Observational constraints on the halo mass function

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Brief summary

In this work, we propose a method to derive **observational constraints on the halo mass function** by exploiting the weak lensing magnification bias effect between sub-millimeter galaxies observed by Herschel at $1.2 < z < 4.0$ and galaxies in the GAMA II survey, at $0.2 < z < 0.8$ through the cross-correlation function. We obtain interesting 95% upper bounds on the high-mass end of our sample and relatively narrow two-sided 95% credible intervals for low masses.

Context

We study the weak lensing effect between

Sub-millimeter galaxies (SMGs) observed by Herschel — Background sample $(1.2 < z < 4.0)$

and

Galaxies observed by the GAMA II survey — Foreground sample $(0.2 < z < 0.8)$

through the foreground-background cross-correlation function, $\boldsymbol{\omega}_{\mathbf{fb}}(\boldsymbol{\theta})$, a manifestation of

Magnification Bias

Excess number of high-redshift sources near low-redshift structures!

Why SMGs?

$\beta \sim 3$

- Steep number counts: $N_S(\theta) = N_S^0 \mu^{\beta-1}(\theta)$
- High redshift
- Low cross-contamination with optically-selected galaxies

What can we do with this?
- Constraints on cosmological parameters (L. Bonavera et al. - arXiv: 2006.09185)
- Constraints on a halo mass funcion (This work!)

Methodology

The cross-correlation function is estimated with the following modified version of the Landy & Szalay estimator

$$\omega(\theta) = \frac{D_f D_b - D_f R_b - D_b R_f + R_f R_b}{R_f R_b}$$

- $D_f D_b$: Foreground-background pair counts
- $D_f R_b$: Foreground-random pair counts
- $D_b R_f$: Background-random pair counts
- $R_f R_b$: Random-random pair counts

and checked against the prediction from the **Halo Model**

$$\omega(\theta) = 2(\beta - 1) \int_0^\infty \frac{dz}{\chi^2(z)} n_f(z)\, W^{lens}(z) \int_0^\infty \frac{dl}{2\pi} l\, P_{g-dm}\left(\frac{l}{\chi(z)}, z\right) J_0(l\theta)$$

Lensing kernel (background source information)

Foreground source distribution

Galaxy-dark matter cross power spectrum

HOD parameters

(Halo Occupation Distribution)

The galaxy-dark matter cross power spectrum contains the **halo mass function:**

$$n(M,z) = \frac{\rho_b}{M^2} f\left(\nu, z; \{p_j\}_j\right) \left|\frac{\partial \log \nu}{\partial \log M}\right|$$

