Tracing the redshift and luminosity evolution of the HOD using magnification bias and galaxy clustering

Les Rencontres de Noirmoutier

June 2, 2026

Juan Alberto Cano Díez (uo271466@uniovi.es)

J. González-Nuevo, L. Bonavera, M.M. Cueli, J.M. Casas,

D. Crespo, R. Fernández Fernández, and V. Franco

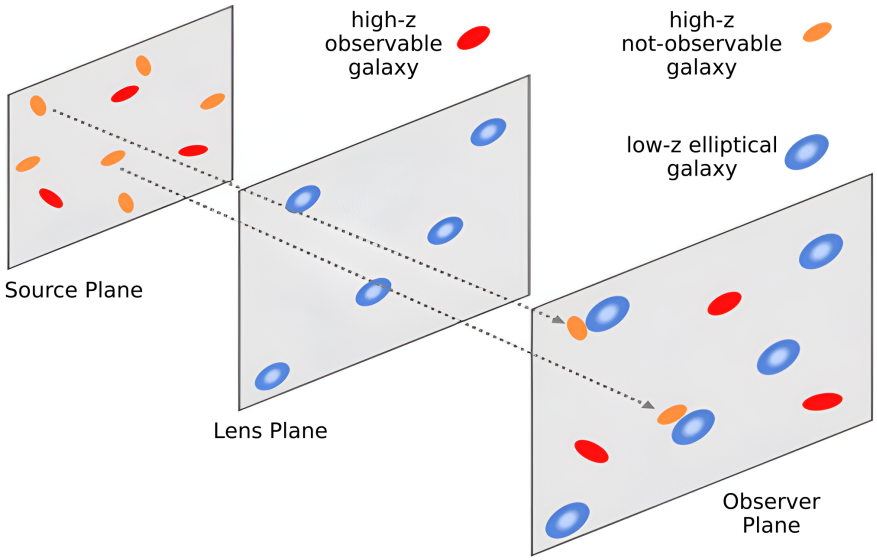
Universidad de Oviedo

ICTEA Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias

Introduction

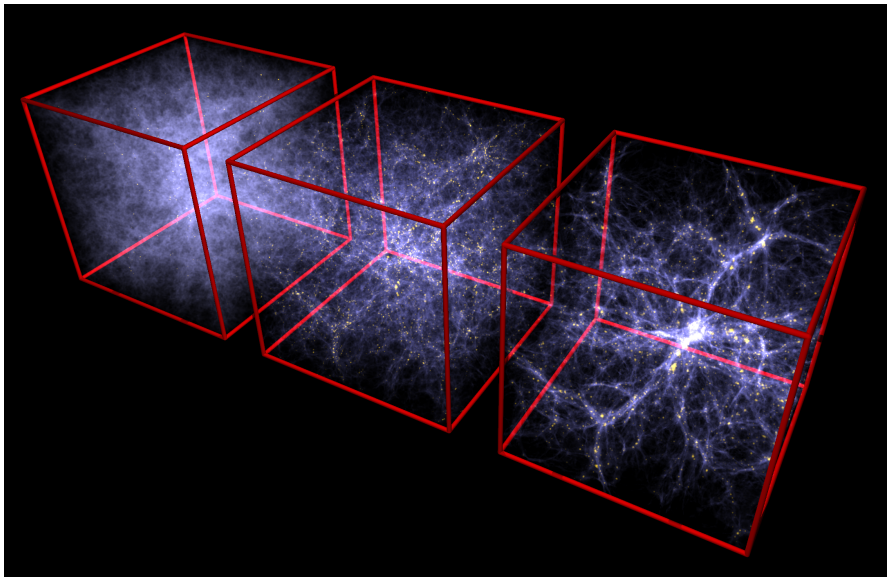
Weak gravitational lensing

Magnification bias



- Excess of background sources around foreground galaxies.
- Traces the matter density distribution directly.
- HOD + cosmology.

Galaxy clustering



Credit: Volker Springel/Max Planck Institute for Astrophysics.

- Spatial distribution of galaxies.
- Galaxies are biased tracers of the dark matter density distribution.
- Tighter HOD constraints.
- Less sensitive to cosmology.

