Title: Probing Baryonic Feedback and Cosmological Tension with Fast Radio Bursts: Insights from CAMELS

Speakers: Isabel Medlock

Collection/Series: Cosmic Ecosystems

Date: August 01, 2025 - 11:50 AM

URL: https://pirsa.org/25080006

Abstract:

Fast Radio Bursts (FRBs) are powerful probes of diffuse ionized baryons, offering unique insights into the cosmic ecosystems from the circumgalactic medium (CGM) to the intergalactic medium (IGM). Utilizing simulation suites from the CAMELS project—IllustrisTNG, SIMBA, and Astrid—we analyze FRB dispersion measures (DMs) across models with varying cosmological and astrophysical parameters. Our analysis shows that DM radial profiles around the CGM are highly sensitive to baryonic effects, with strong ejective feedback causing baryon spread in and around halos. On larger scales, we introduce "baryon spread" as a robust measure of baryonic impact on the matter power spectrum. Our study reveals a strong correlation between FRB statistics, particularly the F-parameter, and baryon spread in CAMELS simulations, independent of subgrid galaxy formation models. This correlation offers a novel pathway for using FRBs to correct for baryonic effects in ongoing and upcoming cosmological surveys, such as DESI, Euclid, Roman, and Rubin. With large FRB samples, our findings highlight the pivotal role of FRBs in bridging astrophysics and cosmology, offering new constraints on the CGM and enhancing the power of next-generation cosmological surveys.

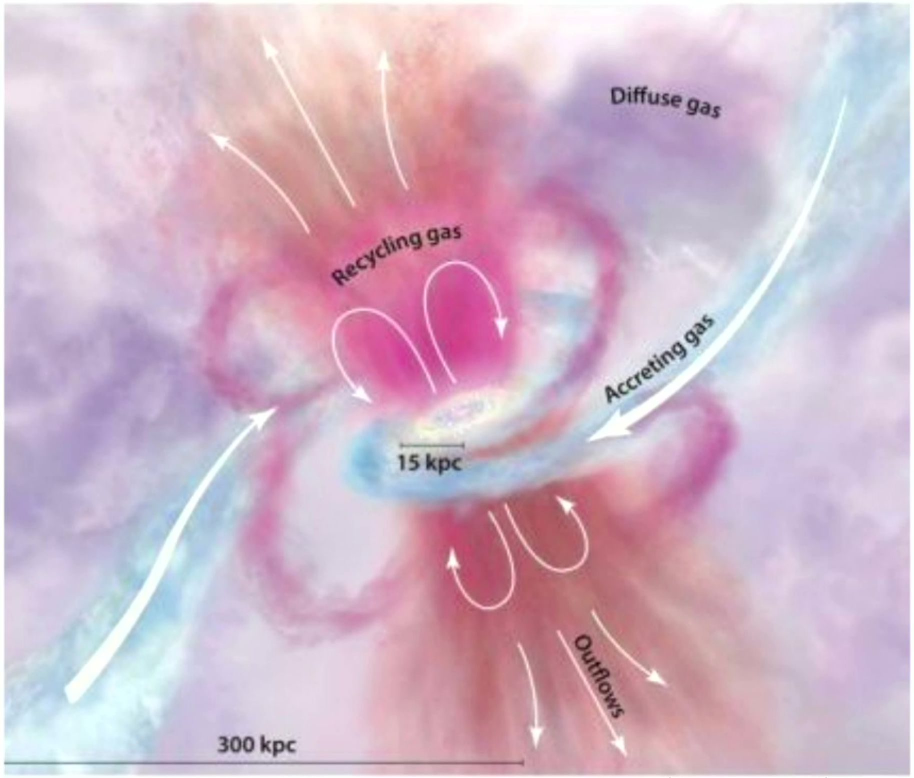
Probing Baryonic Feedback and Cosmological Tension with Fast Radio Bursts

Insights from CAMELS

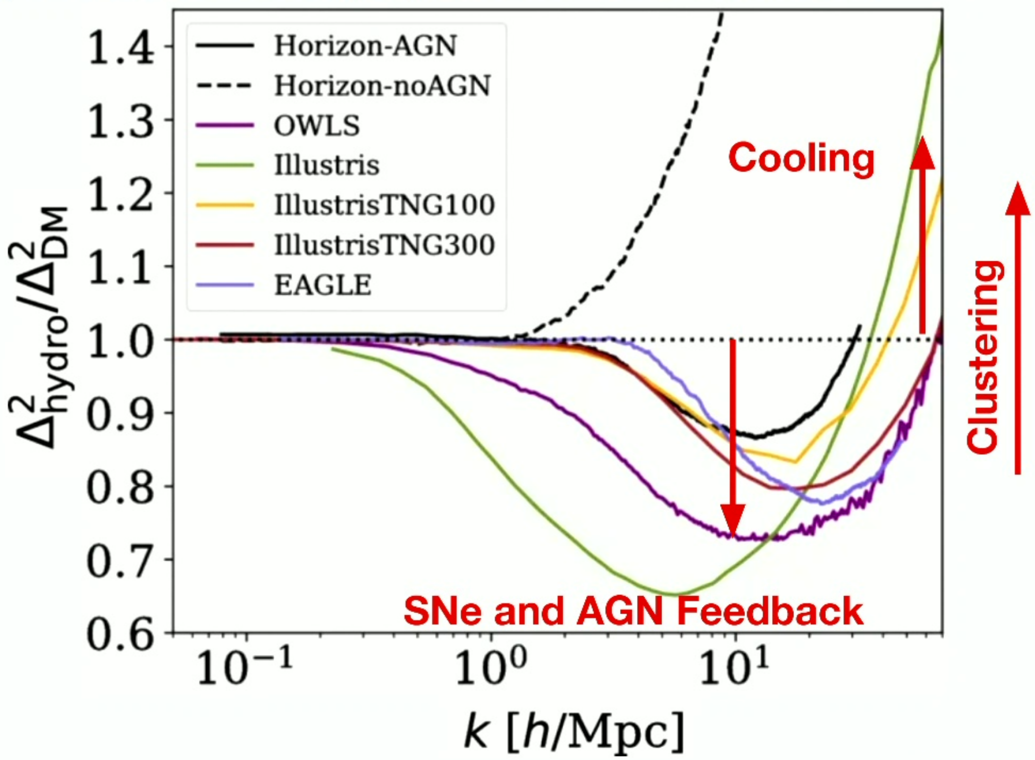
Isabel Medlock, 5th year PhD Candidate at Yale University
with Daisuke Nagai and the CAMELS Collaboration

Baryonic Effects on Cosmology and Astrophysics

Baryons have complex and wide ranging effects on the physics of our Universe



Tumlinson et al. 2017



Chisari et al. 2018

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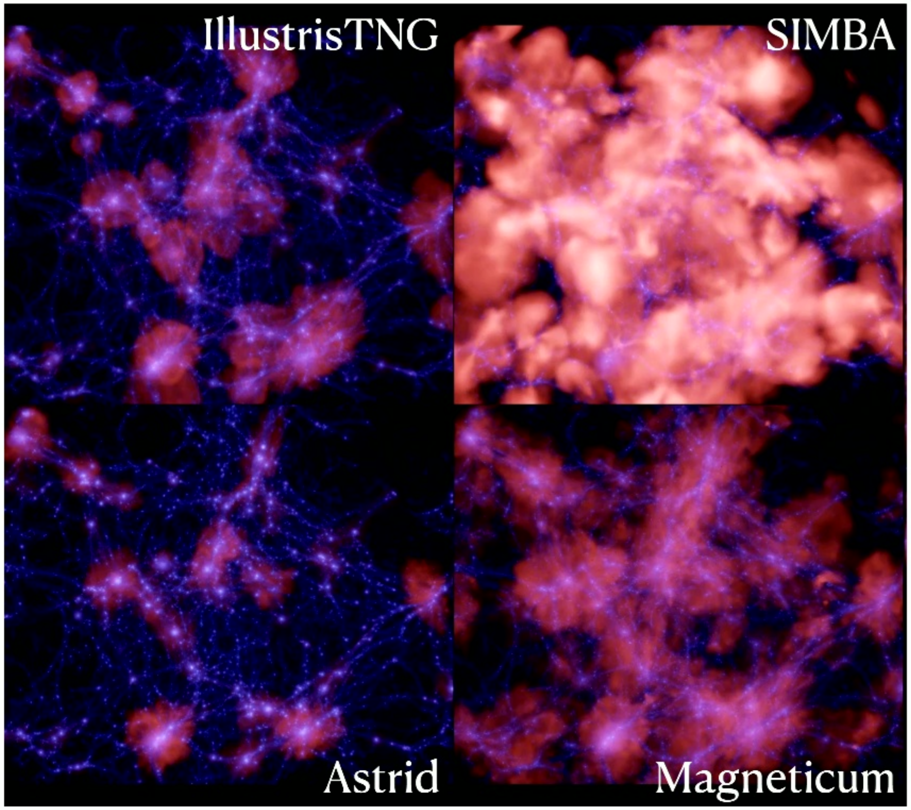
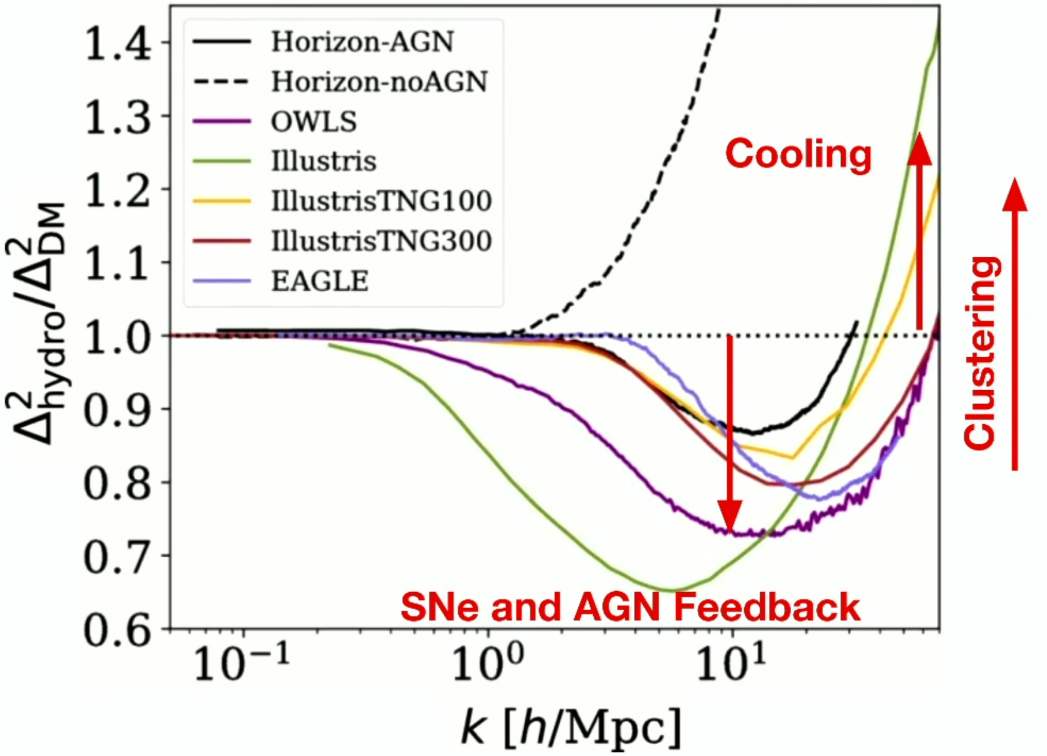
Baryonic Effects on Cosmology and Astrophysics

