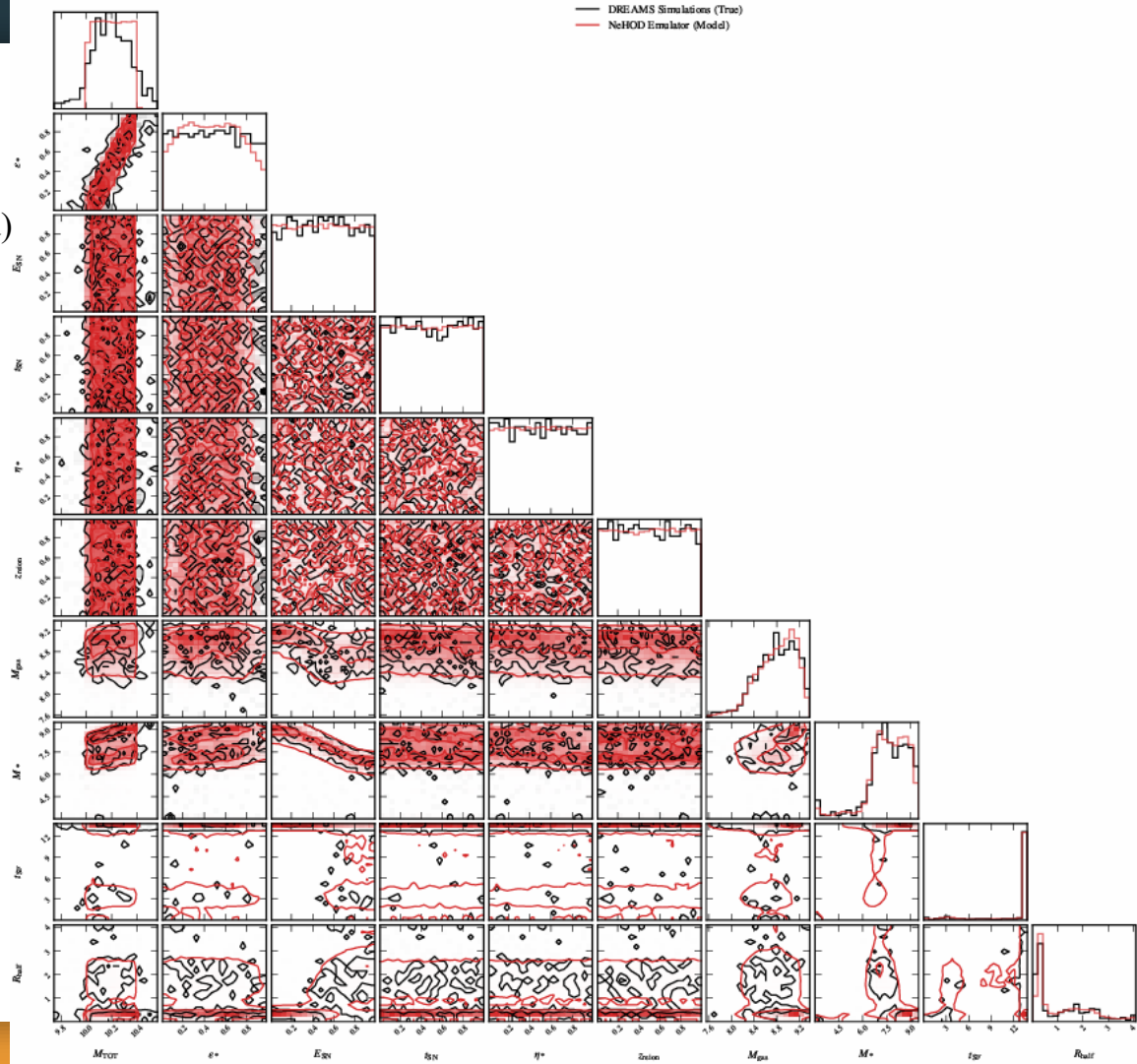
Extra Slides

# Validation

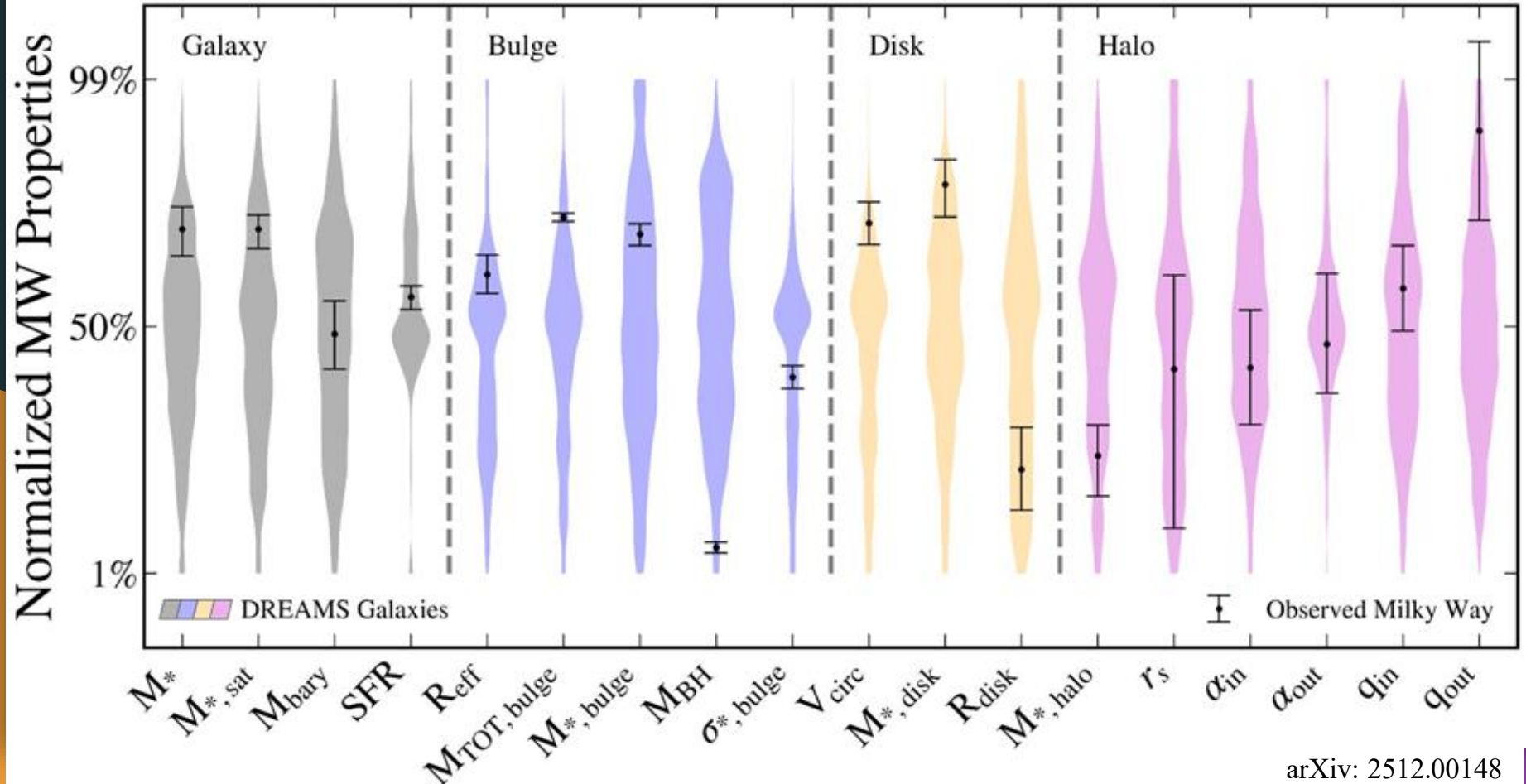
Comparing simulated (black) and emulated (red) datasets

