

Submillimetre galaxies Magnification bias: an independent cosmological probe

J. Gonzalez-Nuevo on behalf of

L. Bonavera, M. M. Cueli, D. Crespo, R. Fernandez-Fernandez, J.A Cano
and CosmoGroup

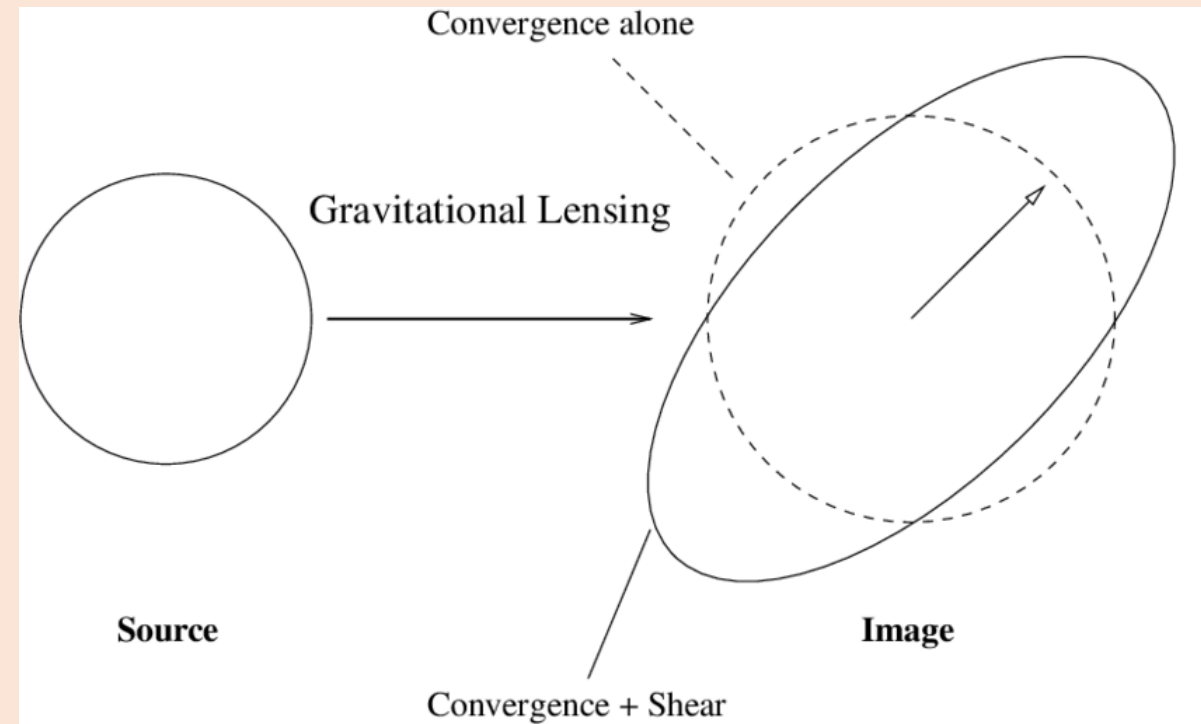
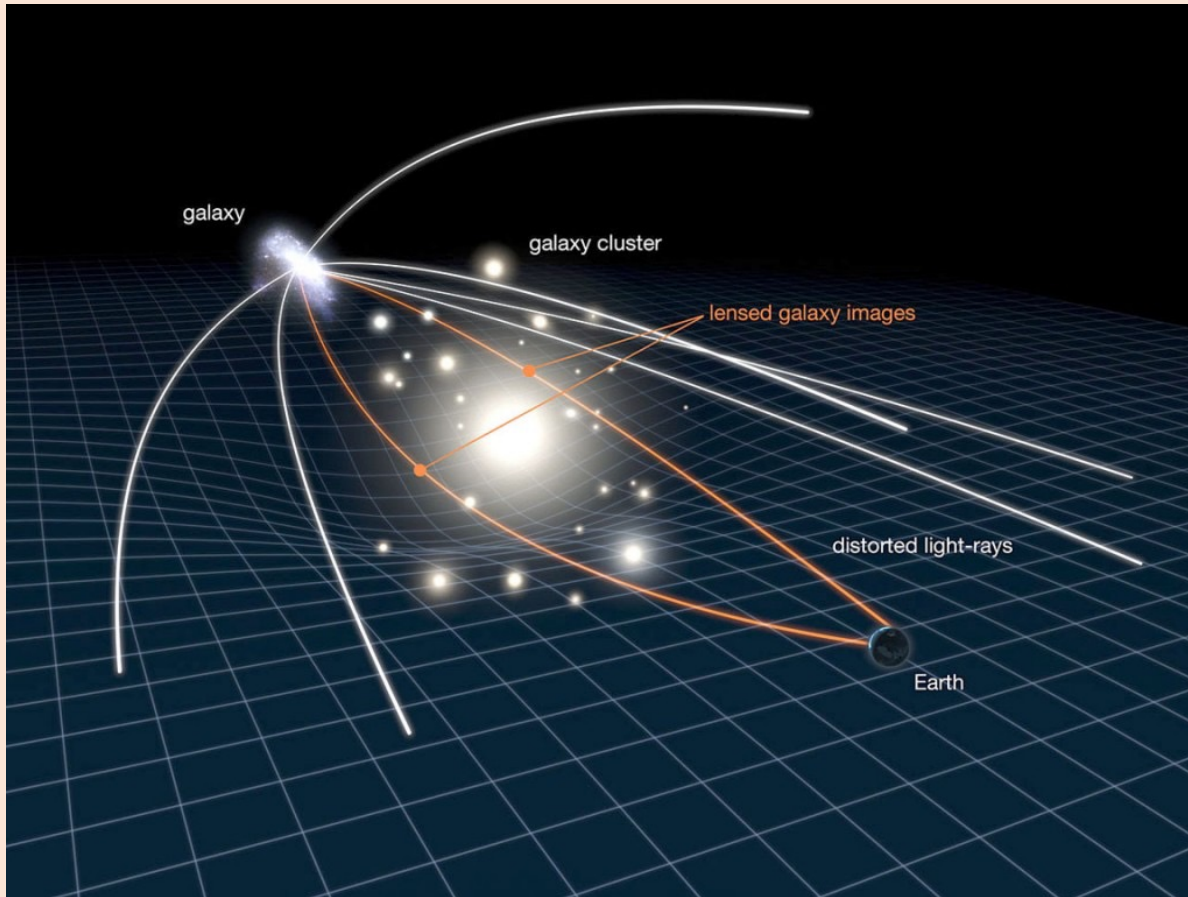
June 4th