The predicted effects of baryons vary significantly, depending on the simulation



CAMELS Project



Chisari et al. 2018

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Baryonic Effects on Cosmology and Astrophysics

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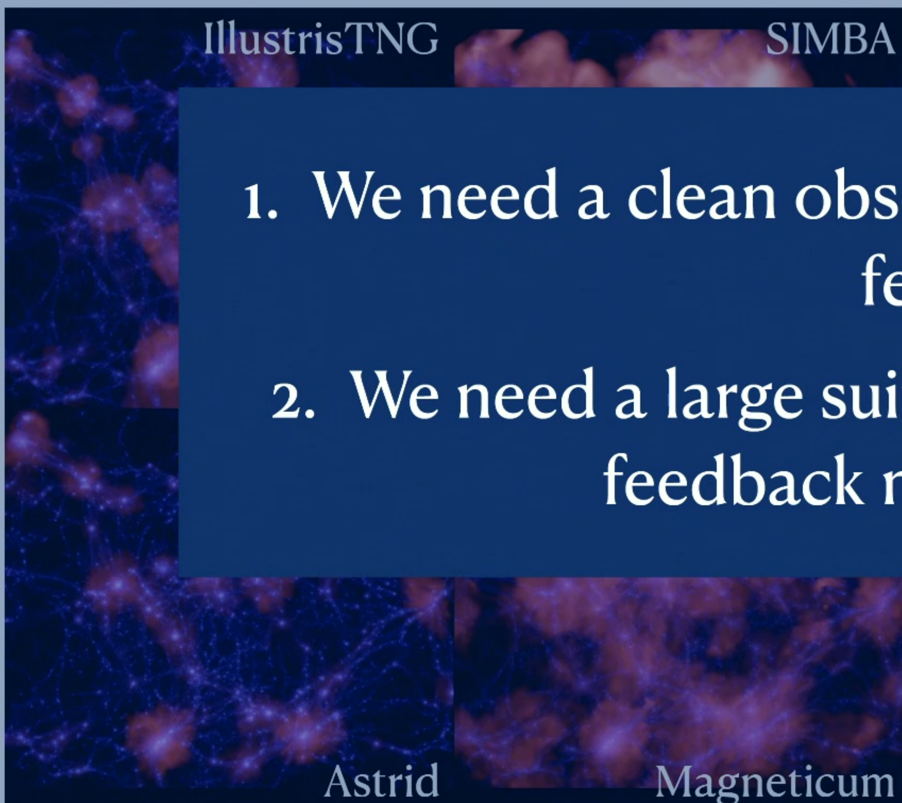
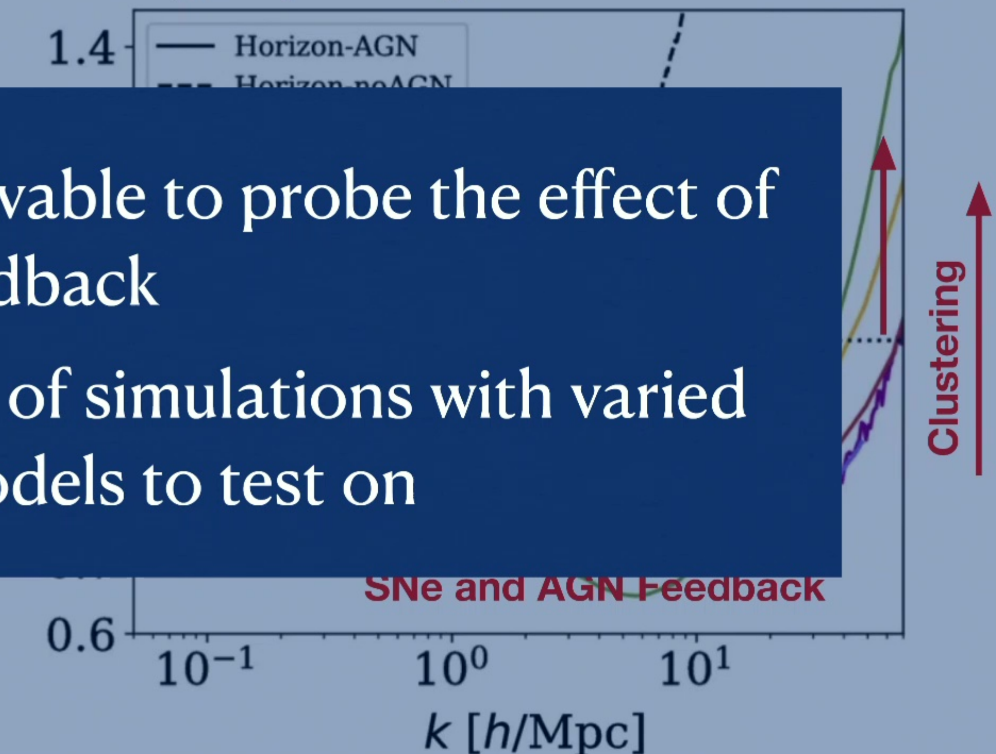


CAMELS Project



Chisari et al. 2018

1. We need a clean observable to probe the effect of feedback
2. We need a large suite of simulations with varied feedback models to test on

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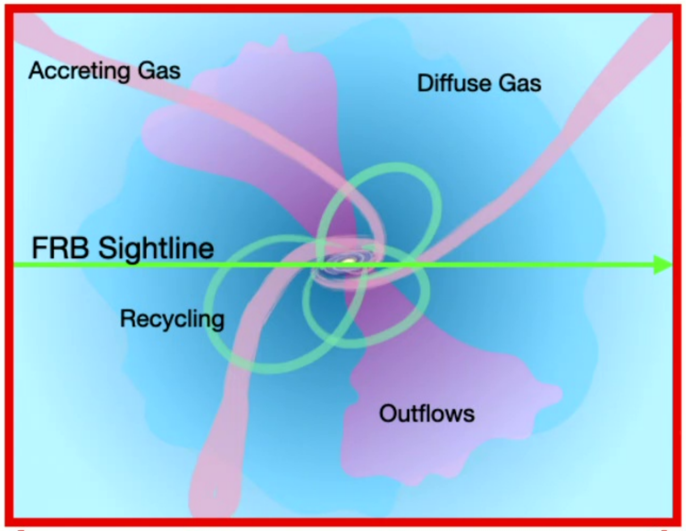
Fast Radio Bursts as Cosmological Probes

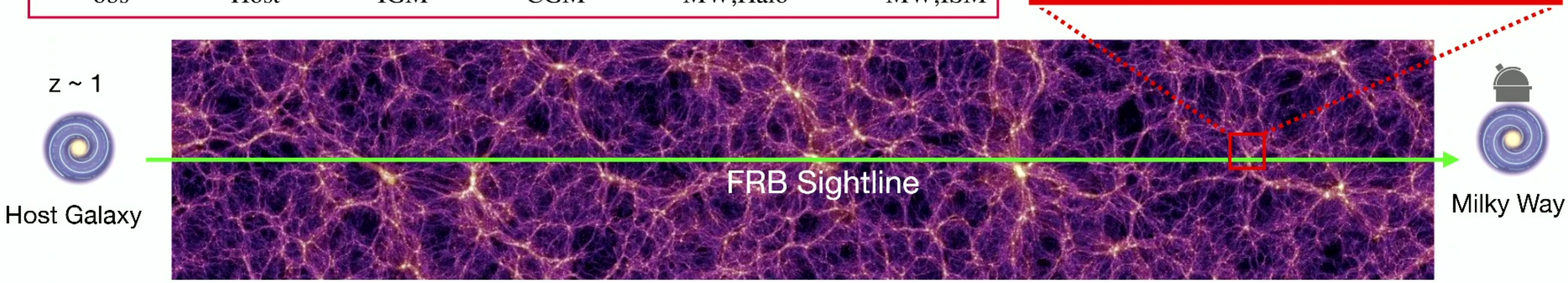
FRBs are direct tracers of ionized baryons in the intervening medium along each sightline

