Cosmic insights from galaxy clusters: Exploring magnification bias on sub-millimetre galaxies

R. Fernández Fernández on behalf of

L. Bonavera, J. González-Nuevo, M.M. Cueli, D. Crespo, J.M. Casas and S. R. Cabo

ICTEA
Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias

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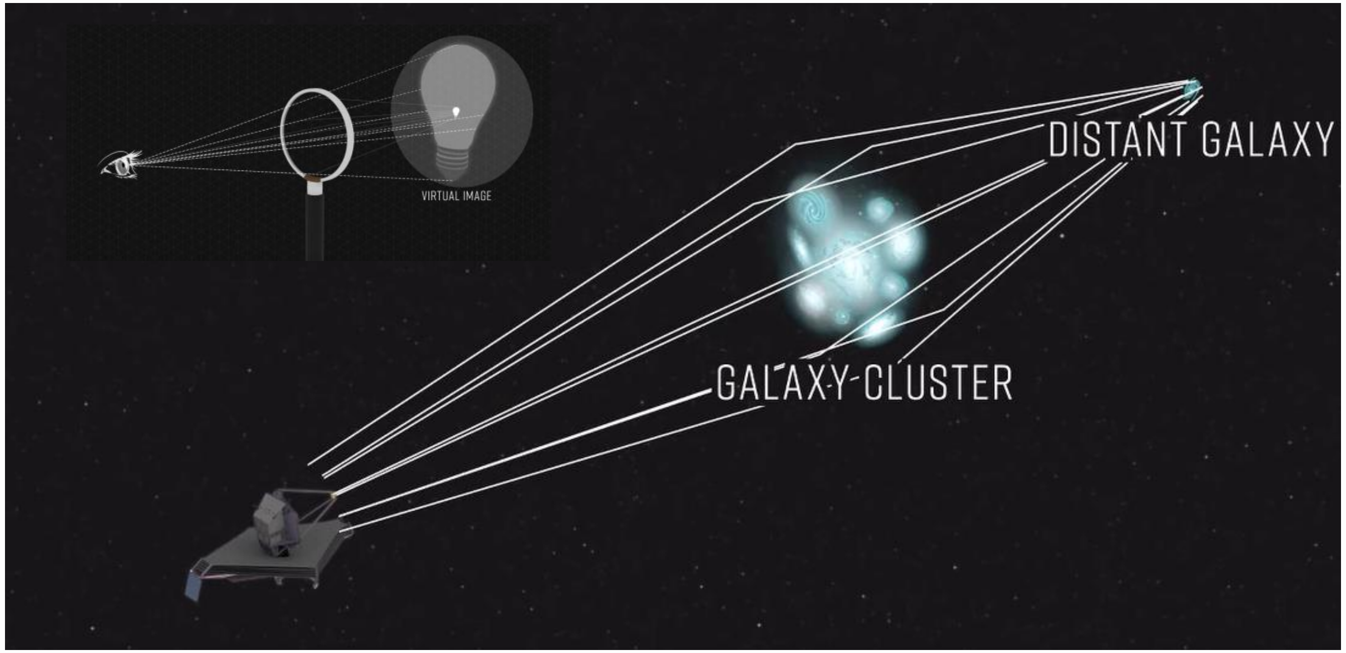
GRAVITATIONAL LENSING

Matter acts like a magnifying glass in space, deflecting light rays. Images of the background object will be magnified* and distorted.