AtLAST Iberian Days Meeting 2026

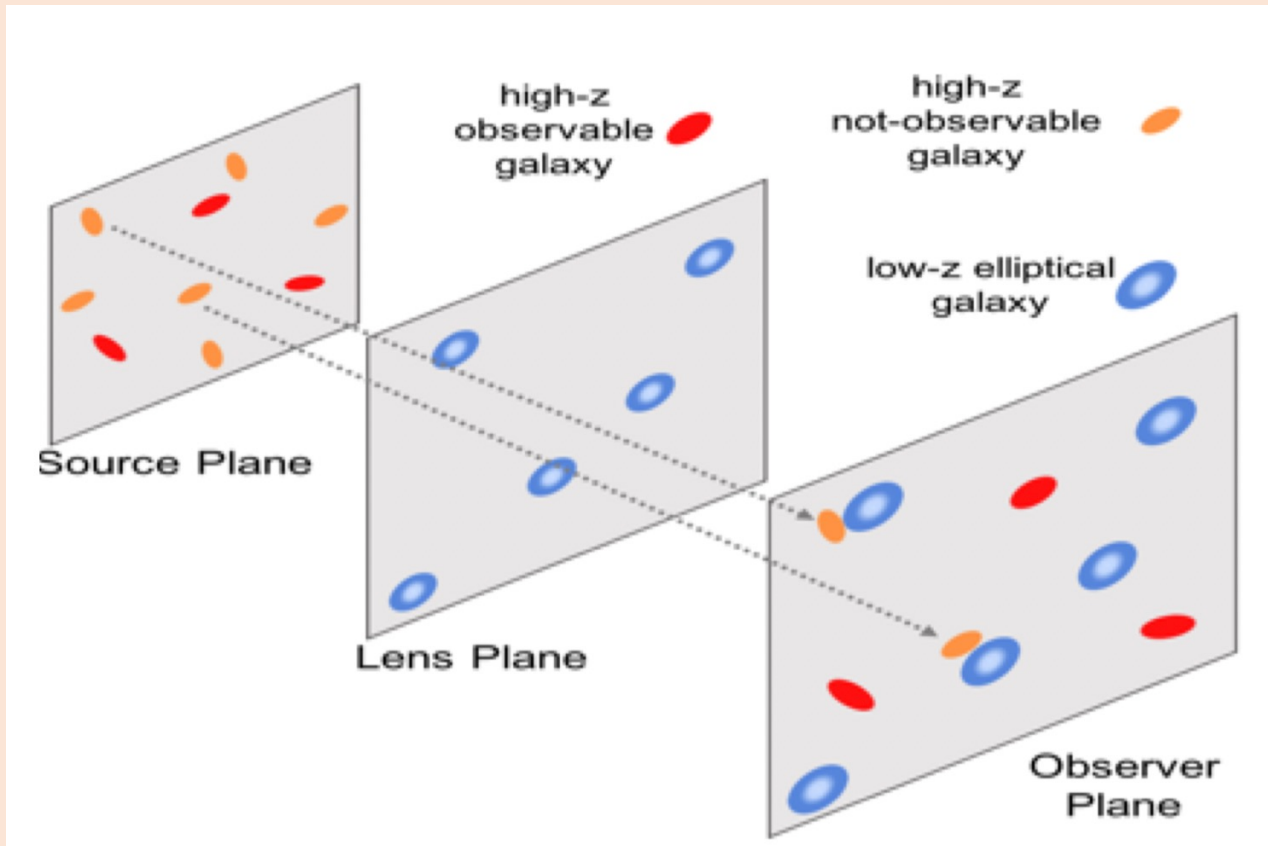


Universidad de
Oviedo

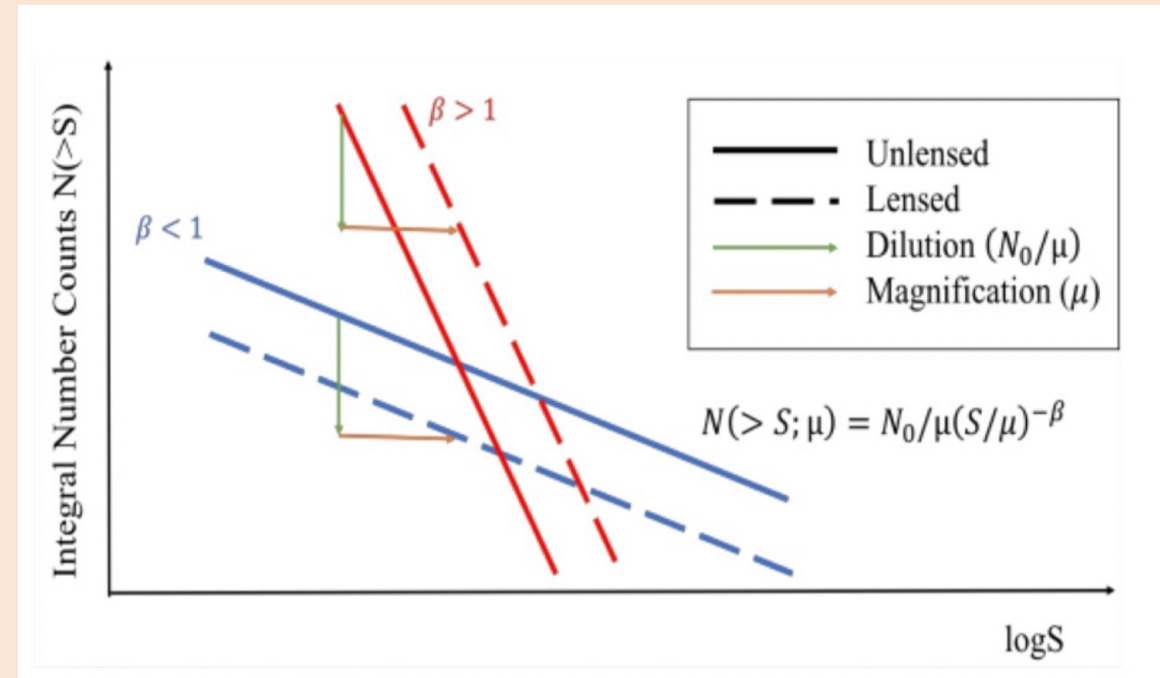
Gravitational Lensing



Magnification bias



See Bonavera et al. (2022)

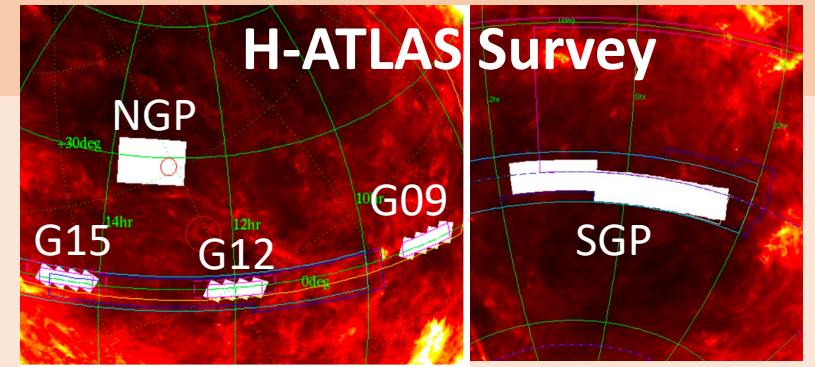


Gravitational lensing modify the background source number counts!

Idialistic: $\beta \gg 1$ or $\beta \sim 0$ for maximum SNR

Submillimetre galaxies: optimal background sample

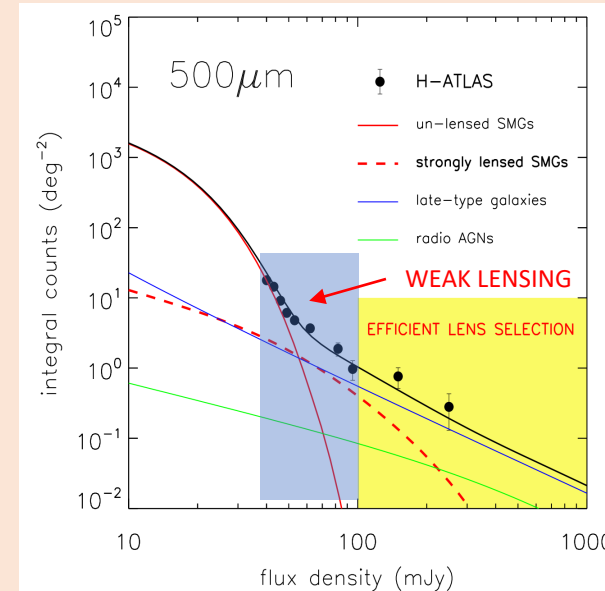
Sub-millimetre galaxies (SMGs) observed by Herschel Space Observatory in the H-ATLAS survey



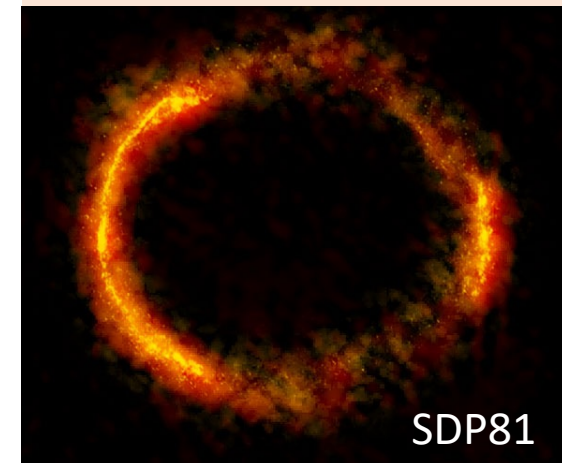
Eales et al. 2010

Optimal properties for lensing studies:

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



Negrello et al. 2010
(Negrello et al. 2007, Lapi et al. 2011)