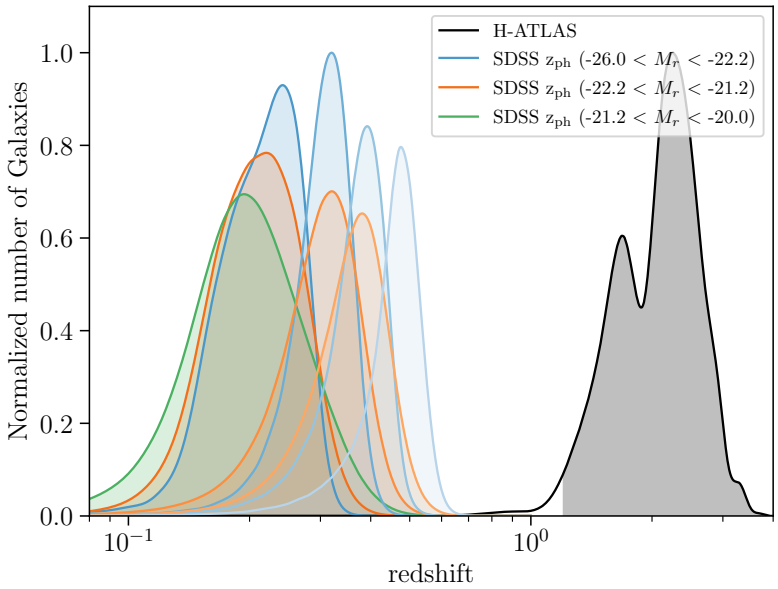
Data

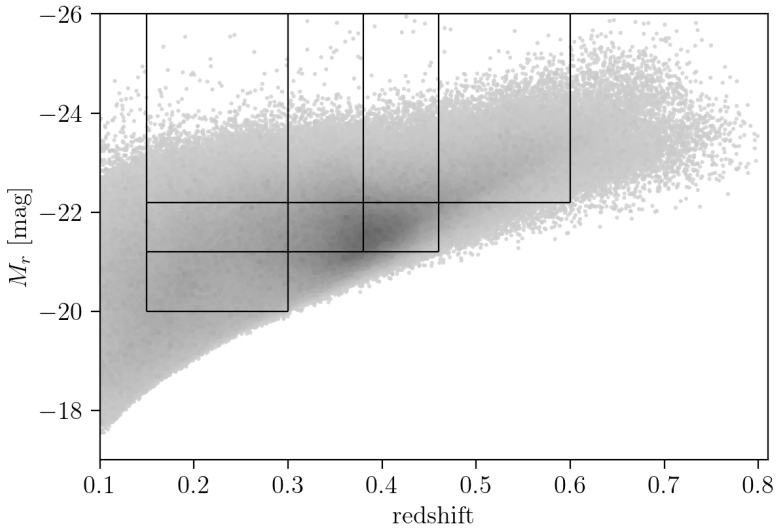
Background: *Herschel* Astrophysical Terahertz Large Area Survey (H-ATLAS).

- Submillimeter galaxies: $1.2 < z < 4.0$.
- $\sim 360\,\mathrm{deg}^2$ common area with SDSS in 4 separate fields: G09, G12, G15, NGP.

Foreground: Sloan Digital Sky Survey (SDSS DR18).

- 3 bins of absolute magnitude between $-26.0 < M_r < -20.0$ mag.
- 4 redshift bins between $0.15 < z < 0.60$.
- Volume-limited samples.
- Photo-z errors $\rightarrow$ Smoothed redshift distributions (Ross et al. 2010).
- Mask poor seeing and dust extinction areas.





Auto- and cross-correlation measurements

Auto-correlation function with the Landy & Szalay (1993) estimator:

$$\hat{w}_{\rm auto}(\theta) = \frac{\mathrm{D_f D_f}(\theta) - 2\mathrm{D_f R_f}(\theta) + \mathrm{R_f R_f}(\theta)}{\mathrm{R_f R_f}(\theta)}$$

Modified by Herranz (2001) for the cross-correlation function:

$$\hat{w}_{\rm cross}(\theta) = \frac{\mathrm{D_f D_b}(\theta) - \mathrm{D_f R_b}(\theta) - \mathrm{D_b R_f}(\theta) + \mathrm{R_f R_b}(\theta)}{\mathrm{R_f R_b}(\theta)}$$

Full covariance error estimation with Bootstrap resampling:

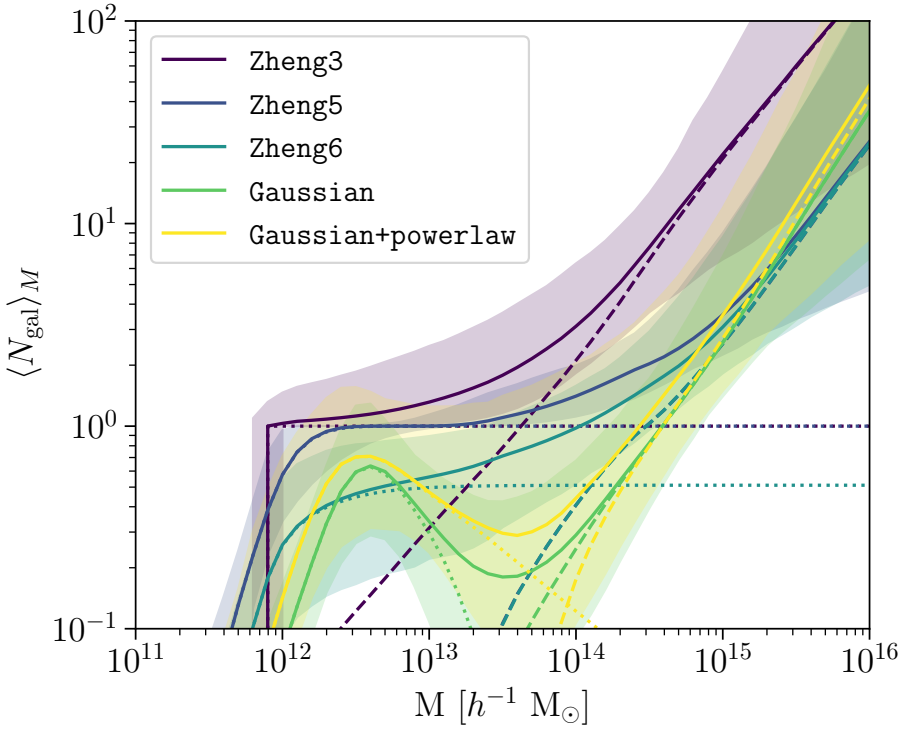
$$\mathrm{Cov}(\theta_i, \theta_j) = \frac{1}{N_b - 1} \sum_{k=1}^{N_b} \Big[\hat{w}_k(\theta_i) - \langle \hat{w}(\theta_i) \rangle\Big] \Big[\hat{w}_k(\theta_j) - \langle \hat{w}(\theta_j) \rangle\Big]$$

