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Breaking $\sum m_\nu$ Parameter Degeneracies with the Bispectrum

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ABSTRACT

abstract

Keywords: cosmology: —

1. INTRODUCTION

very brief into on neutrinos

Brief intro on the impact of massive active neutrinos on the matter powerspectrum and how that's detectable with CMB and LSS

Quick summary of current constraints and where they come from. Talk about the CMB-LSS lever arm. The degeneracy between As and tau and how that's a bottleneck short thing about how τ is hard to constrain.

Fortunately the imprint of neutrinos on the matter distribution leaves imprints on clustering. So with clustering measurements alone we can derive constraints on $\sum m_\nu$ and at the very least tighten constraints.

Brief summary of previous works that look at the powerspectrum. Then Discuss the shortcomings of the powerspectrum only analysis– Not good enough.

However, we don't have to settle for just two point statistics, three-point statistics such as the bispectrum and 3PCF...

In Section blah

2. HADES AND QUIJOTE SIMULATION SUITES

We use a subset of the HADES[1] and Quijote simulation suites. The HADES simulations have been run using the GADGET-III TreePM+SPH code (**?**) in a periodic $(1h^{-1}\mathrm{Gpc})^3$ box. All of the HADES simulations share the values of the following cosmological parameters:

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[1] https://franciscovillaescusa.github.io/hades.html

Table 1. HADES and Quijote simulation suites

Name	$\sum m_\nu$ (eV)	Ω_m	Ω_b	h	n_s	σ_8^m	σ_8^c	realizations
				HADES suite				
Fiducial	0.0	0.3175	0.049	0.6711	0.9624	0.833	0.833	100
	0.06	0.3175	0.049	0.6711	0.9624	0.819	0.822	100
	0.10	0.3175	0.049	0.6711	0.9624	0.809	0.815	100
	0.15	0.3175	0.049	0.6711	0.9624	0.798	0.806	100
	0.0	0.3175	0.049	0.6711	0.9624	0.822	0.822	100
	0.0	0.3175	0.049	0.6711	0.9624	0.818	0.818	100
	0.0	0.3175	0.049	0.6711	0.9624	0.807	0.807	100
	0.0	0.3175	0.049	0.6711	0.9624	0.798	0.798	100
				Quijote suite				
Fiducial	0.0	0.3175	0.049	0.6711	0.9624	0.834	0.834	15,000
$\sum m_\nu^+$	0.1	0.3175	0.049	0.6711	0.9624	0.834	0.834	500
$\sum m_\nu^{++}$	0.2	0.3175	0.049	0.6711	0.9624	0.834	0.834	500
$\sum m_\nu^{+++}$	0.4	0.3175	0.049	0.6711	0.9624	0.834	0.834	500
Ω_m^+	0.0	0.3275	0.049	0.6711	0.9624	0.834	0.834	500
Ω_m^-	0.0	0.3075	0.049	0.6711	0.9624	0.834	0.834	500
Ω_b^+	0.0	0.3175	0.050	0.6711	0.9624	0.834	0.834	500
Ω_b^-	0.0	0.3175	0.048	0.6711	0.9624	0.834	0.834	500
h^+	0.0	0.3175	0.049	0.6911	0.9624	0.834	0.834	500
h^-	0.0	0.3175	0.049	0.6511	0.9624	0.834	0.834	500
n_s^+	0.0	0.3175	0.049	0.6711	0.9824	0.834	0.834	500
n_s^-	0.0	0.3175	0.049	0.6711	0.9424	0.834	0.834	500
σ_8^+	0.0	0.3175	0.049	0.6711	0.9624	0.849	0.849	500
σ_8^-	0.0	0.3175	0.049	0.6711	0.9624	0.819	0.819	500

$\Omega_{\rm m}$=0.3175, $\Omega_{\rm b}$=0.049, Ω_Λ=0.6825, n_s=0.9624, h=0.6711, and $k_{\rm pivot}$ = 0.05 $h{\rm Mpc}^{-1}$. These parameters are in good agreement with Planck constraints **?**.

