The submillimeter galaxy magnification bias as a cosmological probe

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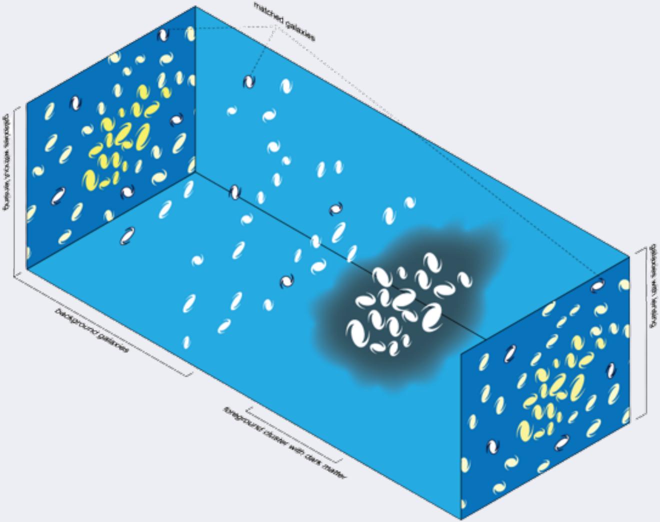
Cosmology from Home 2023

Weak gravitational lensing



Weak gravitational lensing

Weak lensing studies the statistical correlations of magnification and distortion effects between foreground and background sources

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Weak lensing studies the statistical correlations of magnification and distortion effects between foreground and background sources:

- Cosmic shear: ellipticity x ellipticity
- Galaxy-galaxy lensing: ellipticity x position
- Cosmic magnification: position x position

The foreground-background number density correlation also probes the galaxy-matter connection!

$$w(\theta) \equiv \langle \delta n_f(\varphi) \delta n_b(\varphi + \theta) \rangle_\varphi$$

If the two samples do not overlap in redshift, a non-zero signal is a manifestation of magnification bias!

Magnification bias

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The net effect (magnification bias) modifies the integral number counts with respect to no lensing!

Magnification bias

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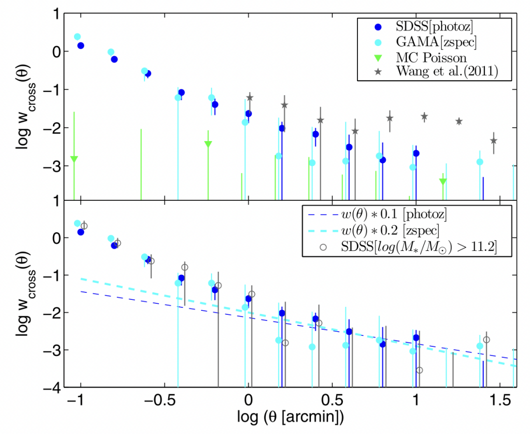

González-Nuevo, J. et al. (2014)

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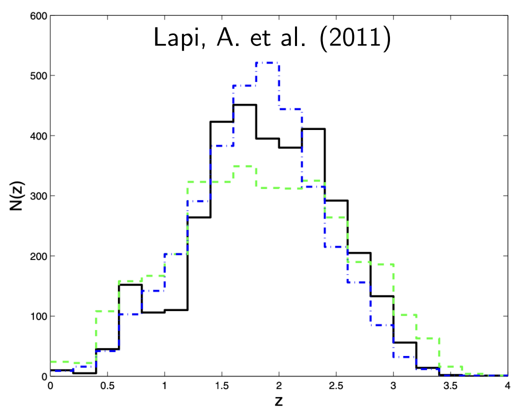

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As shown by Wang, L. et al. (2011) and González-Nuevo, J. et al. (2014), submillimeter galaxies are an optimal background sample:

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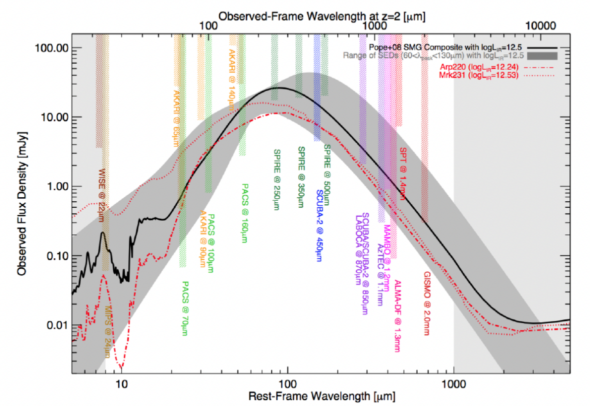