Signals interpreted within the halo model formalism, using MCMC techniques to obtain posterior distributions of the HOD parameters.

HOD models

Halo occupation distribution: describes the probability $P(N_{\text{gal}} \mid M)$ that a halo of mass M hosts N_{gal} galaxies.

Central and satellite components: $\langle N_{\text{gal}} \rangle_M = \langle N_{\text{cen}} \rangle_M + \langle N_{\text{sat}} \rangle_M$.



Luminosity threshold samples: step functions (Zheng et al. 2005).

$$\texttt{Zheng3:} \qquad \langle N_{\text{gal}} \rangle_M = \left[1 + \left(\frac{M}{M_1}\right)^{\alpha}\right] \Theta(M - M_{\text{min}})$$

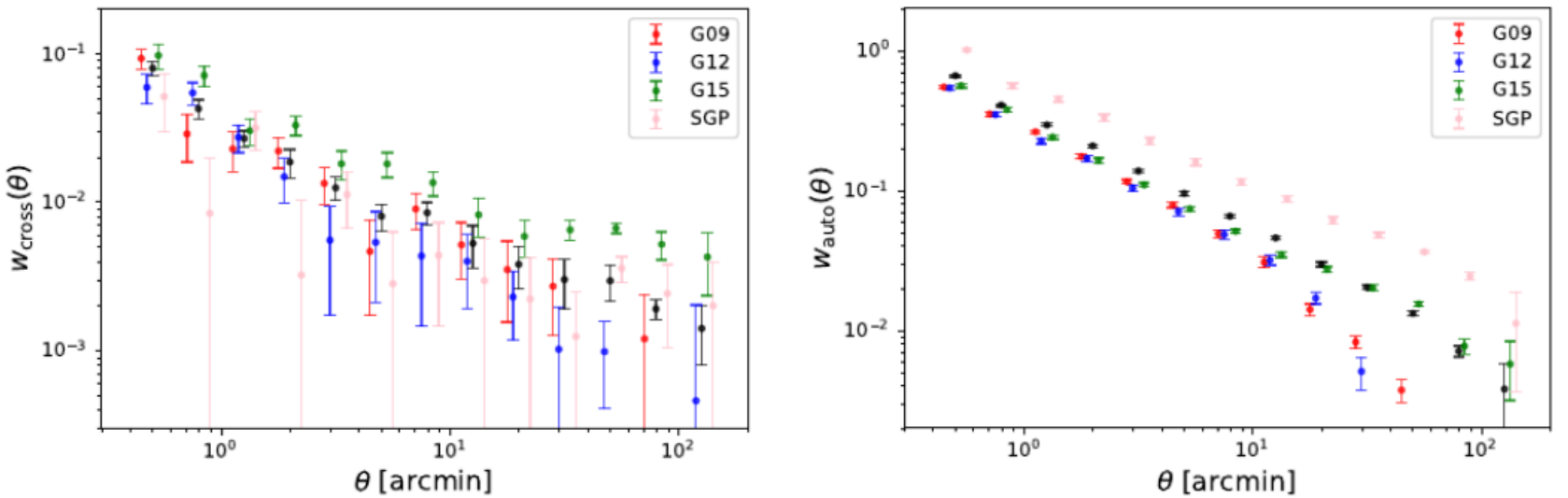
Luminosity bin samples: Gaussian, Guassian+powerlaw (Avila et al. 2020).

$$\texttt{Gaussian:} \qquad \langle N_{\text{cen}} \rangle_M = \frac{A_c}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(\log M - \log M_g)^2}{2\sigma^2}\right)$$

Field-to-field fluctuations

- Significant variations in the clustering and lensing signals.
- Substantially larger than expected.
- Observed in two independent catalogs.
- Affects both small and large angular scales.
- Causes: sample variance, unknown systematics.