Dispersion Measure: $$DM = \int_0^d \frac{n_e(l)}{1+z} dl$$

Expect to observe 10,000s+ (localized) FRBs per year in the near future

$$DM_{\mathrm{obs}} = DM_{\mathrm{Host}} + DM_{\mathrm{IGM}} + DM_{\mathrm{CGM}} + DM_{\mathrm{MW,Halo}} + DM_{\mathrm{MW,ISM}}$$





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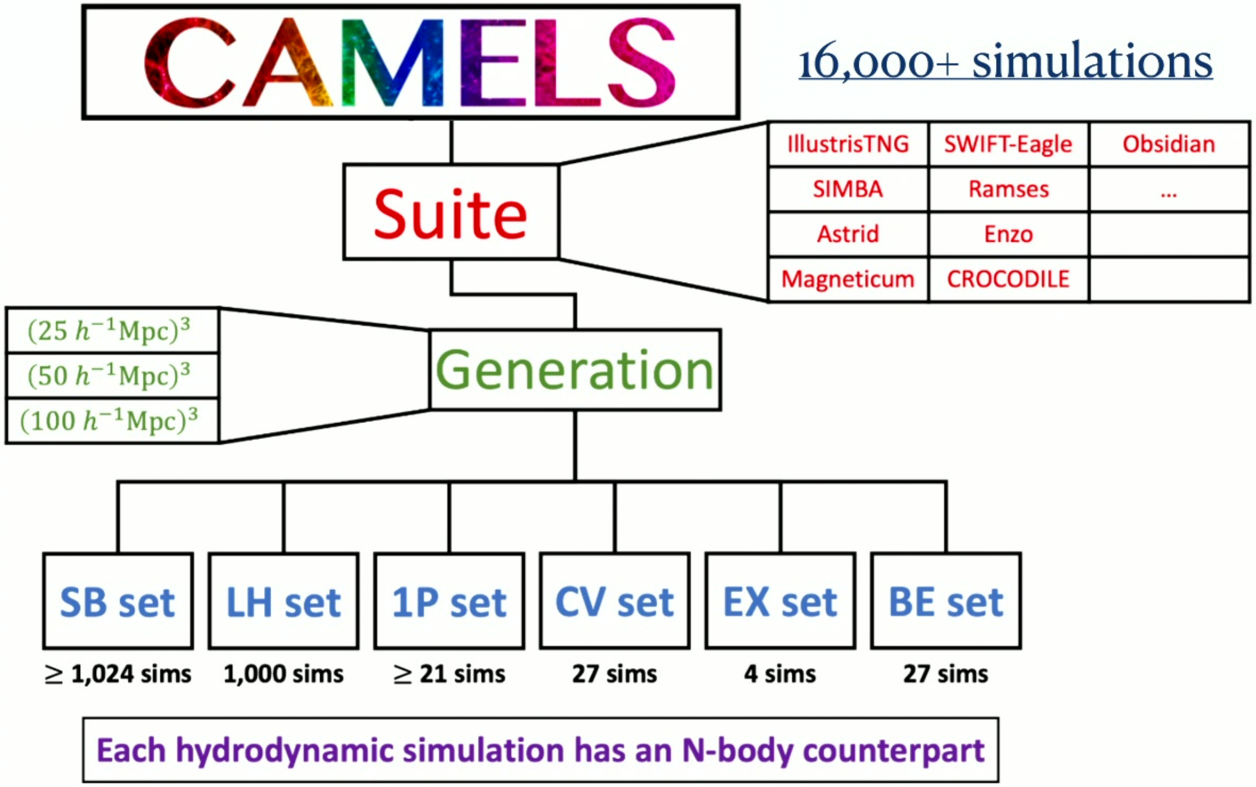
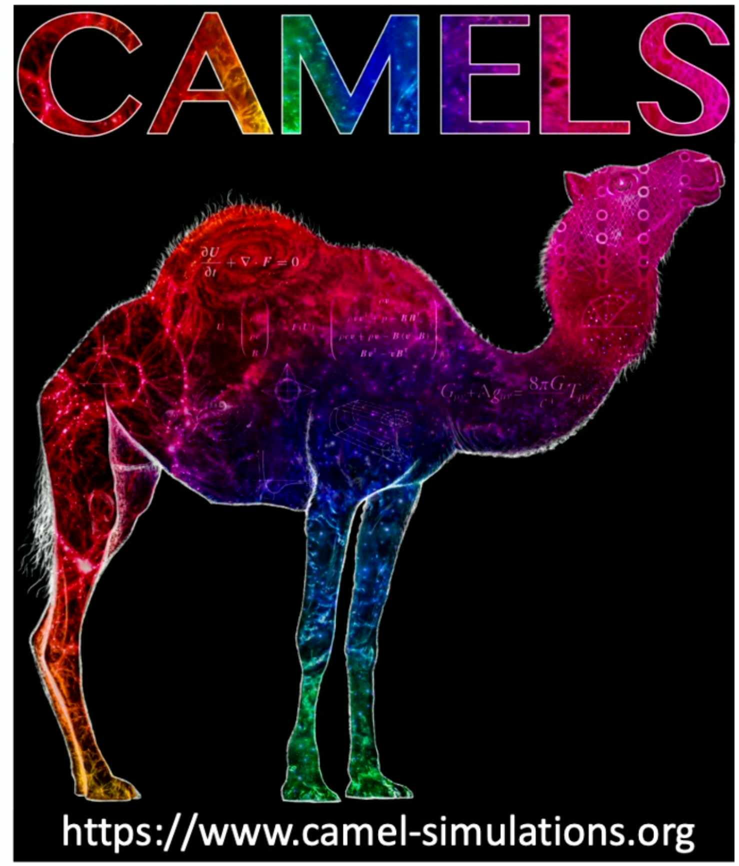
The CAMELS Project



Variations in cosmological & astrophysical parameters



Villaescusa-Navarro et al. 2021, 2023; Ni et al., 2023

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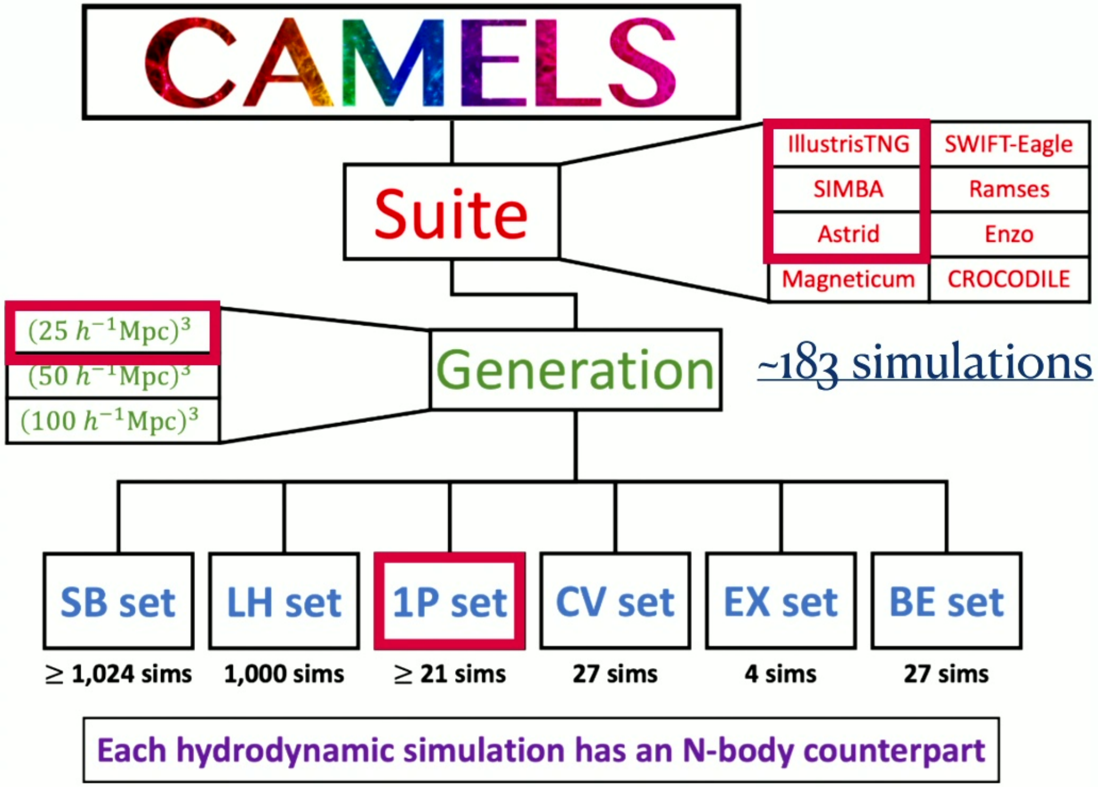
The CAMELS Project



Varied Cosmological Parameters:

Omega Matter (Ω_m), Sigma 8 (σ_8)

Varied Feedback Parameters:

SN1 - Mass Loading; Energy/unit-SFR of Galactic Winds

SN2 - Galactic Wind Velocity

AGN1 - Momentum Flux; Energy/BH-Accretion Rate (Kinetic)