Credit:
ALMA (NRAO/ESO/NAOJ); B.
Saxton NRAO/AUI/NSF

Magnification bias induces a cross-correlation

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

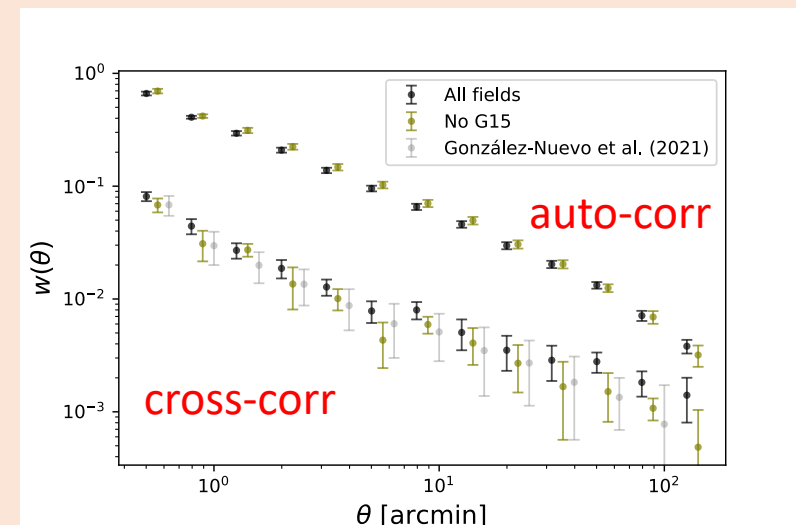
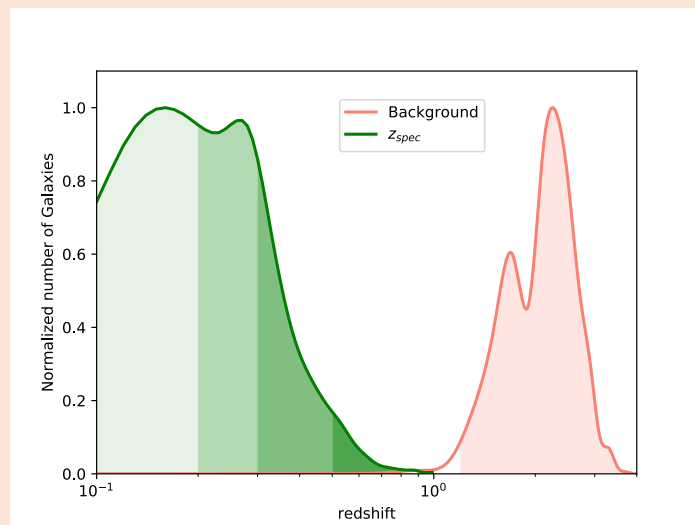
clustering
amplification

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

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

purely produced by magnification bias if the samples do not overlap in redshift!

Estimator: measure the excess probability wrt random at a given angular separation (pair counts)



Magnification bias: a cosmological probe

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

Galaxy overdensity

$$\delta n_f^c(\phi) = \int dz \frac{dN_z}{dz} \delta_g(\chi(z)\theta, z)$$

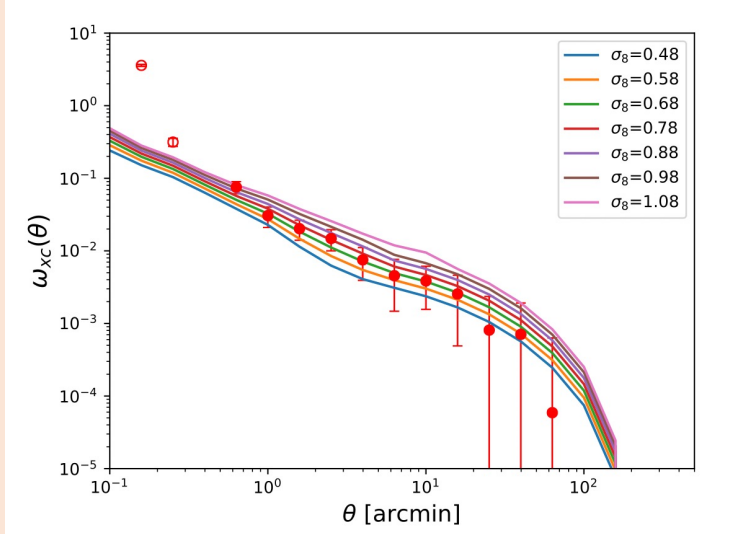
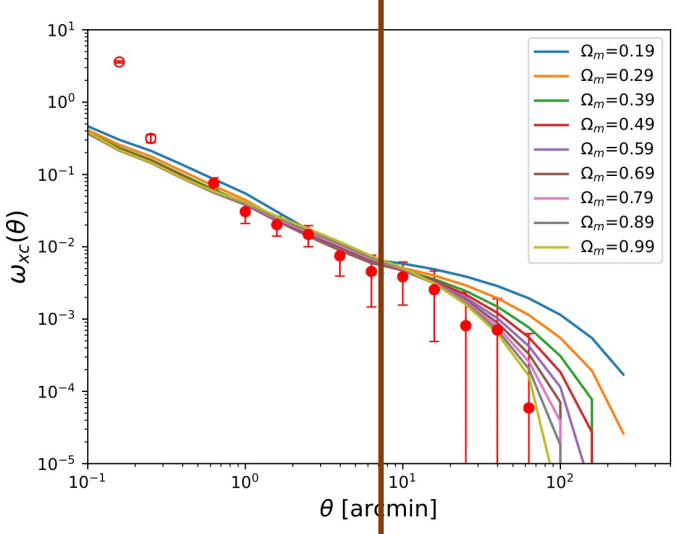
Effective weak lensing convergence

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

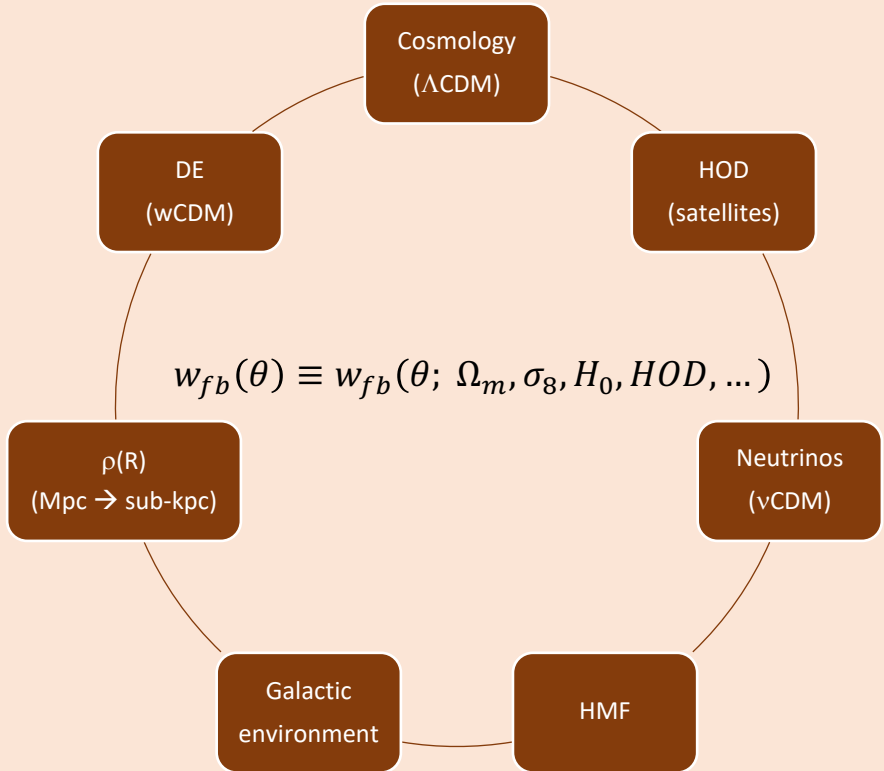
+

Halo Model

1 halo: HOD



2 halo: cosmology



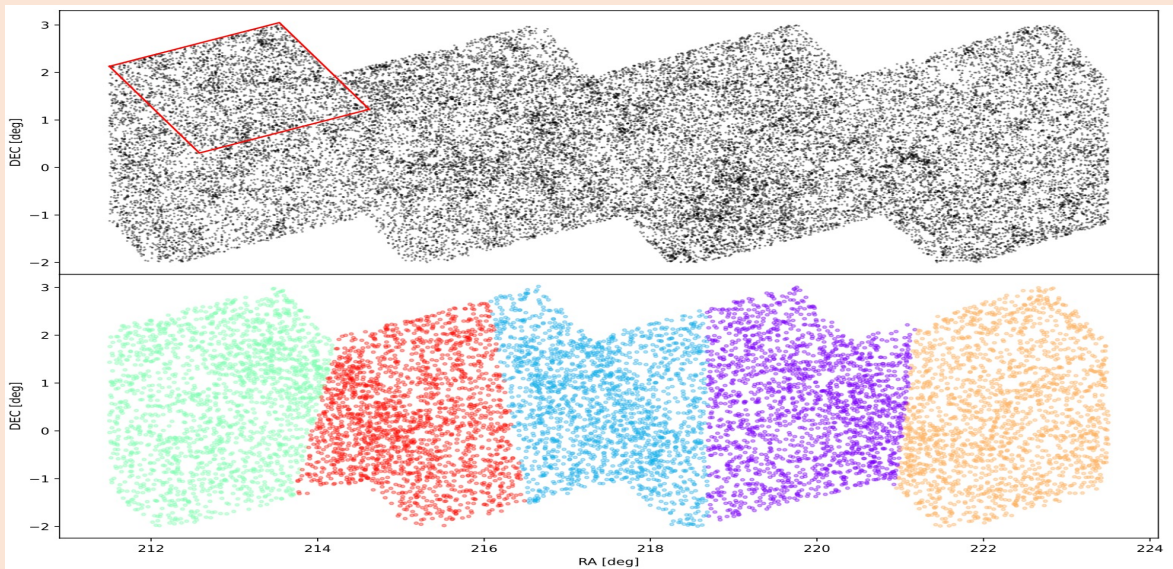
Data

Background sample (sources)