$$\nu(M,z) \equiv \left[\frac{\delta_c}{\sigma(M,z)}\right]^2$$

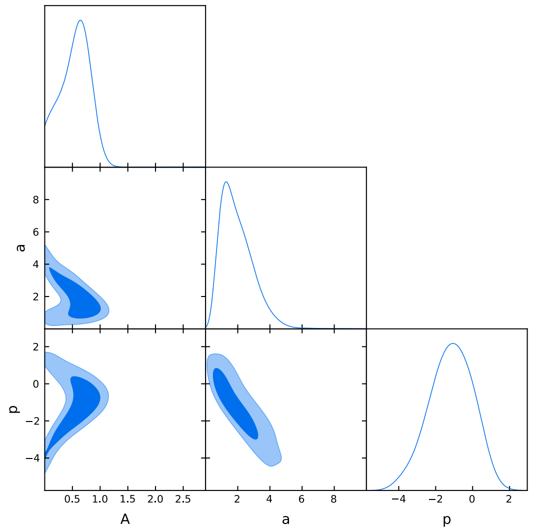
HMF parameters

and its parameters from different models are estimated through an MCMC algorithm

Results

1) Sheth and Tormen universal fit

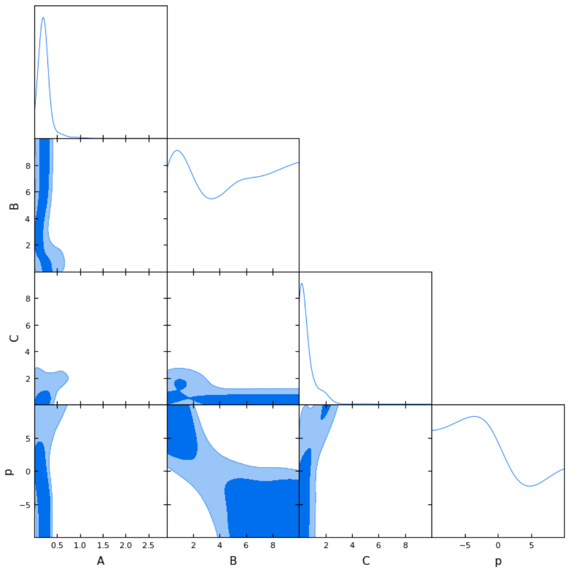
$$f(\nu) = A\sqrt{\frac{a\nu}{2\pi}}\left[1+\left(\frac{1}{a\nu}\right)^{p}\right]e^{-a\nu/2}$$



Wide but constraining 1-dimensional posteriors for all parameters

2) Tinker-like universal fit

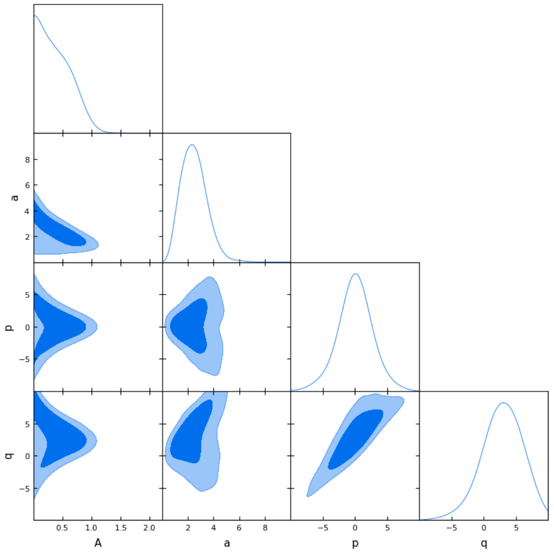
$$f(\nu) = A[1+(B\sqrt{\nu})^{p}]e^{-C\nu}$$



Constraints on parameters A and C, whereas B and p remain unconstrained (but B^{p} small)

3) Bhattacharya-like universal fit

$$f(\nu) = A\sqrt{\frac{(a\nu)^{q}}{2\pi}}\left[1+\left(\frac{1}{a\nu}\right)^{p}\right]e^{-a\nu/2}$$

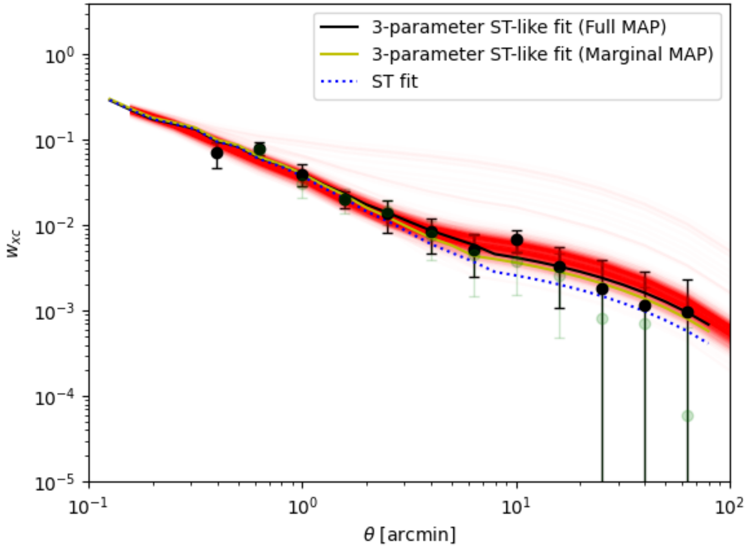


Wide but constraining 1-dimensional posteriors except for parameter A (upper bound).