AGN2 - Jet Velocity; Burstiness; Energy/BH-Accretion Rate (Thermal)

Variations in cosmological & astrophysical parameters

Villaescusa-Navarro et al. 2021, 2023; Ni et al., 2023

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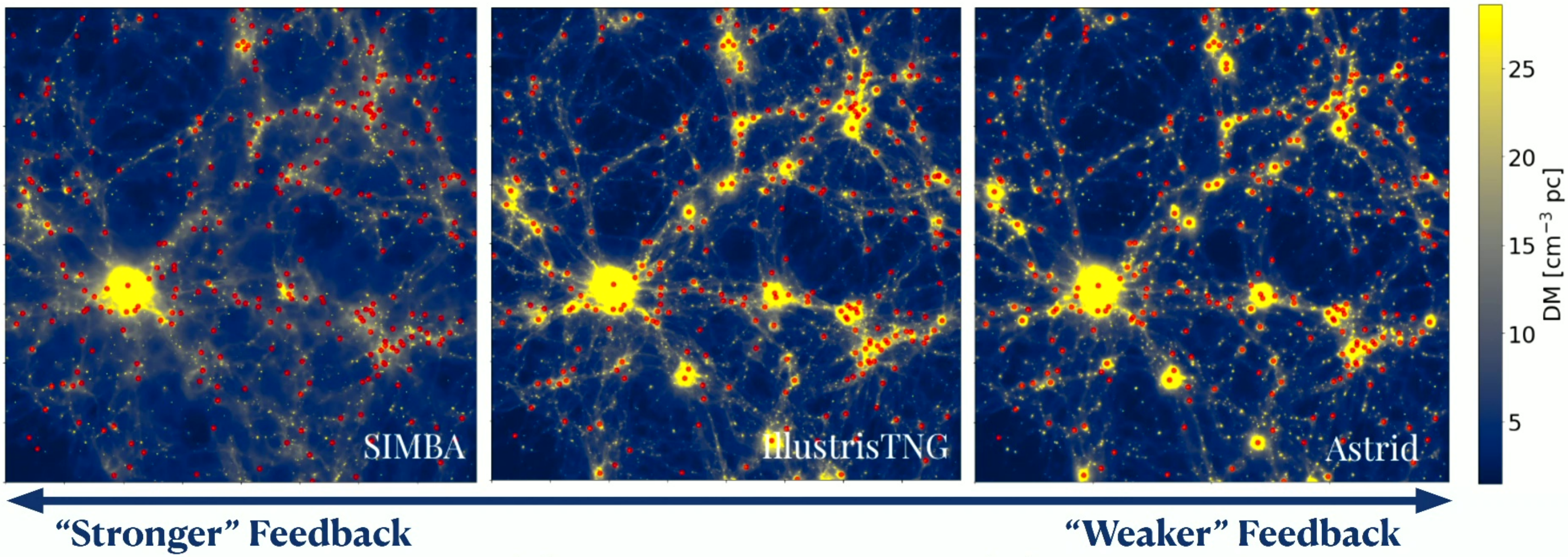
FRB Dispersion Measure Maps

DM Maps over 25 Mpc/h boxes of fiducial CAMELS IllustrisTNG, SIMBA, and Astrid



Red dots - top 300 most massive halos

Medlock et al. 2024

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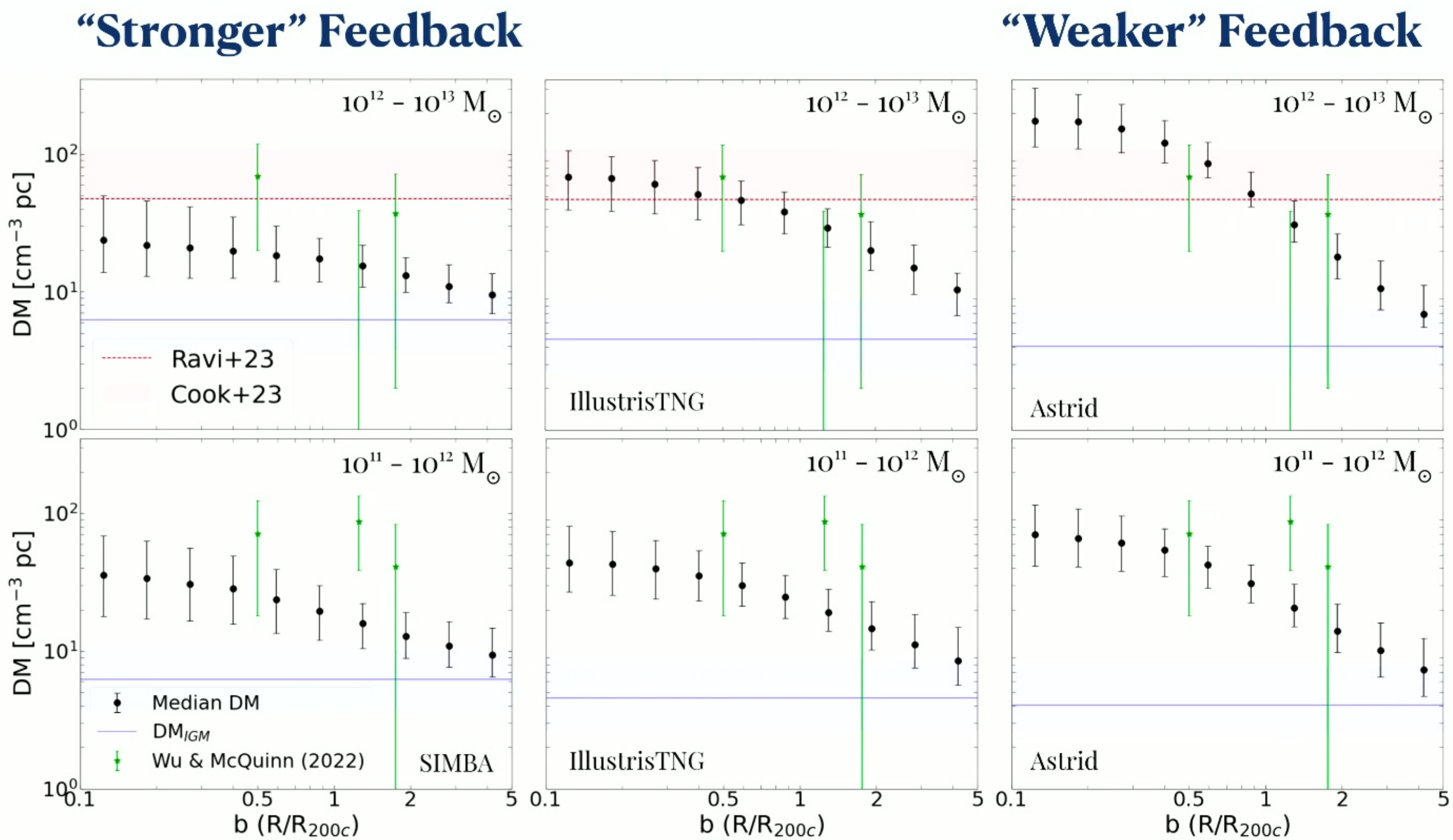
Median Halo Dispersion Measure Profiles

DM excess persists out to $5R_{200c}$

SIMBA halos are most evacuated of baryons, and Astrid has the largest DM excess

FRBs can be used to test proximity to different feedback models



Medlock et al. 2024

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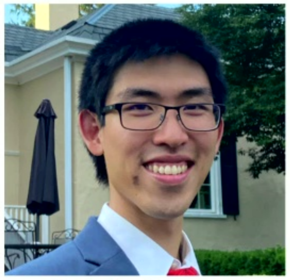
DM_{Host} Prediction Comparison with CHIME



