The Unresolved Gamma-Ray Background and What Gravitational Tracers can Tell Us About It

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Gravitational Probes of Matter

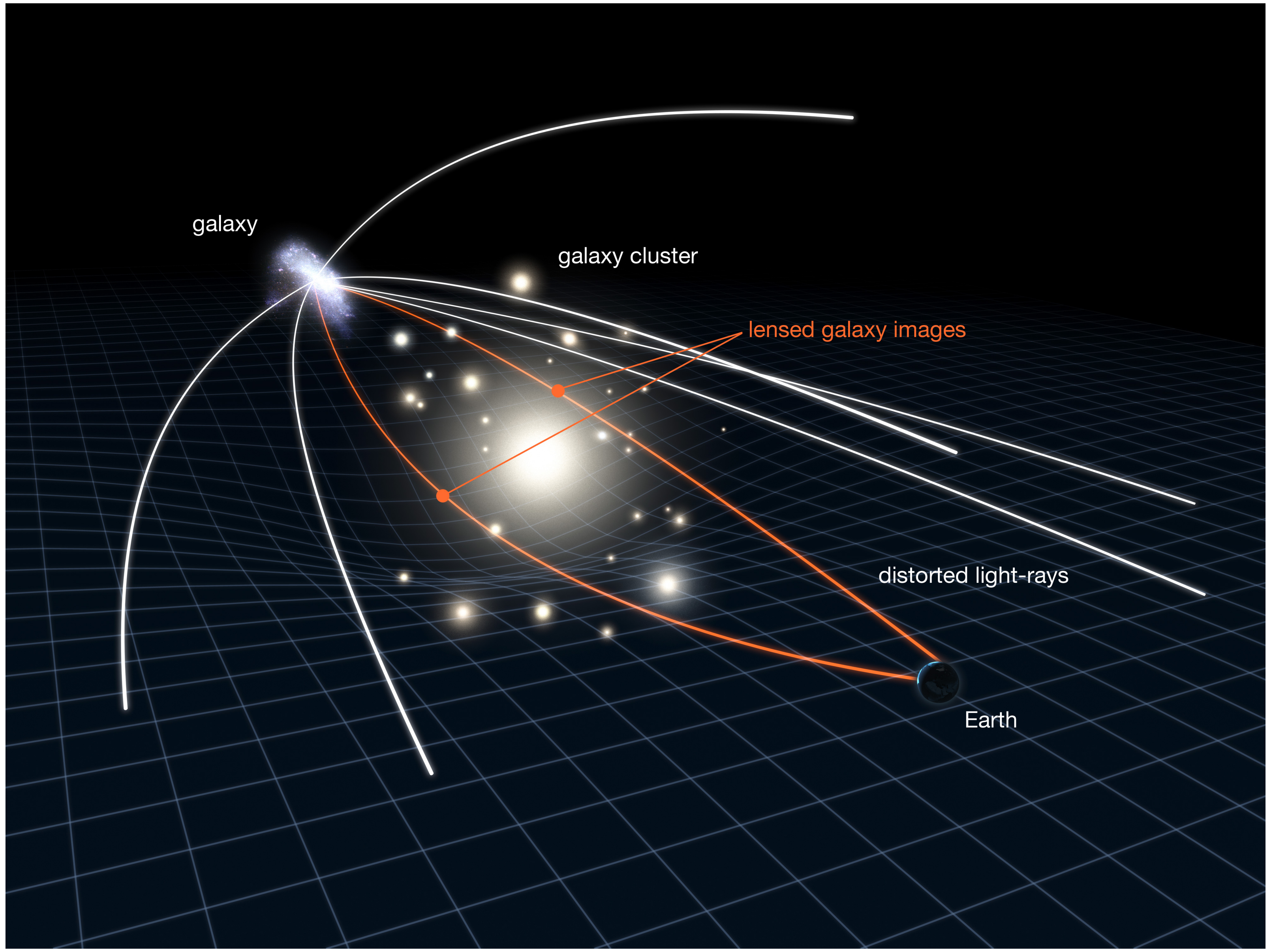
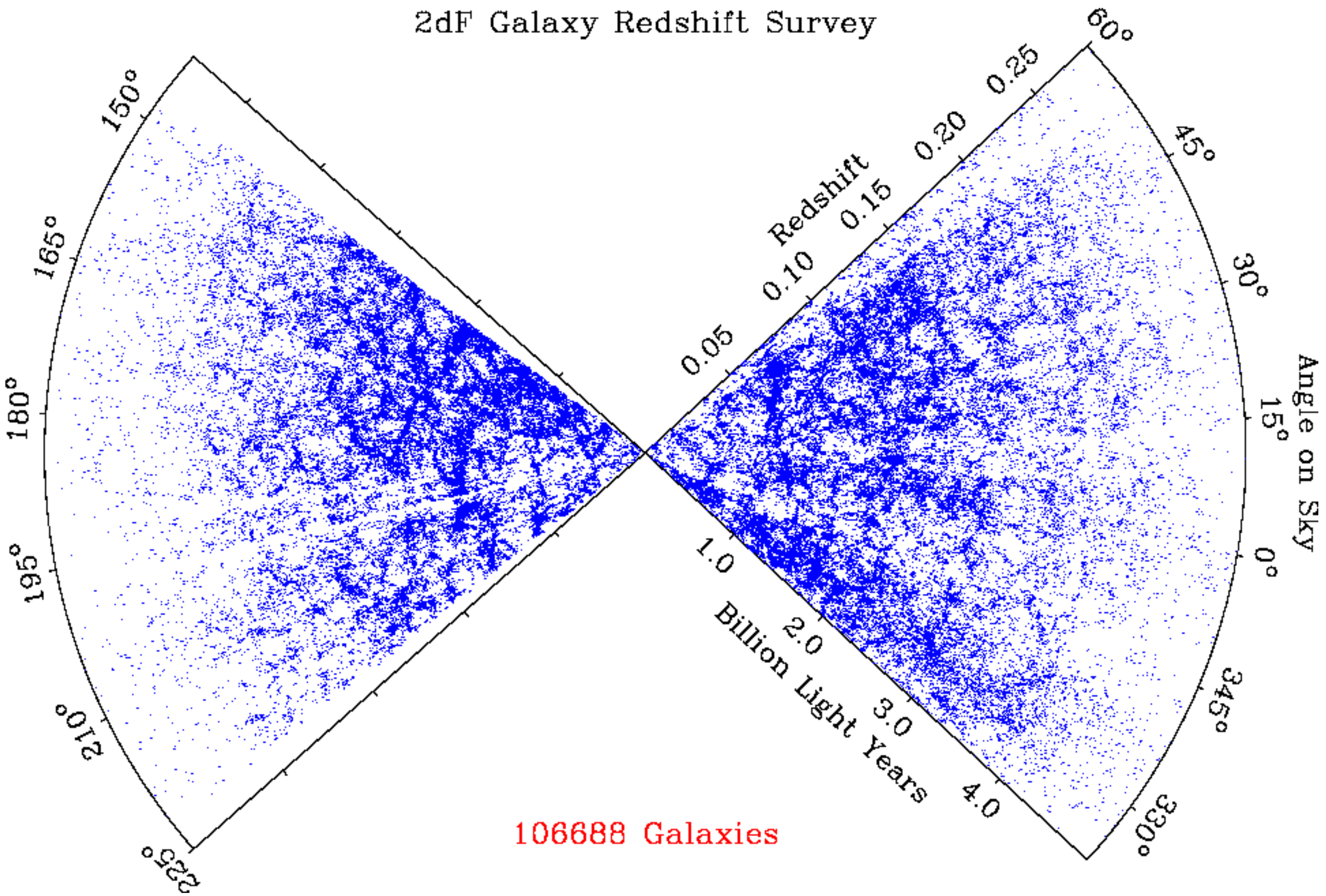
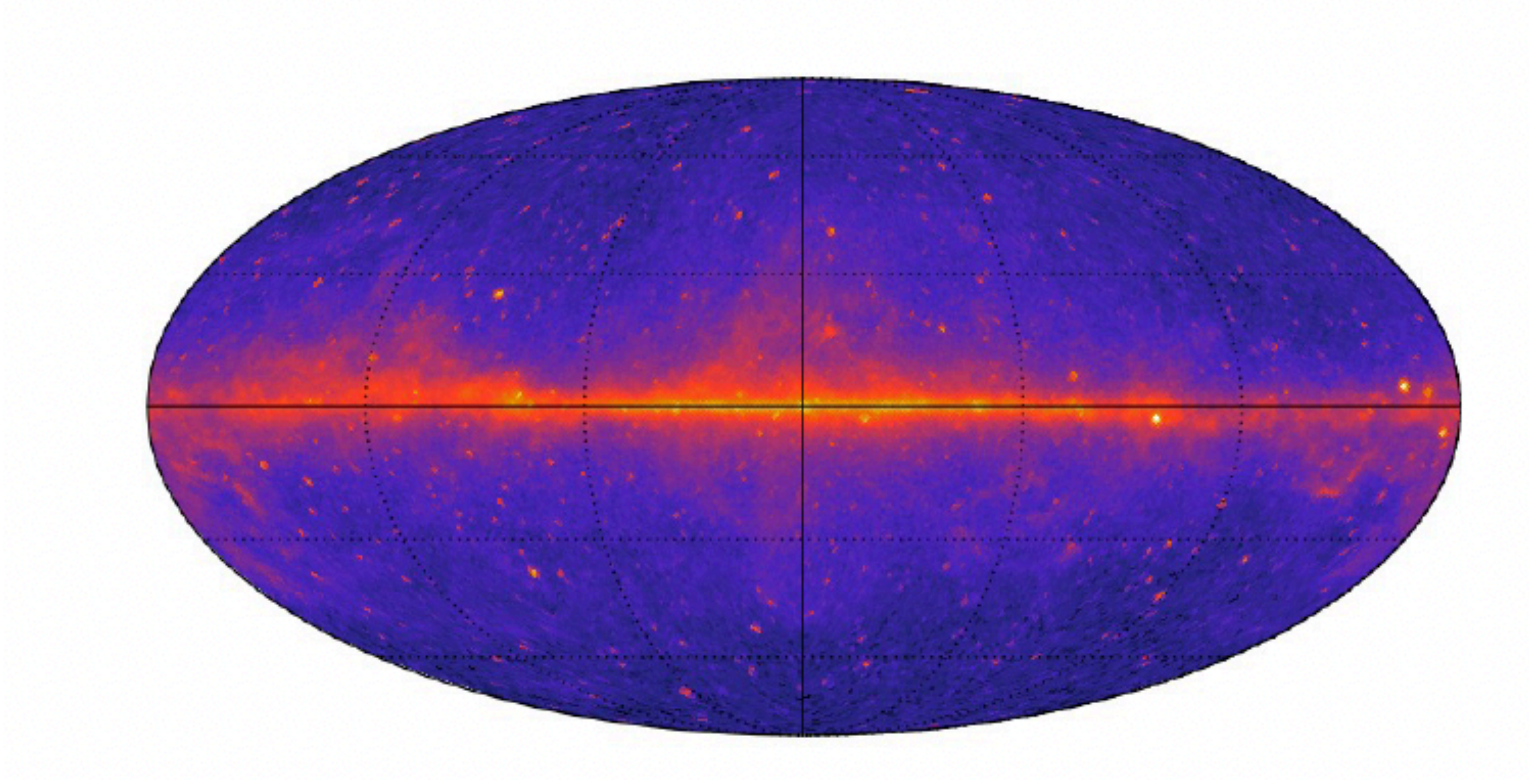
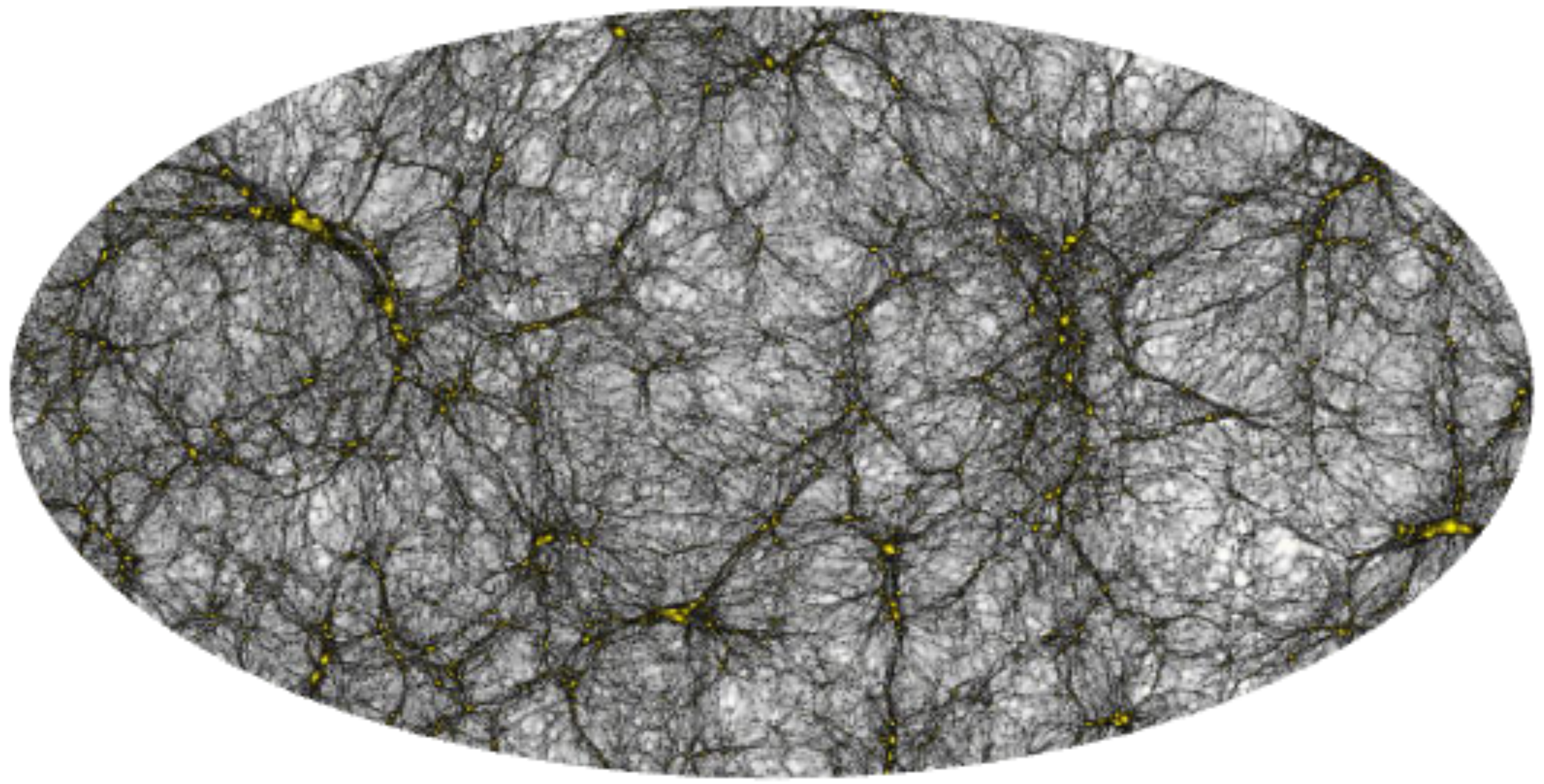