CH: describe quijote simulations

3. BISPECTRUM

Brief description of the Scoccimarro et al. bispectrum estimator here

4. RESULTS

4.1. *Breaking the* $\sum m_\nu$ – σ_8 *degeneracy*

4.2. *Forecasts*

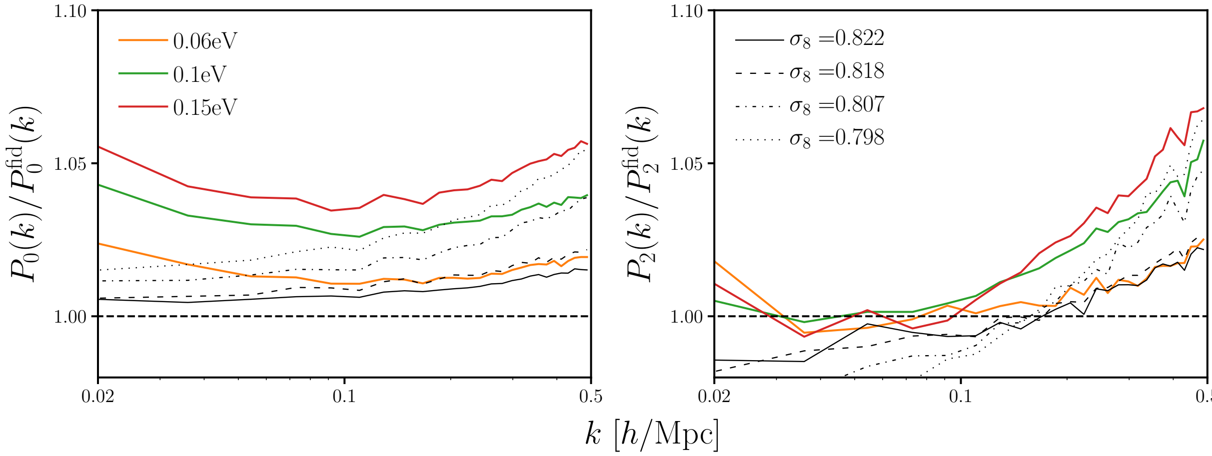

Figure 1. Impact of $\sum m_\nu$ and σ_8 on the redshift-space halo power spectrum monopole and quadrupole. $\sum m_\nu$ and σ_8 produce almost identical effects on halo clustering on small scales ($k > 0.1\,h/\mathrm{Mpc}$). This degeneracy can be partially broken through the quadrupole; however, $\sum m_\nu$ *and* σ_8 *produce, within a few percent, almost the same effect on two-point clustering.*

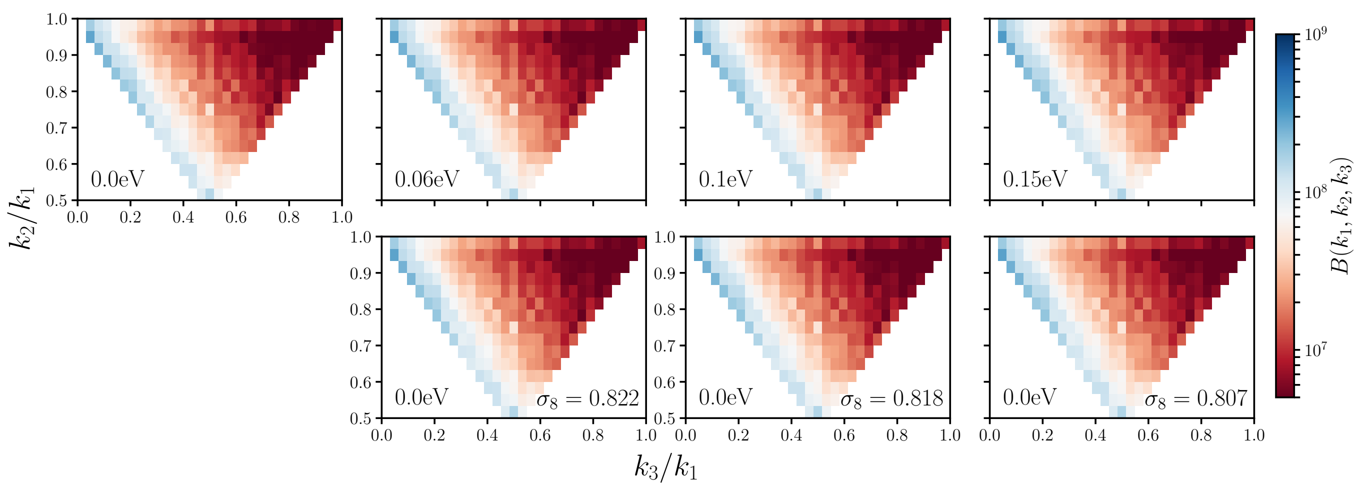

Figure 2. The redshift-space halo bispectrum, $B(k_1, k_2, k_3)$ as a function of triangle configuration shape for $\sum m_\nu = 0.0, 0.06, 0.10$, and $0.15\,\mathrm{eV}$ (upper panels) and $\sigma_8 = 0.822, 0.818$, and 0.807 (lower panels). We describe the triangle configuration shape by the ratio of the triangle sides: k_3/k_1 and k_2/k_1. In each of the panels, the upper left bin contains squeezed triangles ($k_1 = k_2 \gg k_3$); the upper right bin contains equilateral triangles ($k_1 = k_2 = k_3$); and the bottom center bin contains folded triangles ($k_1 = 2k_2 = 2k_3$). We include all triangle configurations with $k_1, k_2, k_3 \leq k_{\rm max} = 0.5\ h/\mathrm{Mpc}$. In the three right-most columns, the HADES simulations of the top and bottom panels have matching σ_8 values. We describe the estimator used to calculate $B(k_1, k_2, k_3)$ in Section 3.