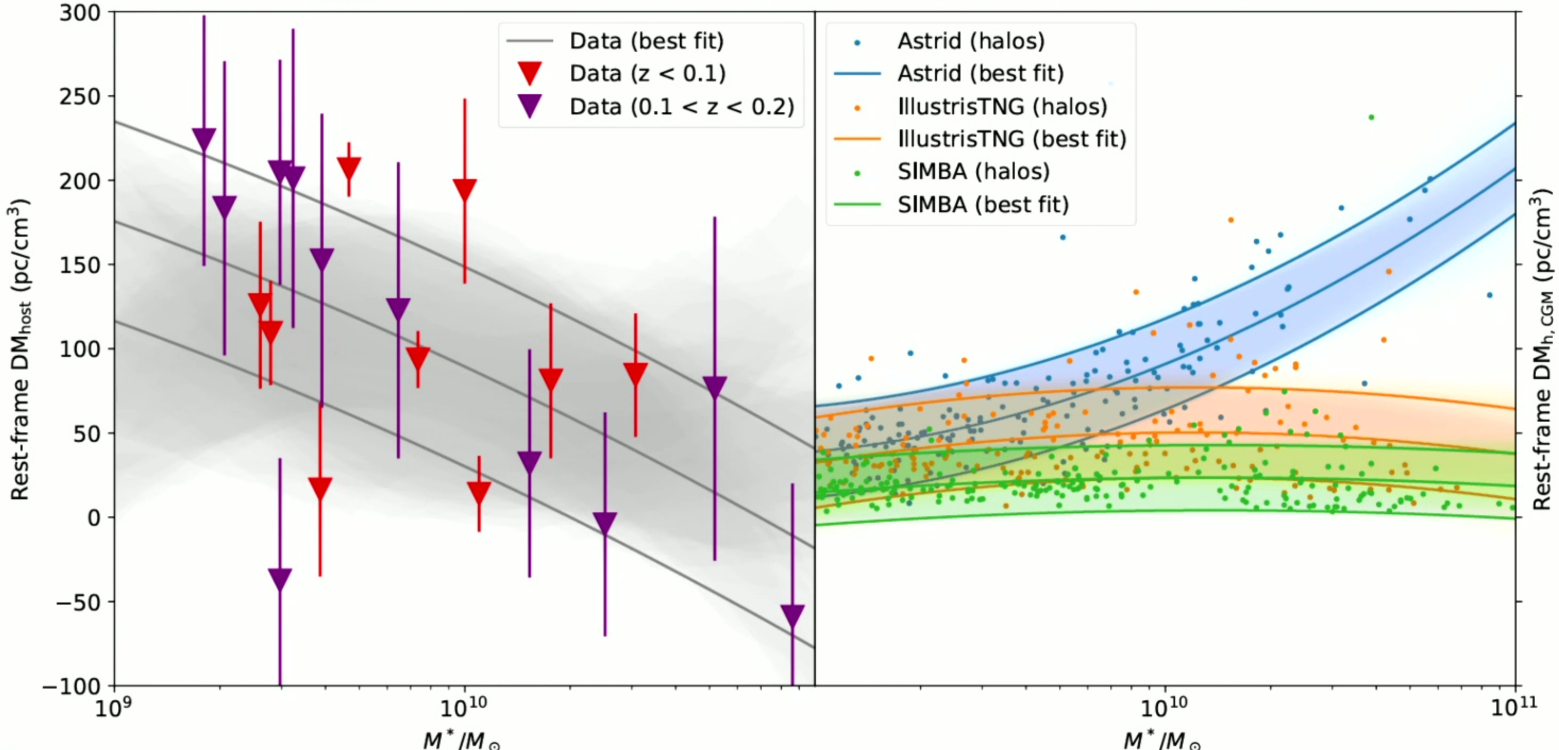
Calvin Leung

Sunil Simha

chime/frb

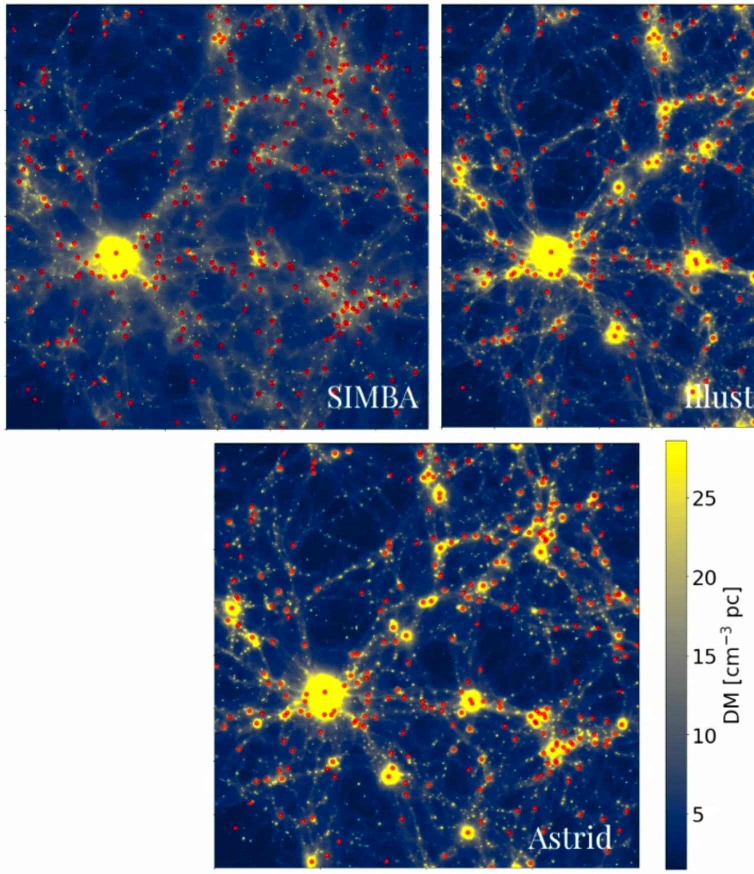
Leung, Simha, Medlock et al. 2025 - arXiv:2507.16816

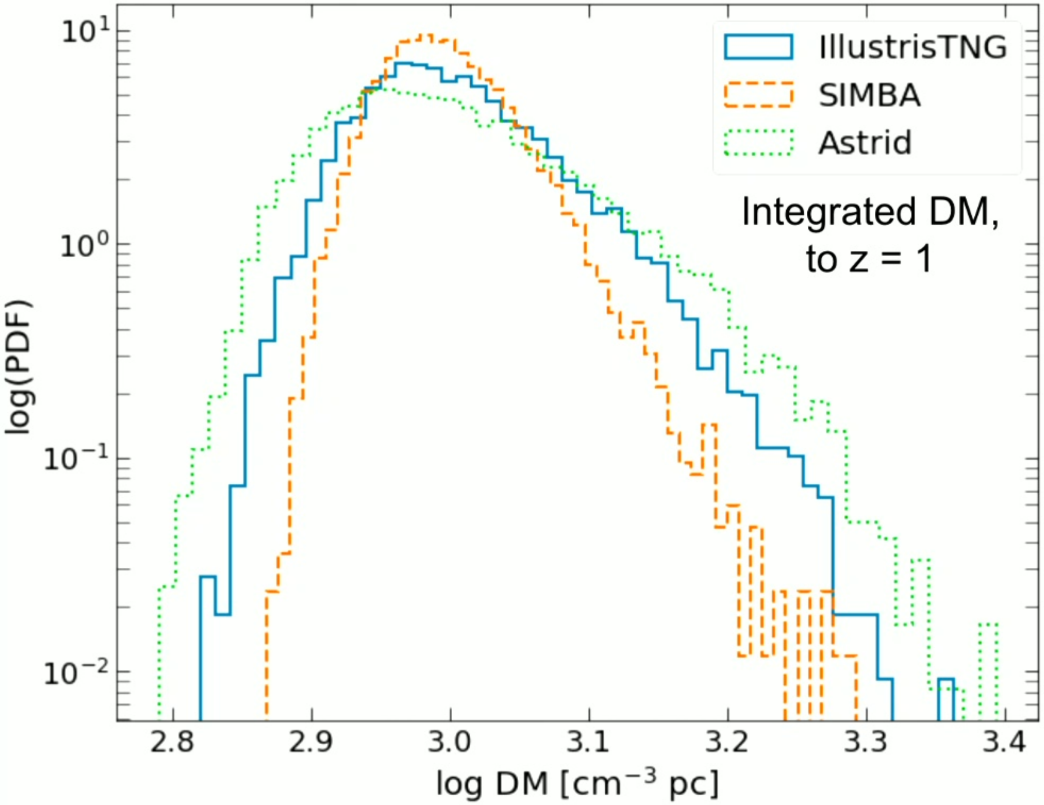
DM_{Host} - Stellar Mass Relation: Observed vs Predicted



Observations disfavor the Astrid ("weaker") feedback model

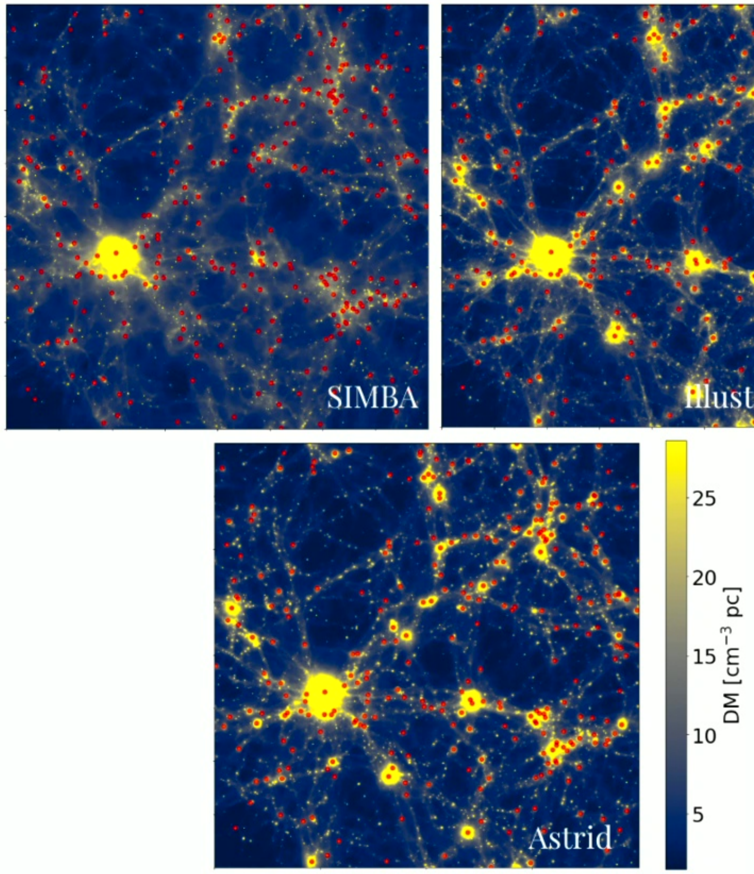
Dispersion Measure Maps and Distributions