Image credit: NASA/ESA

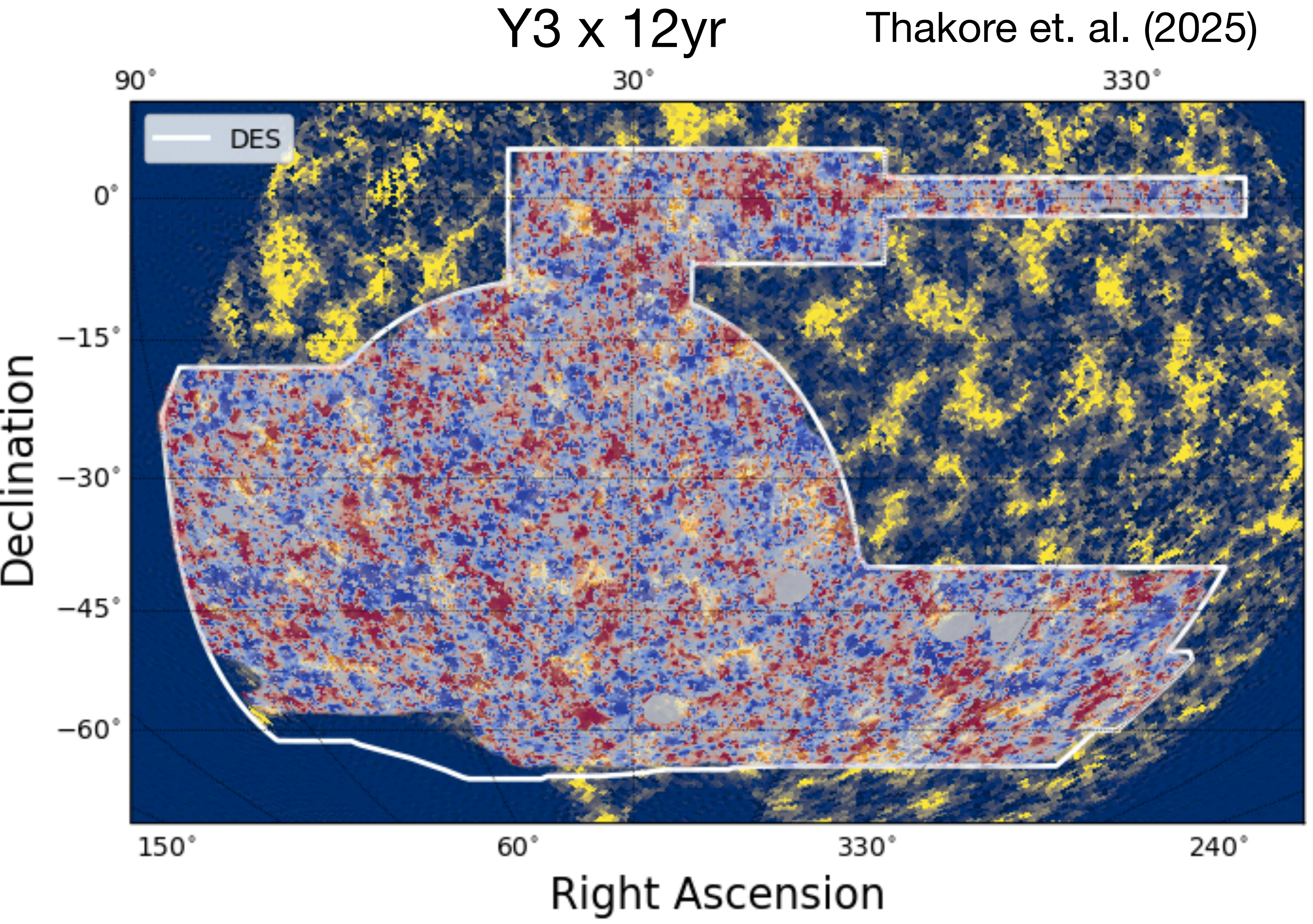


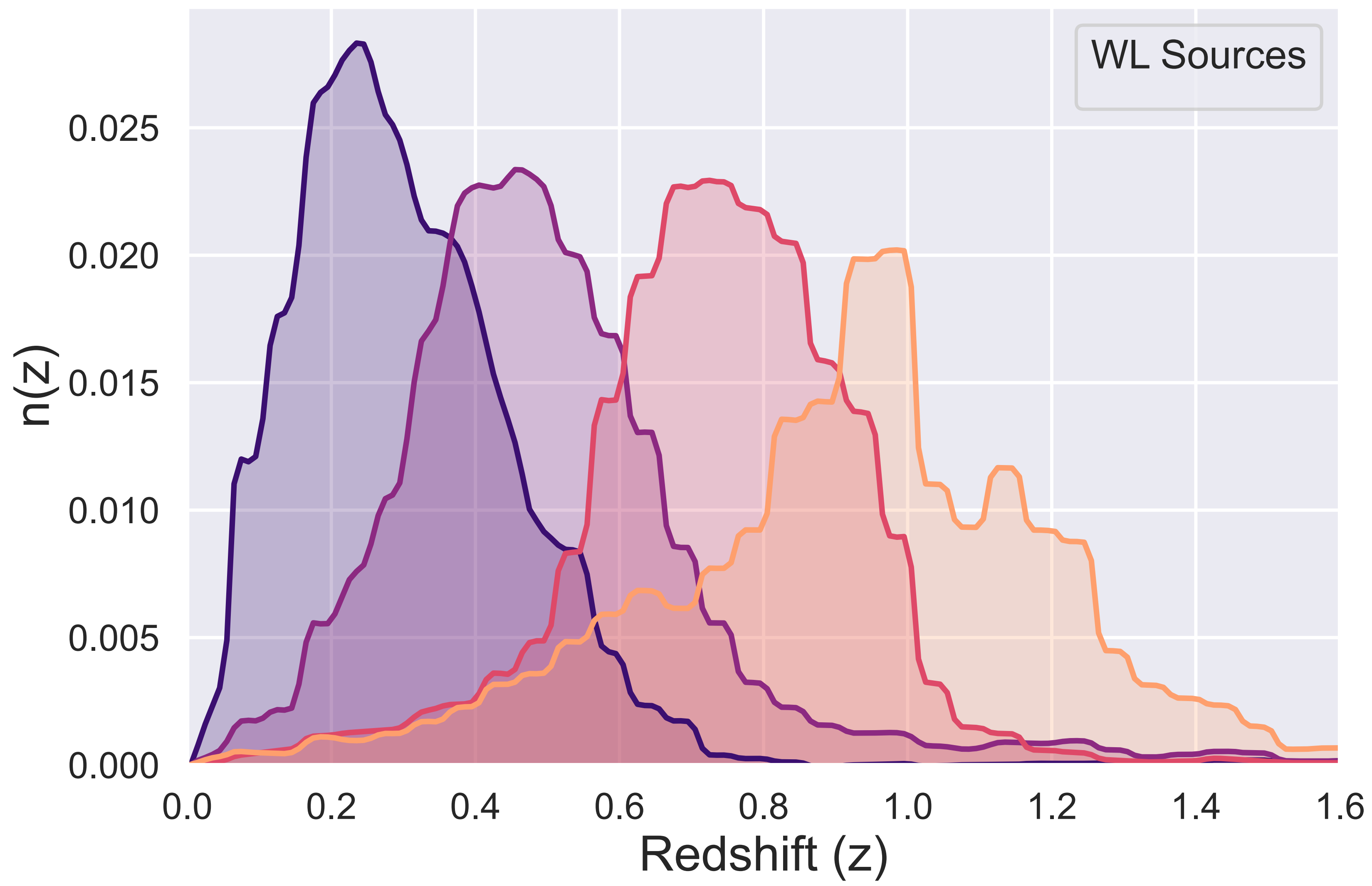
Tomographic Approaches for DM Search

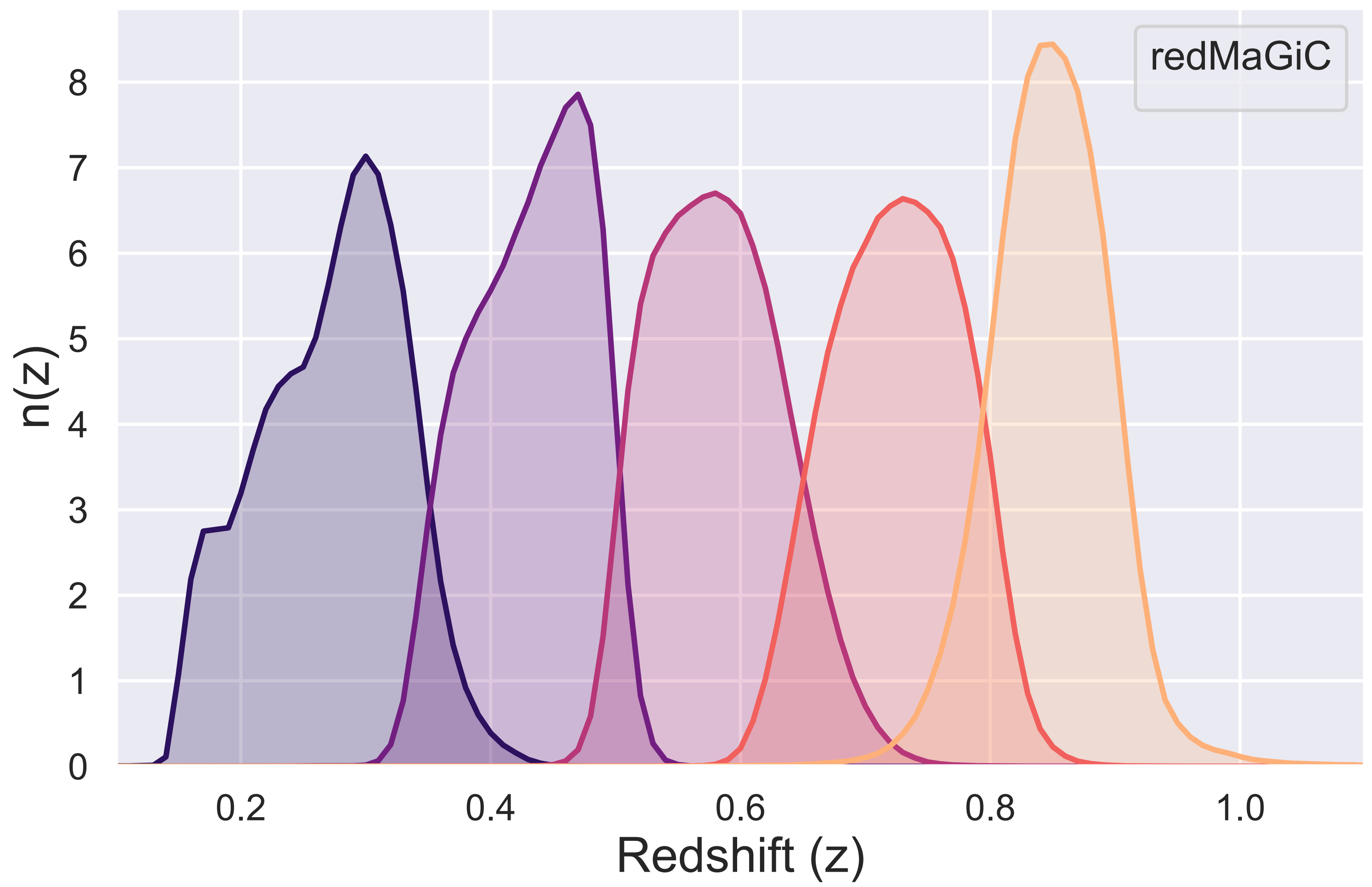




DES Y3 x Fermi 12-yr







E-bins between 0.631 GeV to 1 TeV
Angles between 5 to 600 arcmins

2-pt Correlation Estimator (Lensing)

Tangential ellipticity of source galaxy i, in redshift bin r, relative to pixel j

Photon intensity flux in energy bin a, relative to pixel j

$$\Xi^{ar}(\theta) = \Xi^{\text{signal}}_{\Delta\theta_h,\Delta E_a,\Delta z_r} - \Xi^{\text{random}}_{\Delta\theta_h,\Delta E_a,\Delta z_r} = \frac{\sum_{i,j} e^r_{ij,\text{t}} I^a_j}{R\sum_{i,j} I^a_j} - \frac{\sum_{i,j} e^r_{ij,\text{t}} I^a_{j,\text{random}}}{R\sum_{i,j} I^a_{j,\text{random}}}$$

Angular bin

Energy bin

Redshift bin

Summation over the DES source galaxies and unmasked gamma-ray pixels

Random term, subtracted from the signal to reduce additive shear systematic effects, random very-large-scale structures or chance shear alignments relative to the mask (affecting the variance).

2-pt Correlation Estimator (Clustering)

Galaxy overdensity in i, in redshift bin r, relative to pixel j

Photon intensity flux in energy bin a, relative to pixel j

$$\Xi(\theta) = \Xi^{\rm signal}_{\Delta\theta_h,\Delta E_a,\Delta z_r} - \Xi^{\rm random}_{\Delta\theta_h,\Delta E_a,\Delta z_r} = \frac{D^r_{\delta_g,ij}D^a_{\gamma,j} - D^r_{\delta_g,ij}R^a_{\gamma,j} - R^r_{\delta_g,ij}D^a_{\gamma,j} + R^r_{\delta_g,ij}R^a_{\gamma,j}}{R^r_{\delta_g,ij}R^a_{\gamma,j}}$$