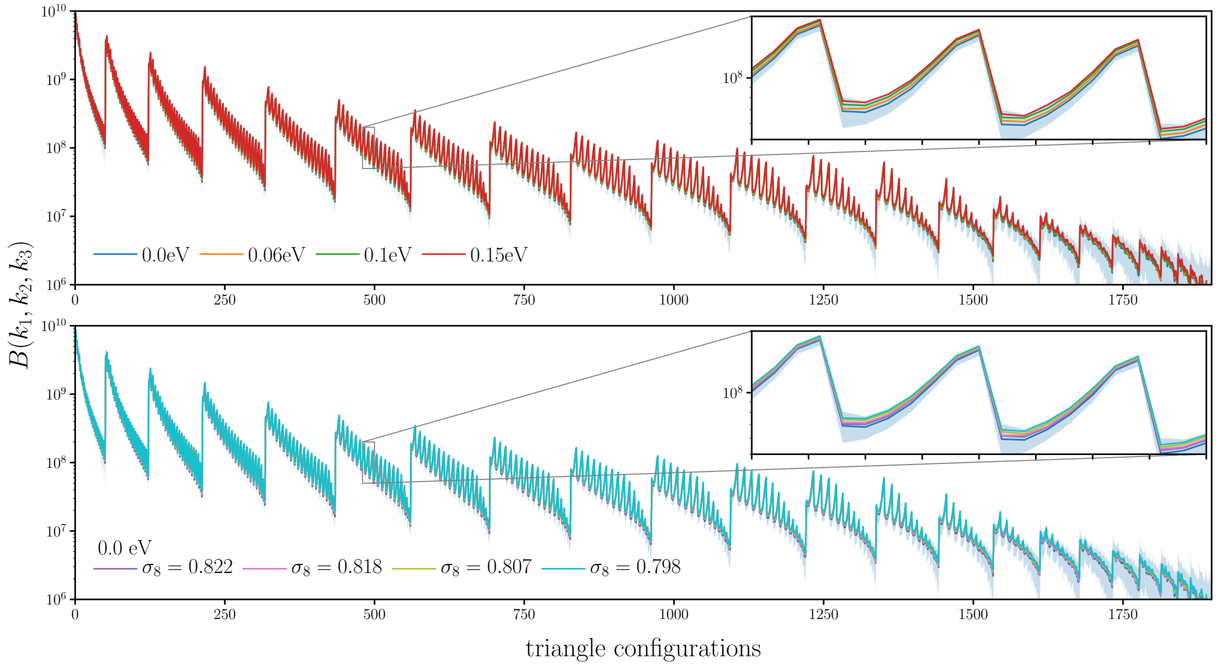

Figure 3. The redshift-space halo bispectrum, $B(k_1, k_2, k_3)$, as a function of triangle configurations for $\sum m_\nu = 0.0, 0.06, 0.10$, and $0.15\,\mathrm{eV}$ (top panel) and $\sum m_\nu = 0.0$ eV, $\sigma_8 = 0.822, 0.818, 0.807$, and 0.798 (lower panel). We include all possible triangle configurations with $k_1, k_2, k_3 \leq k_{\rm max} = 0.5\ h/\mathrm{Mpc}$ where we loop through the configurations with k_3 in the inner most loop and k_1 in the outer most loop satisfying $k_1 \leq k_2 \leq k_3$. In the insets of the panels we zoom into triangle configurations with $k_1 = 0.113$, $0.226 \leq k_2 \leq 0.283$, and $0.283 \leq k_3 \leq 0.377\ h/\mathrm{Mpc}$. The blue shaded regions represent the uncertainties estimated using the $15,000$ fiducial Quijote simulations and illustrate how triangle configurations on small scales are dominated by shot noise.

5. SUMMARY

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It's a pleasure to thank Simone Ferraro, Shirley Ho,

APPENDIX

A. REDSHIFT-SPACE BISPECTRUM

B. TESTING CONVERGENCE

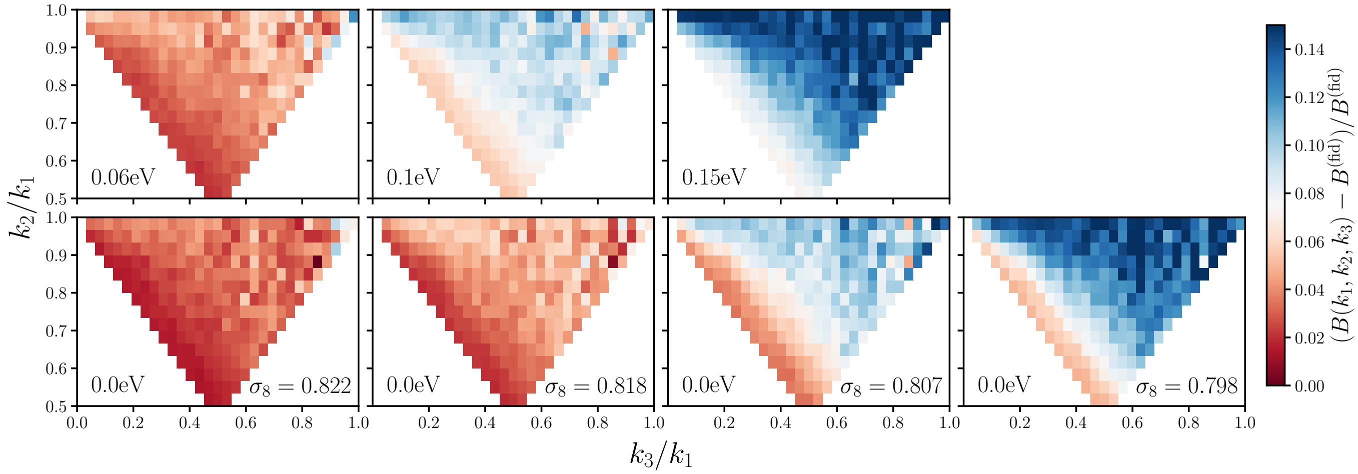

Figure 4. The shape dependence of the $\sum m_\nu$ and σ_8 imprint on the redshift-space halo bispectrum, $\Delta B/B^{(\mathrm{fid})}$. We align the $\sum m_\nu$= $0.06, 0.10$, and $0.15\,\mathrm{eV}$ (upper panels) with $\sum m_\nu$= 0.0 eV, σ_8= 0.822, 0.818, and 0.807 (bottom panels) such that simulations of top and bottom panels in each of the three columns have matching σ_8^c, which produce mostly degenerate imprints on the redshift-space power spectrum. The difference between the top and bottom panels highlight, for instance, that $\sum m_\nu$ leaves a distinct imprint on elongated and isosceles triangles (bins along the bottom left and bottom right edges, respectively) from σ_8. *The imprint of $\sum m_\nu$ has an overall distinct shape dependence on the bispectrum that cannot be replicated by a change of σ_8.*