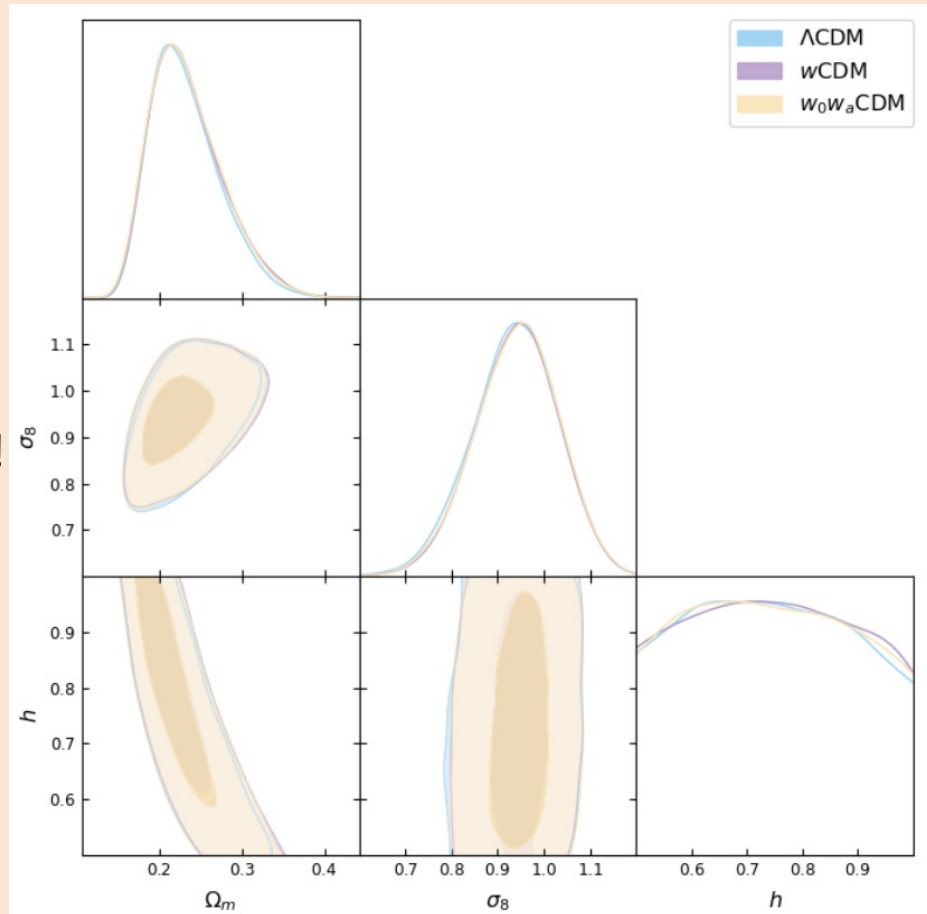
- **H-ATLAS SMGS** (Rigby et al. 2011, Valiante et al. 2016)
 - Area: $\sim 610 \text{ deg}^2$
 - $1.2 < z < 4.0$ (photometric)
 - ~ 66000 galaxies

Foreground samples (lenses)

- **GAMA II spectroscopic survey** (Driver et al. 2011; Baldry et al. 2010, 2014; Liske et al. 2015)
 - Area: $\sim 207 \text{ deg}^2$
 - $0.1 < z < 1$ (spectroscopic)
 - ~ 150000 galaxies
- **But also:**
 - Galaxies: photo-z SDSS (see GN et al. 2021)
 - QSOs (see Bonavera et al. 2019, Crespo et al. 2022)
 - Clusters (see Fernandez-Fernandez et 2024, Crespo et al. 2022,2024, Fernandez et al. 2022)



Cosmological results:



- Single zbin [0.2-0.8]

- Cueli et al. 2024:

$$\Omega_m = 0.23^{+0.03}_{-0.06} ; \sigma_8 = 0.79^{+0.10}_{-0.10}$$

- Tomography

- Bonavera et al. 2021

$$\Omega_m = 0.26^{+0.15}_{-0.09} ; \sigma_8 = 0.87^{+0.13}_{-0.12}$$

- Fernandez-Fernandez et al. in prep

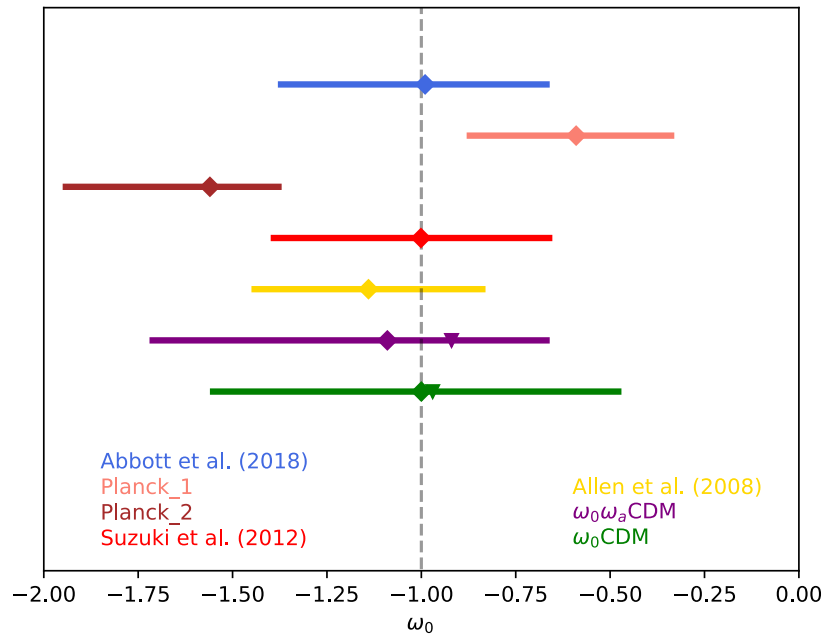
$$\Omega_m = 0.23^{+0.04}_{-0.04} ; \sigma_8 = 0.94^{+0.09}_{-0.09}$$

Robust, complementary independent cosmological probe!

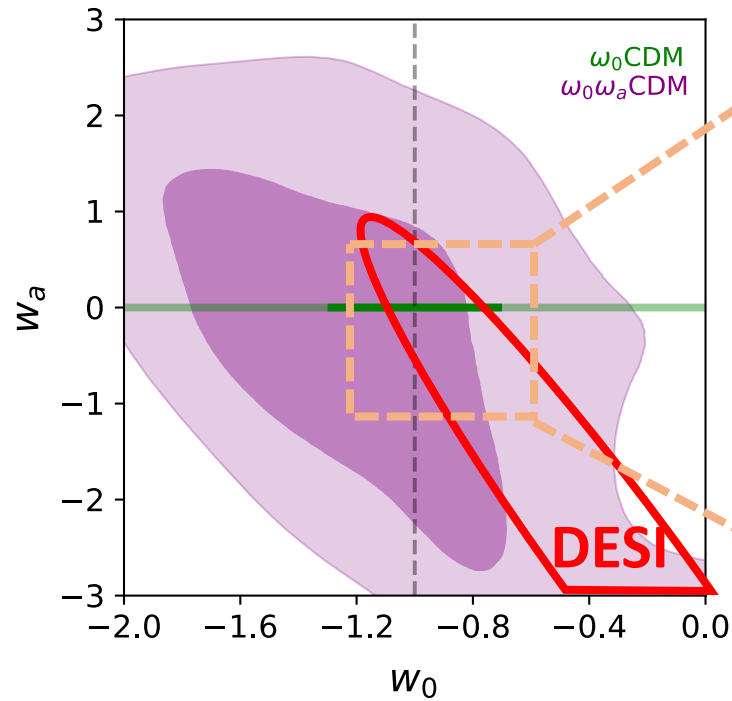
Cosmological results: tomography (wCDM)

Bonavera et al. (2021)

Tension with a cosmological constant?