It is a prediction of General Relativity

↓

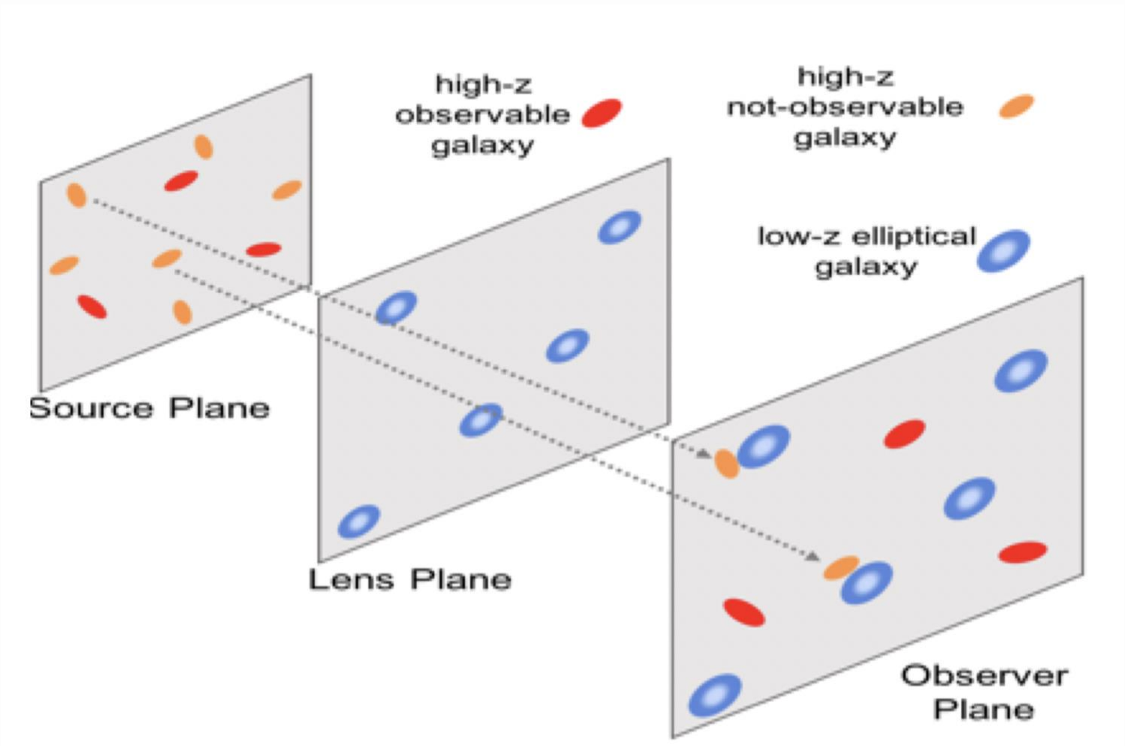
cosmological tool



Credits: JWST

MAGNIFICATION BIAS

Weak lensing effect that increases the background source number counts around the lenses' positions.



See Bonavera et al. (2022)

CROSS-CORRELATION

Magnification bias a induces a cross-correlation, purely produced by magnification bias if the samples do not overlap in redshift.

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clustering

$$w_{fb}(\theta) \equiv \langle \delta n_f^c(\phi) \delta n_b^{\mu}(\phi + \theta) \rangle$$

