Title: A hydrosimulations-based approach to relate the Fast Radio Burst dispersion measure -- redshift relation to the suppression of matter power spectrum

Speakers: Kritti Sharma

Collection/Series: Cosmic Ecosystems

Date: August 01, 2025 - 12:05 PM

URL: https://pirsa.org/25080007

Abstract:

The effects of baryonic feedback on matter power spectrum are uncertain. Upcoming large-scale structure surveys require percent-level constraints on the impact of baryonic feedback effects on the small-scale ($k \gtrsim 1\,h\,$Mpc^{-1}) matter power spectrum to fully exploit weak lensing data. The sightline-to-sightline variance in the fast radio bursts (FRBs) dispersion measure (DM) correlates with the strength of baryonic feedback and offers unique sensitivity at scales upto $k \sim 100\,h\,$Mpc^{-1}. We analytically compute the variance in FRB DMs using the electron power spectrum, which is modeled as a function of cosmological and feedback parameters in IllustrisTNG suite of simulations in CAMELS project. We demonstrate its efficacy in capturing baryonic feedback effects across several simulation suites, including SIMBA and Astrid. We show that with 10,000 FRBs, the suppression of the matter power spectrum can be constrained to percent-level precision at large scales (k < 1 h/Mpc) and ~10% precision at small scales (k > 10 h/Mpc). Insights into the impact of baryons on the small-scale matter power spectrum gained from FRBs can be leveraged to mitigate baryonic uncertainties in cosmic shear analyses.

Probing Baryonic Feedback using FRBs

Kritti Sharma

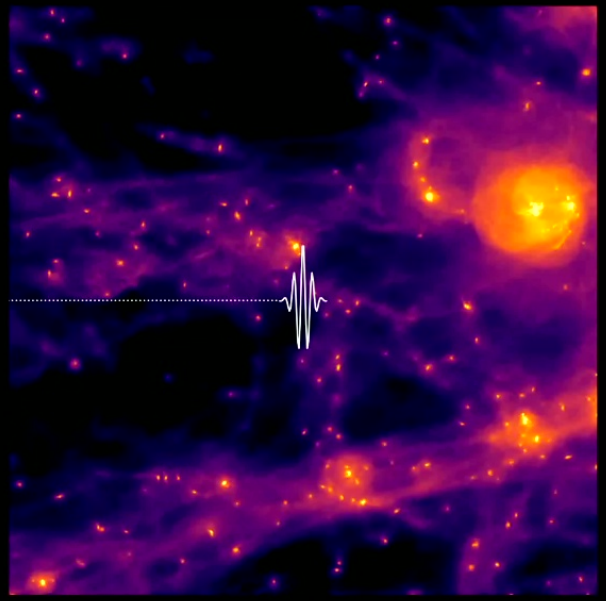
PhD Candidate, California Institute of Technology

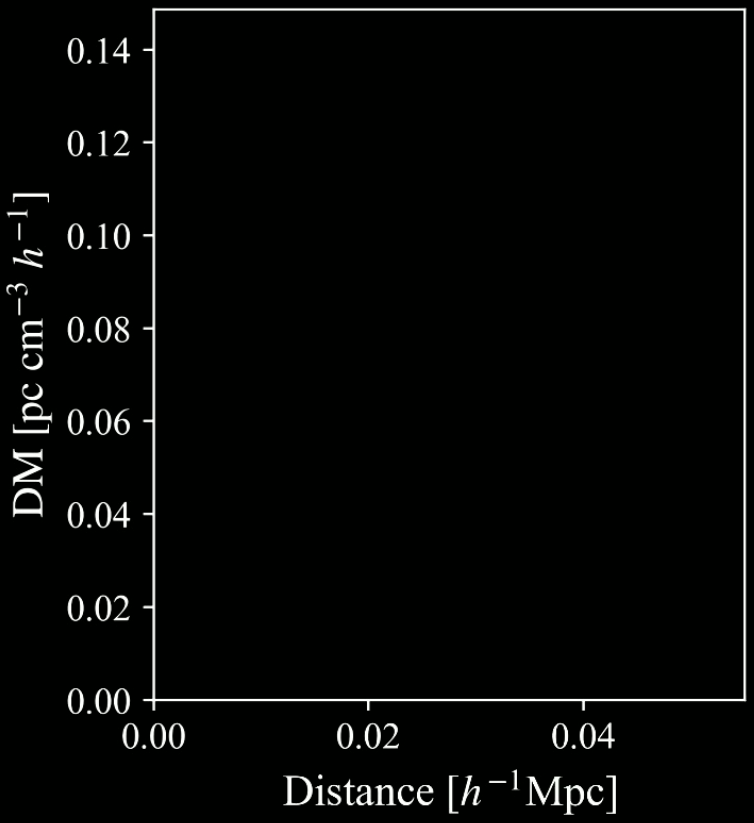
Cosmic Ecosystems, Perimeter Institute for Theoretical Physics

Vikram Ravi **Elisabeth Krause** **Liam Connor** **Robert Reischke**

FRB dispersion measure probes baryons

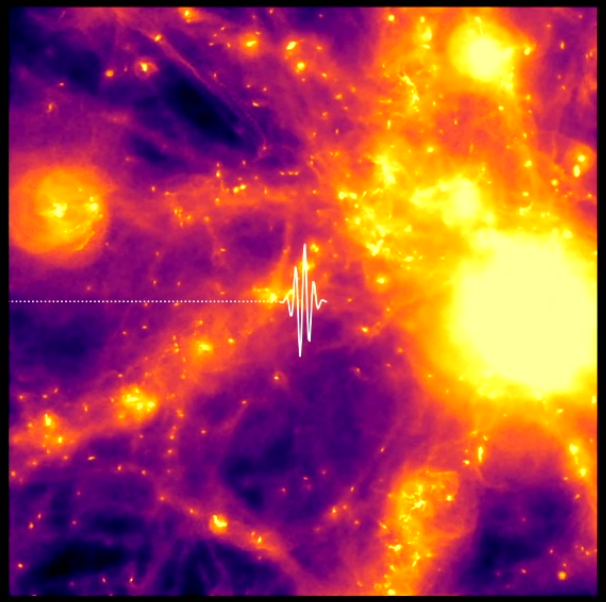
Integrated column density of free electrons along the FRB sightline: $\mathrm{DM} = \int n_\mathrm{e}\,\mathrm{d}l$