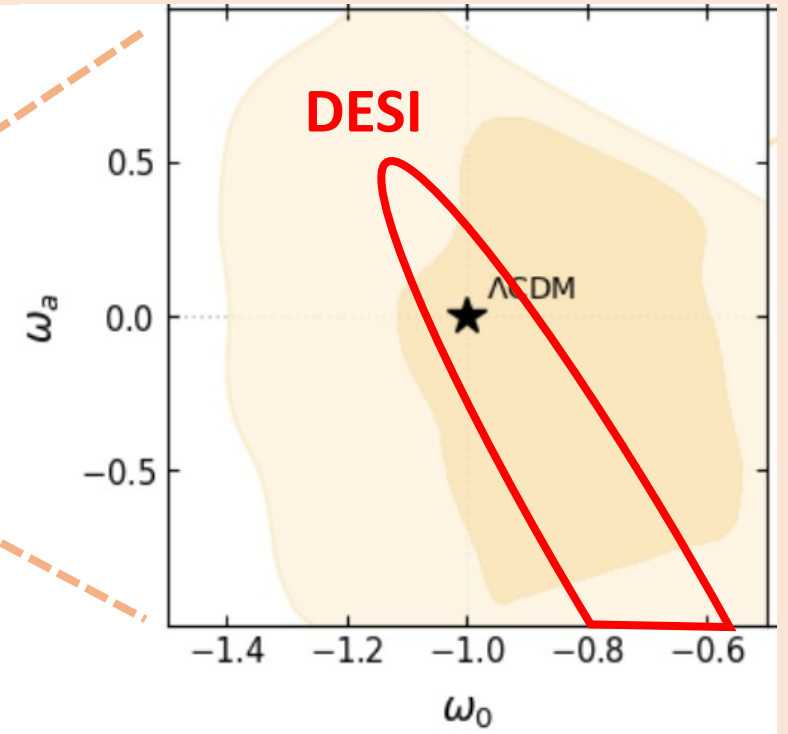


$$w_0 = -1.00^{+0.53}_{-0.56}; w_0 = -1.09^{+0.43}_{-0.63}$$



$$w_a = -0.19^{+1.67}_{-1.69}$$

Anticorrelation at 30%

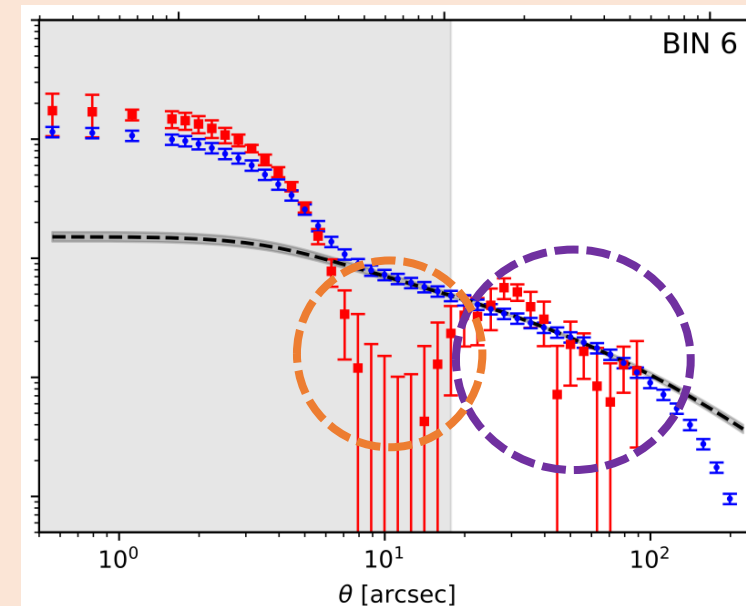
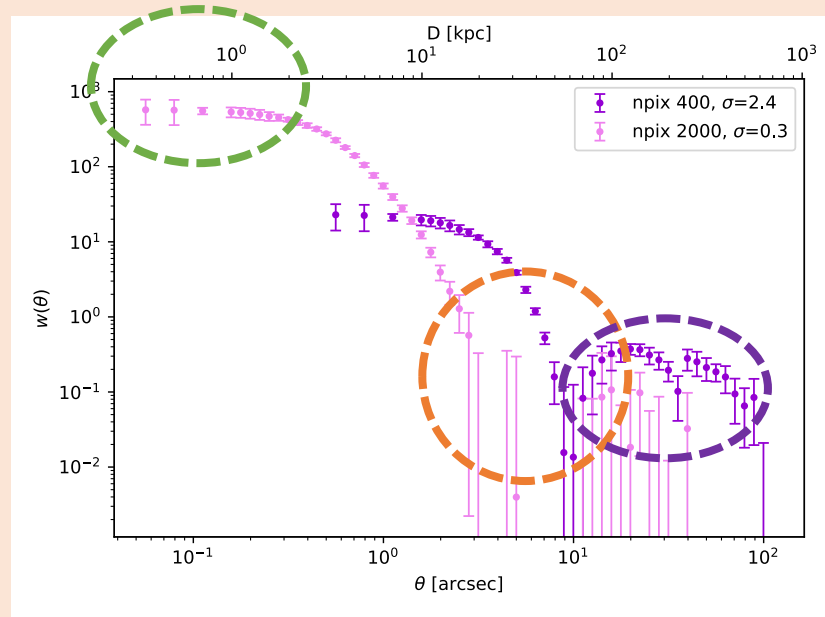
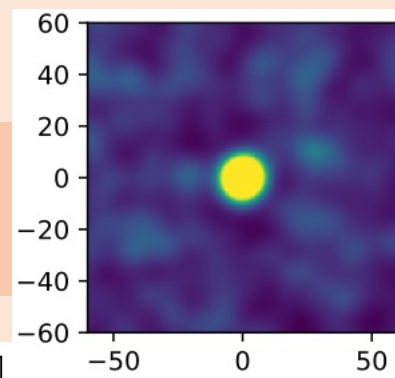


$$w_0 = -0.99 \pm 0.27$$

$$w_a = -0.06 \pm 0.54$$


Fernandez-Fernandez et al. (in prep.)



Mass density profiles: stacking



MagBias
Satellite
distribution
NFW

- High S/N mass density profiles (kpc-Mpc range)
 - BCG + satellites + halo modelling
- Comparison between different type of lenses (galaxies, QSOs, galaxy clusters)

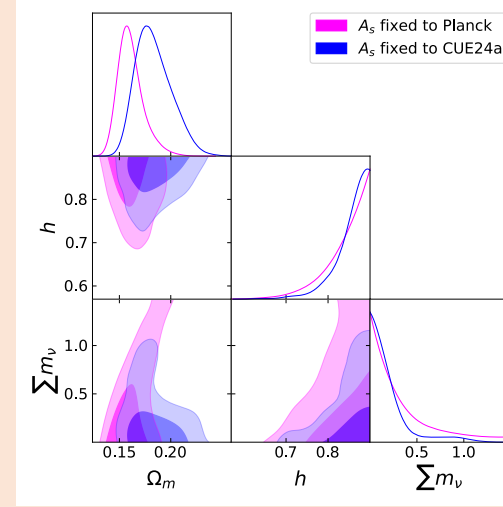
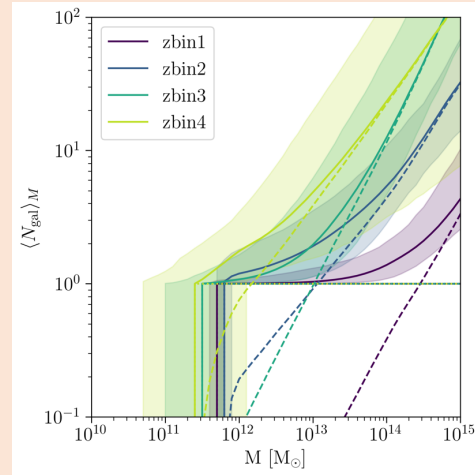
 (+ WISE positional accuracy) **Record scale** (<1 kpc) achieved with lensing alone!

-  **Einstein Gap**: a strong lensing effect.
 - Gone unnoticed with shear until nowadays
 - Satellites lensing signal contribution stronger than expected. (→ Meneghetti et al. 2020, 2023)
-  Oscillatory behaviour in the lensing signal?