Generally match well out to 2 sigma.

To do: match input distributions better.



# Milky Way Properties



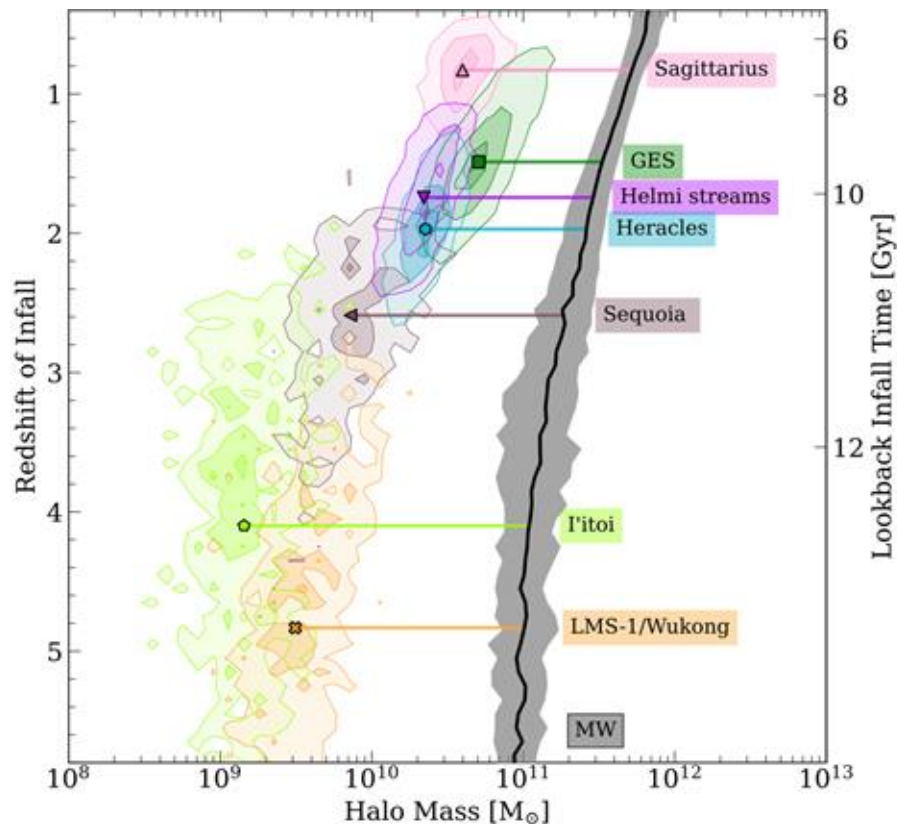
# Are These Milky Way Analogs?