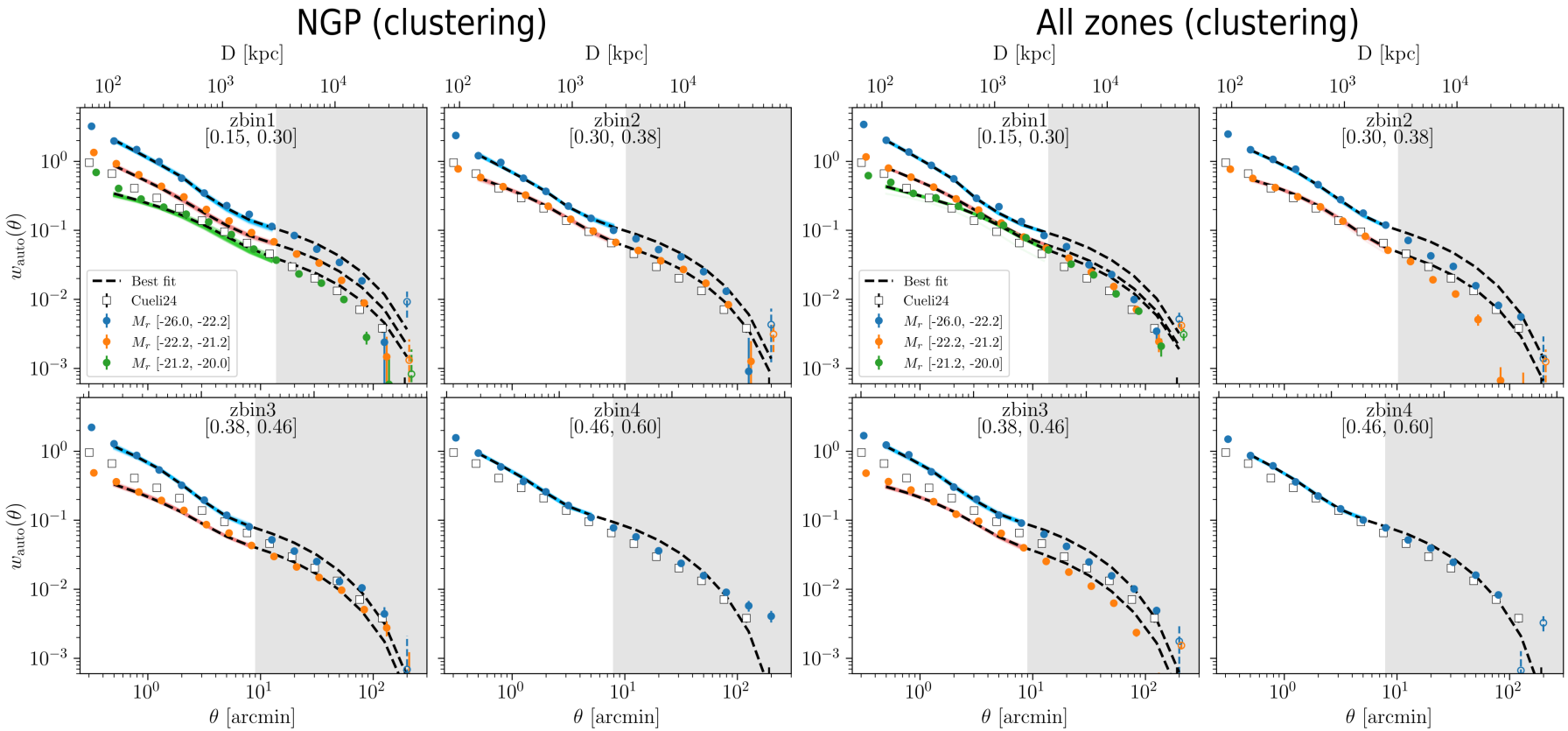
GAMA II catalog (spectroscopic)



Cueli et al. (2024)

Field-to-field fluctuations

- Clustering: restrict measurements to a single field (NGP).
- Full area still considered for cross-correlations for higher S/N.