Other applications

HOD evolution

Cano et al. (in prep)

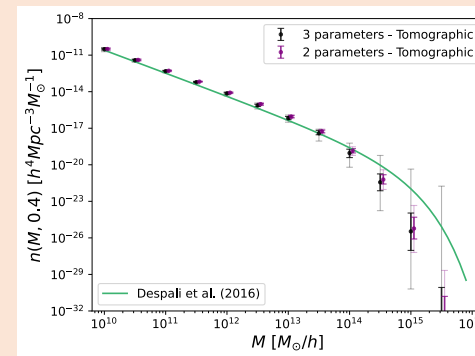
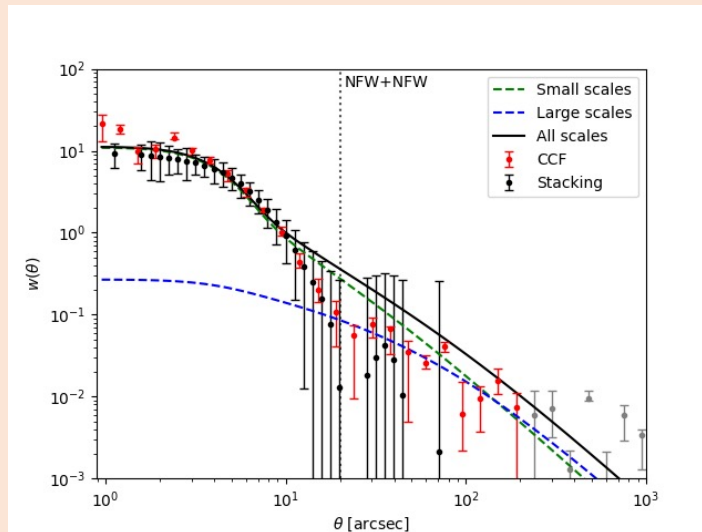


ν CDM
 $\sum m_{\nu} < 0.22 \text{ eV}$
 at 68% CL

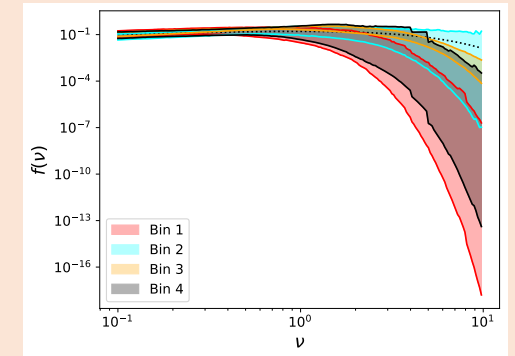
Cueli et al. 2024

Galactic environment
 Satellites distribution

Crespo et al. 2022



Observational constraint of the
 HMF; Test of its universality



Cueli et al. 2021, 2022

Current limitations → AtLAST

- There is no additional Herschel-like large area surveys
 - Increase the density of background sources (SMGs)
- Herschel was not a “survey”:
splitted “small” areas
 - Increase the (continuous) area
- SPIRE resolution not ideal ($\sigma \sim 2.4''$
→ > 15-20 kpc @z=0.3)
 - Increase the resolution and statistics

AtLAST - Cosmology with submillimetre galaxies magnification bias

This white paper was submitted to ESO Expanding Horizons in support of AtLAST

arXiv:2512.13894

AtLAST - Determination of Halo Mass Density Profiles at kpc Scales through Magnification Bias

This white paper was submitted to ESO Expanding Horizons in support of AtLAST

arXiv:2512.13895

AtLAST - A five fold increase in the number of identified Strongly Lensed Galaxies in the sub-millimetre and its consequences

This white paper was submitted to ESO Expanding Horizons in support of AtLAST

arXiv:2512.13896

Simple (AtLAST) simulations

Point Sources (Radio+IRLT+SMGs) + Diffuse (CMB+Dust) [No MARIA & No lensing]

Det lims
 5σ

0.41

0.68

0.95

1.18

1.93

2.19

mJy/beam

217 GHz (7.24")

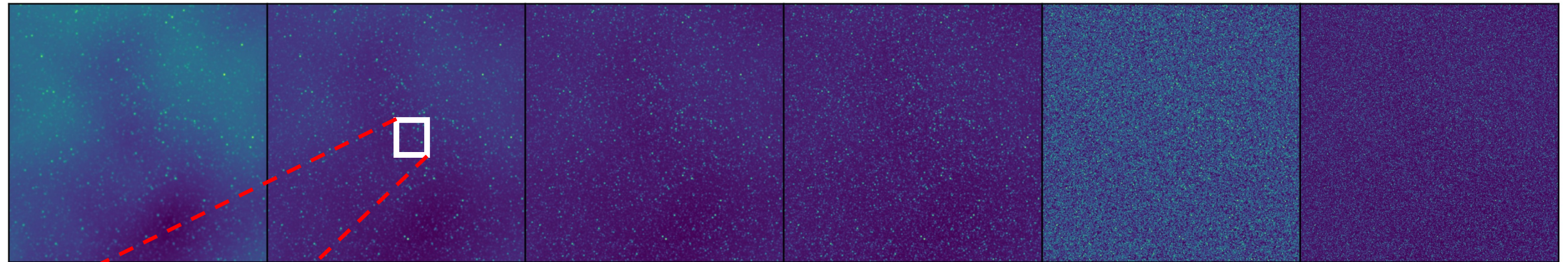
288 GHz (5.46")

350 GHz (4.50")

403 GHz (3.91")

654 GHz (2.41")

845 GHz (1.86")



**~0.08
deg²**

217 GHz (7.24")

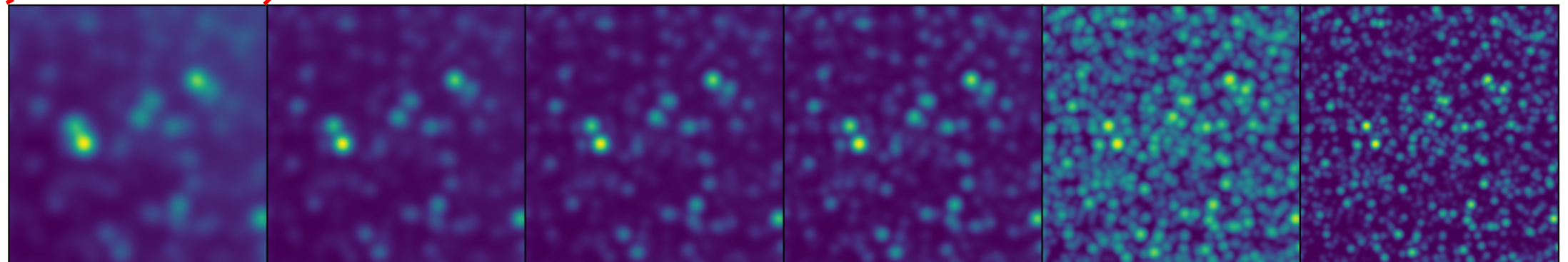
288 GHz (5.46")

350 GHz (4.50")

403 GHz (3.91")

654 GHz (2.41")

845 GHz (1.86")



Simple (AtLAST) simulations

Point Sources (Radio+IRLT+SMGs) + Diffuse (CMB+Dust) [No MARIA & No lensing]

Det lims
 5σ

2.19

2.74

7.31

10.53

18.27

30.10

mJy/beam

AtLAST

40m

15m

10.4m

6m

SPIRE

857 GHz (1.86")

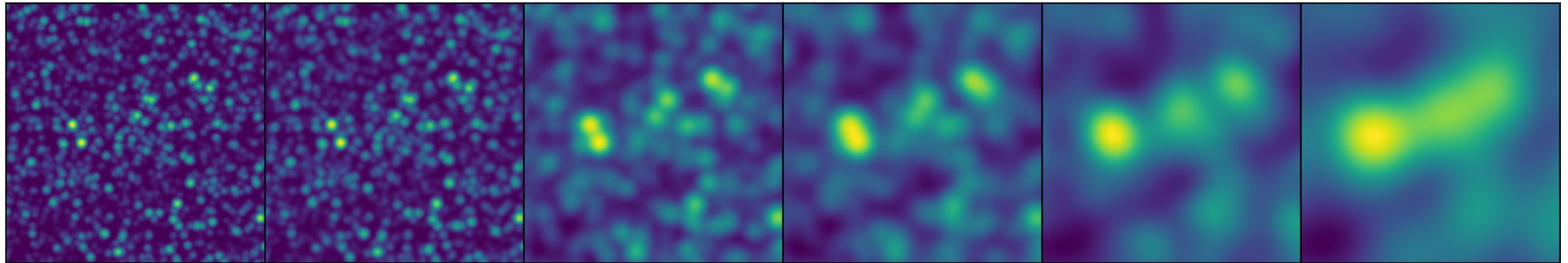
857 GHz (2.33")