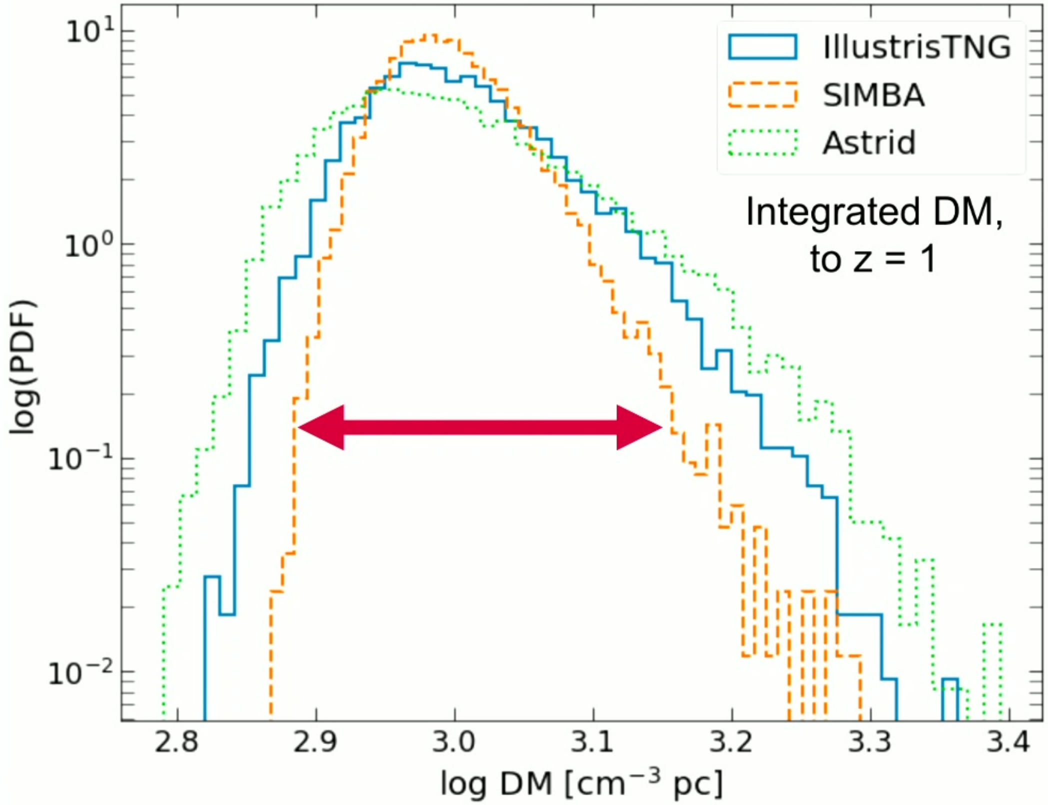




Medlock et al. 2024

Dispersion Measure Maps and Distributions





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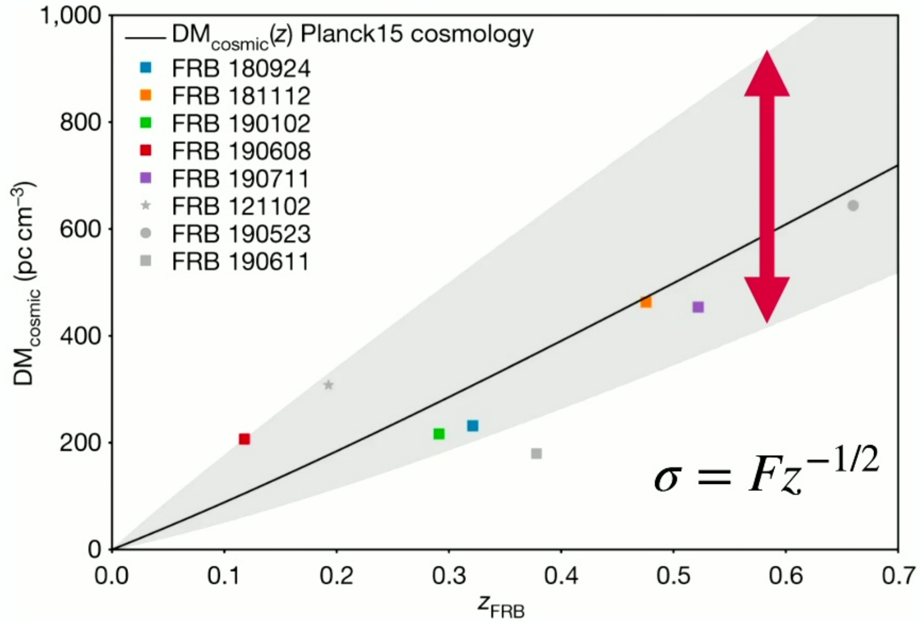
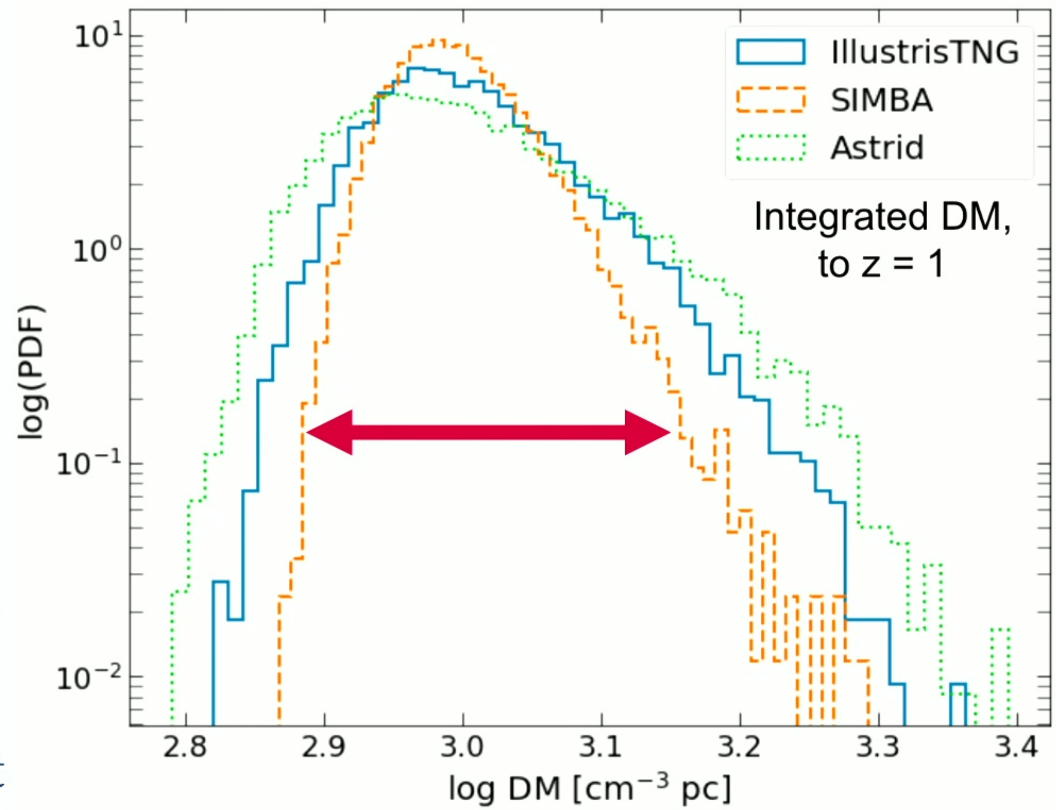
The Macquart Relation and the F-Parameter

The Macquart z-DM relation



F-parameter: measure of how uniformly distributed baryons are at a given redshift