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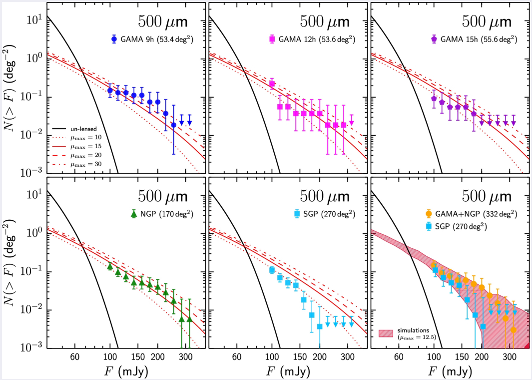
Negrello, M. et al. (2017)



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  For instance, assuming a power-law, $n_{b_0}(>S,z) = A\,S^{-\beta}$, then

$$\delta n_b^{\mu}(\boldsymbol{\theta}) = \frac{n_b(>S,\boldsymbol{\theta}) - n_{b_0}(>S)}{n_{b_0}(>S)} \overset{\text{WL}}{\approx} 2(\beta-1)\kappa(\boldsymbol{\theta})$$

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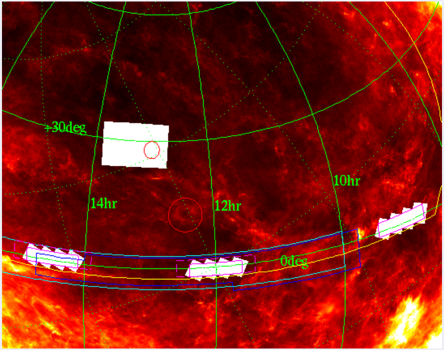
Moreover, the magnitude of the effect depends on cosmology:

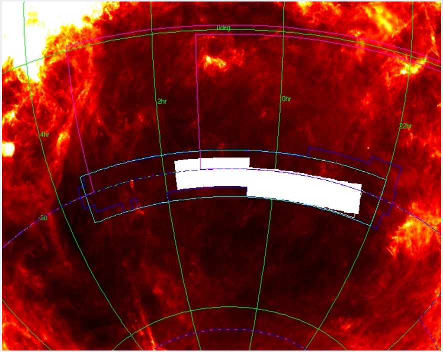
> The submillimeter galaxy magnification bias via $w(\theta)$ can be exploited as an independent cosmological probe!

The foreground and background galaxy samples

The background galaxy sample

The *Herschel*-ATLAS survey observed the NGP and SGP regions as well as three areas on the celestial equator (G09, G12 and G15)...

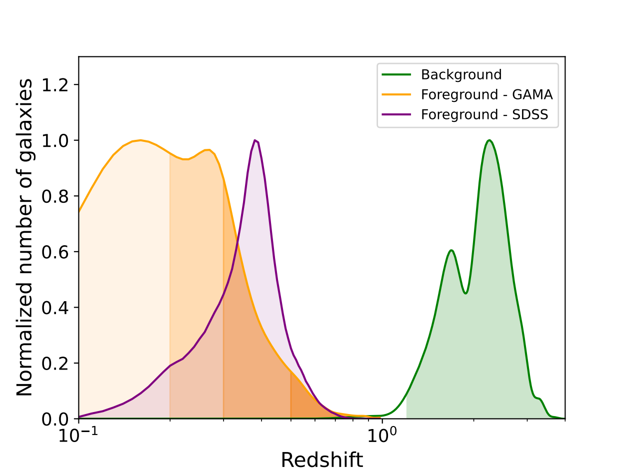




... at 70, 100, 160 (PACS), 250, 350 y 500 μm (SPIRE)