Angular bin

Energy bin

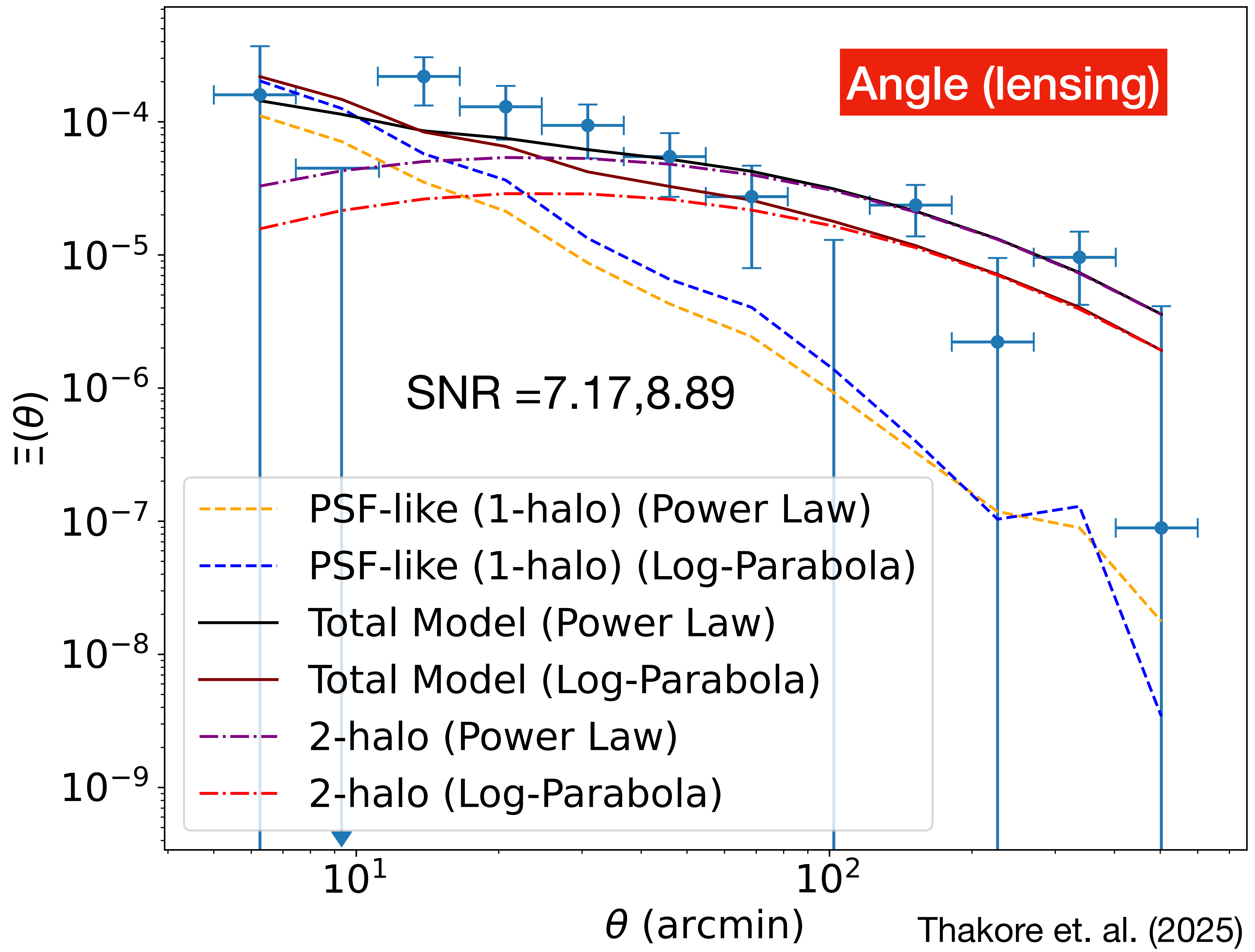
Redshift bin

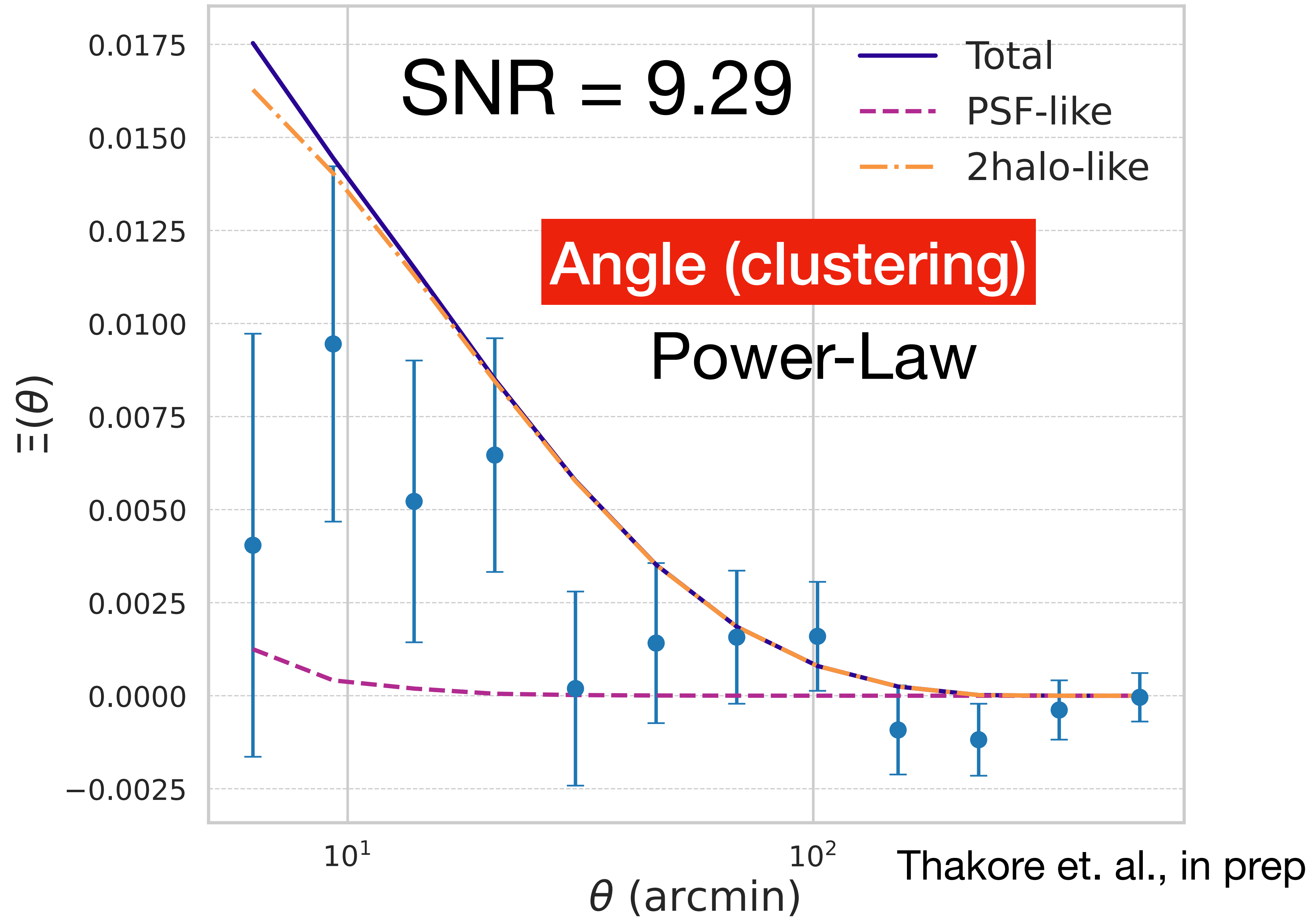
The Phenomenological Models

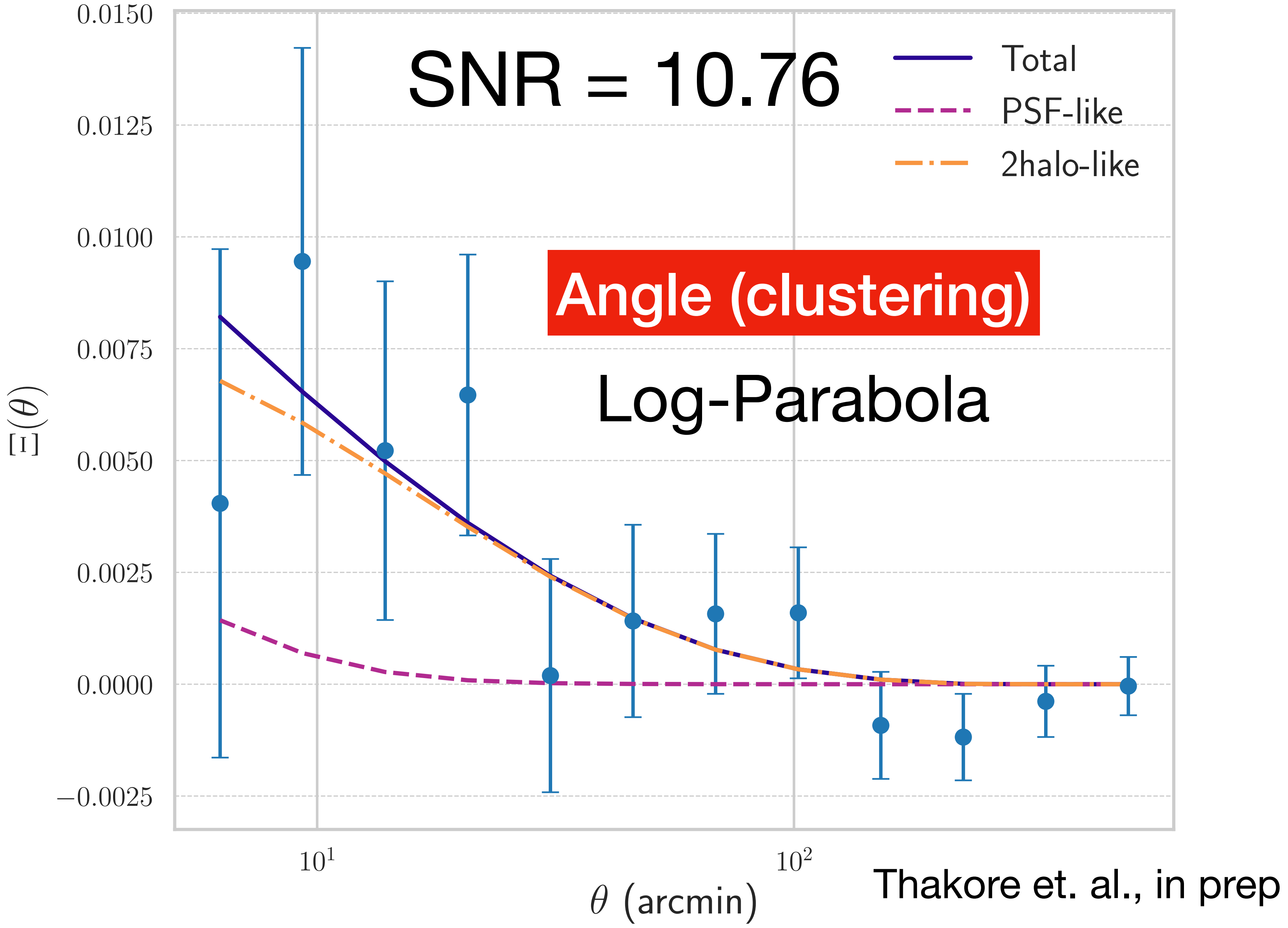
- The considerations of a potential cross-correlation signal were based on two phenomenological models - the power law and the log-parabolic models.