857 GHz (6.21")

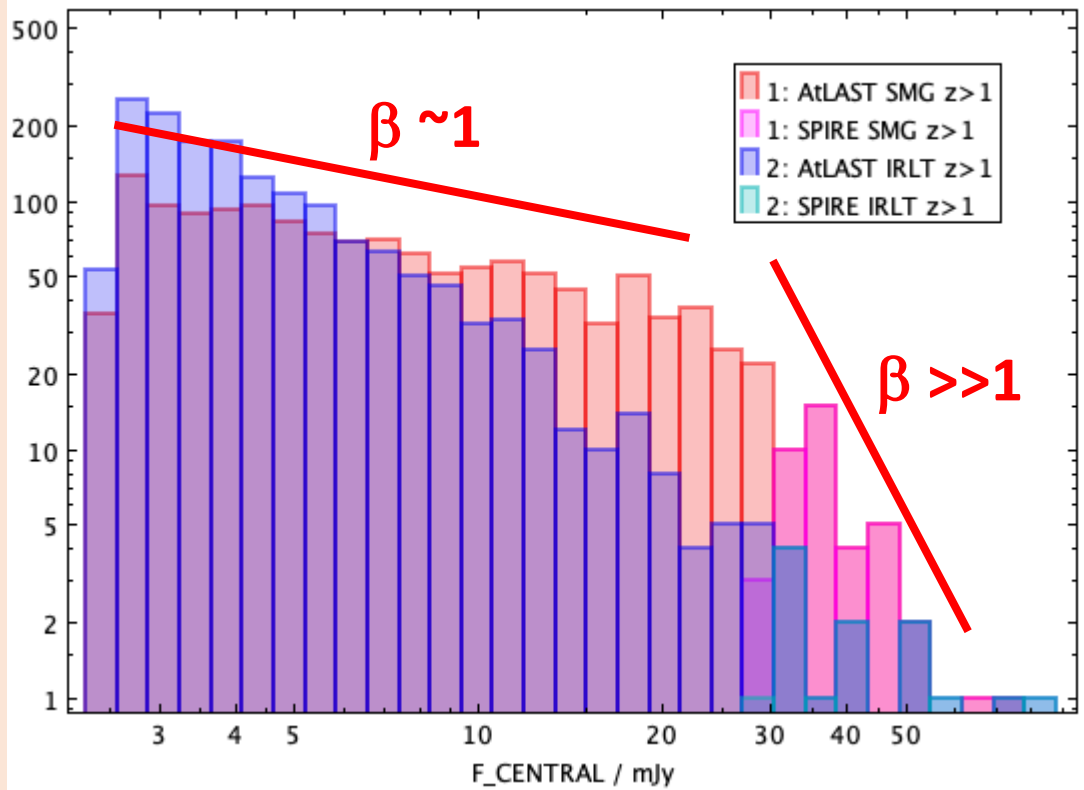
857 GHz (8.95")

857 GHz (15.52")

857 GHz (25.03")



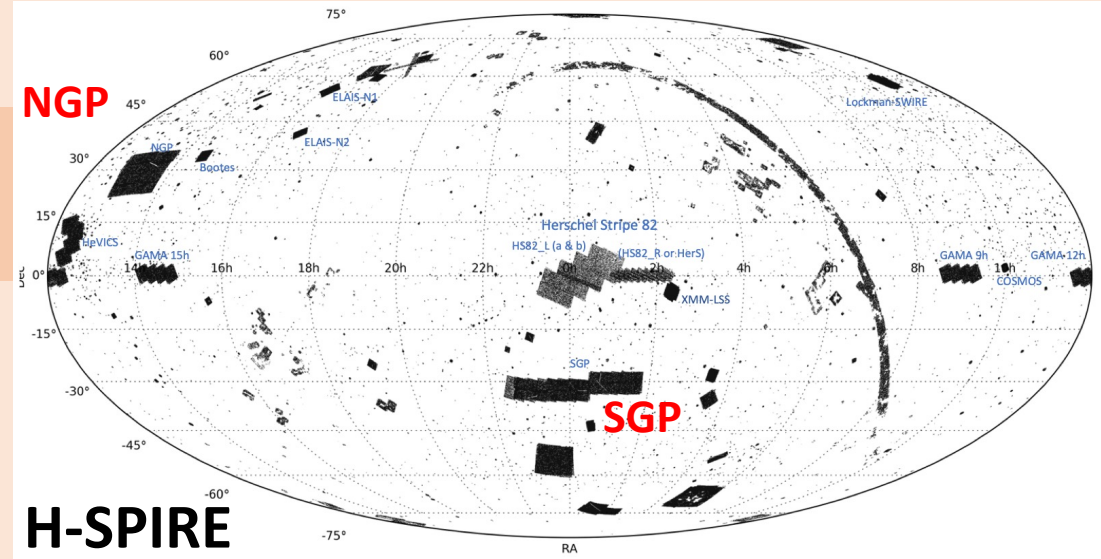
AtLAST forecast



857 GHz (350 μm)

AtLAST \sim SPIRE $\times 3.5$ (>20 mJy) $\times 3$ (area)