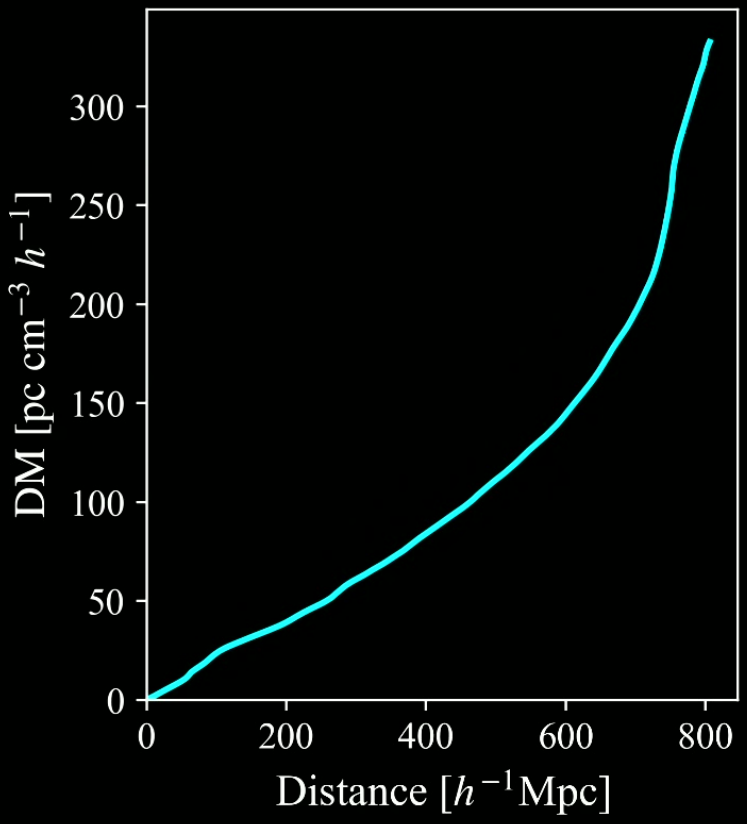




FRB dispersion measure probes baryons

Integrated column density of free electrons along the FRB sightline: $\mathrm{DM} = \int n_{\mathrm{e}} \mathrm{d}l$