The foreground and background galaxy samples

The background galaxy sample



H-ATLAS:

$$1.2 < z < 4.0$$

The foreground and background galaxy samples

The foreground galaxy sample

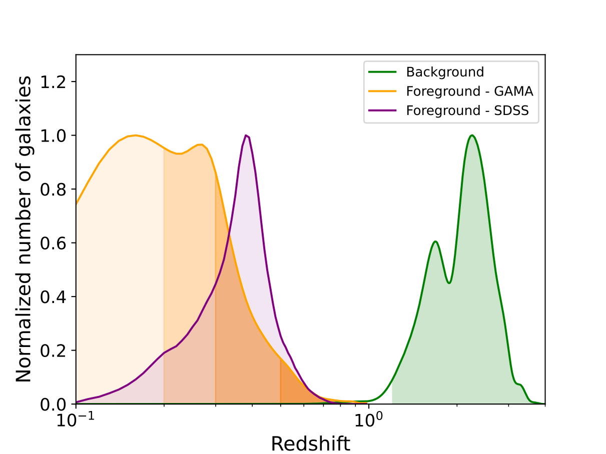
The foreground sample is made up of sources from the spectroscopic GAMA II catalog such that

- they overlap with H-ATLAS-observed regions ($\sim$ 207 deg^2 (!))
- their (spectroscopic) redshift is

$$0.2 < z < 0.8$$

The foreground and background galaxy samples

The foreground galaxy sample



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$$1.2 < z < 4.0$$

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Measuring the angular cross-correlation function

The estimator

Given the definition of the angular cross-correlation function,

$$w(\theta) \equiv \langle \delta n_{\mathsf{f}}(\boldsymbol{\phi}) \delta n_{\mathsf{b}}(\boldsymbol{\phi} + \boldsymbol{\theta}) \rangle_{\boldsymbol{\phi}},$$

how can we estimate this quantity?

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how can we estimate this quantity?

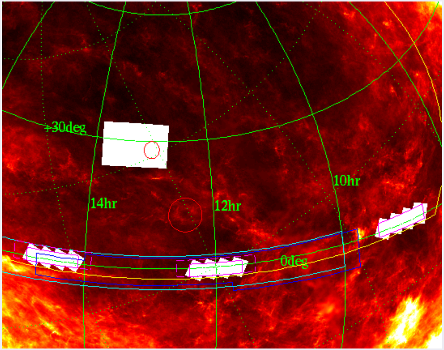
$$\tilde{w}(\theta) = \frac{D_{\mathsf{f}}D_{\mathsf{b}}(\theta) - D_{\mathsf{f}}R_{\mathsf{b}}(\theta) - D_{\mathsf{b}}R_{\mathsf{f}}(\theta) + R_{\mathsf{f}}R_{\mathsf{b}}(\theta)}{R_{\mathsf{f}}R_{\mathsf{b}}(\theta)}$$

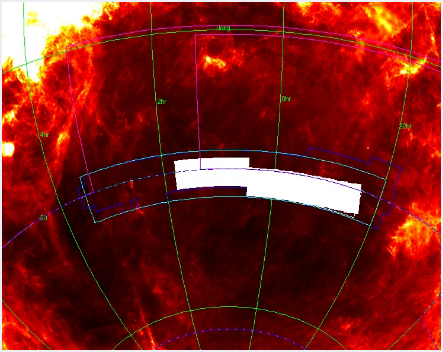
- $D_{\mathsf{f}}D_{\mathsf{b}}$ is the number of data foreground - data background pairs
- $D_{\mathsf{f}}R_{\mathsf{b}}$ is the number of data foreground - random background pairs
- ...

Measuring the angular cross-correlation function

Methodological aspects

We have four spatially-separated regions (G09, G12, G15 and SGP). We can measure the cross-correlation in each of them



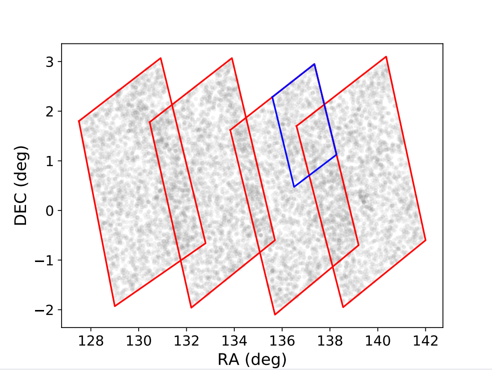


$$\tilde{w}(\theta) = \bar{w}(\theta) \pm \sigma/\sqrt{n}$$

Measuring the angular cross-correlation function

Methodological aspects

Or choose *tiles* ($\sim 4 \times 4$ deg^2) or *minitiles* ($\sim 2 \times 2$ deg^2) as the minimal areas over which to average! **[Bonavera et al. (2021), González-Nuevo et al. (2021)]**