Milky Way Merger Tree from Santi et al.:

- We know of  $\sim 10$  significant mergers in the Milky Way's past
- Most stars from these mergers reside in the Milky Way's stellar halo
- These have rough estimates for their mass and merger times

The Gaia-Sausage-Enceladus Merger:

- The largest galaxy to merge with the Milky Way (until the LMC)
- The last major merger with the Milky Way
- Occurred  $\sim 9$  Gyr ago



# Selecting a Sub-Population (GSEs)

GAIA-Sausage-Enceladus (GSE) Merger selection criteria:

1. The stellar mass ratio must be at least 1:5 .

$$M_{\text{MW}}/M_{\text{gse}} < 5$$

1. The merger must occur between  $z=1$  and  $z=2$ .

$$t_{\text{gse}} \in [0.33, 0.5]$$

1. The time of the next major merger (ratio > 1:50) must be before  $z=1$ .

$$t_{\text{mm}} < 0.5$$

1. The merger debris must make up at least half the  $z=0$  stellar halo.

$$f > 0.5$$

1. It must have been a radial merger.

$$\beta = 1 - \frac{\sigma_{\phi}^2 + \sigma_{\theta}^2}{2\sigma_r^2}$$

Population that passes the selection criteria:

1. 304 of 803 simulations (20%)

- a. 304 of 803 (38%)

1. 121 of 304 simulations (40%)

- a. 353 of 803 (44%)

1. 77 of 121 simulations (64%)

- a. 233 of 803 (29%)

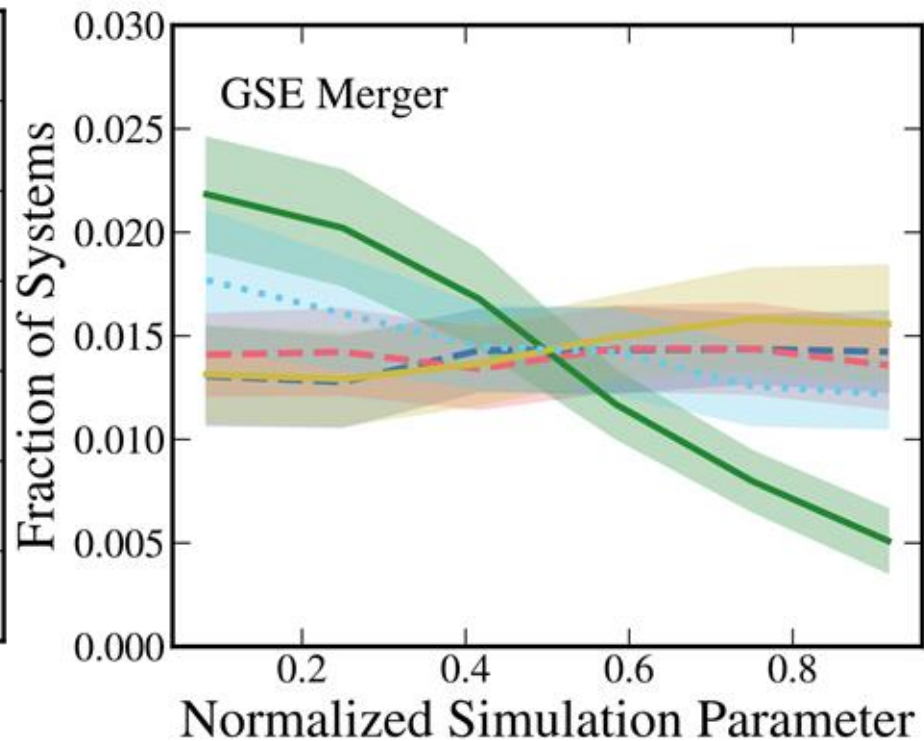
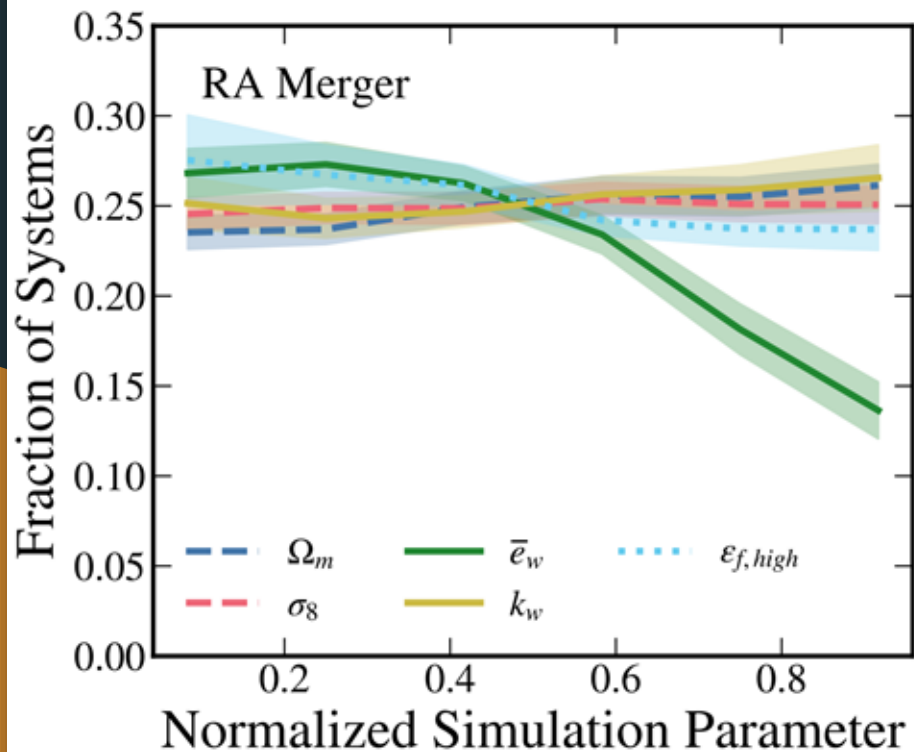
1. 21 of 77 simulations (27%)