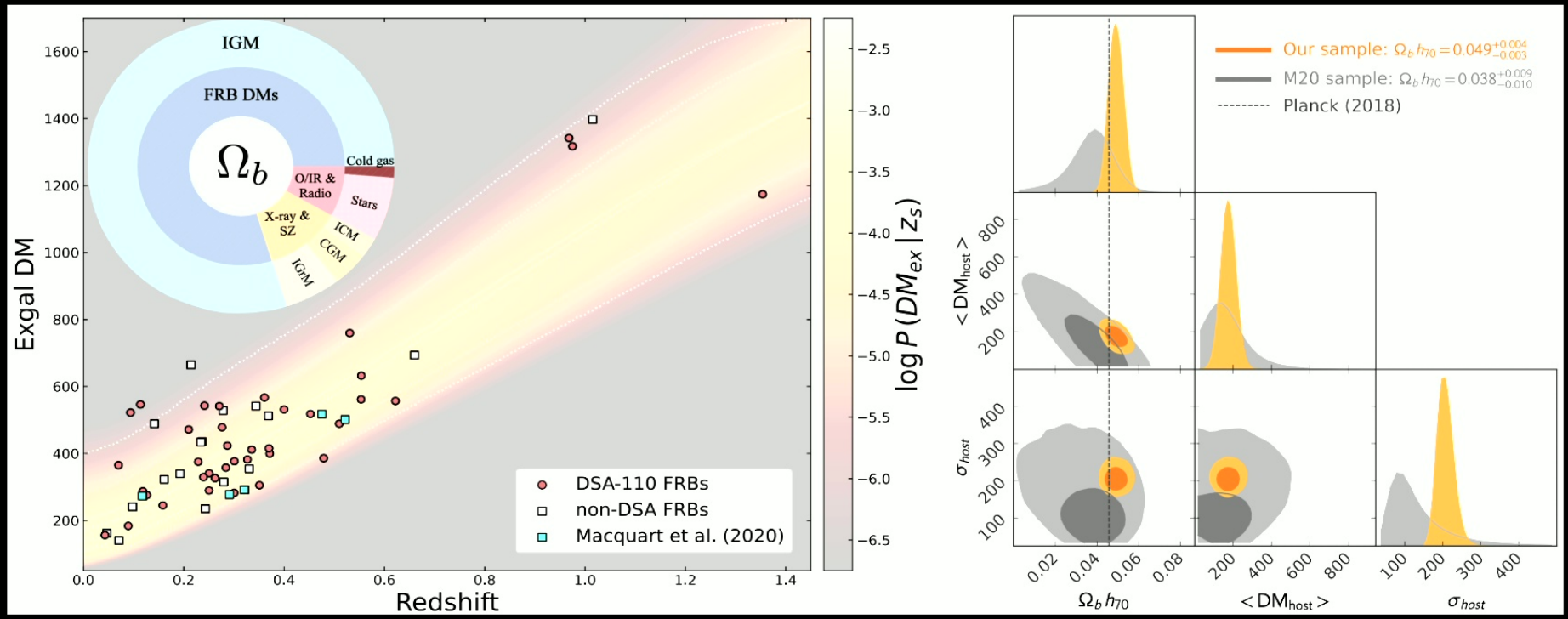




DM-Redshift relation: Information in Mean

Explicit dependence on cosmological parameters ⟶

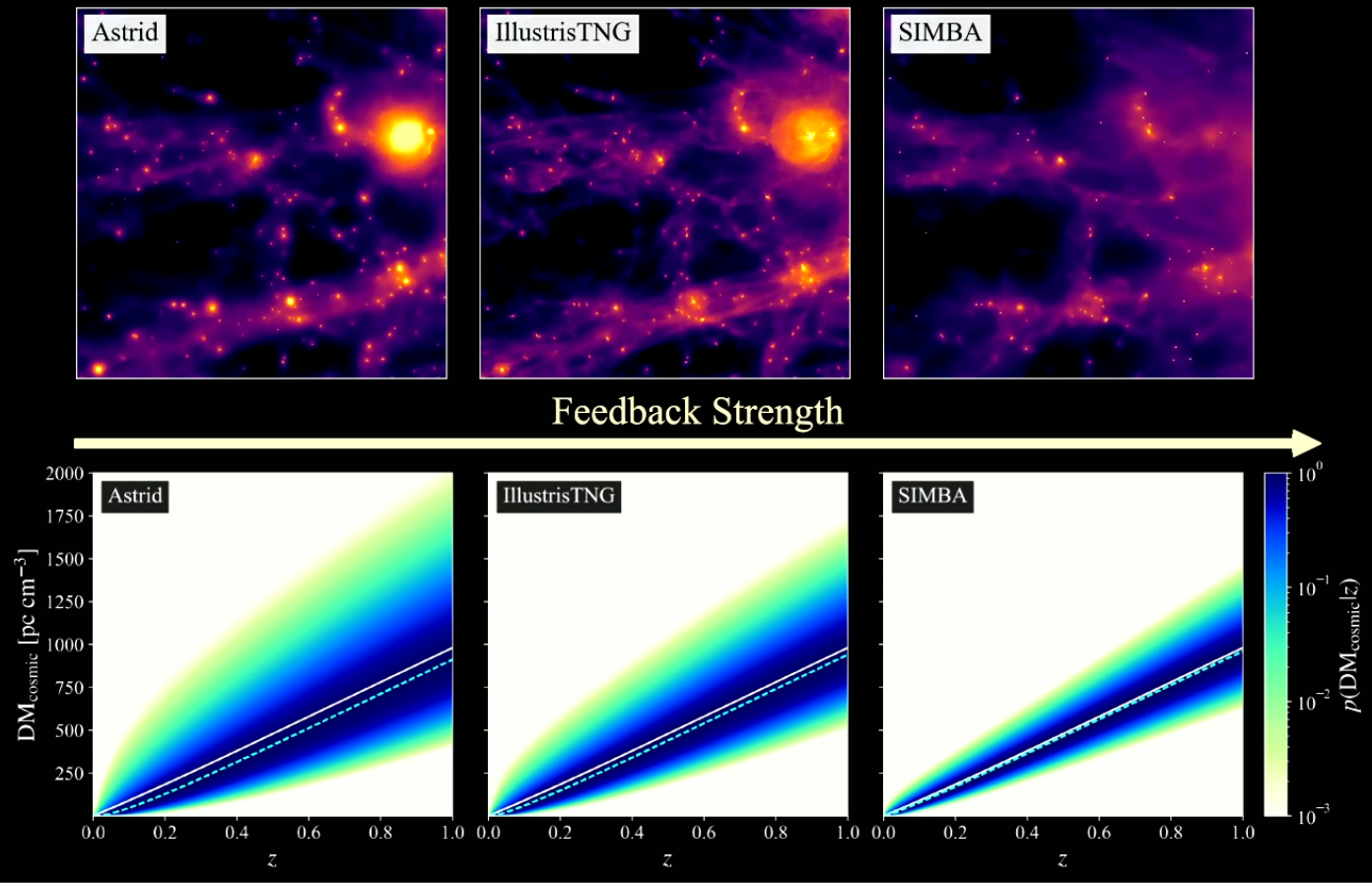
$$\langle \mathrm{DM_{cosmic}}(z_\mathrm{s}) \rangle = \int_0^{z_\mathrm{s}} \frac{3c\chi_\mathrm{e}\Omega_\mathrm{b}H_0}{8\pi G m_\mathrm{p}} \frac{f_\mathrm{d}(z)(1+z)\mathrm{d}z}{\sqrt{\Omega_\mathrm{m}(1+z)^3+\Omega_\Lambda}}$$



Connor+2024

DM-Redshift relation: Information in Variance

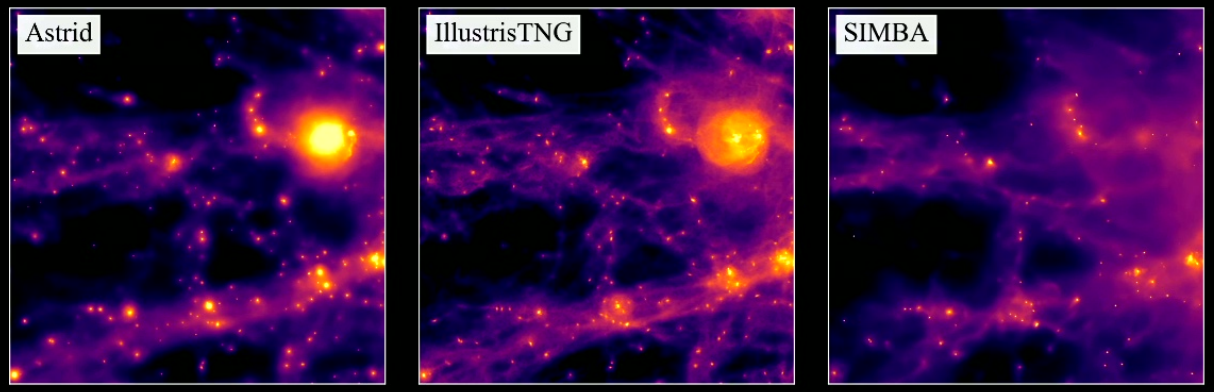
Sightline-to-sightline variance in DM depends on the degree of clustering of baryons



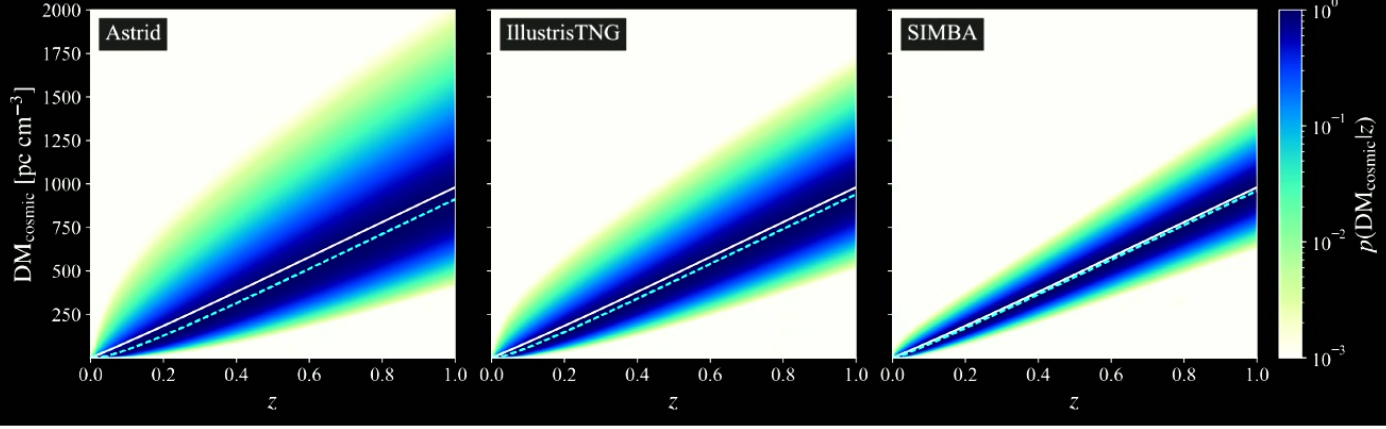
Sharma+2025a

DM-Redshift relation: Information in Variance

Sightline-to-sightline variance in DM depends on the degree of clustering of baryons