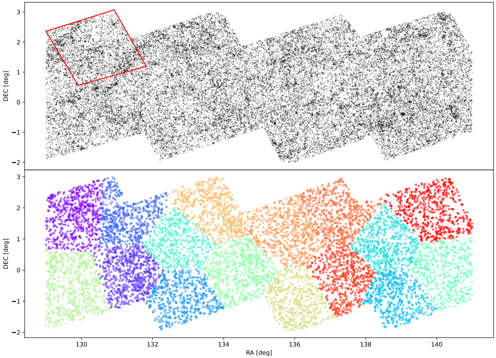


However, the increase in n also carries a reduction of the maximum scale...

Measuring the angular cross-correlation function

Methodological aspects

Or perform a global measurement and assign errors via Bootstrap subsampling **[Cueli et al. (2023), González-Nuevo et al. (2023)**, submitted to A&A]



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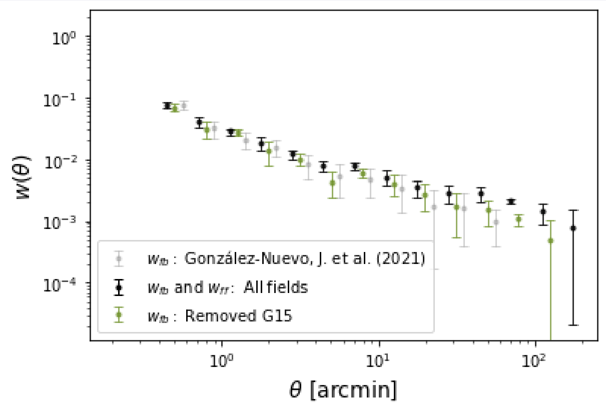

Modeling the angular cross-correlation function

Cosmology enters directly in the weak lensing-based theoretical expression:

$$w(\theta) = 2(\beta - 1) \int_0^\infty \frac{dz}{f_K^2(\chi(z))} p_{z_\mathsf{f}}(z) W_z^{\mathsf{lens}}(z) \int_0^\infty \frac{dl}{2\pi} \, l \, P_{\mathsf{g\text{-}m}}\left(\frac{l}{f_K(\chi(z))}, \chi(z)\right) J_0(l\theta)$$

We use the halo model, which gives an analytic description of the galaxy-matter power spectrum.

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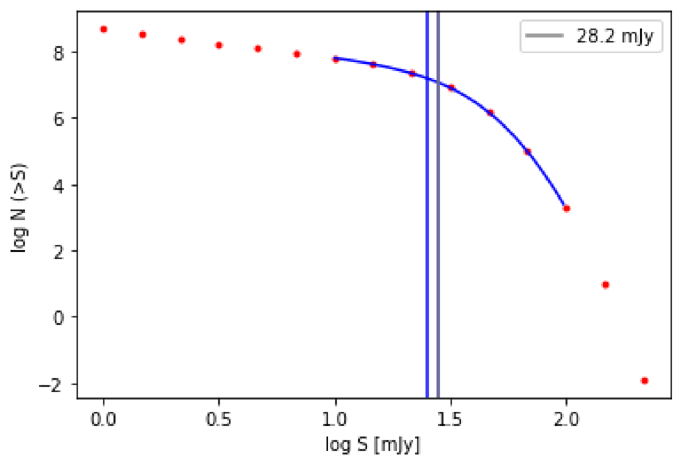
- Cosmology within flat ΛCDM (Ω_m, σ_8, h)
- Logarithmic slope of number counts (β)
- Halo Occupation Distribution (M_{min}, M_1 and α)