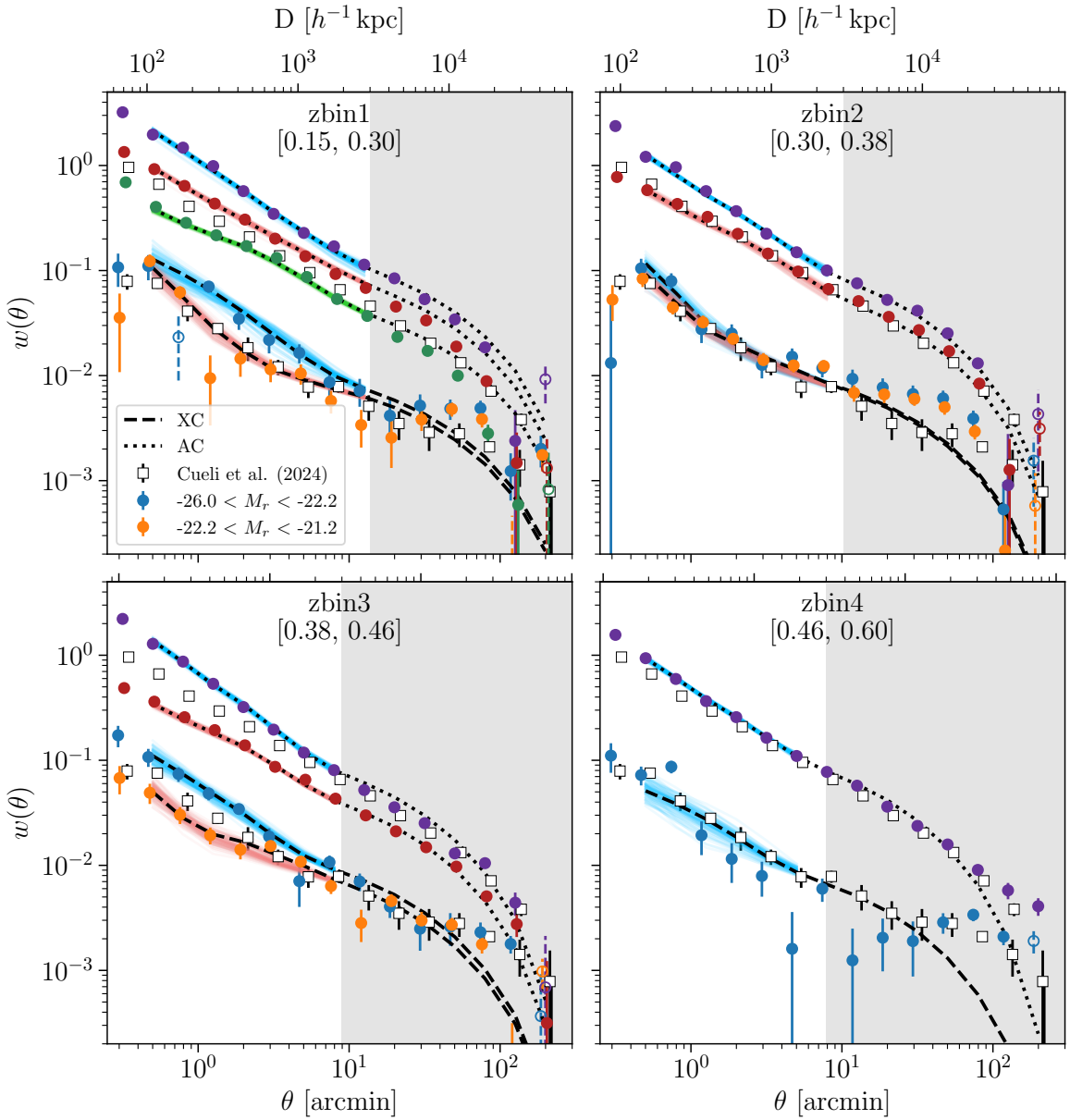


Auto- and cross-correlation analysis

Flat ΛCDM cosmology

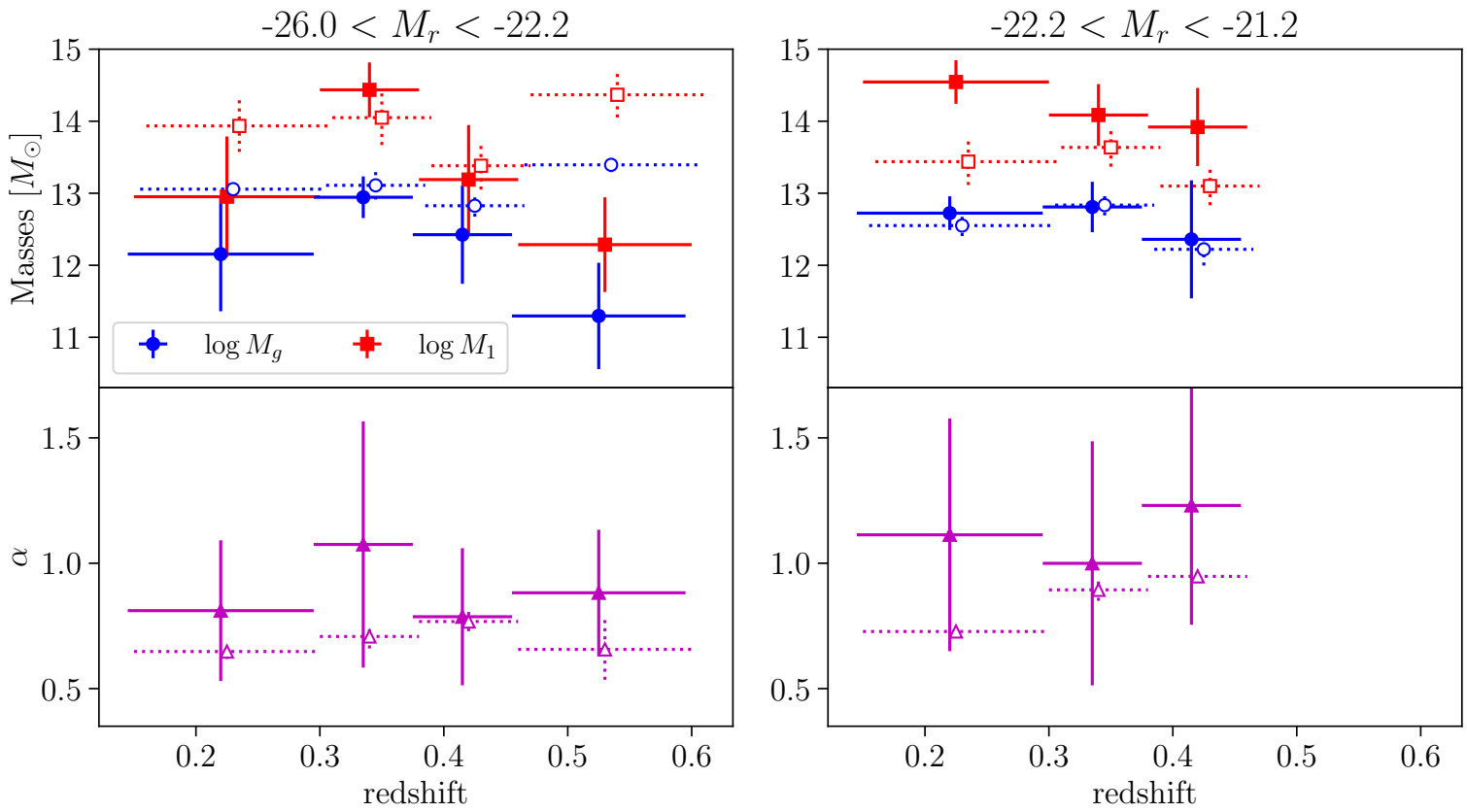
Weak lensing (> 0.5 arcmin)