Feedback Strength



$$n_e(z,\hat{x}) = \bar{n}_e(z)(1+\delta_e(z,\hat{x})) = \bar{n}_{e,0}(1+z)^3(1+\delta_e(z,\hat{x}))$$

electron density contrast

$$\mathrm{cov}_{ij} := \langle \mathrm{DM_{LSS}}(\hat{\boldsymbol{x}}_i, z_i)\mathrm{DM_{LSS}}(\hat{\boldsymbol{x}}_j, z_j)\rangle - \mathrm{DM_{LSS}}(z_i)\mathrm{DM_{LSS}}(z_j)$$

$$= \int_0^{z_i} \mathrm{d}z_i' W_{\mathrm{DM}}(z_i') \int_0^{z_j} \mathrm{d}z_j' W_{\mathrm{DM}}(z_j') \langle \delta_e(\hat{\boldsymbol{x}}_i, z_i')\delta_e(\hat{\boldsymbol{x}}_j, z_j')\rangle$$

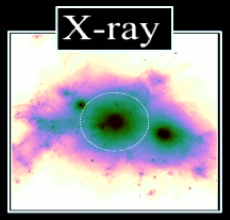
electron auto-correlation function

$$\int \frac{\mathrm{d}^3k}{(2\pi)^3} e^{i\boldsymbol{k}\cdot(\boldsymbol{x}_i-\boldsymbol{x}_j)} P_e(k, z_i, z_j)$$

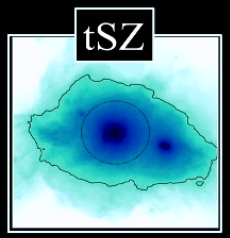
electron power spectrum

Sharma+2025a

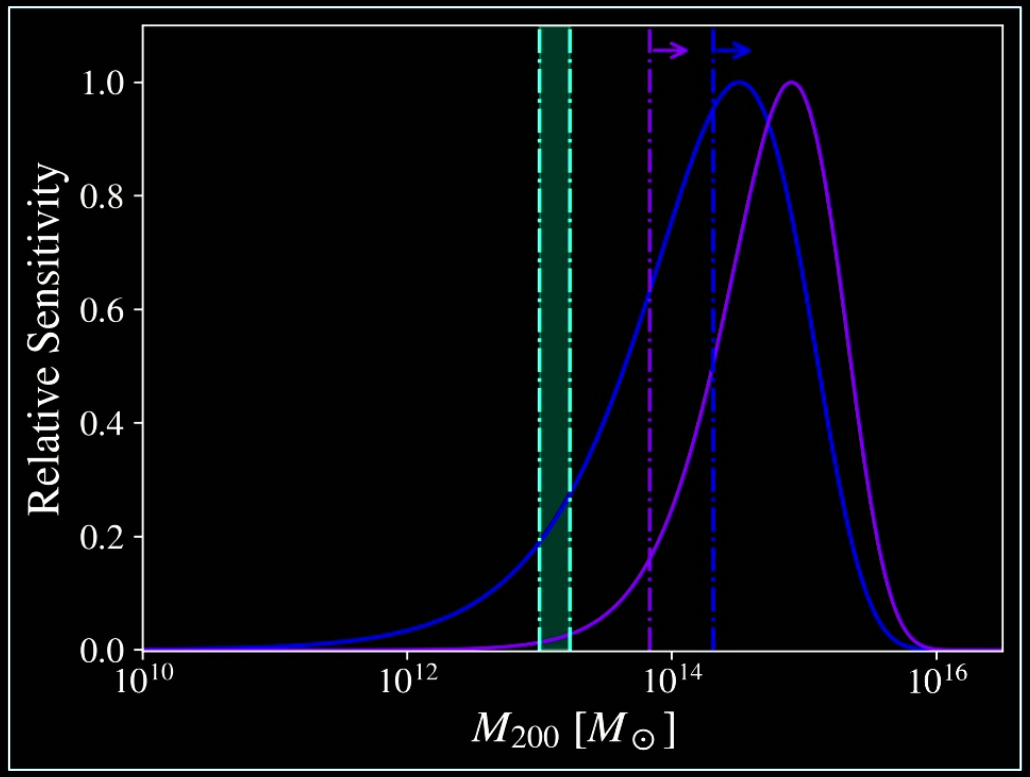
DMs serve as a complementary probe of baryons



X-ray Observations $[n(M)M^{7/3}]$
eRASS-1



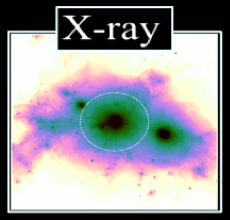
Thermal SZ Effect $[n(M)M^{5/3}]$
SPT-Pol