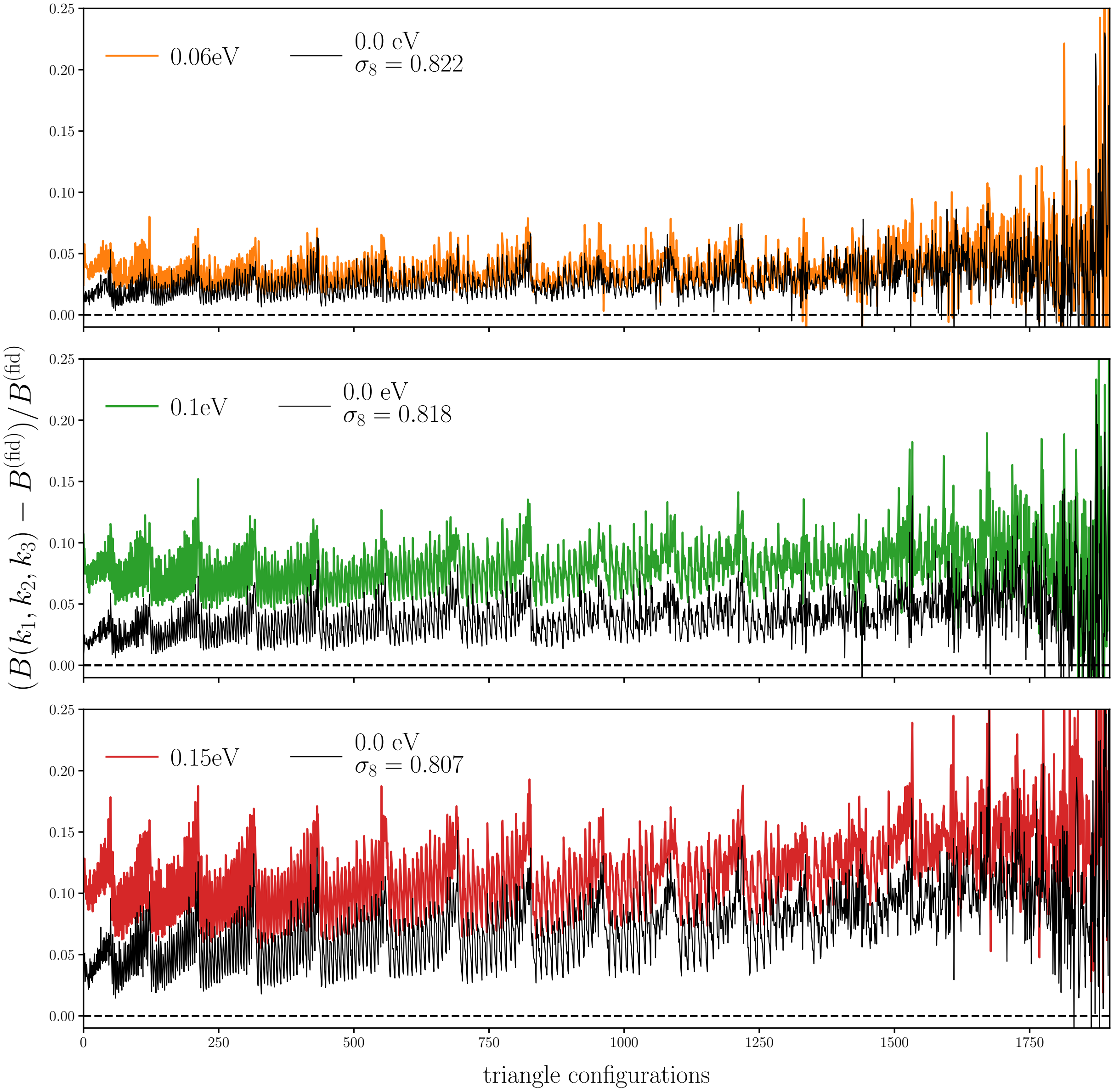

Figure 5. The impact of $\sum m_\nu$ and σ_8 on the redshift-space halo bispectrum, $\Delta B/B^{(\mathrm{fid})}$, for triangle configurations with $k_1, k_2, k_3 \leq 0.5h/\mathrm{Mpc}$. We compare $\Delta B/B^{(\mathrm{fid})}$ of the HADES simulations with $\sum m_\nu =$ 0.06 (top), 0.10 (middle), and 0.15 eV (bottom) to $\Delta B/B^{(\mathrm{fid})}$ of $\sum m_\nu = 0.0$ eV HADES simulations with matching σ_8. The impact of $\sum m_\nu$ on the bispectrum has a significantly different amplitude than the impact of σ_8. For instance, $\sum m_\nu = 0.15\,\mathrm{eV}$ (red) has a $\sim 5\%$ stronger impact on the bispectrum than $\sum m_\nu = 0.0$ eV, $\sigma_8 = 0.798$ (black). Meanwhile, these two simulations have power spectrums that differ by $< 1\%$ (Figure 1). Combined with the shape-dependence of Figure 4, *the distinct impact of $\sum m_\nu$ and σ_8 on the redshift-space halo bispectrum illustrate that the bispectrum can break the degeneracy between $\sum m_\nu$ and σ_8 that degrade constraints from two-point analyses.*