- a. 322 of 803 (40%)

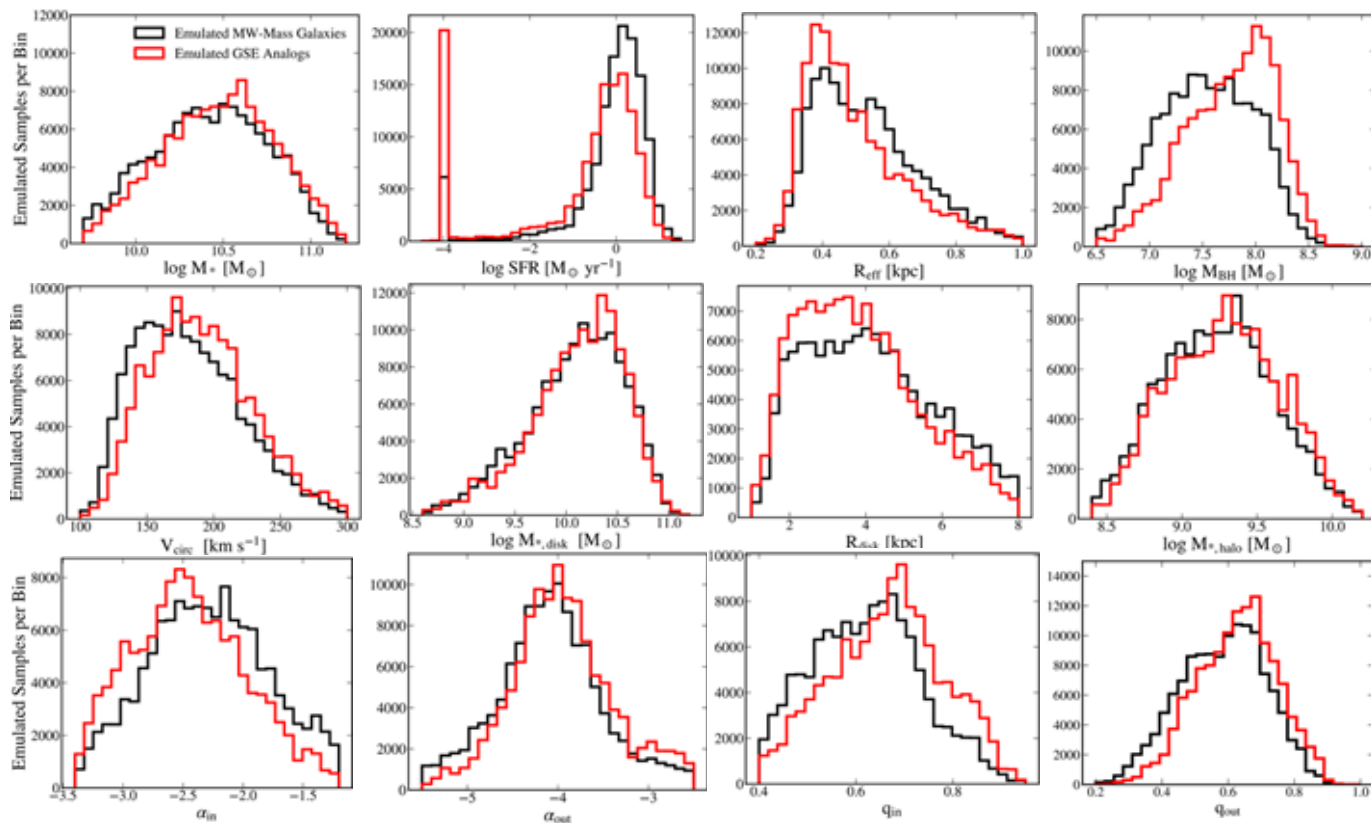
1. 11 of 21 simulations (52%)

- a. 495 of 803 (62%)