1-halo term ($< 3\,h^{-1}$ Mpc)



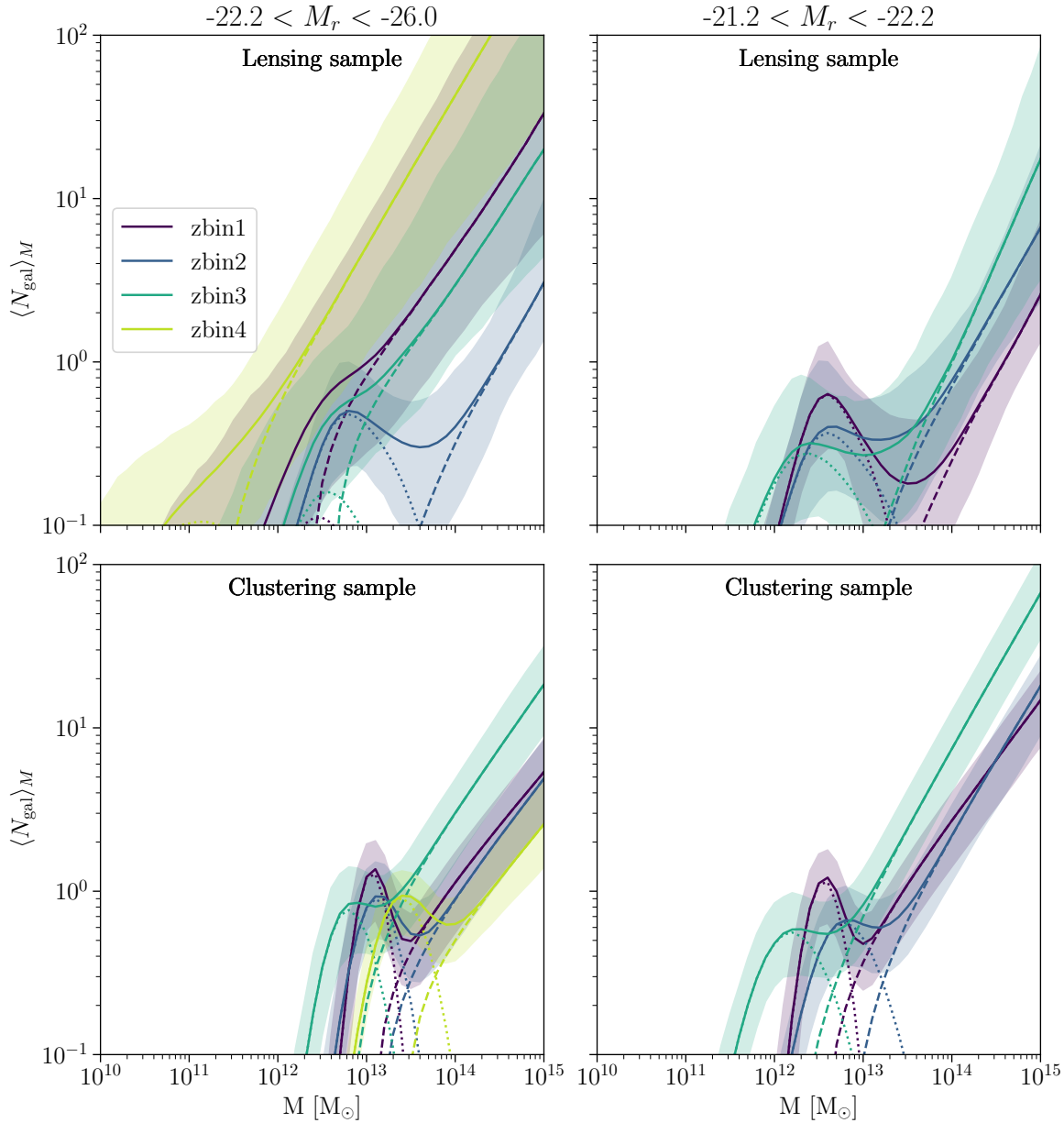
HOD redshift evolution

- Clustering/lensing amplitudes decreasing at fainter magnitudes.
- Clustering: $M_{\rm min}$ increasing with redshift.