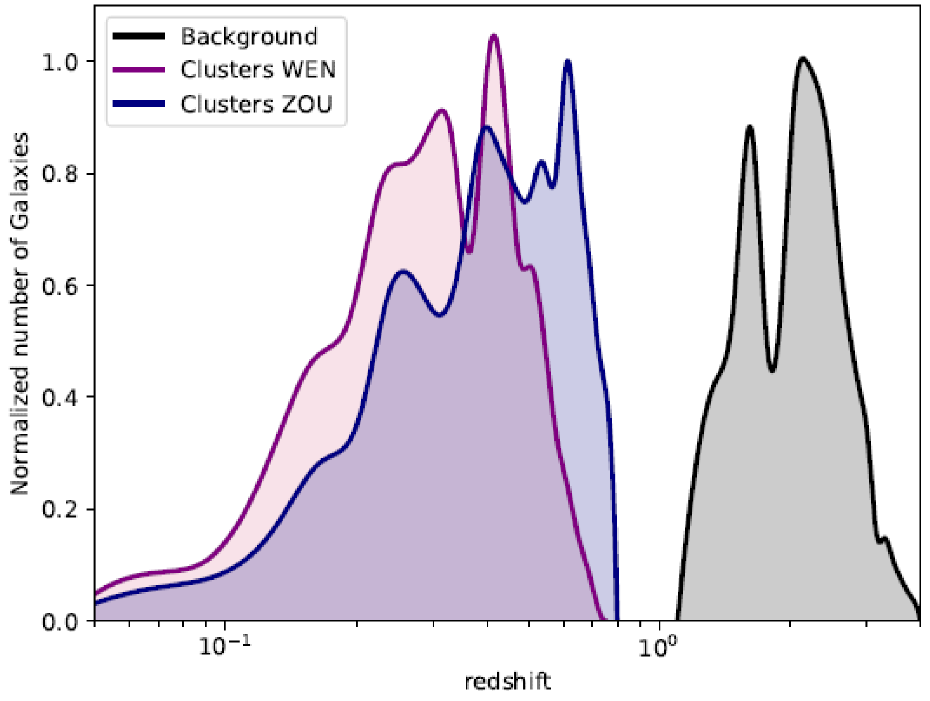
amplification

In weak lensing regime:

$$\delta n_b^{\mu}(\theta) \approx 2(\beta - 1)\kappa(\theta) \leftarrow$$

Halo model (Coorey and Sheth, 2002)

$$\boxed{w_{fb}(\theta) \equiv w_{fb}(\theta; cosmology, HOD)}$$



MEASUREMENTS

CROSS-CORRELATION ESTIMATOR

Measures the excess probability wrt random at a given angular separation (pair counts).

$$\tilde{w}_{fb}(\theta) = \frac{D_f D_b(\theta) - D_f R_b(\theta) - D_b R_f(\theta) + R_f R_b(\theta)}{R_f R_b(\theta)}$$

Landy & Szalay (1993); Herranz et al. (2001).

MCMC

Constraints on HOD and cosmological parameters were obtained via MCMC.

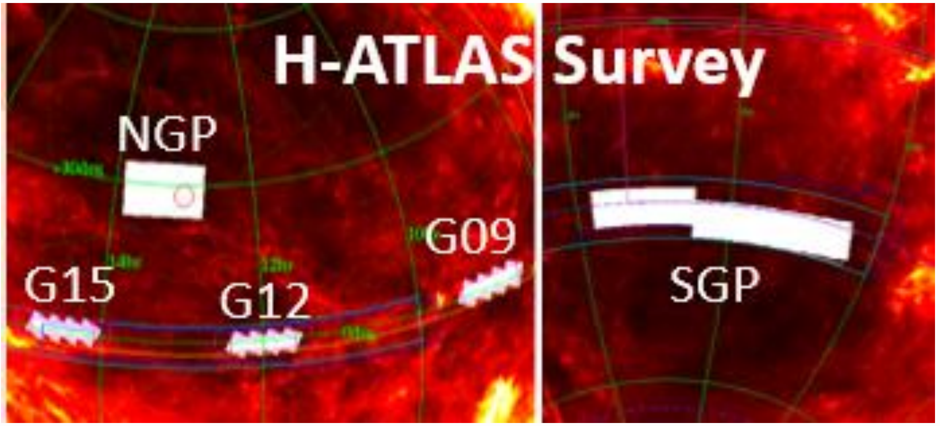
Astro		Cosmo	
Parameter	Prior	Parameter	Prior
$\log M_{\rm min}$	$\mathcal{U}[12.5{-}15.5]$	$\Omega_{\rm m}$	$\mathcal{U}[0.1{-}0.8]$
$\log M_1$	$\mathcal{U}[12.6{-}15.6]$	σ_8	$\mathcal{U}[0.6{-}1.2]$
α	$\mathcal{U}[0.5{-}1.5]$	h	$\mathcal{U}[0.5{-}1.0]$
β	$\mathcal{N}[2.8, 0.1]$		

DATA:BACKGROUND

SMGs observed by Herschel Space Observatory in the **H-ATLAS survey** (Rigby et al. 2011, Valiante et al. 2016).

Optimal properties for lensing:

1. High redshift distribution (z>1)
2. Steep source number counts (β~3!)
3. Fairly invisible in the optical band (minimum cross-contamination)



Eales et al. 2010

- Area: ~327 deg^2
- ~57000 galaxies
- 1.2 < z < 4.0 (photometric)
- <z>=2.2

LENSES:

ZOU CATALOGUE (ZOU ET AL. 2021)

Cluster catalogue based on DESI (Dark Energy Spectroscopic Instrument) legacy imaging surveys.