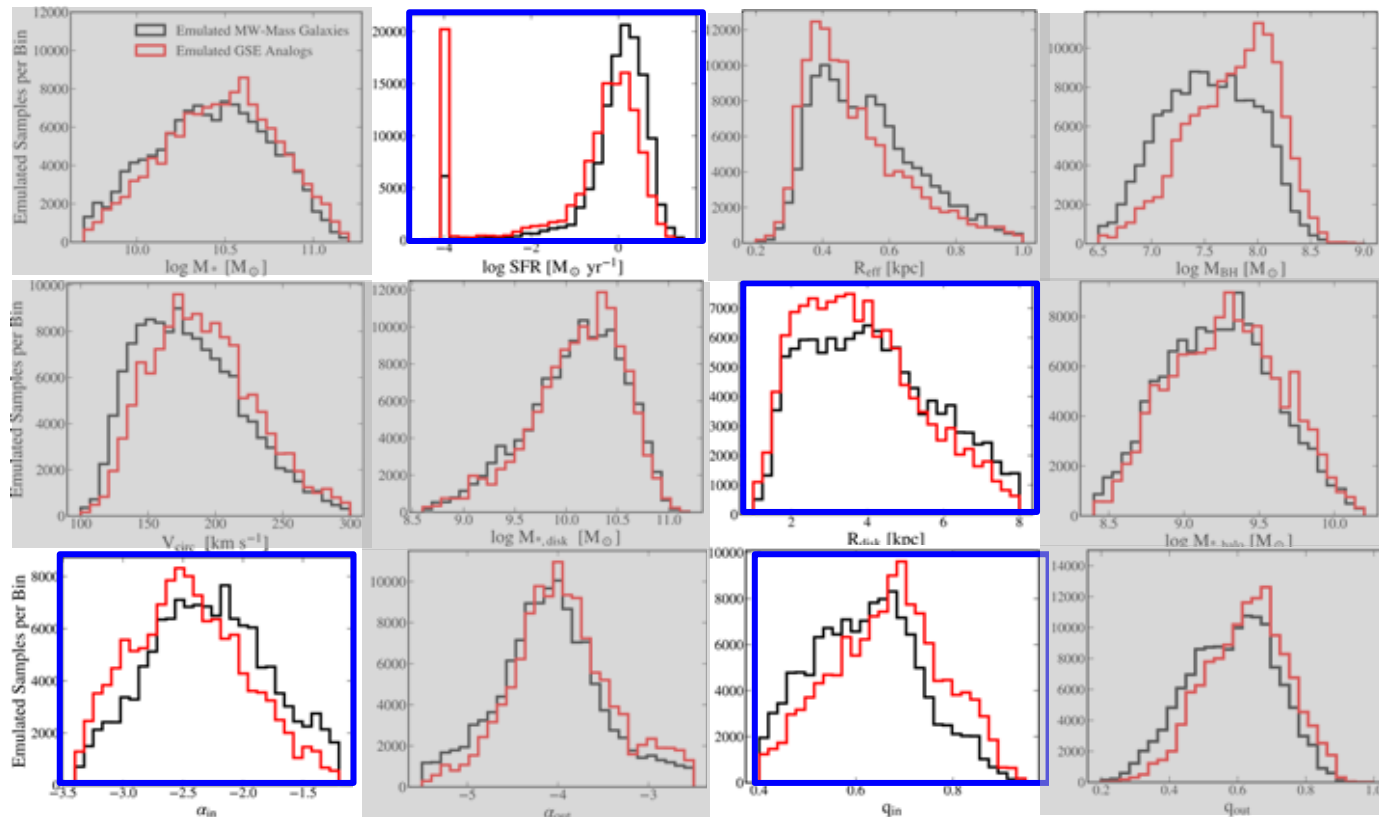
# GSE Frequency



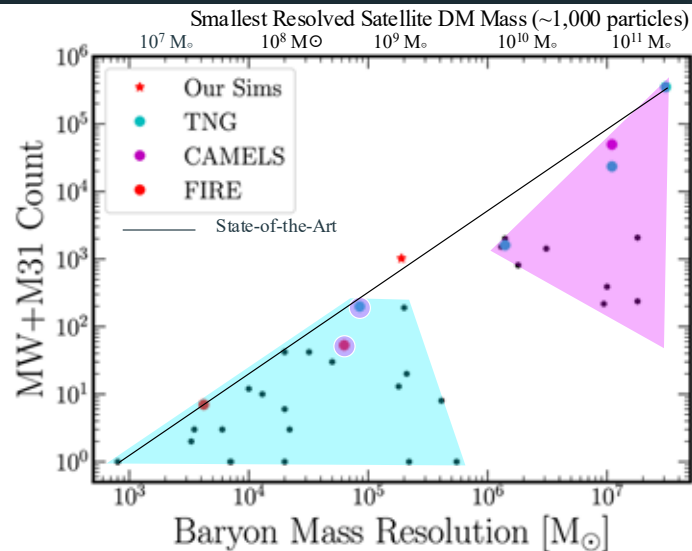
# Unnormalized GSE Results



# Unnormalized GSE Results



# Simulation Landscape

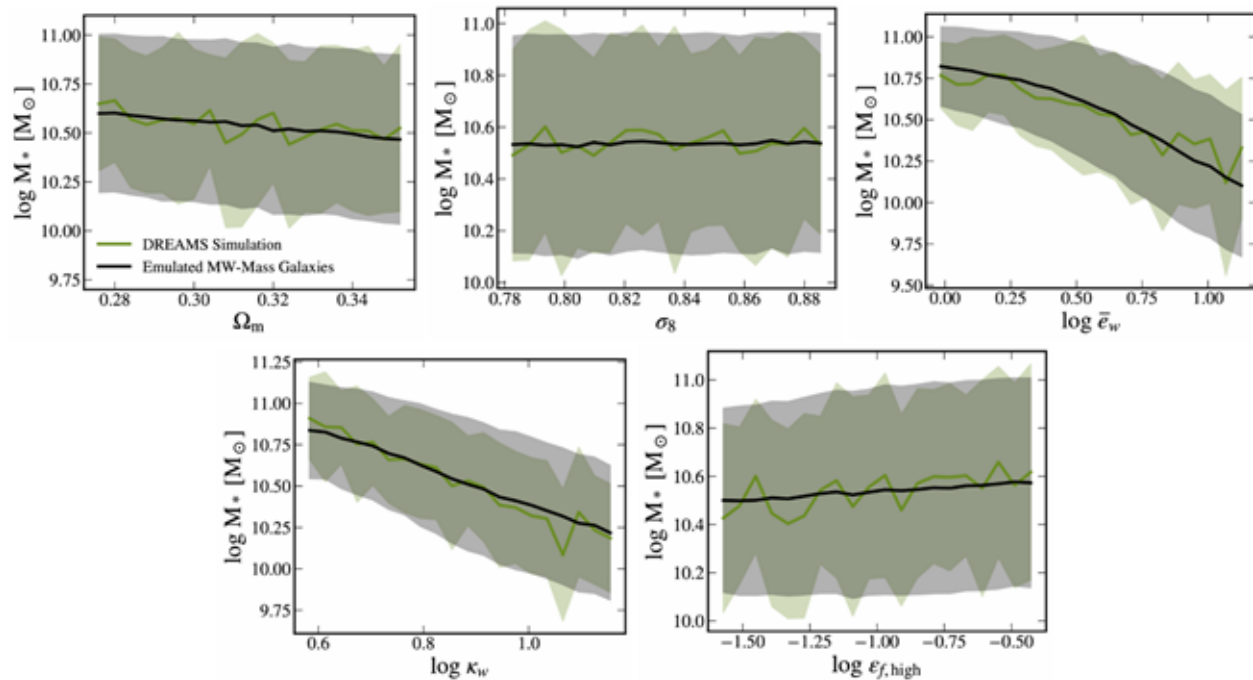


| Dark Matter Prescription | # of Sims | Simulation Type | Baryon Prescription | Cosmology | Mass Resolution [ $h^{-1}\Omega_m M_\odot$ ] | Spatial Resolution [ $h^{-1}$ pc] | Notes                              |
|--------------------------|-----------|-----------------|---------------------|-----------|----------------------------------------------|-----------------------------------|------------------------------------|
| Cold Dark Matter         | 1024      | Milky Way       | N-body              | Varied    | $4.0 \times 10^6$                            | 305                               | Rose et al. in prep.               |
|                          | 1024      | Milky Way       | TNG                 | Varied    | $4.0 \times 10^6$                            | 305                               | Rose et al. in prep.               |
|                          | 1024      | M10             | Ramses              | Varied    | $1.0 \times 10^4$                            | 50                                | Forthcoming                        |
|                          | 1024      | M10             | FIRE                | Varied    | $1.0 \times 10^4$                            | 50                                | Forthcoming                        |