- Lensing: $M_{\rm min}$ affected by the lensing probability.

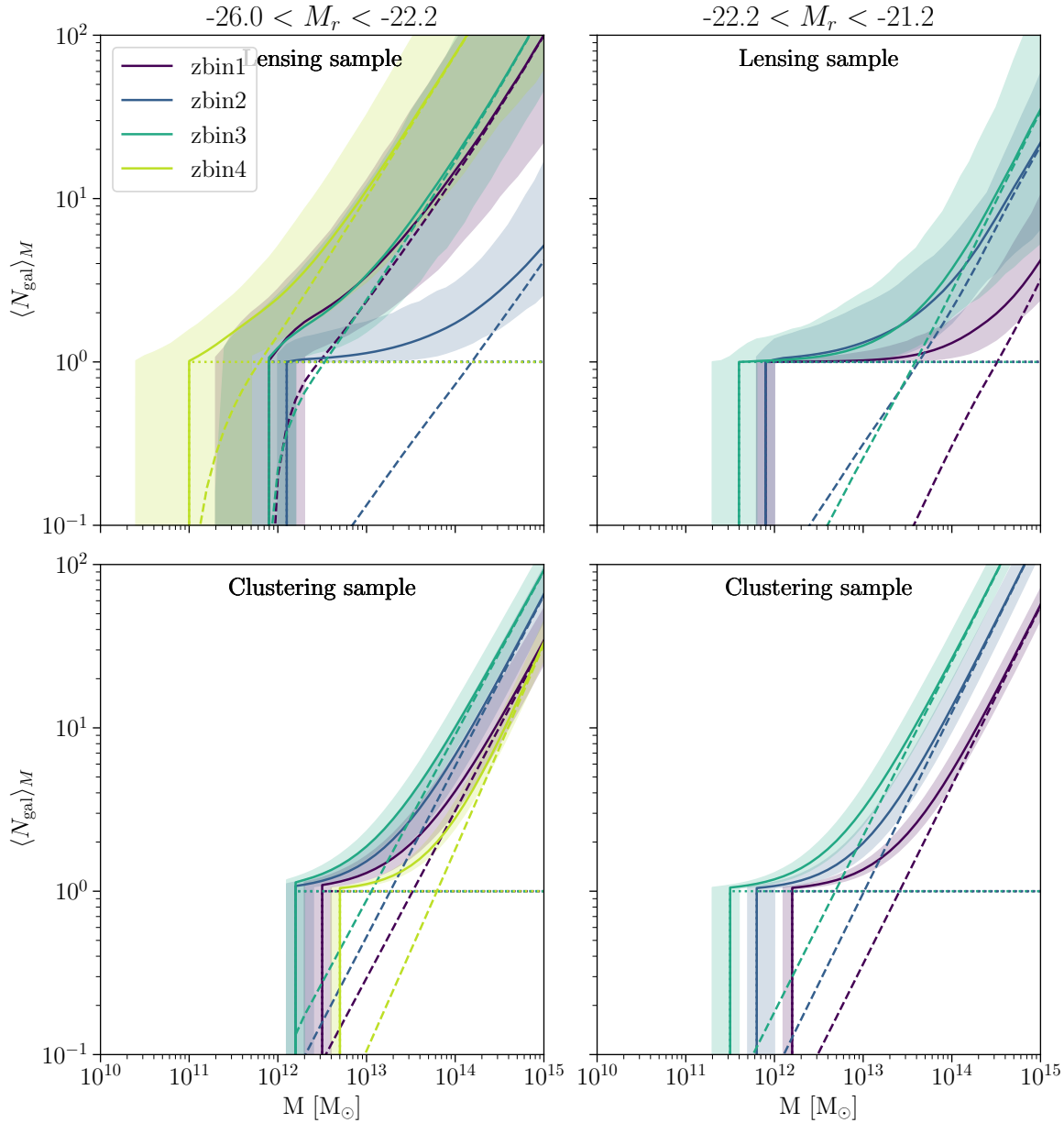


HOD parameters as a function of redshift, for the lensing (solid lines) and clustering signals (dottled).