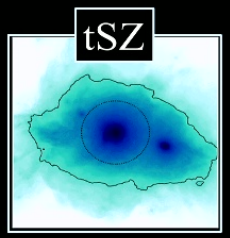
Kinematic SZ Effect
ACT LRG Stacks

Sharma+2025a

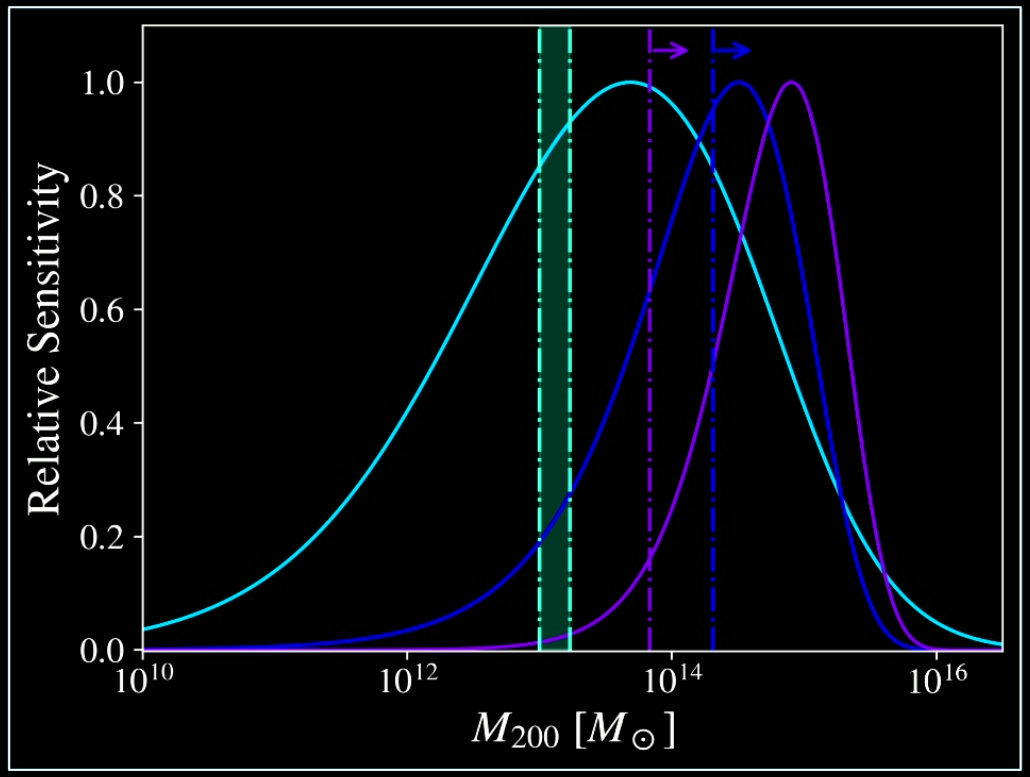
DMs serve as a complementary probe of baryons



X-ray Observations $[n(M)M^{7/3}]$
eRASS-1



Thermal SZ Effect $[n(M)M^{5/3}]$
SPT-Pol



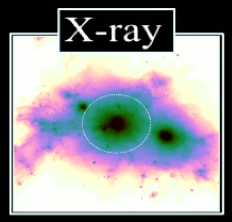
Kinematic SZ Effect
ACT LRG Stacks

Cosmic Shear

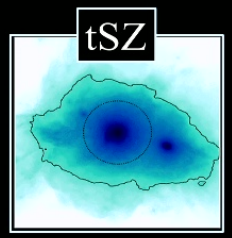
Weak Lensing $[C^{\kappa\kappa}]$

Sharma+2025a

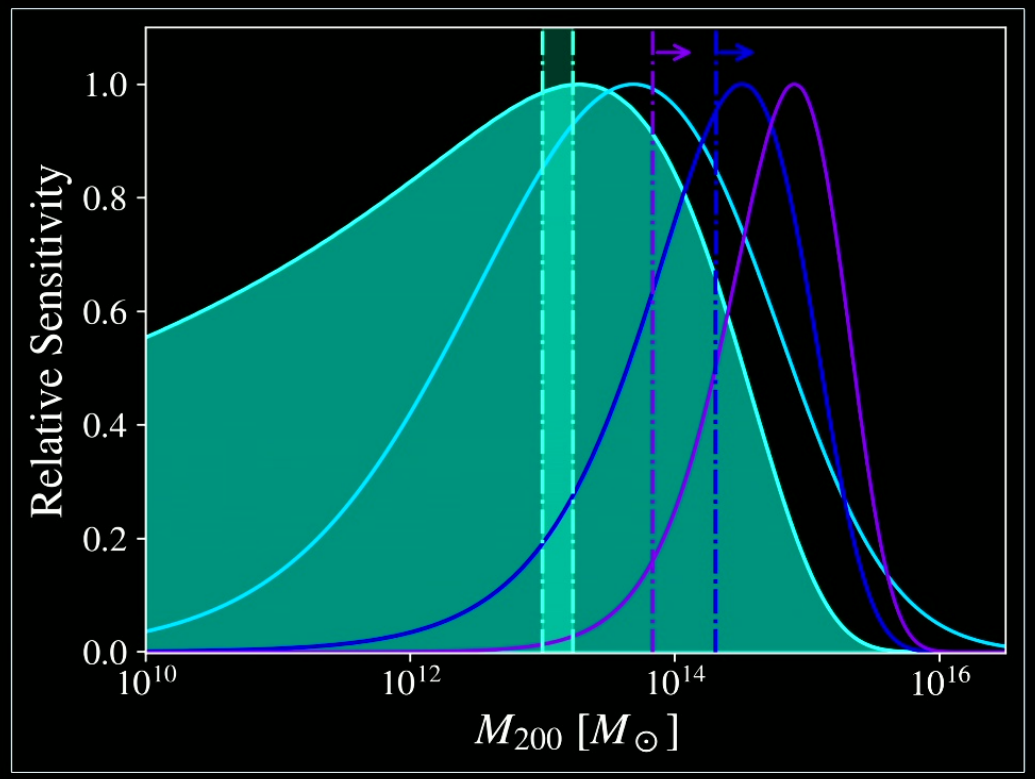
DMs serve as a complementary probe of baryons