|                          | 1024      | M10             | Changa              | Varied    | $1.0 \times 10^4$                            | 50                                | Forthcoming                        |
| Warm Dark Matter         | 200       | Uniform Box     | N-body              | Fixed     | $3.3 \times 10^7$                            | 1000                              | <a href="#">Rose et al. (2024)</a> |
|                          | 1000      | Uniform Box     | N-body              | Varied    | $2.6 \times 10^8$                            | 1000                              | <a href="#">Rose et al. (2024)</a> |
|                          | 1024      | Uniform Box     | TNG                 | Varied    | $2.6 \times 10^8$                            | 1000                              | <a href="#">Rose et al. (2025)</a> |
|                          | 1024      | Milky Way       | TNG                 | Fixed     | $4.0 \times 10^6$                            | 305                               | <a href="#">Rose et al. (2025)</a> |

# Validation Tests

## Validation Tests:

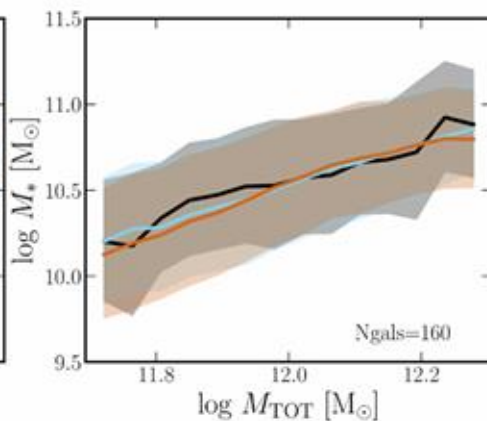
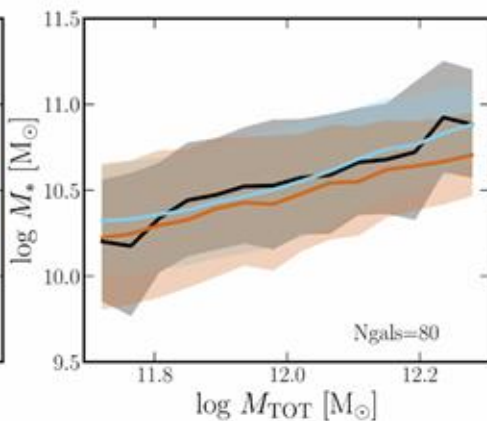
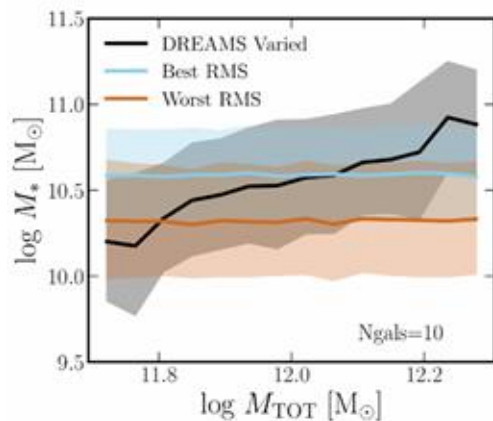
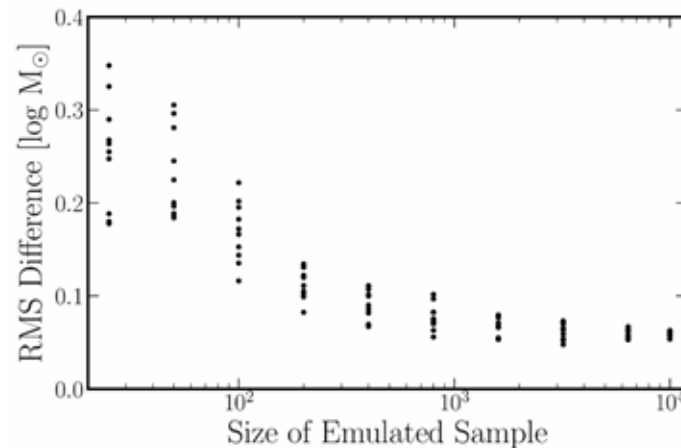
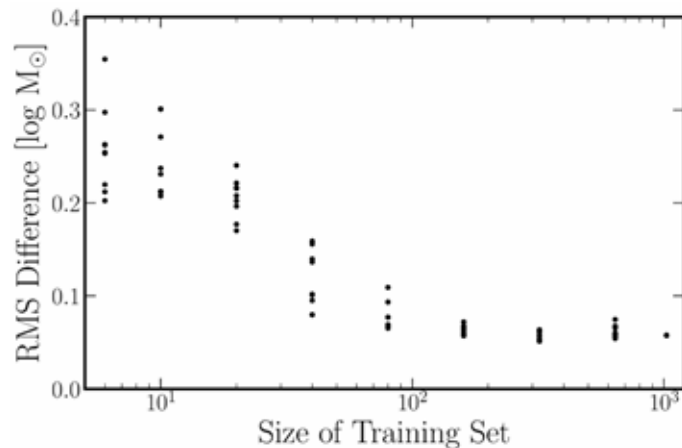
- Converged to size of training set
- Converged to size of emulated sample
- The network is learning the 1D trends between each parameter