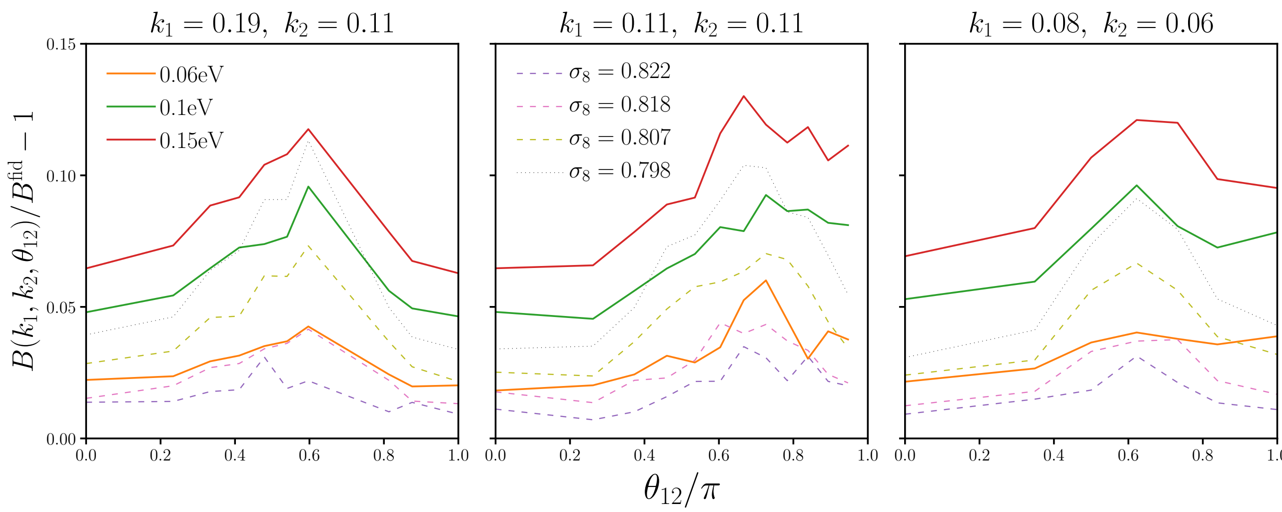

Figure 6. The impact of $\sum m_\nu$ and σ_8 on the redshift-space halo bispectrum, $\Delta B/B^{(\rm fid)}$, for triangles that have $[k_1, k_2] = [0.19, 0.11], [0.11, 0.11]$ and $[0.08, 0.06]$ h/Mpc (left to right) with different angles in between, θ_{12}. Again, the HADES simulations with $\sum m_\nu = 0.06$, 0.10, and 0.15 eV (orange, green, red) have matching σ_8^c with the $\sum m_\nu = 0.0$ eV, $\sigma_8 = 0.822$, 0.818, and 0.807 (purple, pink, yellow dashed). Comparison between these two sets of simulations further illustrate the distinct imprint of the $\sum m_\nu$ on the bispectrum. We also include $\sum m_\nu = 0.0$ eV, $\sigma_8 = 0.798$ (black dashed) to highlight that change in σ_8 cannot reproduce the imprint of $\sum m_\nu$.

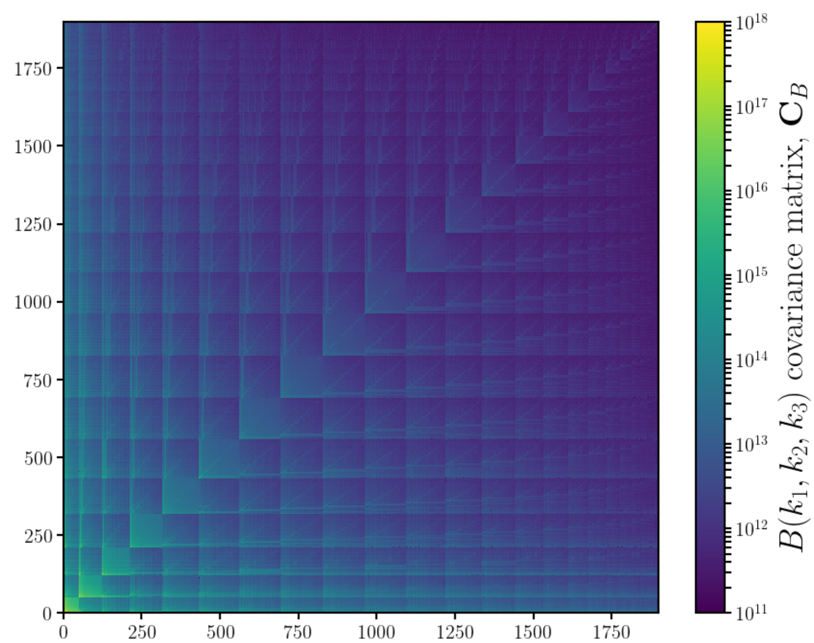

Figure 7. Covariance matrix of the redshift-space halo bispectrum estimated using the 15,000 realizations of the Qujiote simulation suite with the fiducial cosmology: $\Omega_{\rm m}$=0.3175, $\Omega_{\rm b}$=0.049, h=0.6711, n_s=0.9624, σ_8=0.834, and $\sum m_\nu$=0.0 eV. The triangle configurations (the bins) have the same ordering as in Figures 3 and 6.