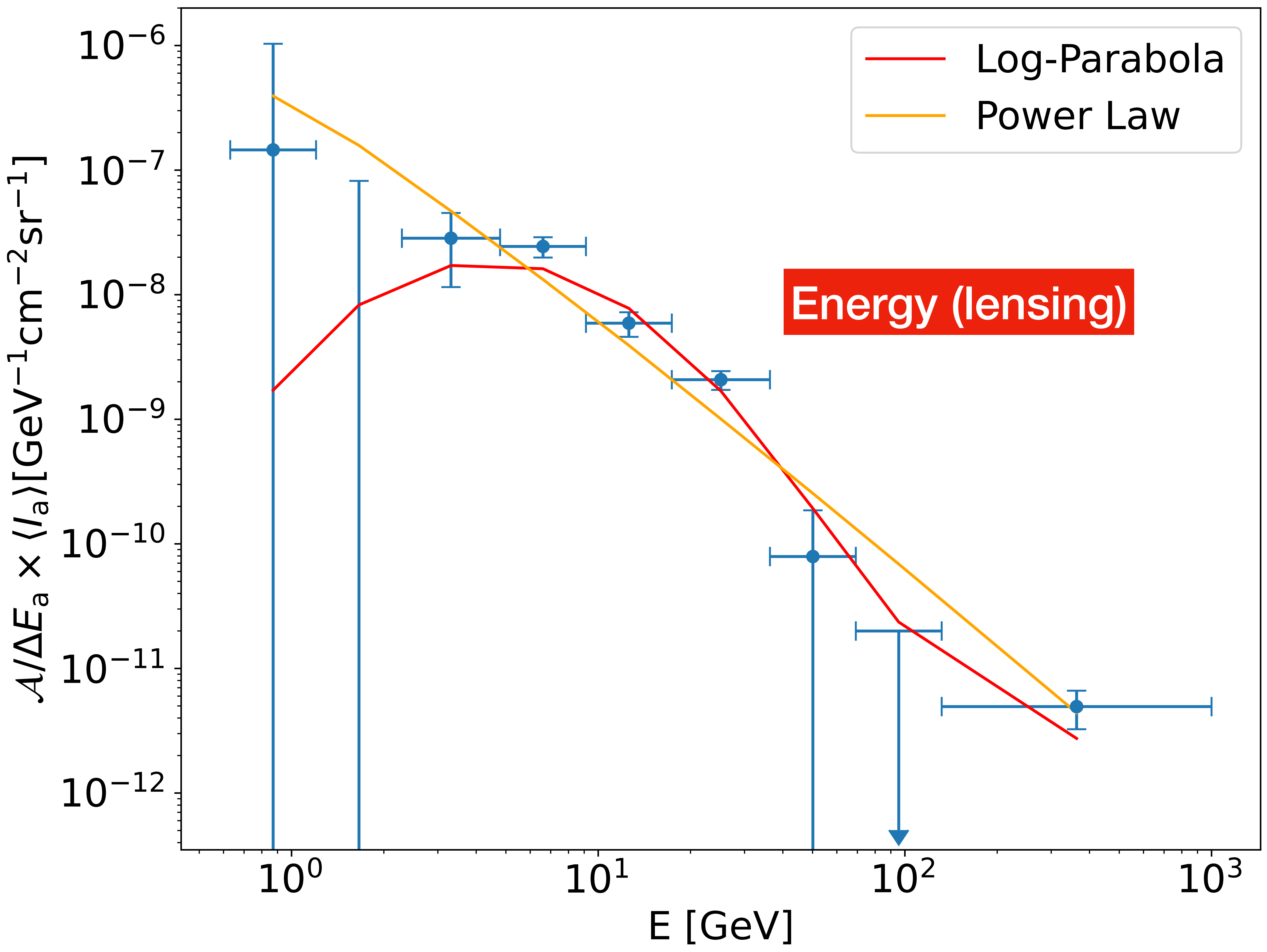
$$\Xi(\theta)_{\mathrm{PL}} = A_1 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_1} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_1} \times \hat{\Xi}^{a}_{1-\mathrm{halo}}(\theta) + A_2 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_2} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_2} \times \hat{\Xi}^{ar}_{2-\mathrm{halo}}(\theta)$$

$$\Xi(\theta)_{\mathrm{LP}} = A_1 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_1-\gamma_1 \log_{10}\frac{E_a}{E_p}} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_1} \times \hat{\Xi}^{a}_{1-\mathrm{halo}}(\theta) + A_2 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_2-\gamma_2 \log_{10}\frac{E_a}{E_p}} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_2} \times \hat{\Xi}^{ar}_{2-\mathrm{halo}}(\theta)$$

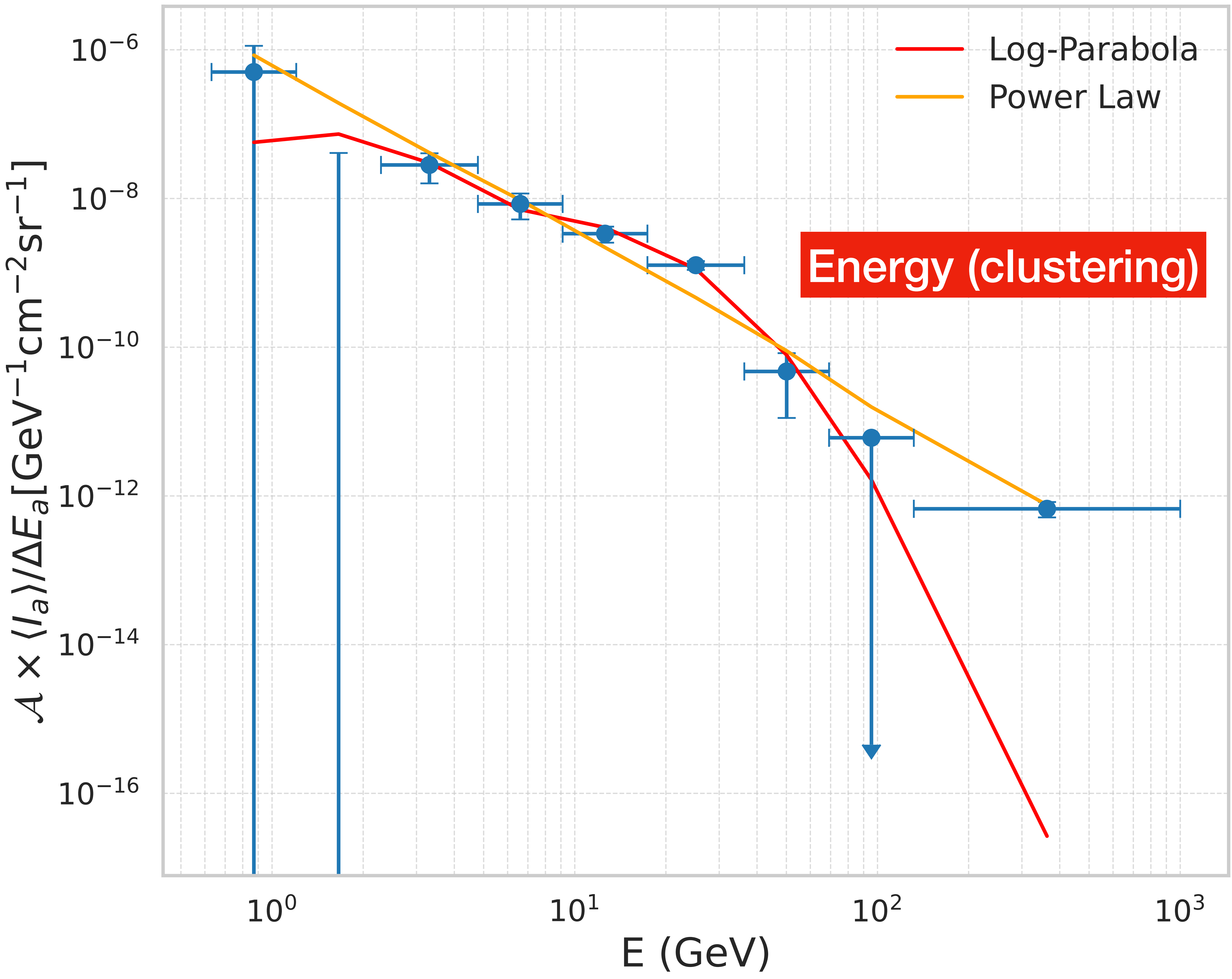

Angle (lensing)
SNR =7.17,8.89
PSF-like (1-halo) (Power Law)
PSF-like (1-halo) (Log-Parabola)
Total Model (Power Law)
Total Model (Log-Parabola)
2-halo (Power Law)
2-halo (Log-Parabola)
Ξ(θ)
θ (arcmin)
Thakore et. al. (2025)


SNR = 9.29
Total
PSF-like
2halo-like
Angle (clustering)
Power-Law
Ξ(θ)
θ (arcmin)
Thakore et. al., in prep