# Validation Tests

Validation Tests:

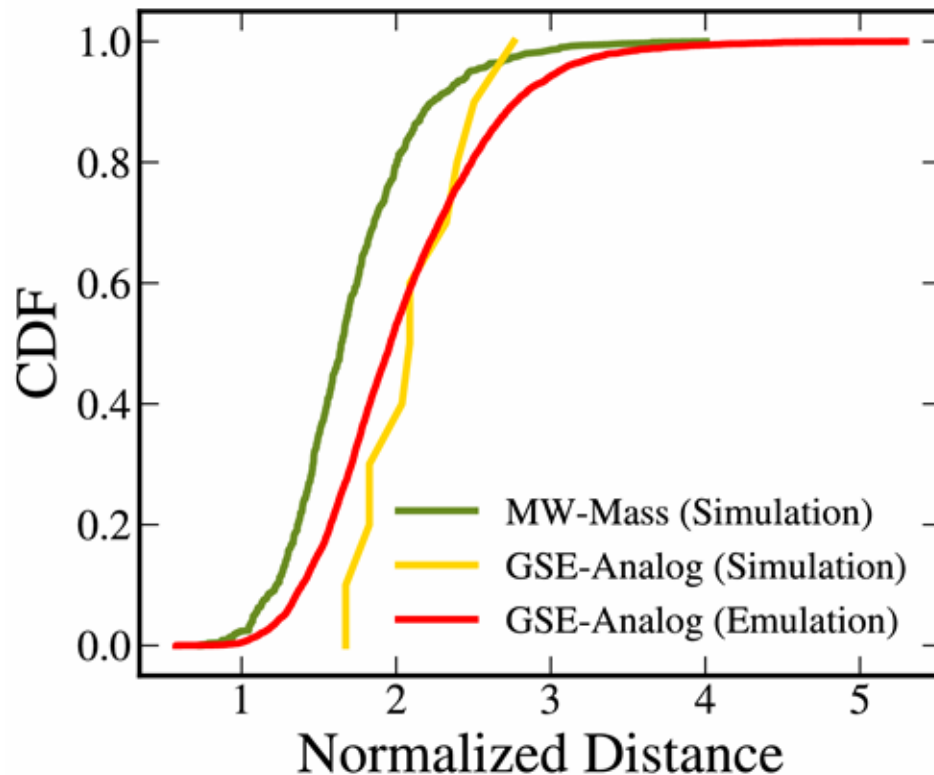
- Converged to size of training set
- Converged to size of emulated sample