HOD redshift evolution

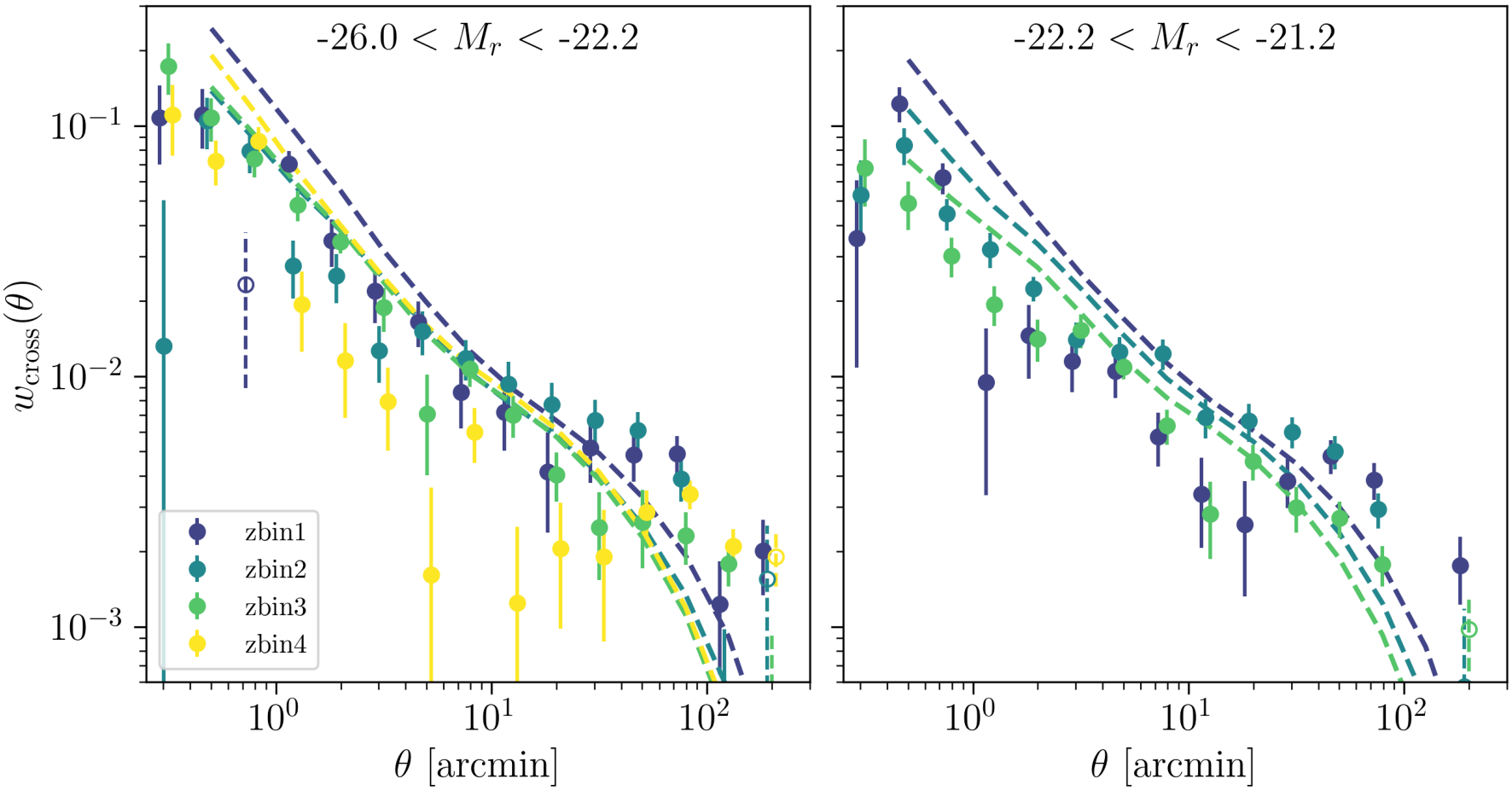


HOD redshift evolution



Joint analysis

- Are the clustering results compatible with cross-correlation data?
- Lensing is low problem? $\rightarrow$ assembly bias, segregation of satellite galaxies, baryonic effects, etc.



Conclusions

HOD evolution

- Gaussian model improves HOD reconstruction.
- Expected redshift and luminosity evolution on HOD parameters.
- Lensing results affected by the lensing probability.
- Results may be limited by sample variance and field-to-field fluctuations.

Future steps

- Explore tensions between clustering and magbias results.
- Tighter cosmological constraints with improved HOD models.
- Improved HOD modelization for future sub-mm surveys (AtLAST).

Conclusions

HOD evolution

- Gaussian model improves HOD reconstruction.
- Expected redshift and luminosity evolution on HOD parameters.
- Lensing results affected by the lensing probability.
- Results may be limited by sample variance and field-to-field fluctuations.

Future steps

- Explore tensions between clustering and magbias results.
- Tighter cosmological constraints with improved HOD models.
- Improved HOD modelization for future sub-mm surveys (AtLAST).

Thank you very much for your attention!