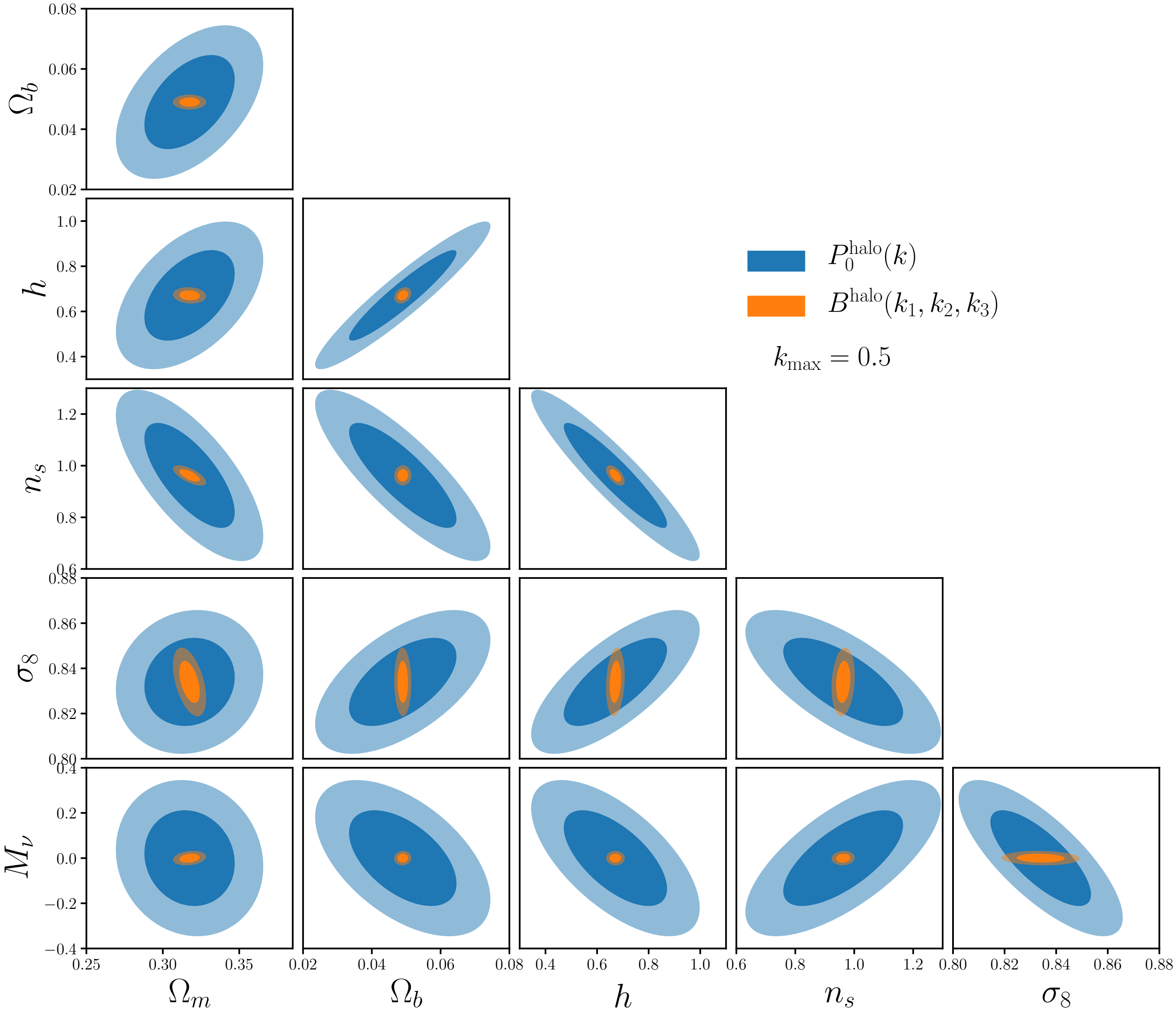

Figure 8. Fisher forecast constraints on cosmological parameters from the redshift-space halo power spectrum monopole (blue) and bispectrum (orange) derived using the Quijote simulation suite. For both the power spectrum and bispectrum constraints, we set $k_{\rm max} = 0.5$ h/Mpc. The contours mark the 68% and 95% confidence interals. The bispectrum *substantially* improves constraints on all of the cosmological parameters over the power spectrum. *For* $\sum m_\nu$, *the bispectrum improves the constraint from* $\sigma_{\sum m_\nu}$= 0.279 *to* 0.0258 *— over an order of magnitude improvement over the power spectrum.*