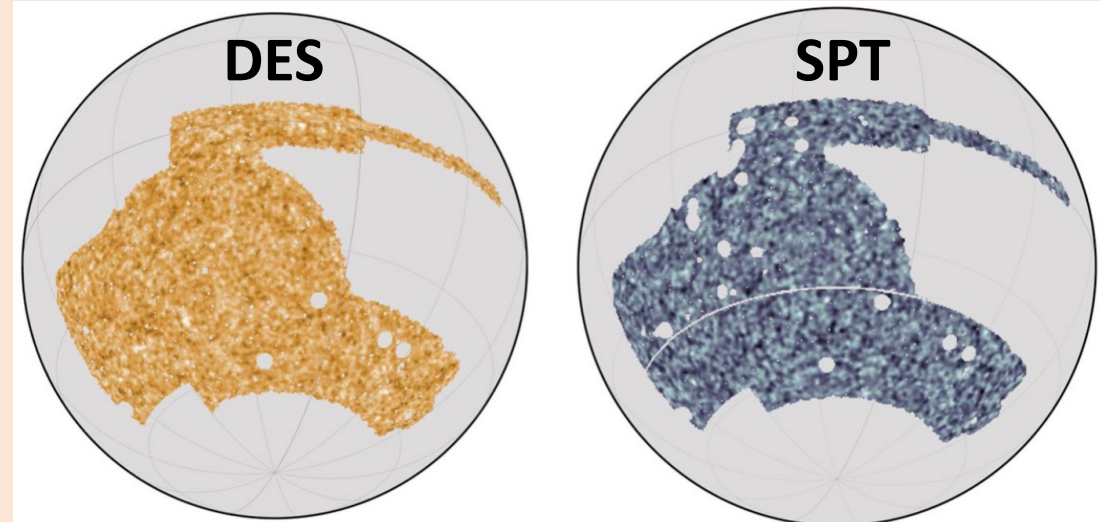
= **SPIRE $\times 10$!!**



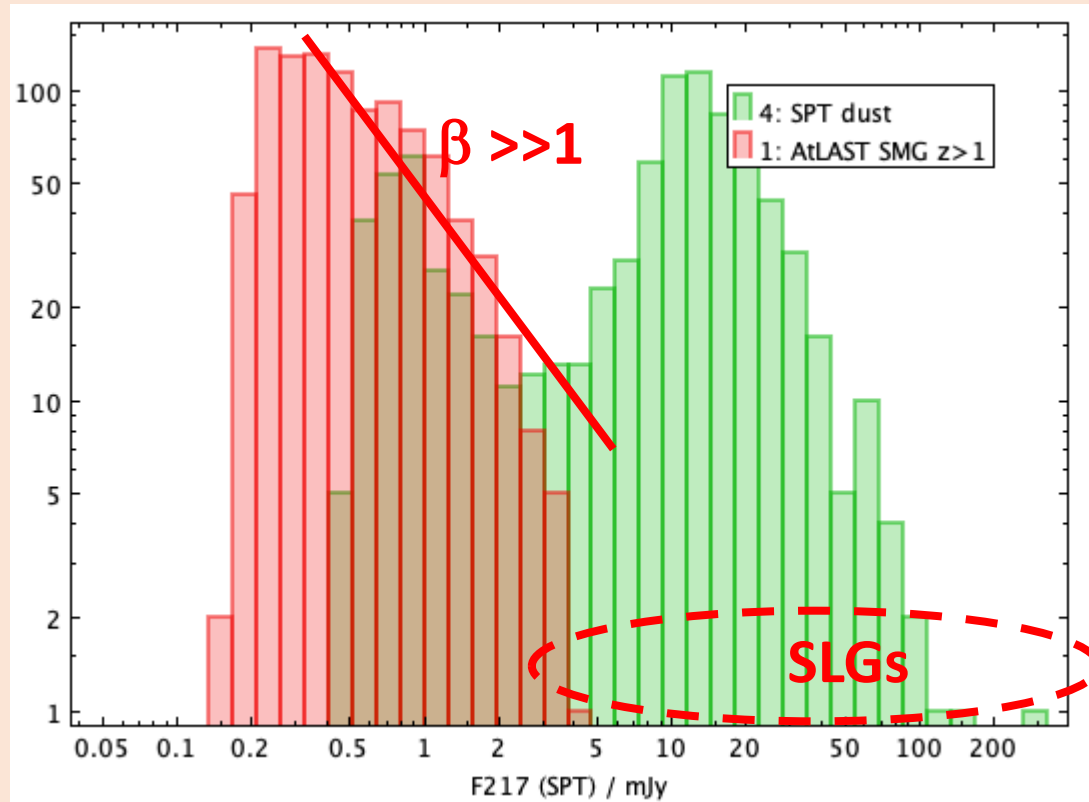
H-ATLAS $\sim 600 \text{ deg}^2$

NGP $\sim 180 \text{ deg}^2$
SGP $\sim 300 \text{ deg}^2$

AtLAST $\sim 1000\text{-}2000 \text{ deg}^2$



AtLAST forecast



217 GHz

AtLAST (217 GHz) \sim AtLAST (857 GHz) $\times 3.7$
= **SPIRE $\times 37$!!**

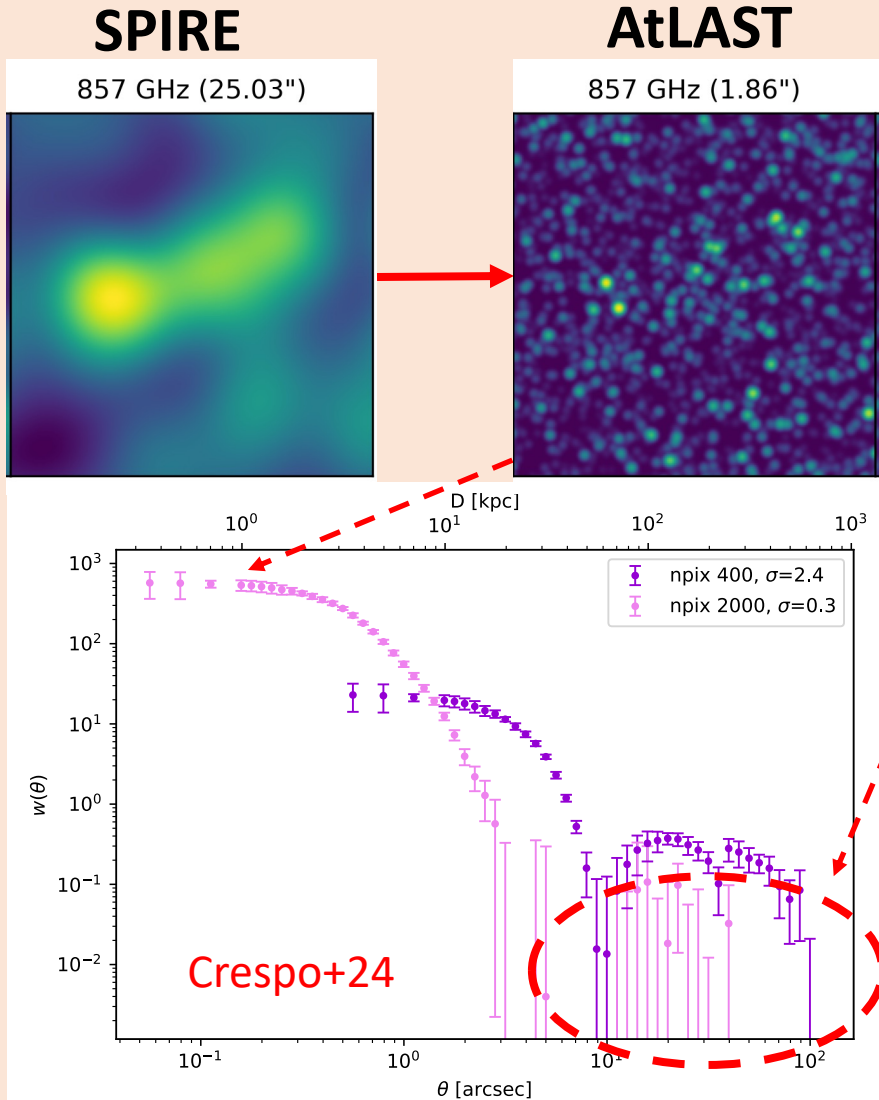
- SPT (Everett et al., 2020): 2530 deg²
865 dusty (~ 346 SMGs) \rightarrow 0.14 #/deg²
- AtLAST Sims: 0.081deg²
 ~ 522 SMGs \rightarrow **>6000 #/deg² !!!**

+

Hundreds of SLGs (Strongly Lensed Galaxies)

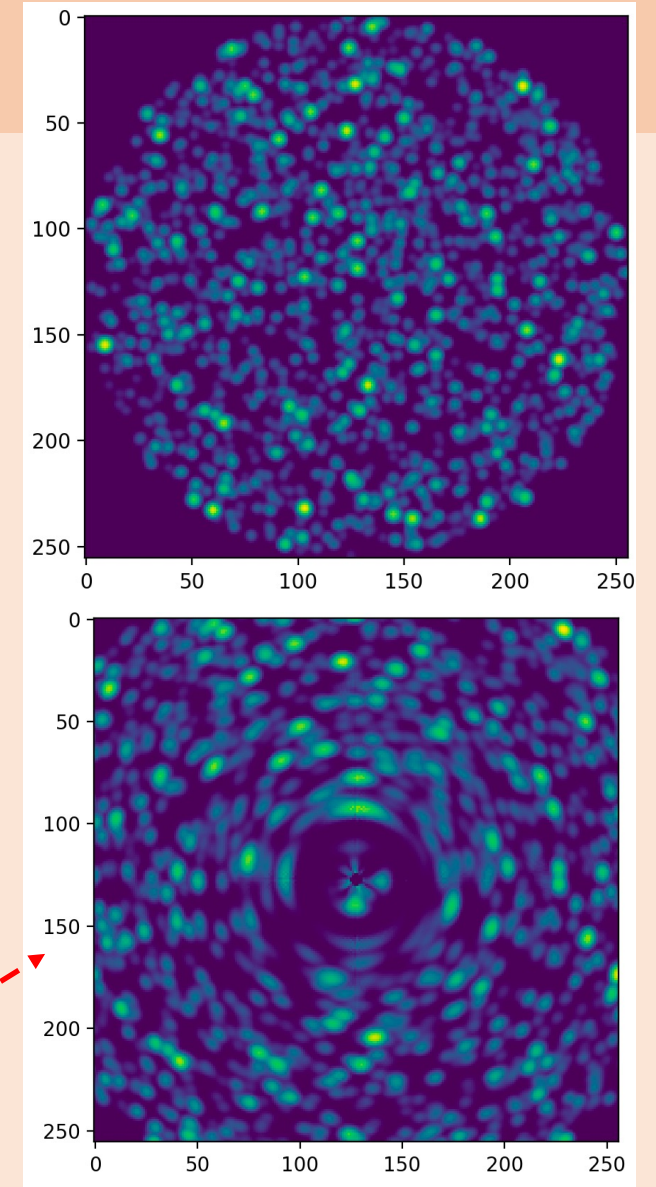
- Really easy identification (>5 mJy not “local IRLT”, $z_{\text{phot}} > 1$)

AtLAST forecast



Mass density profiles (stacked):

- better resolution \rightarrow sub-kpc resolution
 - Stars+BCG sub-halo
- Increased statistics to homogeneously covering sub-kpc -- Mpcs
 - [1-halo] BCG + satellites + halo
 - [2-halo] Splashback + environment
- **Directly observable for individual lenses!!**



Conclusions

- SMGs are the perfect background sample for lensing studies
- SMGs MagBias provides an independent, versatile and complementary cosmological probe.
- By increasing continuous area, resolution, and sensitivity, **AtLAST** will reduce sample variance and substantially improve the robustness and precision of the measurements.

Thanks!

Bibliography

- MagBias astrophysical studies (Gonzalez-Nuevo et al. [2014](#), [2017](#))
- MagBias cosmological analysis:
 - Non-tomographic analysis (Bonavera et al. [2020](#); González-Nuevo et al. [2021](#), [2026](#); Cueli et al. [2024](#); Fernandez-Fernandez et al. [2024](#))
 - Tomographic analysis (Bonavera et al. [2021](#), [2024](#))
- Mass density profiles (Bonavera et al. [2019](#); Fernandez et al. [2022](#); Crespo et al. [2022](#), [2024](#), [2025](#))
- Direct observation with ALMA (Dunne et al. [2020](#))
- Other applications:
 - HMF (Cueli et al. [2021](#), [2022](#));
 - Neutrinos (Cueli et al. [2024](#))

MagBias review:
Cueli et al. [2025](#)

Theoretical model

MagBias:

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

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

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:

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

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

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

HOD Model:

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

DE Model:

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

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

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