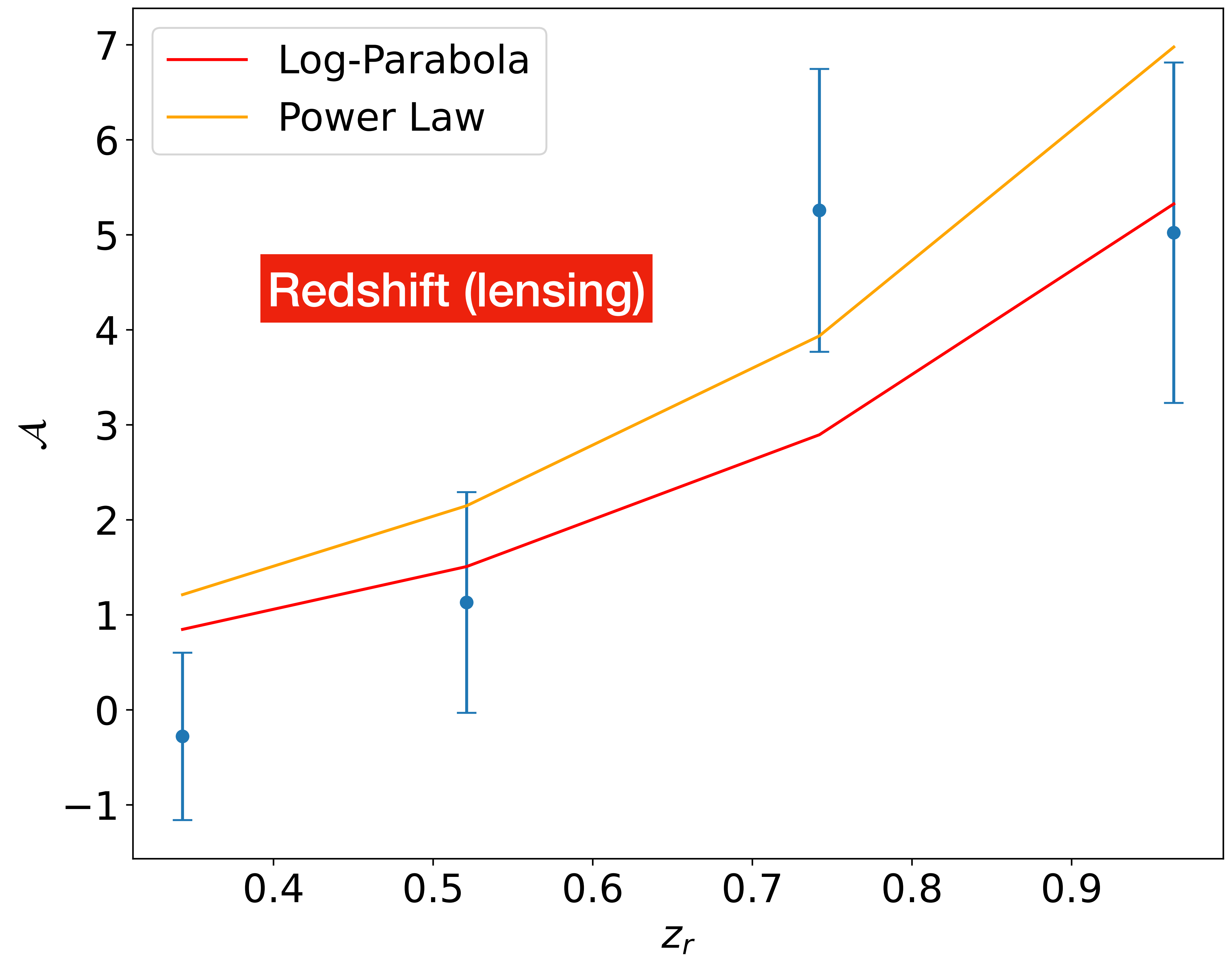

SNR = 10.76
Total
PSF-like
2halo-like
Angle (clustering)
Log-Parabola
Ξ(θ)
θ (arcmin)
Thakore et. al., in prep



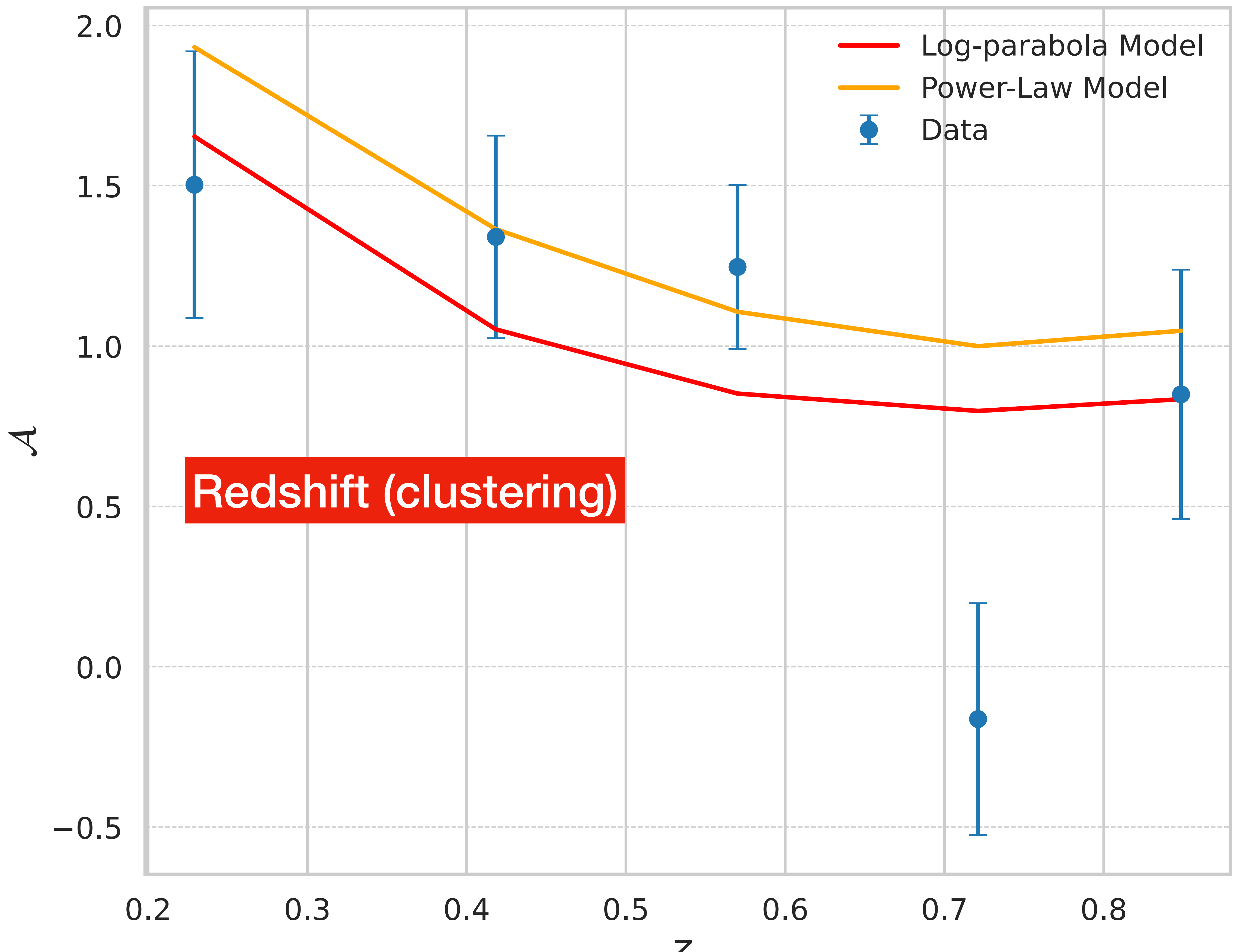
Thakore et. al. (2025)



Thakore et. al., in prep



Thakore et. al. (2025)



Thakore et. al., in prep

The Physical Model

- The physical model considerations were divided into two primary categories:
  1. Astrophysics-only contributions, consisting of Blazar components.
  2. A dark matter component, consisting of a certain dark-matter model.

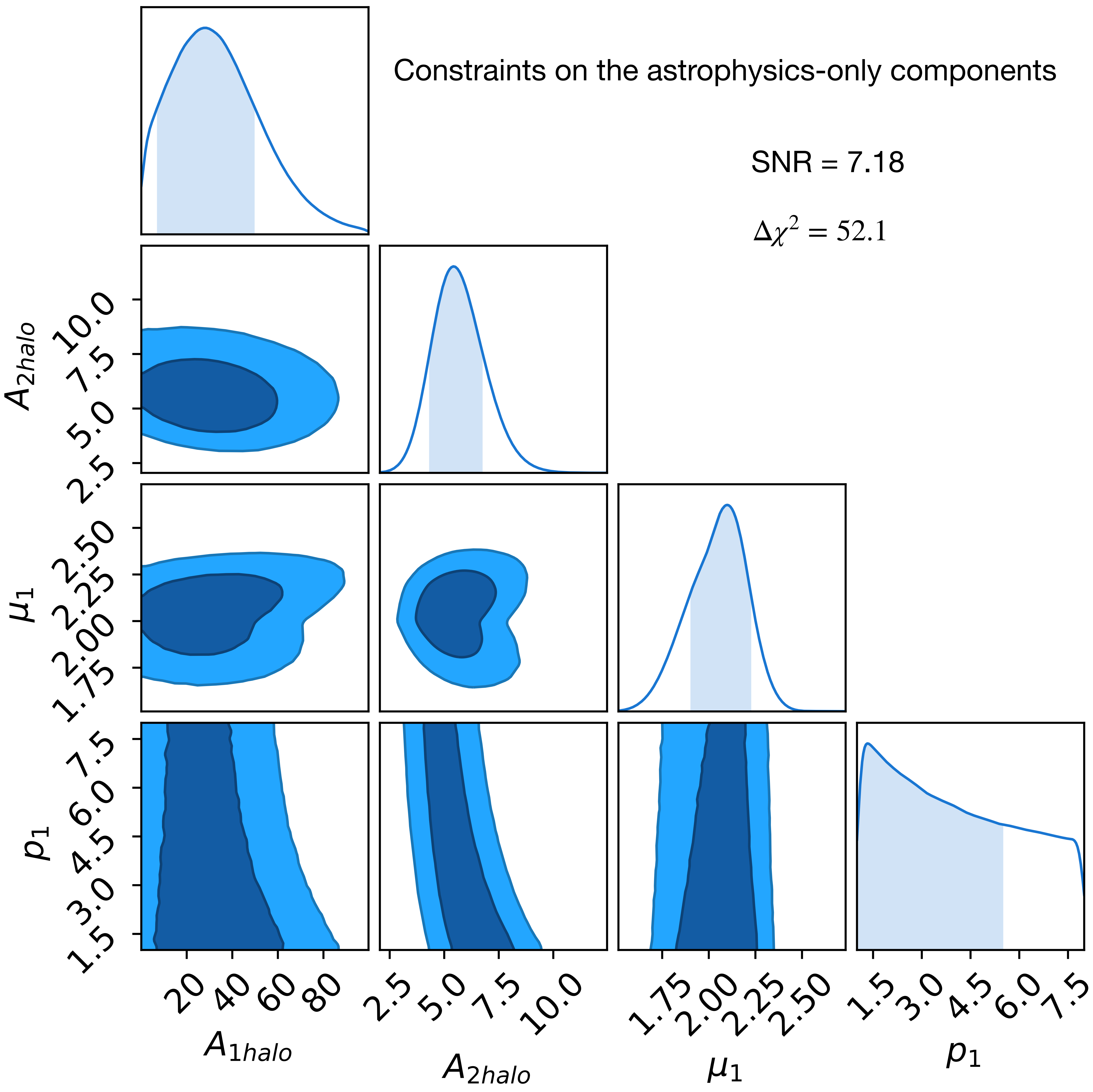
$$\Xi(\theta) = \overbrace{\underbrace{A_{\mathrm{BLZ-1halo}} \times \hat{\Xi}^{ar}_{\mathrm{BLZ-1halo}}(\theta, \mu, p_1) + A_{\mathrm{BLZ-2halo}} \times \hat{\Xi}^{ar}_{\mathrm{BLZ-2halo}}(\theta, \mu, p_1)}_{\text{Astrophysical components}} + A_{\mathrm{DM}} \times \hat{\Xi}^{ar}_{\mathrm{DM}}(\theta)}^{\text{Added DM component}}$$