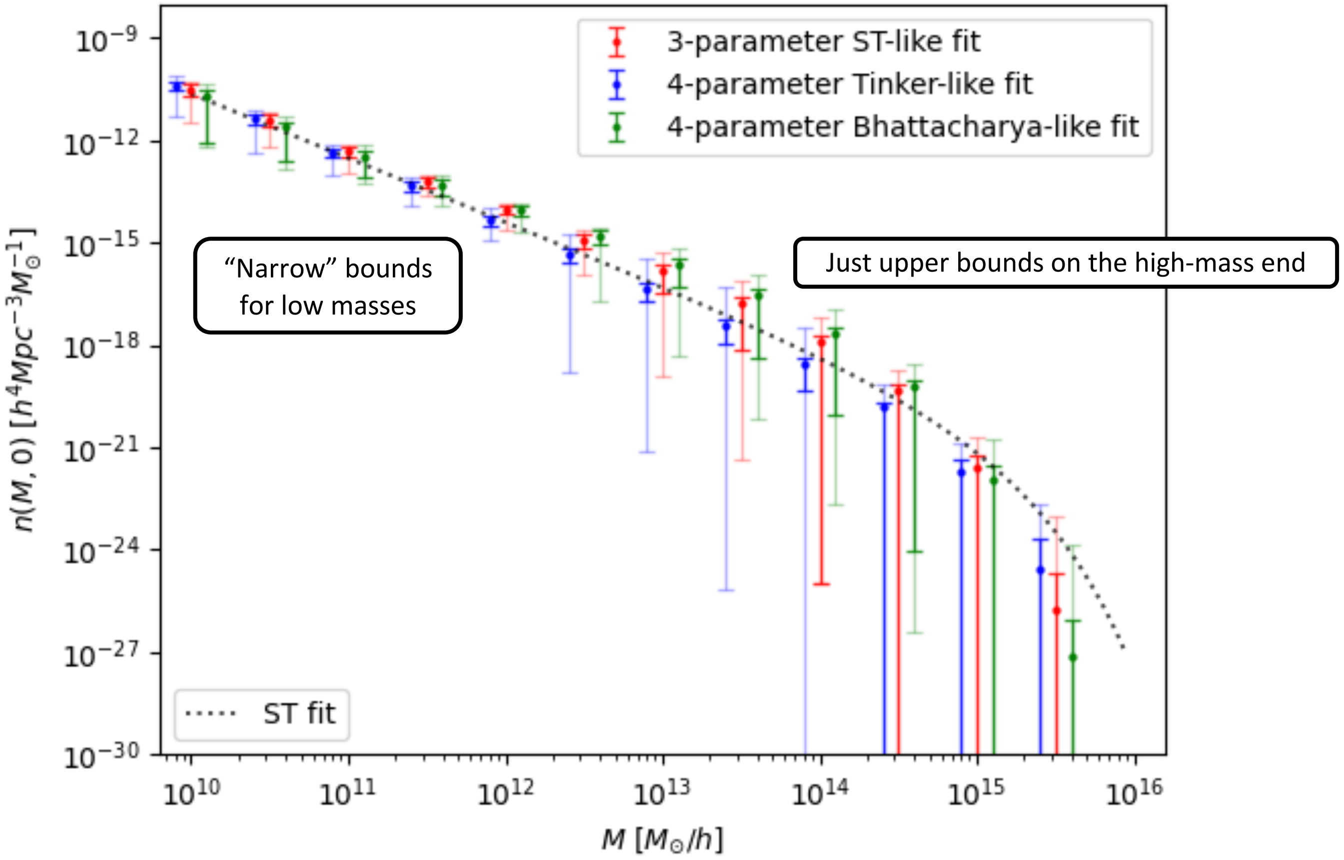
Allowing for gaussian priors on the HOD parameters produces **no significant differences.**

Results

A sampling of the full posterior distribution allows to **tabulate the halo mass function** at any redshift:



Best-fit cross-correlation results from the 3-parameter ST-like fit: full MAP, marginal MAP and sampling of the full posterior.



Tabulation of the ($z = 0$) halo mass function for several values of M: 68% (solid) and 95% (faint) credible intervals for the three fits at the same M

Impact and future prospects

To our knowledge, these are the **first observational constraints** on a halo mass function

Our results are in agreement with typical fits from N-body simulations, but offer a **complementary** and **observation-based** check

We expect to improve our results in the future by

- **Reducing the error bars** on the cross-correlation measurements on large scales
- Performing a **tomographic analysis** to consider the (likely) redshift variation of the HOD parameters and the possibility of a **non-universal** halo mass function
- Considering the effect of **massive neutrinos**