X-ray Observations $[n(M)M^{7/3}]$
eRASS-1



Thermal SZ Effect $[n(M)M^{5/3}]$
SPT-Pol



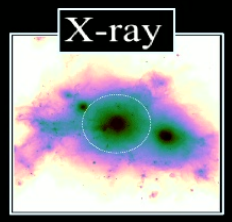
Kinematic SZ Effect
ACT LRG Stacks

Cosmic Shear

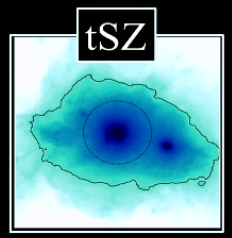
Weak Lensing $[C^{\kappa\kappa}]$

Sharma+2025a

DMs serve as a complementary probe of baryons

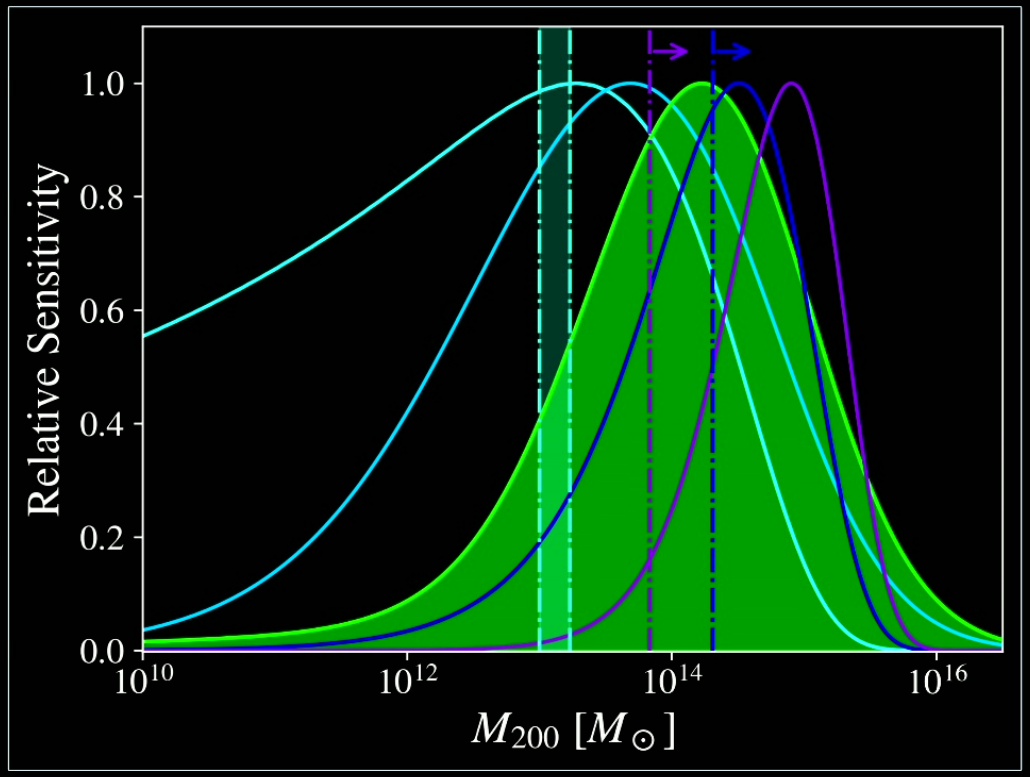


X-ray Observations $[n(M)M^{7/3}]$
eRASS-1



Thermal SZ Effect $[n(M)M^{5/3}]$
SPT-Pol

DM Mean $[\langle \mathrm{DM_{cosmic}} \rangle \propto n(M)M^{1}]$
DM Variance $[\sigma^2(\mathrm{DM_{cosmic}}|z)]$