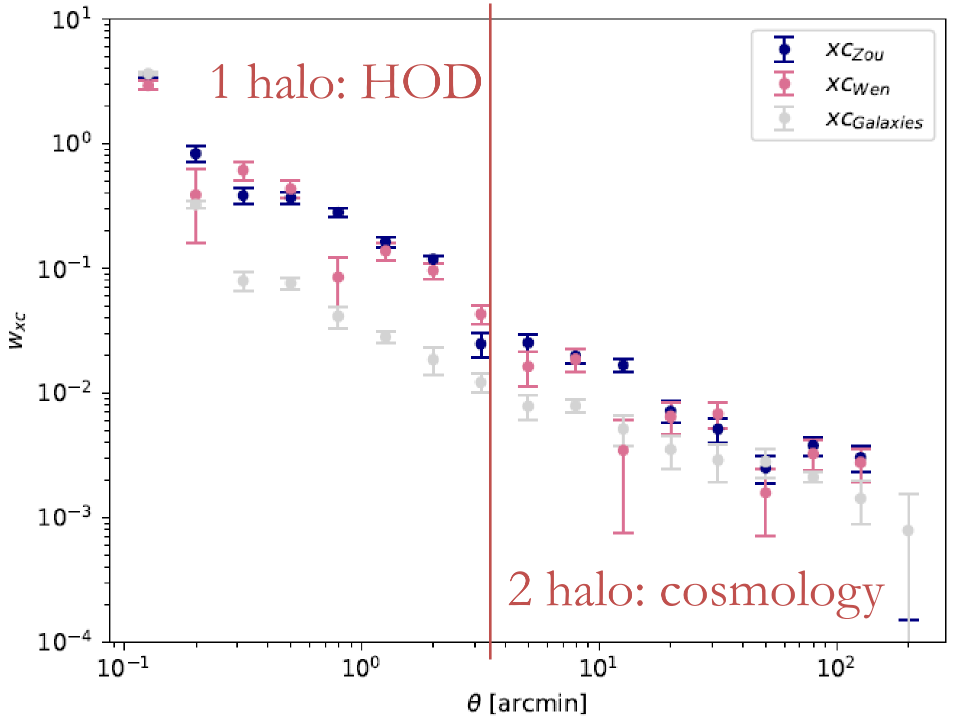
- Clusters: ~ 9000
- z<0.8, $\langle z \rangle = 0.50^{+0.24}_{-0.30}$

WEN CATALOGUE (WEN ET AL. 2012)

Cluster catalogue extracted from SDSS-III.

- Clusters: ~3600
- z<0.8, $\langle z \rangle = 0.38^{+0.23}_{-0.22}$

RESULTS: CROSS-CORRELATION



In grey results from Cueli et al. 2024, where a sample of ~150000 galaxies (GAMA II survey) was used as lenses.

- Stronger signal (in low-mid angular distances)→ mass.
- More pronounced one-halo to two-halo regime transition (2-3 arc-min, ~1Mpc)
- Increased signal at angular scales >60arcmin (detected in González-Nuevo et al. 2023, Cueli et al. 2024).