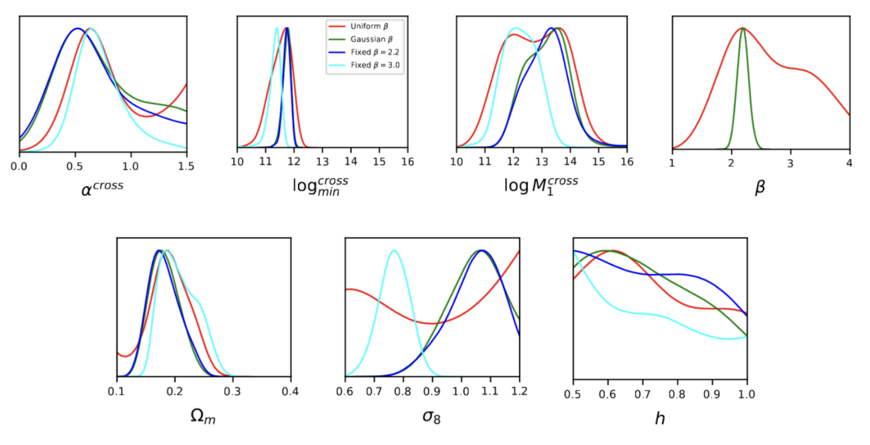
$$\langle N \rangle_M = \langle N_c \rangle_M + \langle N_s \rangle_M = \Theta(M - M_{\mathsf{min}}) \left[1 + \left(\frac{M}{M_1} \right)^\alpha \right]$$

The value of β had been commonly fixed to 3 in previous works (Lapi, A. et al. (2011) ...



... but the behavior "around" the detection limit needs to be captured

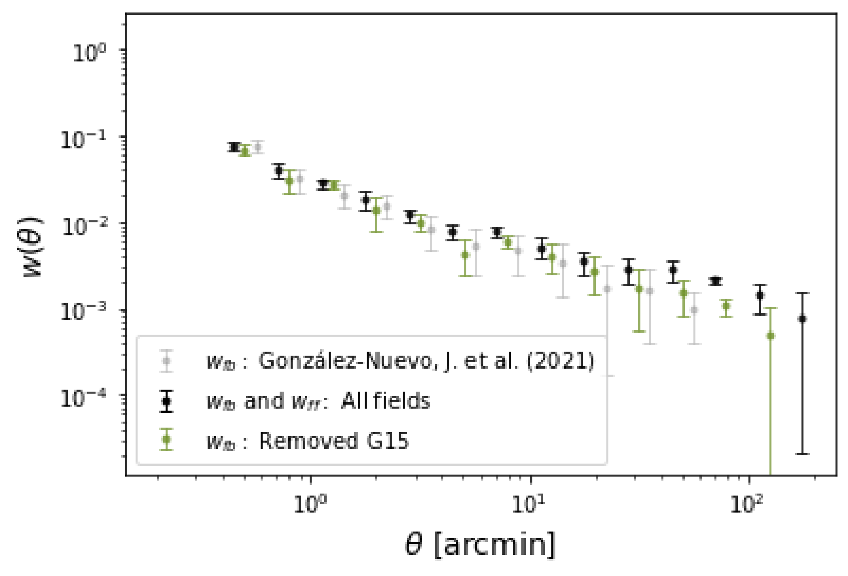
The value of β mainly affects σ_8 and M_1, while Ω_m is unaffected!

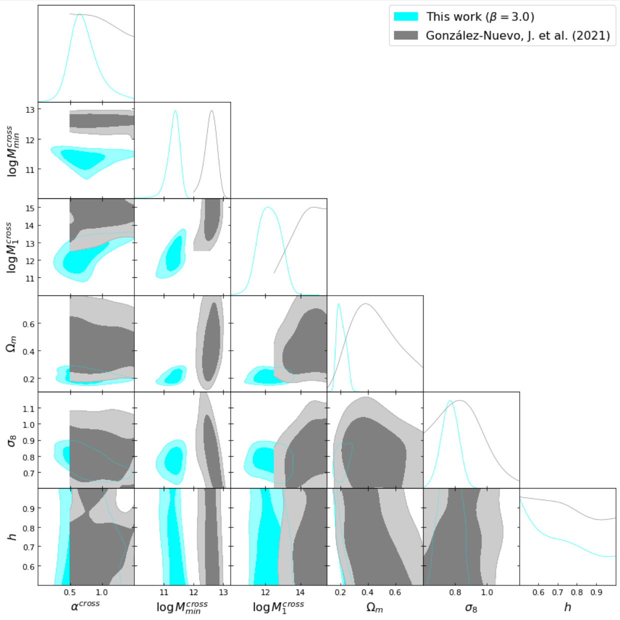


$\log M_1/M_\odot = 12.24^{+0.65}_{-0.64}$ $\sigma_8 = 0.77^{+0.05}_{-0.06}$ $\Omega_m = 0.21^{+0.02}_{-0.04}$

$\log M_1/M_\odot = 13.14^{+0.75}_{-0.73}$ $\sigma_8 = 1.04^{+0.12}_{-0.06}$ $\Omega_m = 0.19^{+0.02}_{-0.04}$

If we compare with the constraints from González-Nuevo et al. (2021)...