Kinematic SZ Effect
ACT LRG Stacks

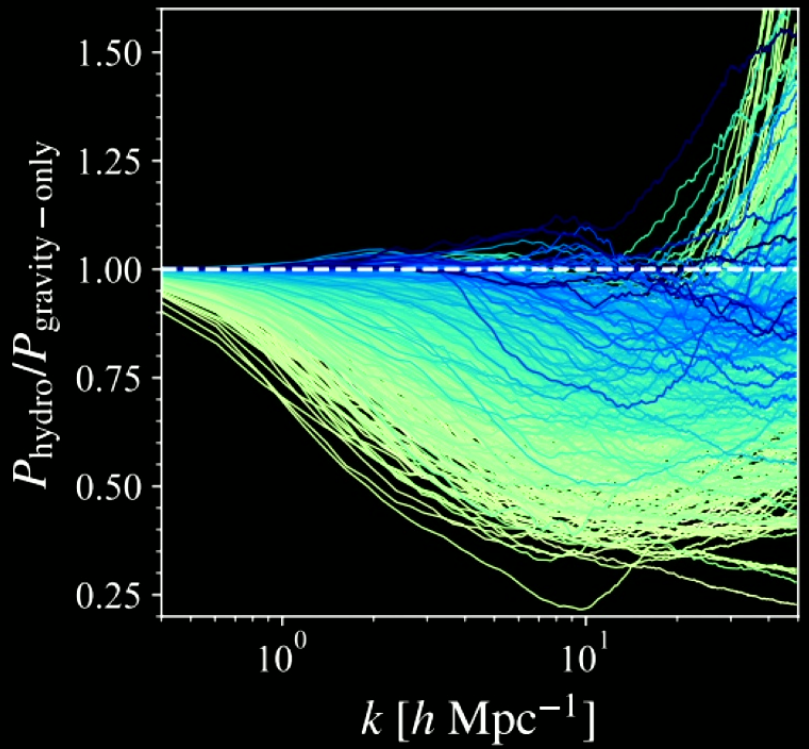
Cosmic Shear

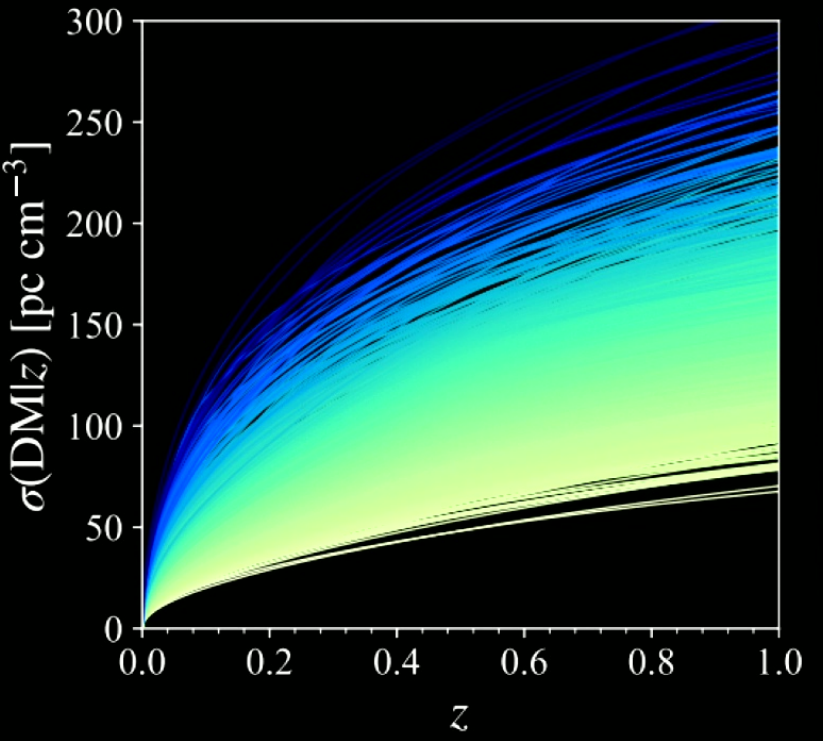
Weak Lensing $[C^{\kappa\kappa}]$

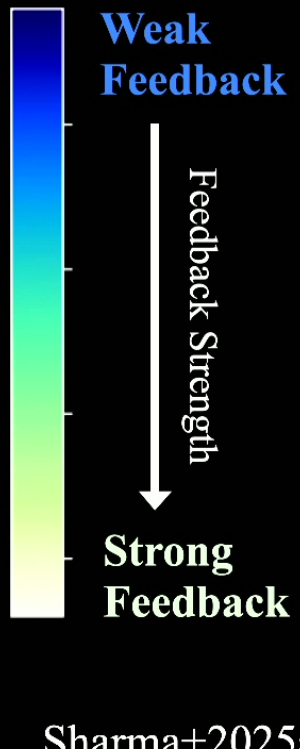
Sharma+2025a

Hydrosimulations-based inference

- DM-redshift relation inference using 1000 cosmology & feedback variations in CAMELS
- 1-to-1 mapping b/w matter power suppression and DM variance



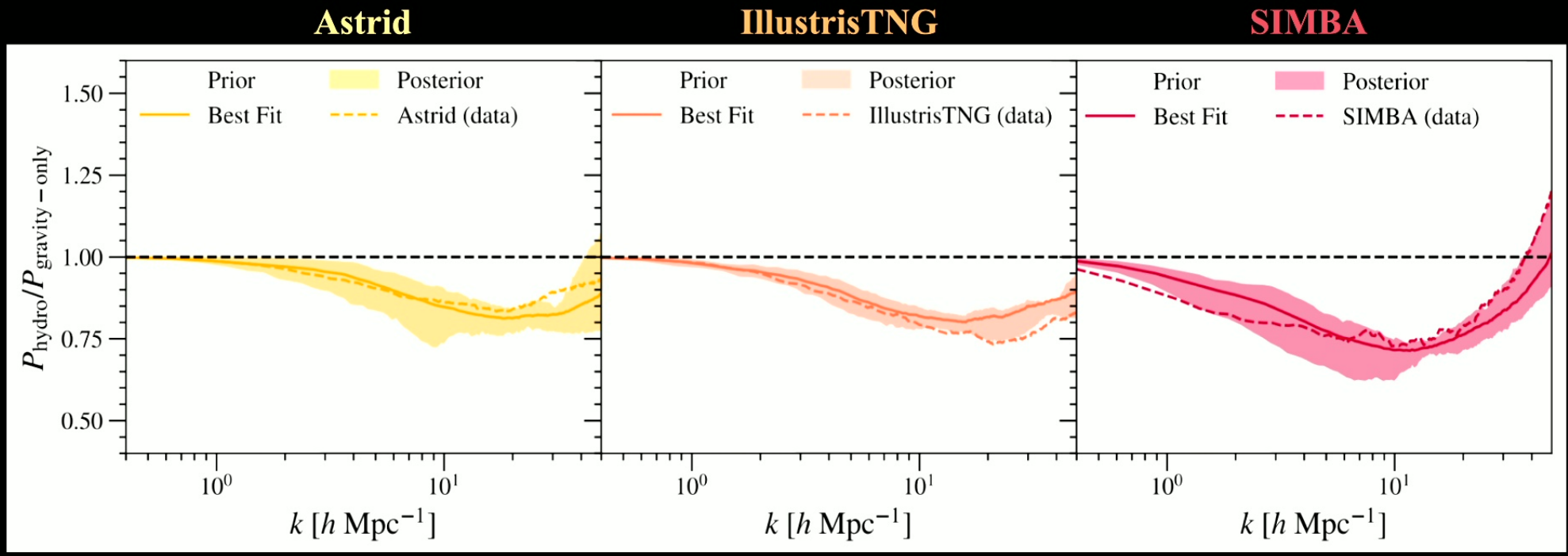




Sharma+2025a

10^4 FRBs ⇒ 1% precision on $P_m(k)$ at large-scales

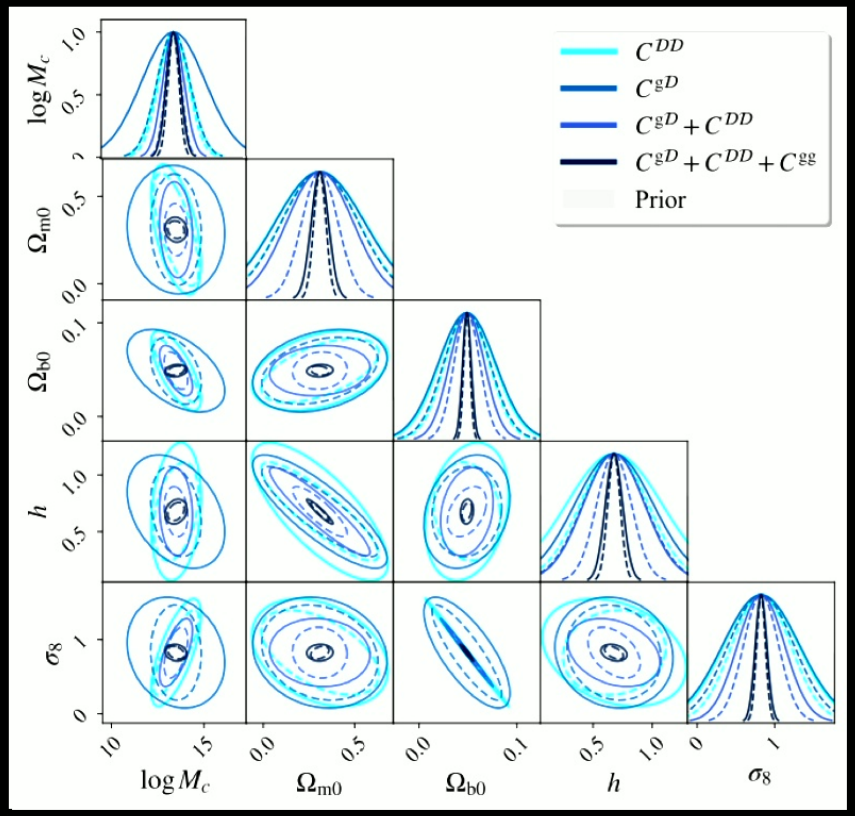
- Expected constraining power: ~1% precision at large-scales and ~10% precision at small-scales
- Robust to capture the suppression caused by at least different subgrid feedback physics



Sharma+2025a

Statistical DM-galaxy cross-correlations

Will be competitive to WL+kSZ!