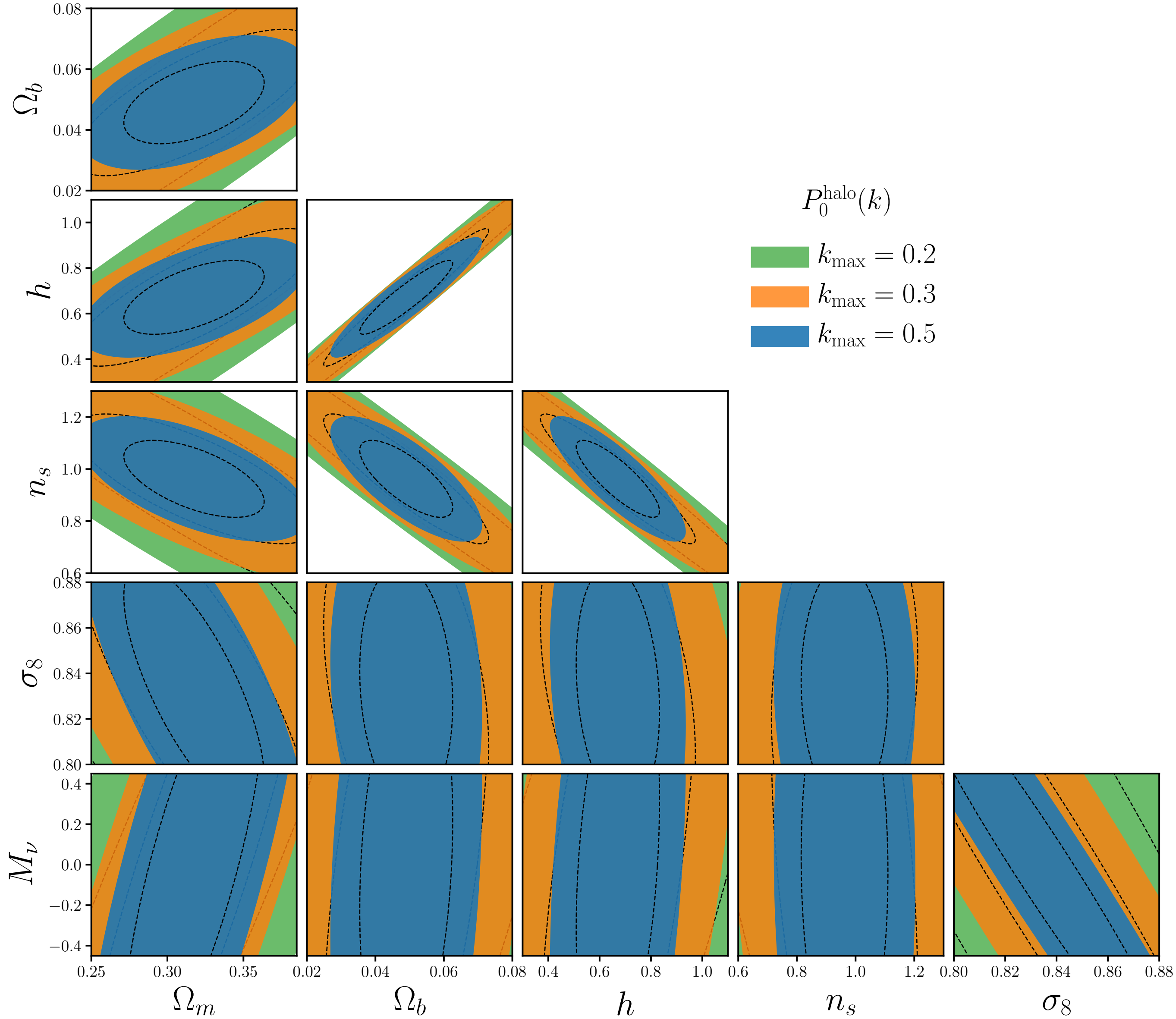

Figure 9. Fisher forecast constraints on cosmological parameters from the redshift-space halo power spectrum monopole for $k_{\max} = 0.2$ (green) 0.3 (orange), and 0.5 h/Mpc (blue). The contours mark the 68% (black dashed) and 95% confidence intervals. The contours illustrate the degeneracy between $\sum m_\nu$ and σ_8 we find in the power spectrum comparisons of the HADES simulations (Figure 1).

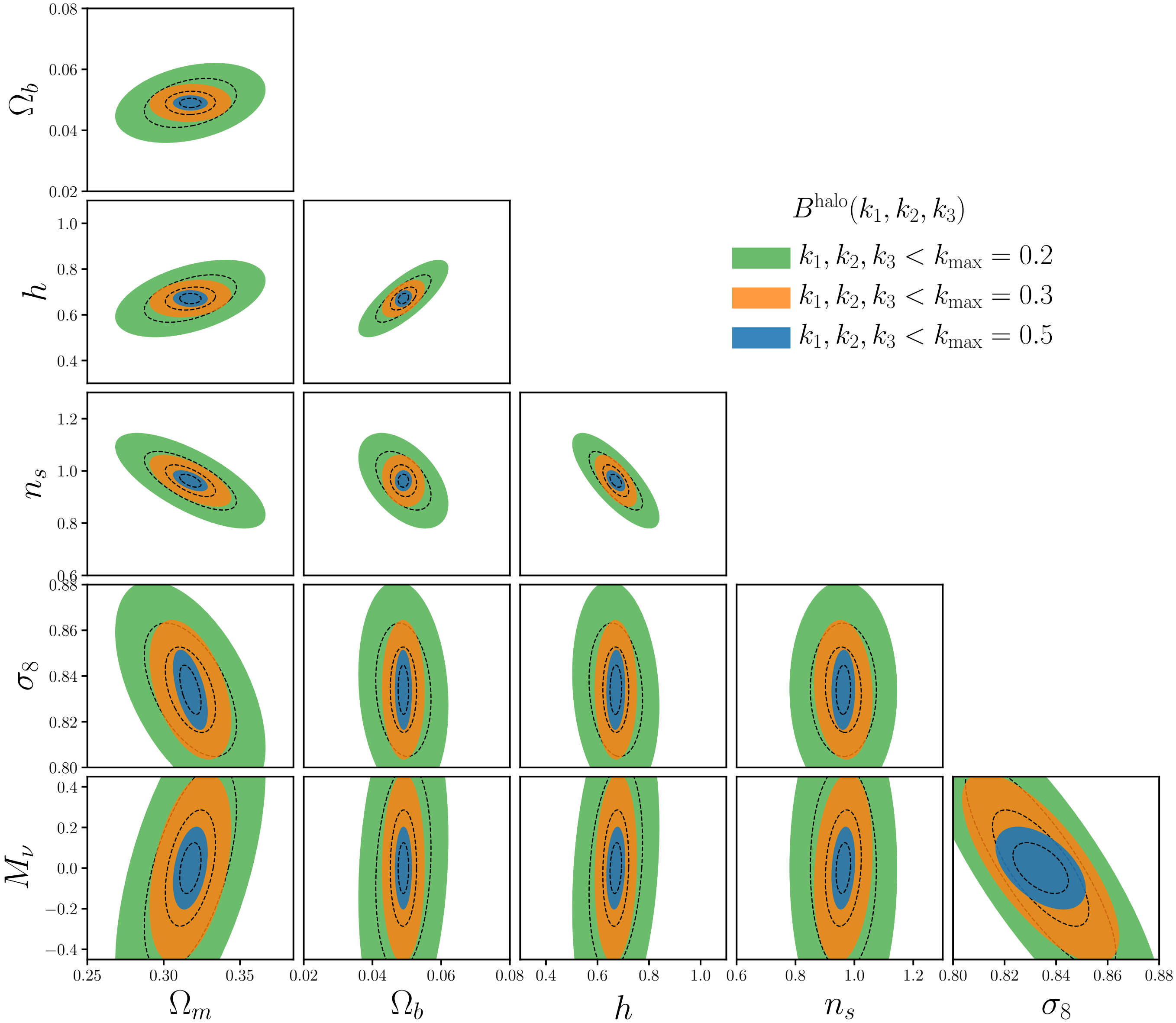

Figure 10. Constraints on cosmological parameters from the redshift-space halo bispectrum for $k_1, k_2, k_3 \leq k_{\rm max} = 0.2$ (green) 0.3 (orange), and 0.5 h/Mpc (blue). The contours mark the 68% (black dashed) and 95% confidence intervals. As we find with the bispectrum comparisons of the HADES simulations (Section 4.1, the bispectrum breaks the degeneracy with σ_8. **CH:** probably want to say more things