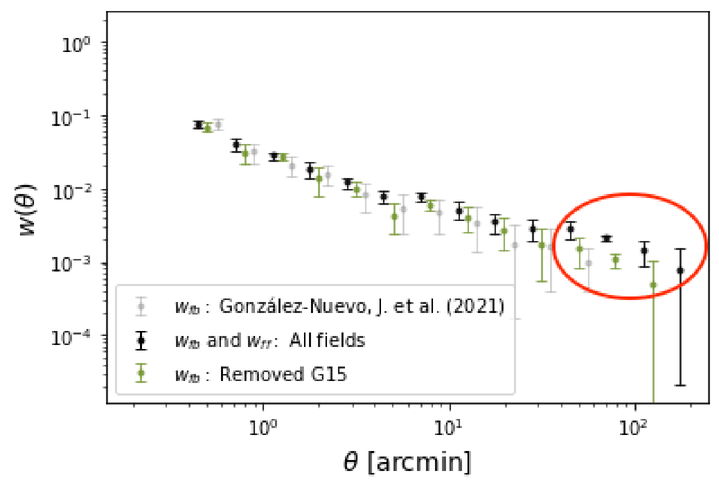

This work ($\beta = 3.0$)
González-Nuevo, J. et al. (2021)
$\log M_{min}^{cross}$
$\log M_1^{cross}$
Ω_m
σ_8
h
α^{cross}

If we compare with the constraints from González-Nuevo et al. (2021)...

- Improvement in cosmological uncertainties (σ_8 and Ω_m)

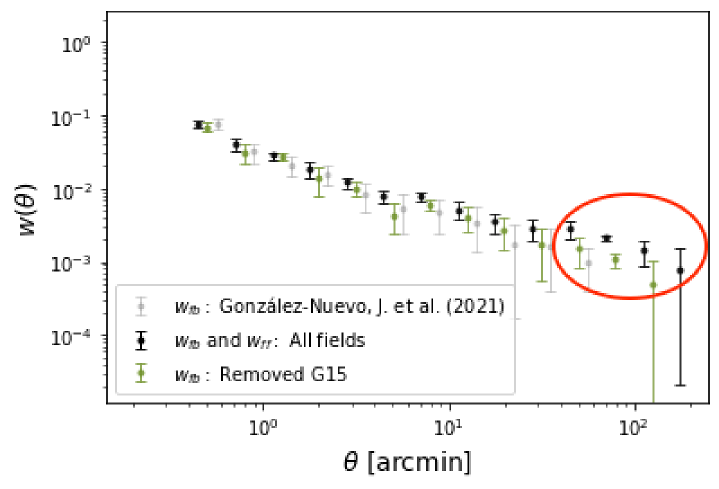
- Discrepancies in halo masses (M_{min} and M_1) and Ω_m...
  1. Integral constraint correction is relatively arbitrary
  2. Average over "minitiles" washes out larger-scale inhomogeneities

If we compare with the data from González-Nuevo et al. (2021)...



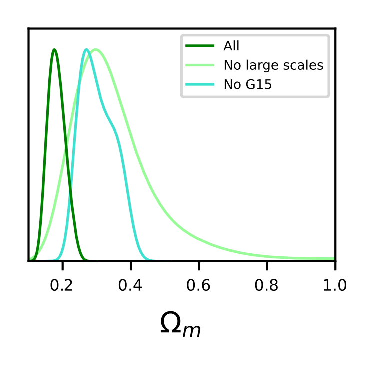
Is the large-scale signal anomalous?

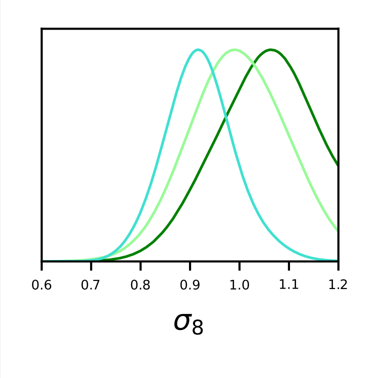
Removing the G15 region weakens the signal on large scales!



What is the effect on parameter estimation?