# Validation Tests

## Validation Tests:

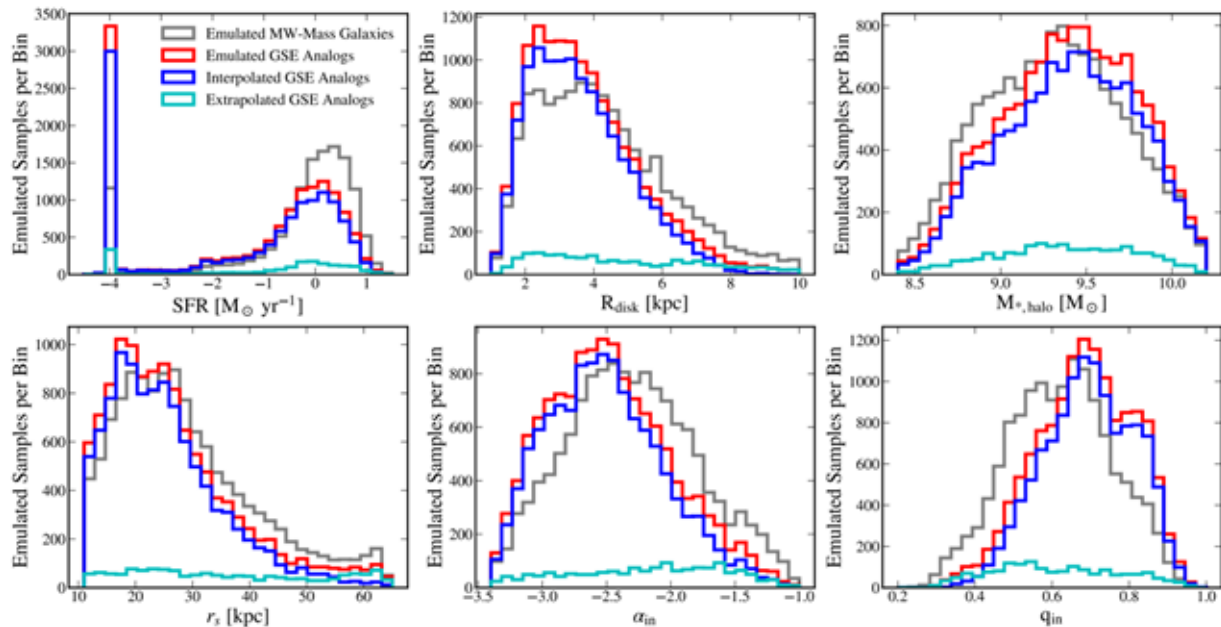
- Converged to size of training set
- Converged to size of emulated sample
- The network is learning the 1D trends between each parameter
- The network is learning the 2D covariances between parameters.
- The network is mostly interpolating in the region with GSE simulations



# Validation Tests

## Validation Tests:

- Converged to size of training set
- Converged to size of emulated sample
- The network is learning the 1D trends between each parameter
- The network is learning the 2D covariances between parameters.
- The network is mostly interpolating in the region with GSE simulations
- Our results do not change if we only use interpolated (distance < 2.7) samples



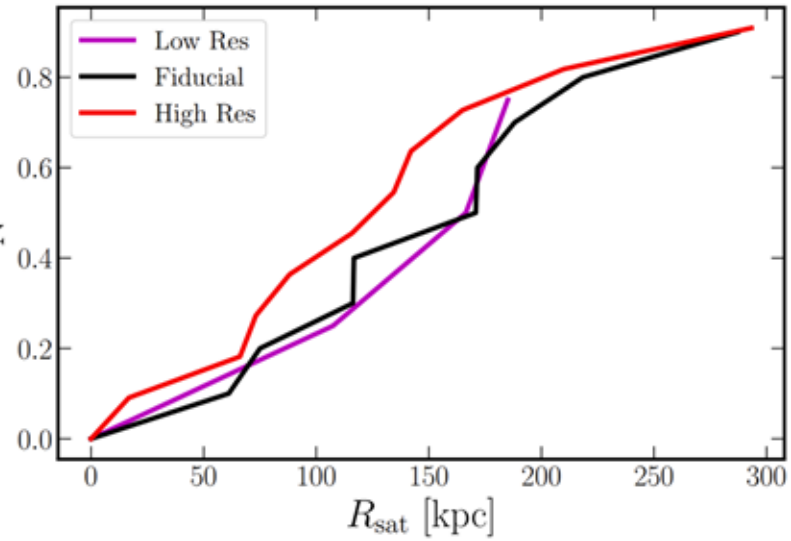
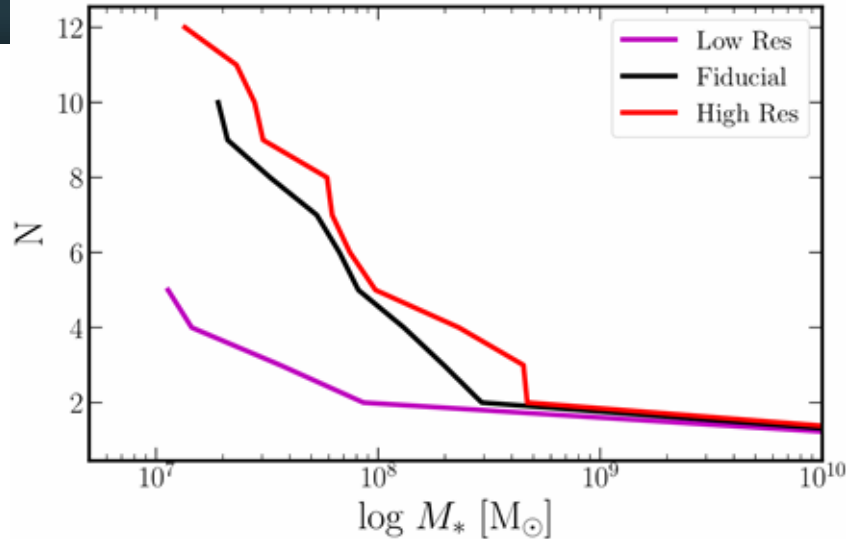
# Resolution Test

## Satellite Mass Function

- Satellite numbers similar between fiducial and high-re
- Stellar masses increase with increasing resolution (knc

## Radial Distribution

- Radii are similar but high-res simulation are slightly cl



# Resolution Test

Dark Matter Profile Slope:

- Fiducial and high-res are similar up to  $\sim 10^{9.5}$
- Low-res simulations not resolved at this radius

Satellite Sizes:

- TNG not limited by subgrid pressure floor at these r