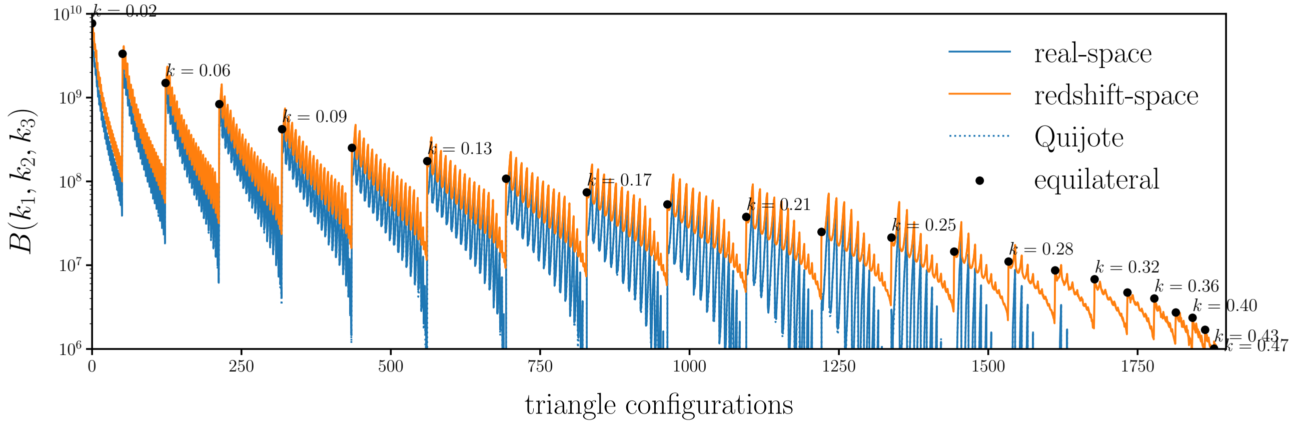

Figure 11. Comparison of the fiducial HADES simulation real and redshift-space halo bispectrum (blue and orange).

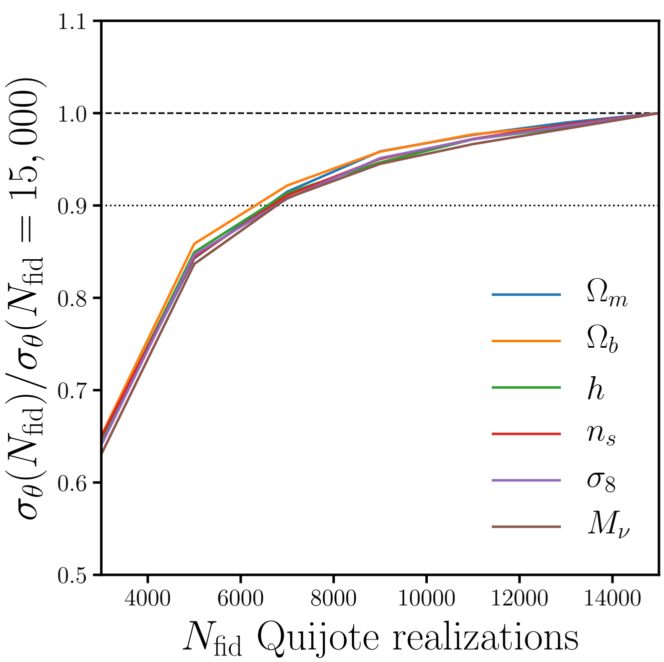

Figure 12.

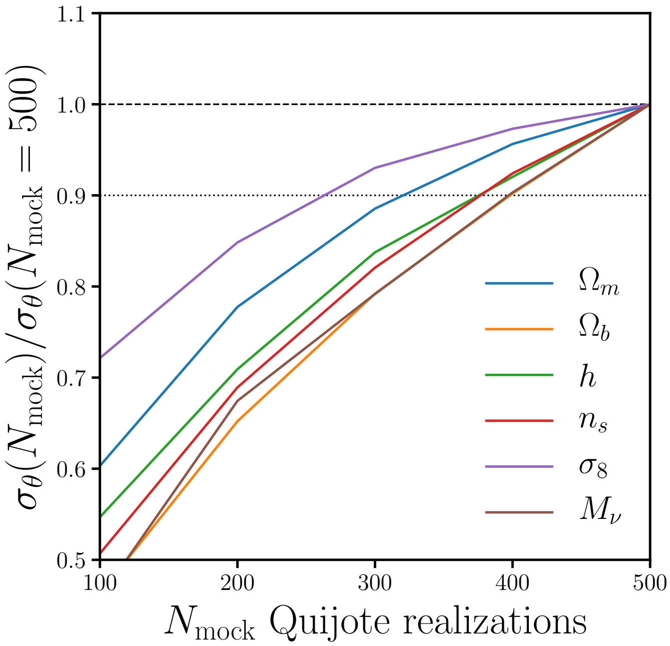
$\sigma_\theta(N_{\rm mock})/\sigma_\theta(N_{\rm mock}=500)$
1.1
1.0
0.9
0.8
0.7
0.6
0.5
100
200
300
400
500
$N_{\rm mock}$ Quijote realizations
Ω_m
Ω_b
h
n_s
σ_8
M_ν

Figure 13.