Blazars Shine Through Endless Night

Constraints on the astrophysics-only components

SNR = 7.18

$\Delta\chi^2 = 52.1$

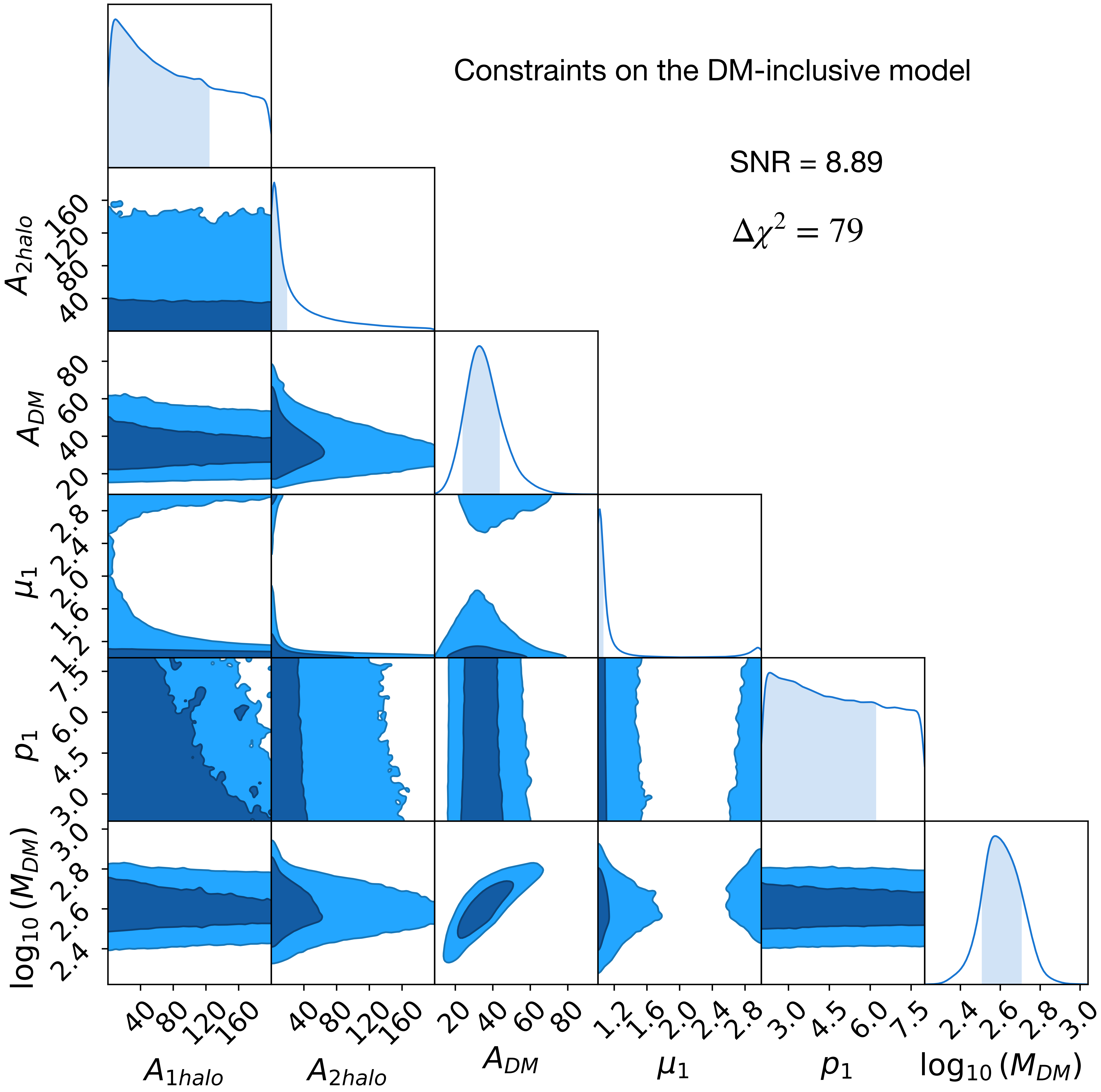


Thakore et. al. (2025)

Constraints on the DM-inclusive model

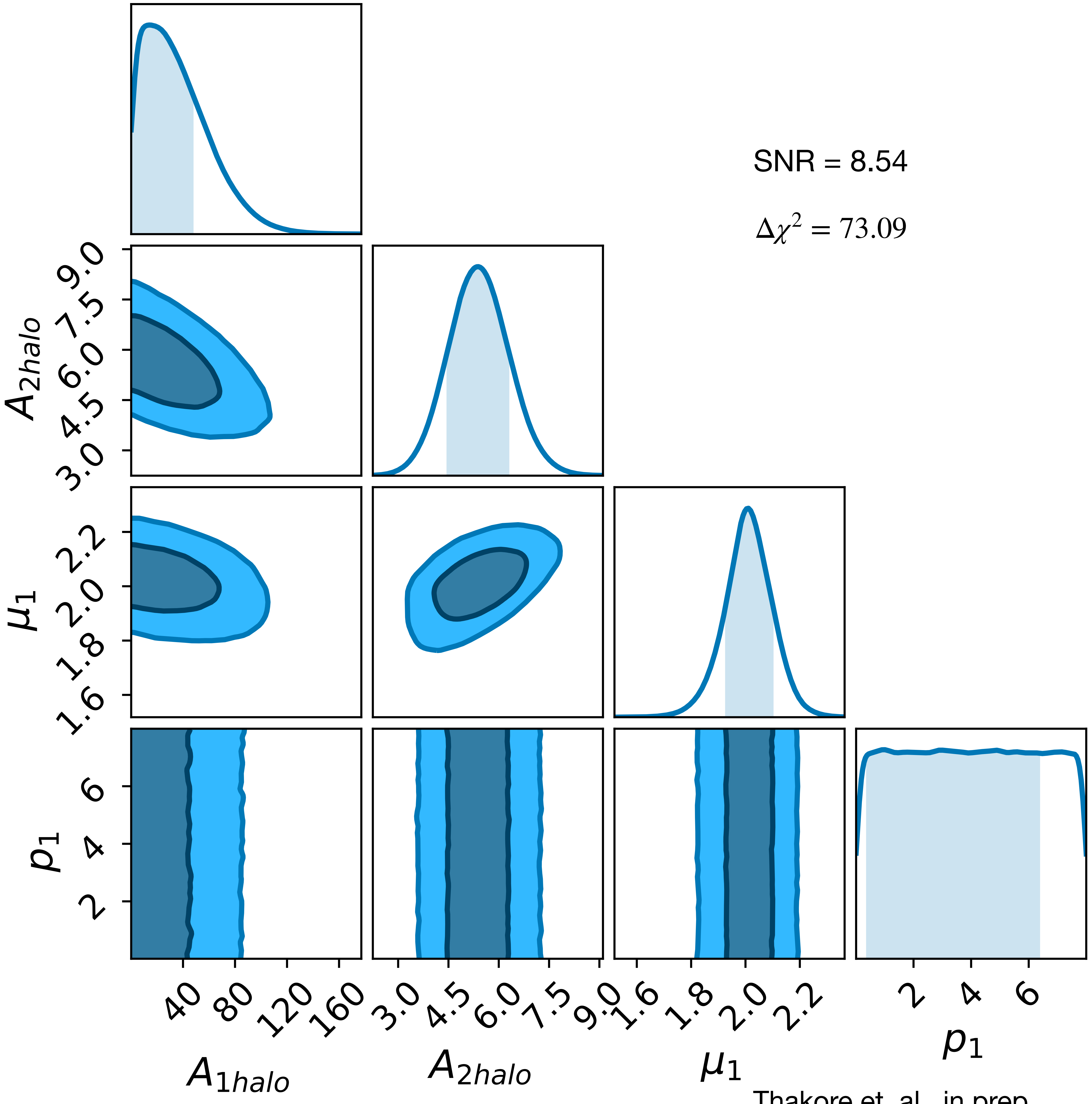
SNR = 8.89

$\Delta\chi^2 = 79$



Thakore et. al. (2025)