Removing G15 mainly affects Ω_m and σ_8! For $\beta = 2.2$...

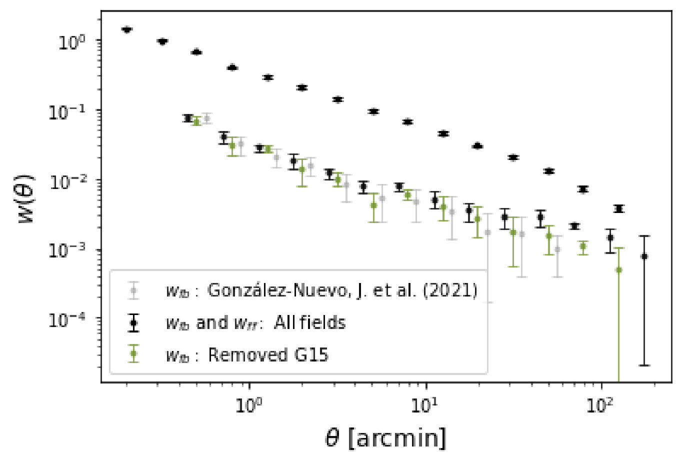




$\Omega_m = 0.19^{+0.02}_{-0.04}$ $\sigma_8 = 1.04^{+0.12}_{-0.06}$

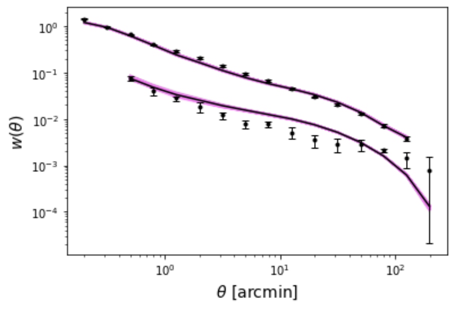
$\Omega_m = 0.30^{+0.05}_{-0.06}$ $\sigma_8 = 0.92^{+0.07}_{-0.07}$

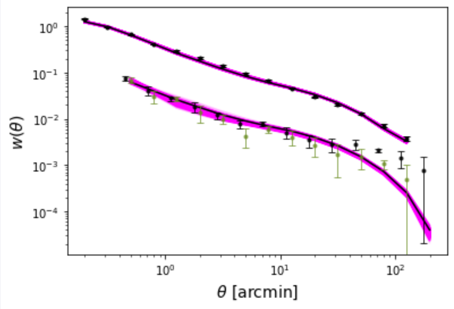
We can also measure the angular clustering of the foreground sample



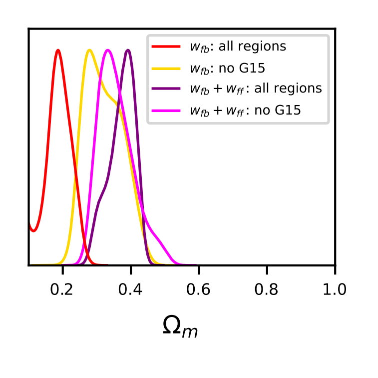
and describe it within the halo model

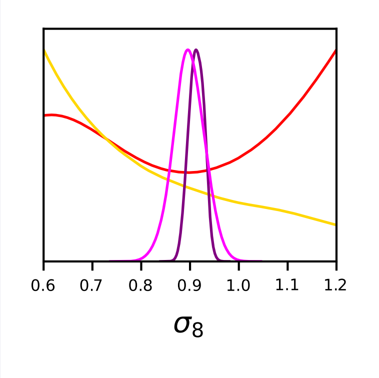
Excluding the G15 regions seems to be necessary for a good fit...





But the information about β is no longer necessary!





$\Omega_m = 0.36^{+0.03}_{-0.07}$ $\sigma_8 = 0.90^{+0.03}_{-0.03}$

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- The submillimeter galaxy magnification bias can be exploited as an independent and complementary cosmological probe:
  - Most sensitive to Ω_m and σ_8
  - No sign of the usual $\Omega_m - \sigma_8$ degeneracy
  - The β parameter is crucial for determining σ_8
  - Hints of an anomalous large-scale signal related to G15
  - Galaxy clustering tightens constraints and eliminates the need for β information

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  - Galaxy clustering tightens constraints and eliminates the need for β information
- Promising future with a larger area and tomographic analyses!