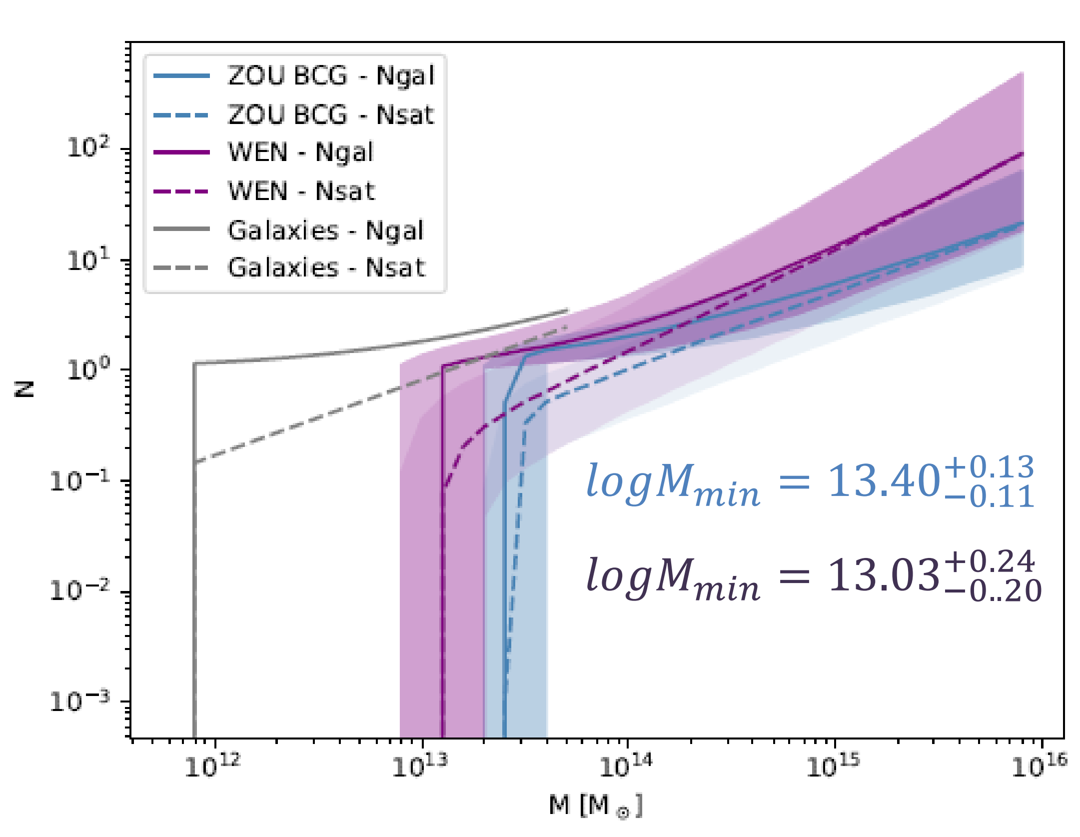
Sampling variance? Large-scale structure?

RESULTS

- Constraints on HOD parameters are **consistent with** the **catalogue** characteristics **and** the cosmological parameters are complatible with current **cosmological models**.
- With WEN catalogue, distributions are broader due to more limited statistics, but $\boldsymbol{\sigma_8}$ **is effectively constrained**.

	ZOU			ZOU: no large scales			WEN cluster: all data			WEN cluster: no large scales		
Parameter	Mean	Mode	68% CI	Mean	Mode	68% CI	Mean	Mode	68% CI	Mean	Mode	68% CI
$\log M_{\mathrm{min}}$	13.18	13.15	[13.09, 13.28]	13.40	13.43	[13.29, 13.53	12.91	12.94	[12.75, 13.09]	13.03	13.07	[12.83, 13.27]
$\log M_1$	14.03	13.55	[13.25, 14.33]	14.07	13.79	[13.48, 14.27	14.19	14.00	[13.43, 14.73]	13.81	13.62	[13.14, 14.20]
α	0.76	–	[0.50, 0.81]	0.75	–	[0.50, 0.80]	0.97	–	[0.50, 1.50]	0.97	–	[0.5, 1.13]
Ω_{m}	0.19	0.16	[0.15, 0.21]	0.27	0.25	[0.20, 0.32]	0.21	0.20	[0.17, 0.24]	0.41	0.27	[0.18, 0.52]
σ_8	0.85	–	[0.60, 0.94]	0.76	–	[0.60, 0.79]	0.86	0.77	[0.66, 0.99]	0.84	0.76	[0.62, 0.93]
h	0.72	–	[0.50, 0.81]	0.67	–	[0.50, 0.71]	0.72	–	[0.50, 0.80]	0.73	–	[0.50, 0.81]
β	2.79	2.80	[2.69, 2.89]	2.79	2.70	[2.79, 2.90]	2.80	2.81	[2.71, 2.90]	2.79	2.81	[2.70, 2.90]