The Physical Model (Clustering)



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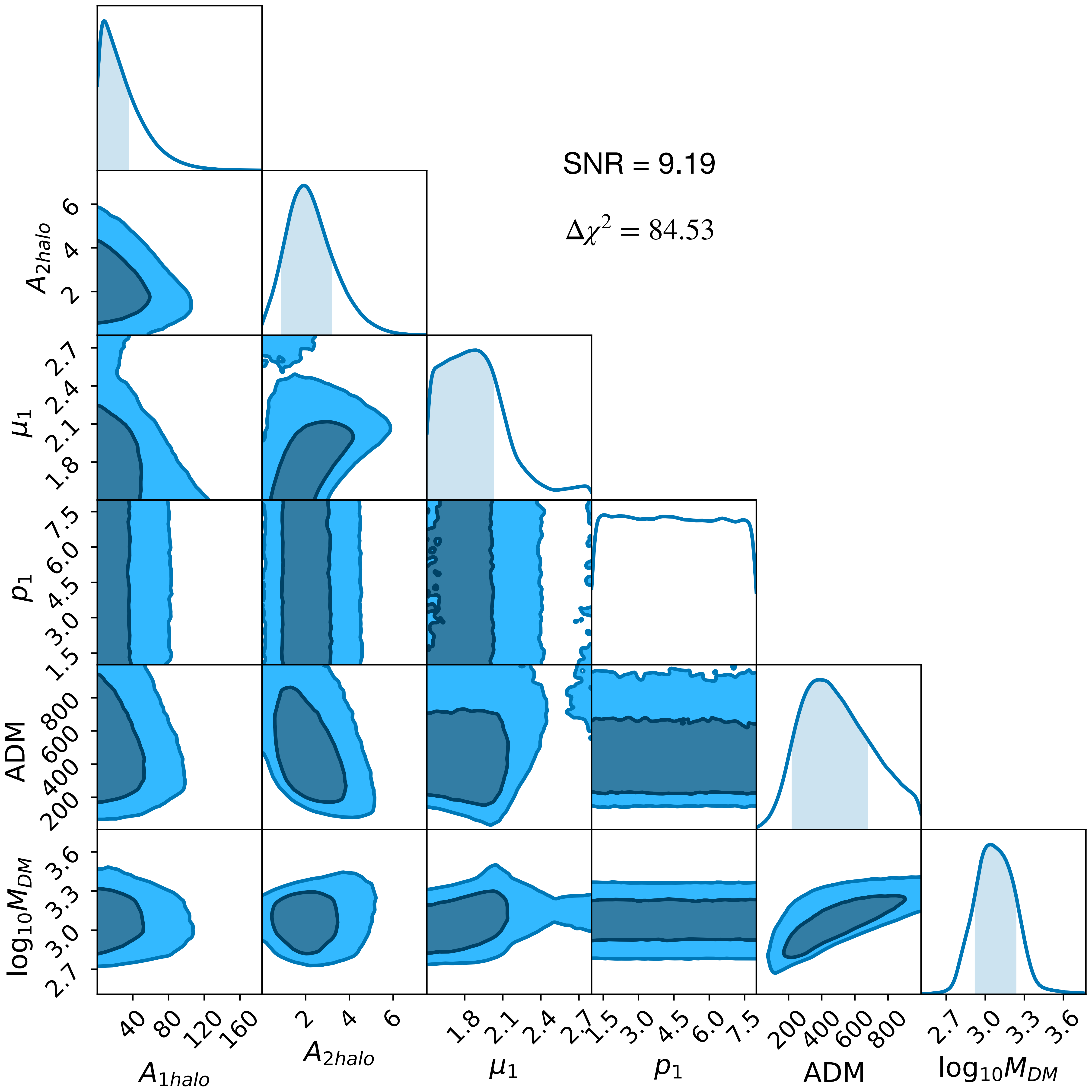
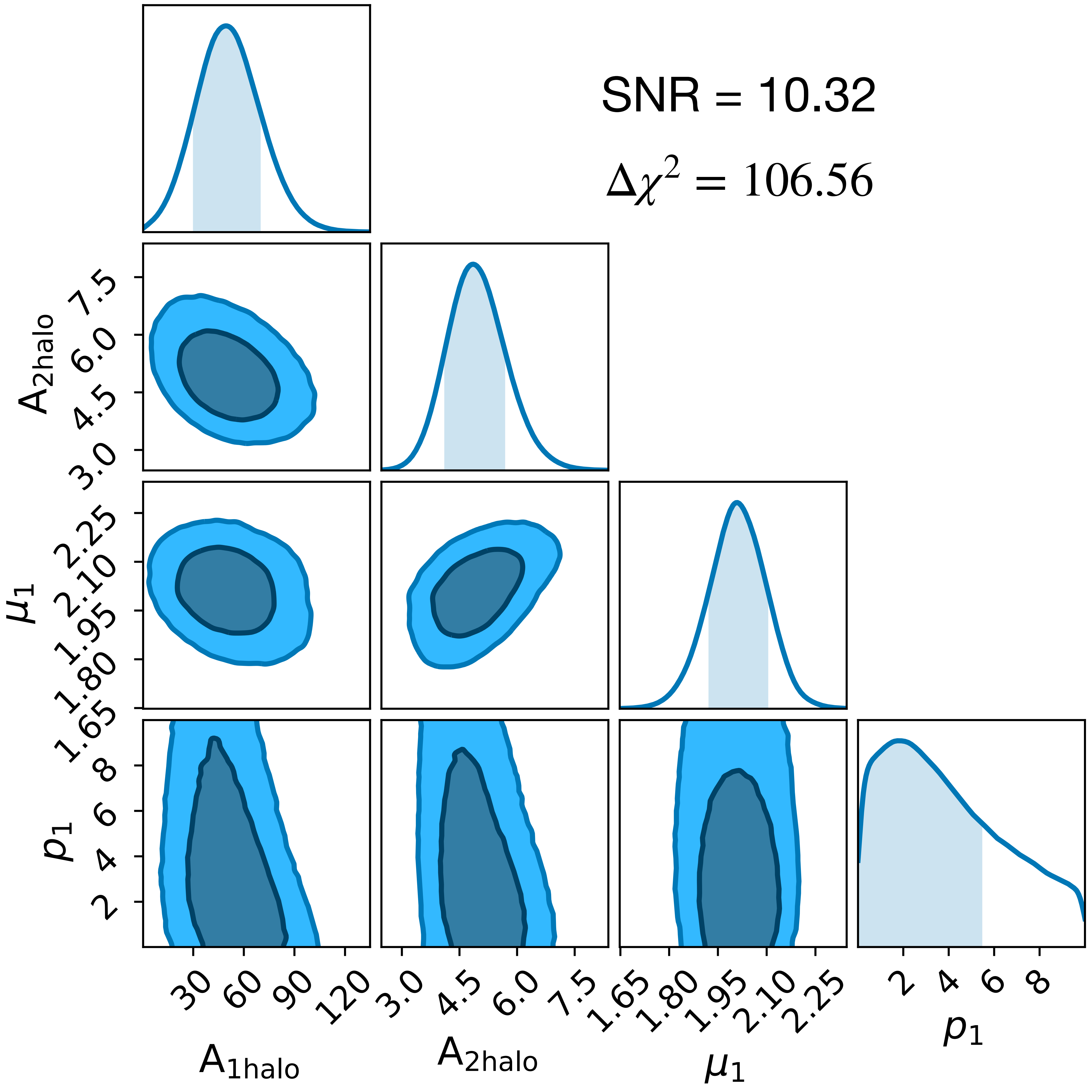


Thakore et. al., in prep

What if we combine datasets?



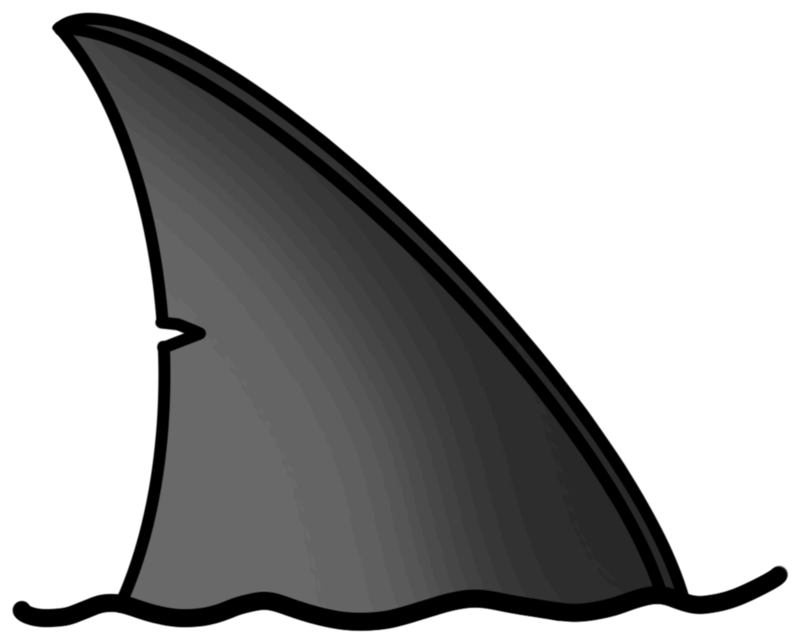
Summary

- Cross-correlations between the UGRB and tracers of large-scale structure are able to disentangle astrophysical signals from (potential) DM annihilation/decay due to their triaxial dependence on energy, redshift, and angular separation.

- Phenomenologically, cross-correlations using both weak lensing and galaxy clustering lead to detections of a signal.

- The spectral indices from the power-law in weak lensing point towards a dominant blazar component. This is also shown to be the case physically in weak lensing. For galaxies, there appears to be an additional astrophysical component contribution to the power-law formulation.

- By combining lensing and clustering observations one can obtain even larger signals and potentially constrain parameters for both the astrophysical and dark matter cases more strongly.



Fin.