Macquart et al. 2020



Medlock et al. 2024

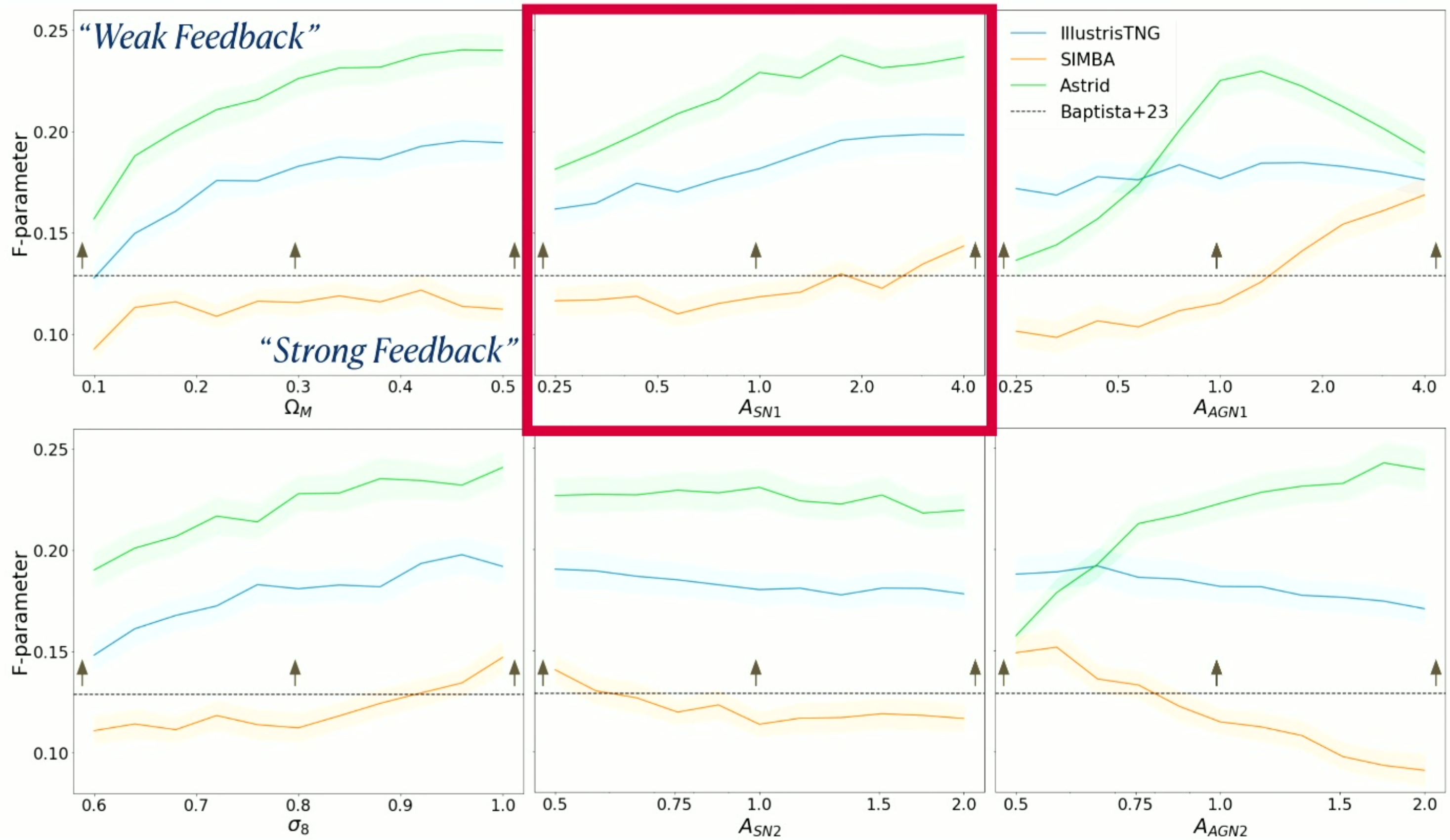
Measuring the *F*-Parameter with CAMELS

Why does *F* increase with ASN1?

Increasing ASN1 inhibits the growth of black holes

This delays the onset of kinetic mode of feedback

Total cumulative feedback energy is lower



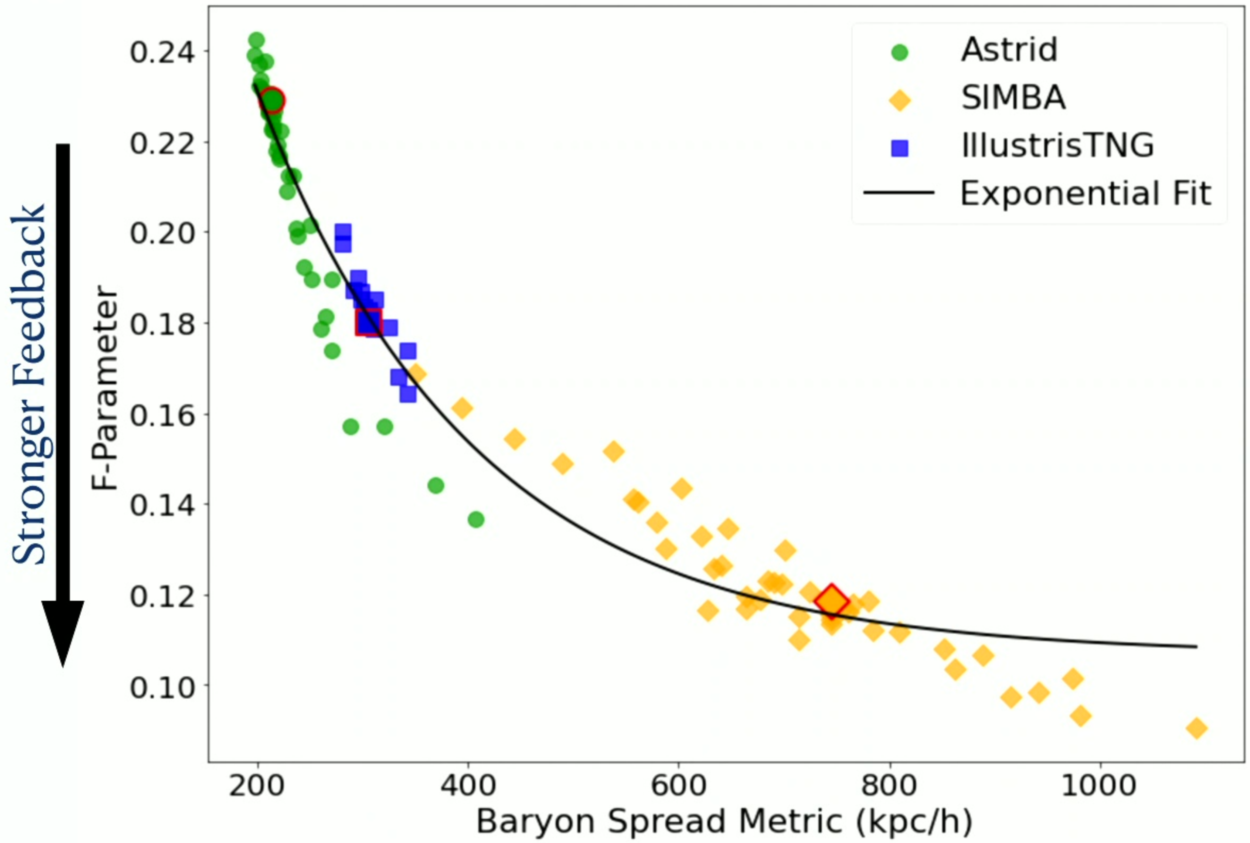
Medlock, Neufeld, et al. 2025

Medlock et al. 2024

F-Parameter and Baryon Spread Correlation

Baryon spread: the distance a gas particle in a simulation moves from its nearest dark matter particle neighbor at initialization to the final snapshot

FRBs and the F-parameter are a robust observational probe for baryonic spread



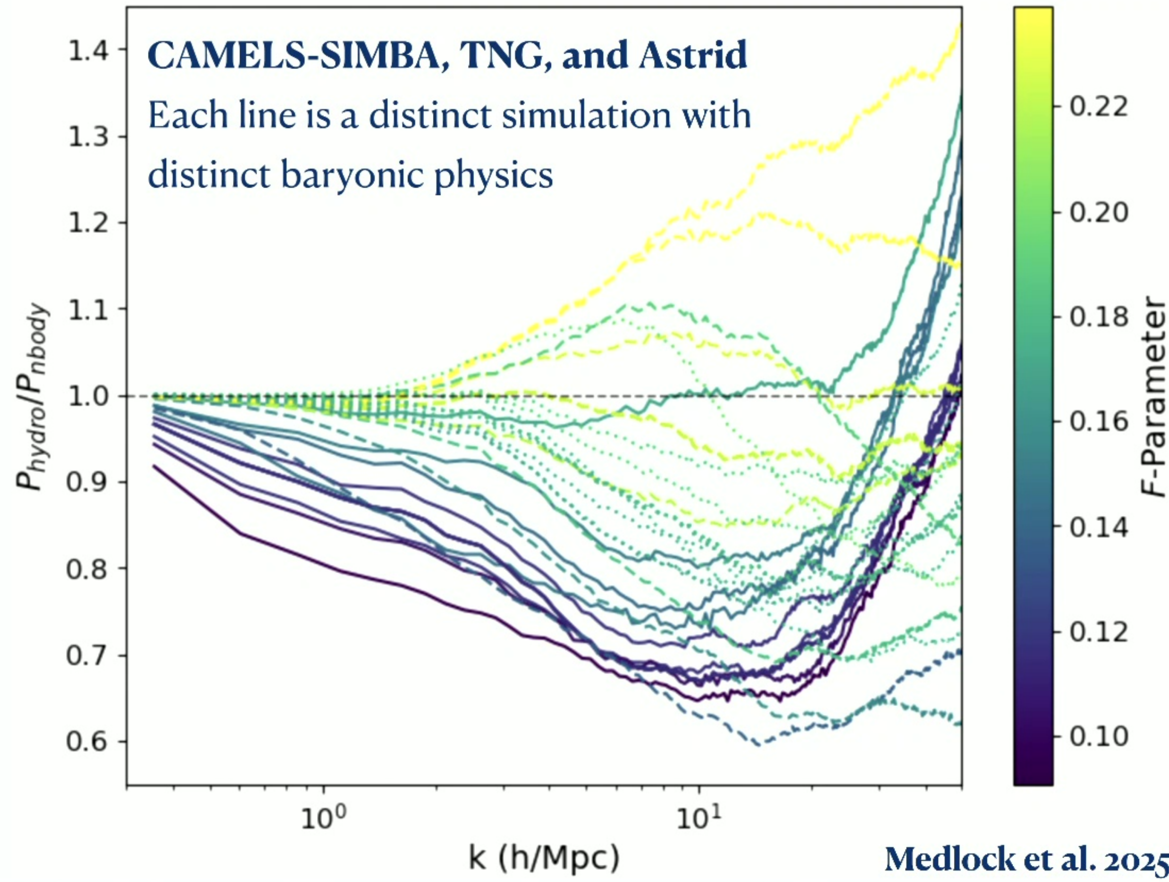
Medlock et al. 2025b

FRB-based Baryonic Effect Correction Model

Clear correlation between suppression and F-parameter especially for k < 10 h/Mpc

FRB statistics are promising probes of baryon effects on the matter power spectrum

Proof of concept - much more work to be done!