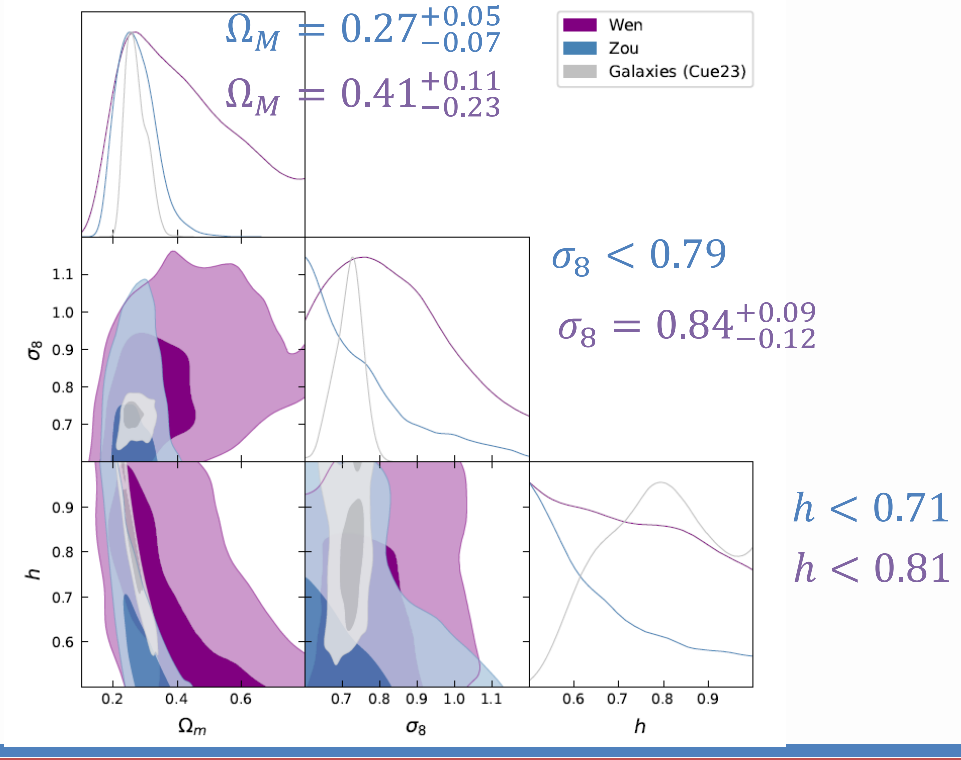
RESULTS: HOD

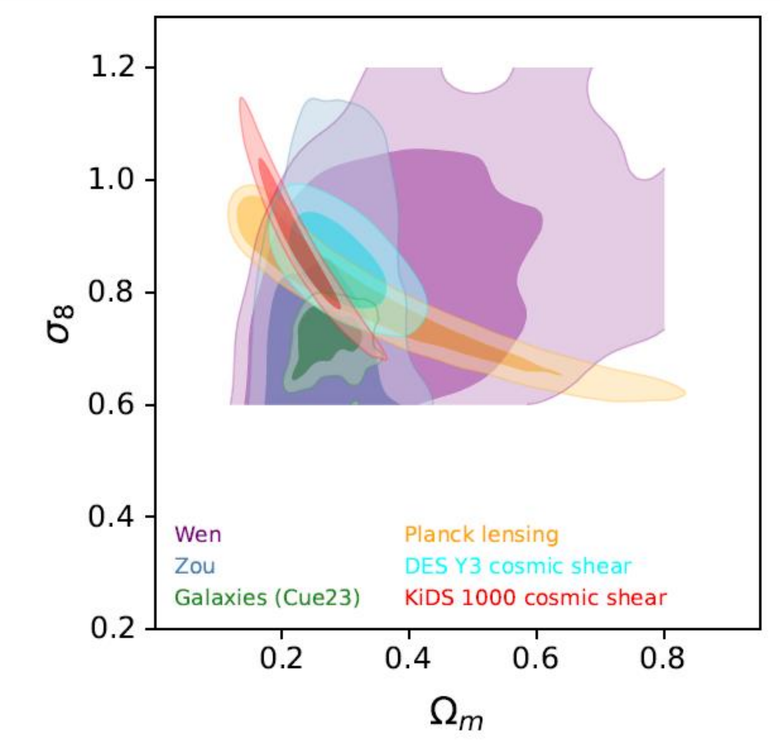


- Estimation of the minimum halo mass (M_{min}>$10^{13} M_\odot$) consistent with literature.
- M_{min} estimated for the WEN smaller than that for ZOU, consistent with previous studies (Crespo et al. 2024).
- Lensing is primarily driven by the central galaxies + secondary massive satellites, rather than the collective halo mass.

RESULTS: COSMOLOGICAL PROBE

Constraints established on cosmological parameters remain consistent across both cluster datasets. Cluster-based results only provide rough upper limits on h.





CONCLUSIONS AND NEXT STEPS

Despite the relatively low amount of available lenses, constraints consistent with prevailing consensus values were obtained by studying the magnification bias produced by galaxy clusters on SMGs.

Further work to be done:

- Better understanding of systematics.
- Statistics → increase the covered areas.

Thanks!

THEORETICAL MODEL:

MagBias:

$$n_0(>S,z) = AS^{-\beta}$$

$$n(>S,z;\vec{\theta}) = \frac{1}{\mu(\vec{\theta})} n_0\left(>\frac{S}{\mu(\vec{\theta})}, z\right) \qquad \frac{n(>S,z;\vec{\theta})}{n_0(>S,z)} = \mu^{\beta-1}(\vec{\theta})$$

Cross-correlation function:

$$w_{fb} = 2(\beta-1)\int_0^{z_s} \frac{dz}{\chi^2(z)} \frac{dN_f}{dz} W^{lens}(z) \int_0^{\infty} \frac{ldl}{2\pi} P_{gal-dm}(l/\chi^2(z), z) J_0(l\theta),$$

where

$$W^{lens}(z) = \frac{3}{2}\frac{H_0^2}{c^2} E^2(z) \int_z^{z_s} dz' \frac{\chi(z)\chi(z'-z)}{\chi(z')} \frac{dN_b}{dz'}$$

Halo Model:

$$P_{\text{g-dm}}(k,z) = P^{1h}_{\text{g-dm}}(k,z) + P^{2h}_{\text{g-dm}}(k,z)$$ Cooray & Sheth (2002)

$$P^{1h}_{\text{g-dm}}(k,z) = \int_0^{\infty} dM\, M \frac{n(M,z)}{\bar{\rho}(z)} \frac{\langle N_g \rangle_M}{\bar{n}_g(z)} |u_{\text{dm}}(k,z|M)||u_g(k,z|M)|^{p-1}$$

$$P^{2h}_{\text{g-dm}}(k,z) = P^{\text{lin}}_{\text{mm}}(k,z)\left[\int_0^{\infty} dM\, M \frac{n(M,z)}{\bar{\rho}(z)} b_1(M,z) u_{\text{dm}}(k,z|M)\right] \cdot \left[\int_0^{\infty} dM\, n(M,z) b_1(M,z) \frac{\langle N_g \rangle_M}{\bar{n}_g(z)} u_g(k,z|M)\right]$$

HOD Model:

$$N_{\text{cen}}(M_h) = \begin{cases} 0 & \text{if } M_h < M_{\min} \\ 1 & \text{otherwise} \end{cases} \qquad N_{\text{sat}}(M_h) = N_{\text{cen}}(M_h) \cdot \left(\frac{M_h}{M_1}\right)^{\alpha_{\text{sat}}}$$

DE Model:

$$\omega(z) = \omega_0 + \omega_a \frac{z}{1+z}$$

$$E(z) \equiv \sqrt{\Omega_M(1+z)^3 + \Omega_{\text{DE}} f(z)},$$

$$f(z) = (1+z)^{3(1+\omega_0+\omega_a)} e^{-3\omega_a \frac{z}{1+z}}$$