Sharma+2025b

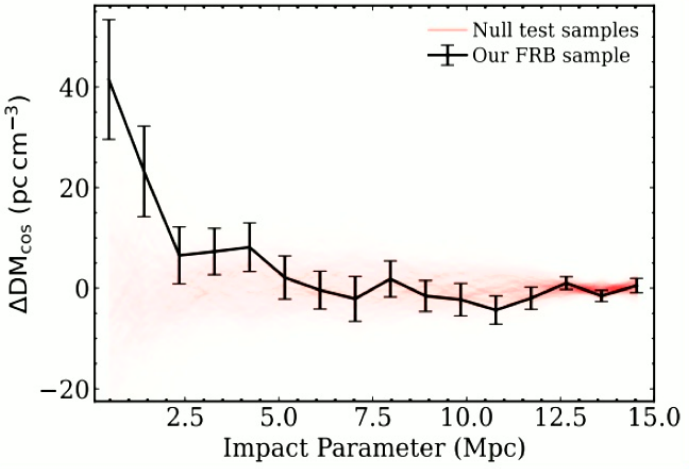
angular galaxy-DM cross-power spectrum

galaxy-electron cross-power spectrum

$$C^{g\mathcal{D}}_{\rm cosmic}(\ell, z_s) = \int_0^{\chi_s} d\chi \frac{W_{\mathcal{D}}(\chi) W_g(\chi)}{\chi^2} P_{ge}\left(k = \frac{\ell + 1/2}{\chi}, z(\chi)\right)$$

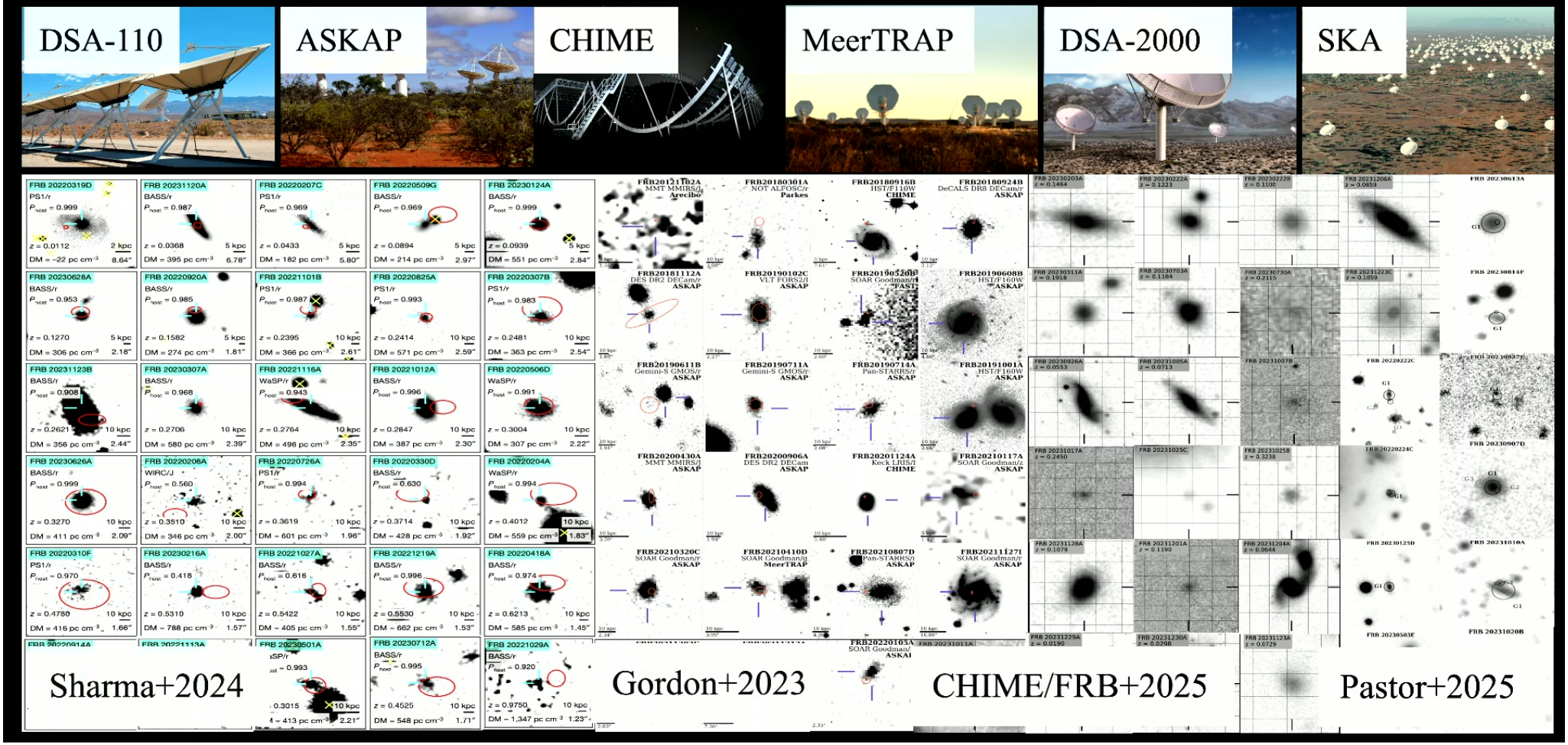
Under Limber Approximation

First detections!



Hussaini+2025

Continued efforts to build large FRB samples



Summary

- FRBs probe distribution of baryons down to scales of ~100 kpc
- Sightline-to-sightline scatter in FRB DMs ("variance") probe the small-scale suppression of matter power spectrum
- FRB DM - galaxy cross-correlations ⟷ galaxy - galaxy lensing
- First detection of FRB DM-galaxy cross-correlations by CHIME and stacking analyses
- Several ongoing efforts to build large FRB samples!

Summary

- FRBs probe distribution of baryons down to scales of ~100 kpc
- Sightline-to-sightline scatter in FRB DMs ("variance") probe the small-scale suppression of matter power spectrum
- FRB DM - galaxy cross-correlations ⟷ galaxy - galaxy lensing
- First detection of FRB DM-galaxy cross-correlations by CHIME and stacking analyses
- Several ongoing efforts to build large FRB samples!

Thank you!