Medlock et al. 2025b

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Caveats and Challenges

Caveat: First Generation CAMELS box size (L = 25 Mpc/h) is too small to properly capture cosmic variance and large scale structure that FRBs are sensitive to

Ideal: 100s-1000s of large volume (L > 100 Mpc/h) simulations with widely varied astrophysical feedback models

Challenge: Disentangling Contributions to the observed Dispersion Measure (DM_{MW}, DM_{Host}, etc)

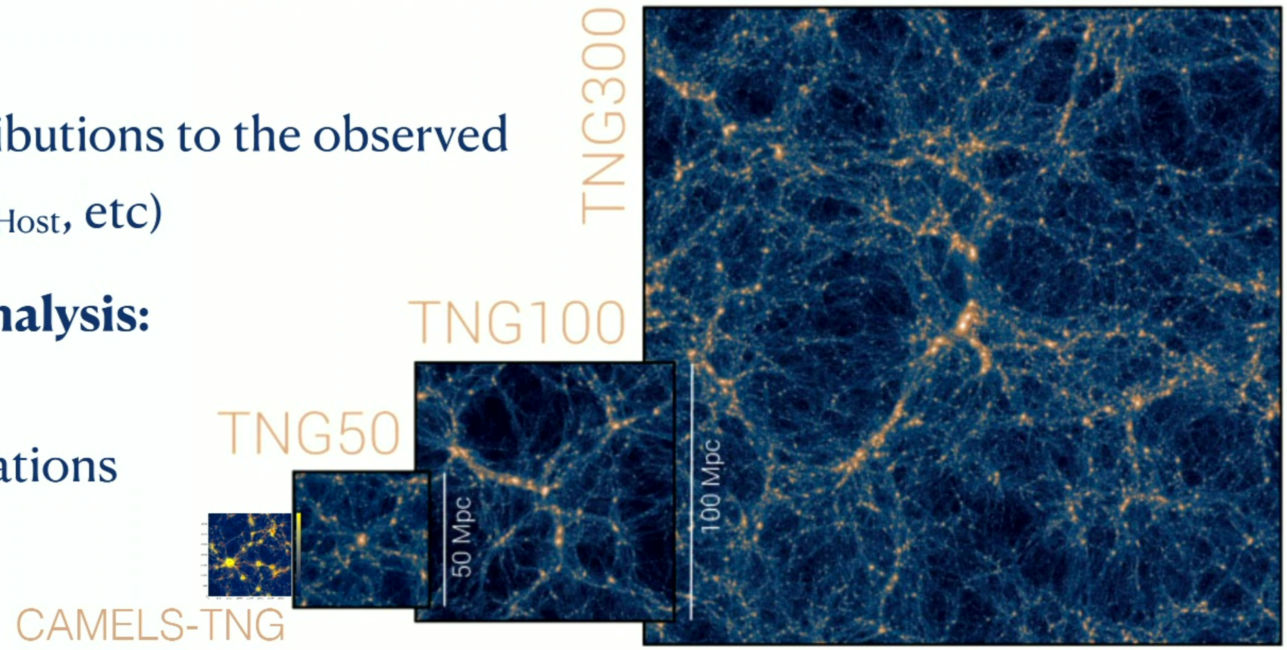
Challenges in Modeling and Analysis:

Modeling Scatter in DMcosmic

Accurate Predictions from Simulations

Sharma et al, 2025 - Next Talk

Konietzka et al, 2025



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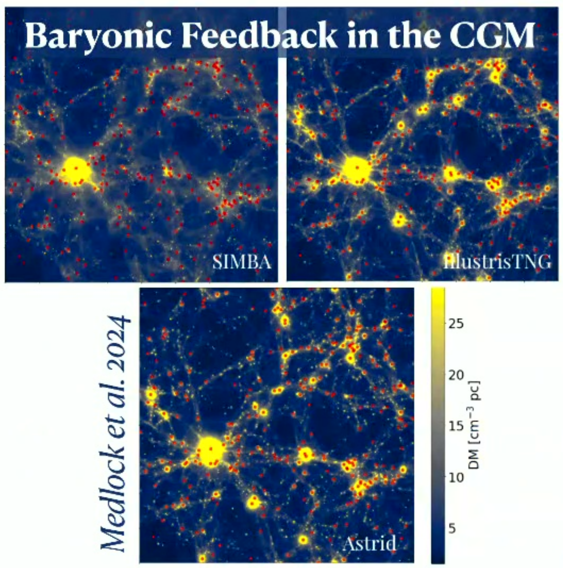
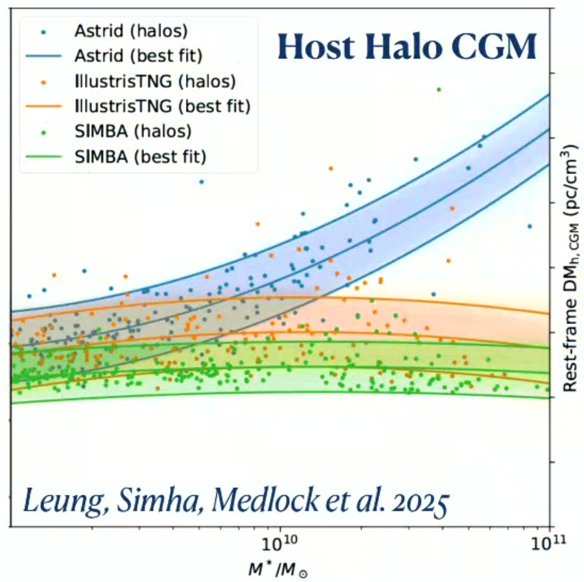
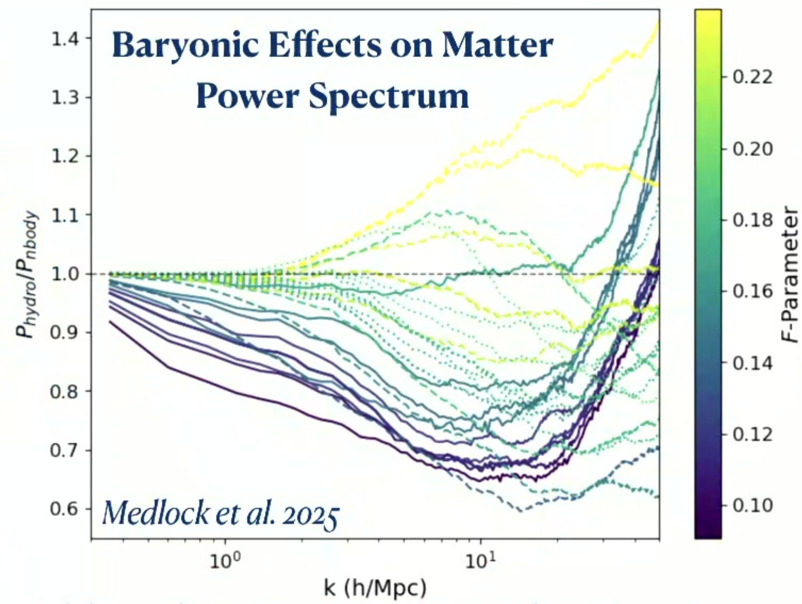
Conclusions and Summary

Fast radio bursts are powerful and promising probes of cosmology and galaxy physics and are complimentary to other probes like kSZ, tSZ, X-ray, etc







With the upcoming large numbers of FRB detections and localizations now is the time to do the modeling and simulations!

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Future Directions

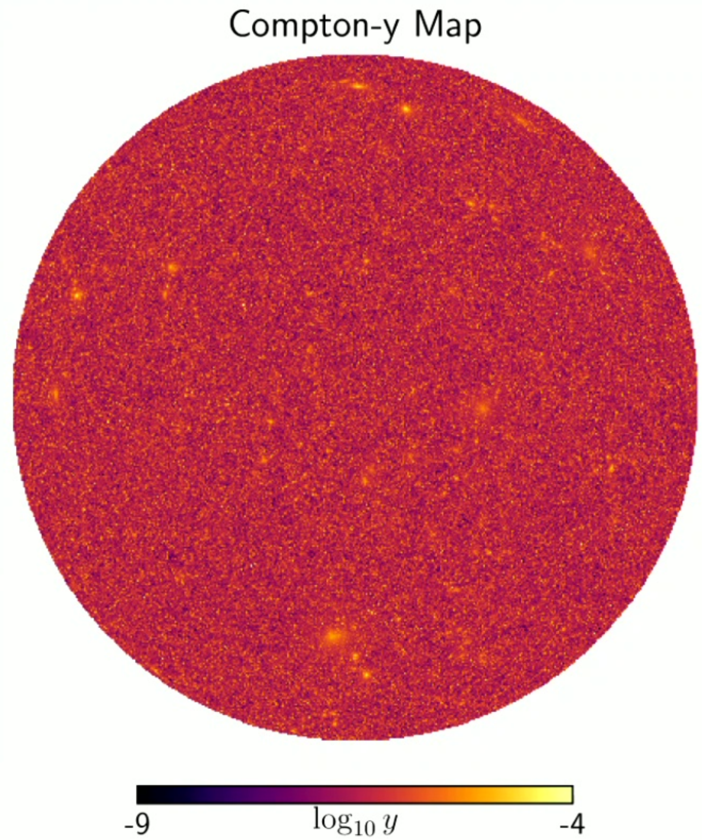
Existing/Upcoming large volume simulations, ideally with variations in feedback models (ex. MilleniumTNG, Flamingo, Colibre, Frontier, etc.)

Develop a computationally fast and efficient method for making mock FRB maps by building on the baryon pasting halo model and adding filaments (in progress)

Comparing to observations at the halo level (ex: DM_{Host})

Multi-Wavelength Approach - take advantage of FRB's complementarity with other probes such SZ, X-Ray, etc

Focus on FRB observables that transcend specific subgrid models



Lau et al., 2025

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