The Effective Field Theory of Large-Scale Structure and Multi-tracer

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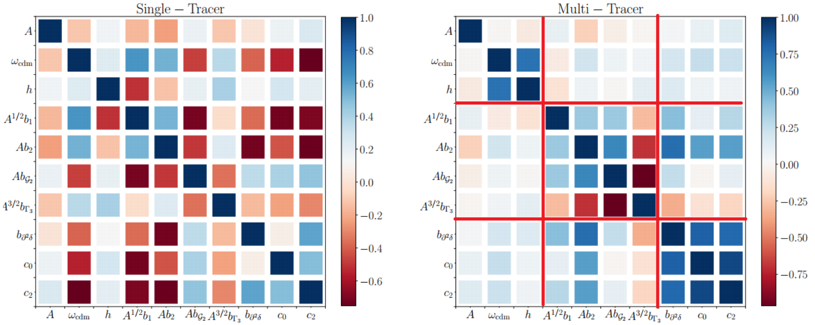
Main Result

Multi-tracer block diagonalize the correlation matrix of parameters!



Thiago Mergulhão, Henrique Rubira, RV, L. Raul Abramo, 2021.

(Gaussian) Fisher Forecast

For two tracers, the fisher matrix is diagolanized by the three degrees of freedom (L. Raul Abramo, *et al.*, 2021):

$$\mathcal{Q}_1 = \mathcal{P}\left[1 + \frac{1}{2}\log\left(\frac{\mathcal{P}_{11}^2 + \mathcal{P}_{22}^2 + 2\mathcal{P}_{12}^2}{\mathcal{P}^2}\right)\right] ,$$

$$\mathcal{Q}_2 = \log\left(\frac{\mathcal{P}_{11}^2 + \mathcal{P}_{12}^2}{\mathcal{P}_{22}^2 + \mathcal{P}_{12}^2}\right) ,$$

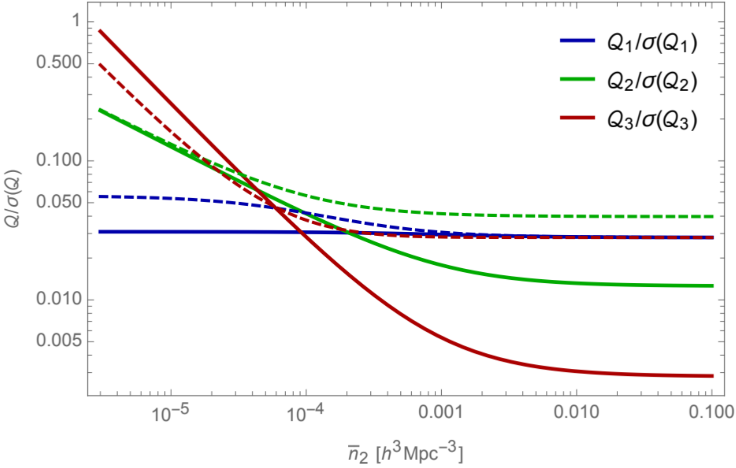
$$\mathcal{Q}_3 = \frac{\mathcal{P}_{12}^2 - \mathcal{P}_{11}\mathcal{P}_{22}}{\mathcal{P}^2} .$$

In the linear limit where $\mathcal{P}_{12}^2 = \mathcal{P}_{11}\mathcal{P}_{22}$ these reduces to:

$$(\mathcal{Q}_1, \mathcal{Q}_2, \mathcal{Q}_3) = \left(\mathcal{P}, \log\left(\mathcal{P}_{11}/\mathcal{P}_{22}\right), 0\right).$$

(Gaussian) Fisher Forecast

The information in the cross-spectrum is of the same order of the information in the auto-spectra.



L. Raul Abramo, *et al.*, 2021.

Real Space EFT

The power spectra, for multi-tracer, is given by [computed with CLASS-PT (Anton Chudaykin, Mikhail M. Ivanov, Oliver H.E. Philcox and Marko Simonović, 2020)]:

$$
\begin{aligned}
P^{AB}(k) = {} & b_1^A b_1^B \left[P_0(k) + P_1(k)\right] + \frac{1}{2}\left(b_1^A b_2^B + b_1^B b_2^A\right)\mathcal{I}_{\delta^2}(k) + \left(b_1^A b_{\mathcal{G}_2}^B + b_1^B b_{\mathcal{G}_2}^A\right)\mathcal{I}_{\mathcal{G}_2}(k) \\
& + \left[\left(b_1^A b_{\mathcal{G}_2}^B + b_1^B b_{\mathcal{G}_2}^A\right) + \frac{2}{5}\left(b_1^A b_{\Gamma_3}^B + b_1^B b_{\Gamma_3}^A\right)\right]\mathcal{F}_{\mathcal{G}_2}(k) \\
& + \frac{1}{4} b_2^A b_2^B \mathcal{I}_{\delta^2\delta^2}(k) + b_{\mathcal{G}_2}^B b_{\mathcal{G}_2}^A \mathcal{I}_{\mathcal{G}_2\mathcal{G}_2}(k) + \frac{1}{2}(b_2^A b_{\mathcal{G}_2}^B + b_2^B b_{\mathcal{G}_2}^A)\mathcal{I}_{\delta^2\mathcal{G}_2}(k) \\
& + P^{AB}_{\nabla^2\delta}(k) + P_{\varepsilon^A\varepsilon^B}(k)\,,
\end{aligned}
$$

where

$$
\begin{aligned}
P^{AB}_{\nabla^2\delta} &= -\,k^2 P_0\left[2\frac{c_s^2 b_1^A b_1^B}{k_{\mathrm{NL}^2}} + b_1^A\left(R_*^B\right)^2 + b_1^B\left(R_*^A\right)^2\right] \\
&= -\left(b^A_{\nabla^2\delta} b_1^B + b^B_{\nabla^2\delta} b_1^A\right) k^2 P_0\,,
\end{aligned}
$$

and

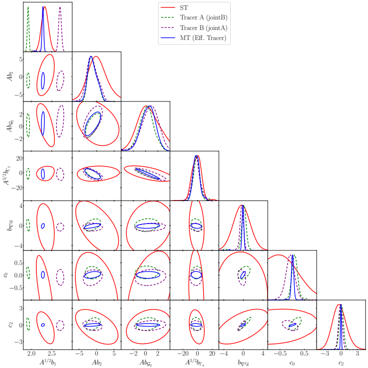
$$
P_{\varepsilon^A\varepsilon^B}(z,k) = \frac{1}{\sqrt{\bar{n}_A \bar{n}_B}}\left[c_0^{AB} + c_2^{AB}\frac{k^2}{k^2_{\mathrm{norm}}} + \mathcal{O}(k^4)\right].
$$

$\{b_1^A, b_2^A, b_{\mathcal{G}_2}^A, b_{\Gamma_3}^A, b_{\nabla^2\delta}^A, b_1^B, b_2^B, b_{\mathcal{G}_2}^B, b_{\Gamma_3}^B, b_{\nabla^2\delta}^B, c_0^{AA}, c_2^{AA}, c_0^{BB}, c_2^{BB}, c_0^{AB}, c_2^{AB}\} - 16\,\text{parameters}$

Simulation

We have used the halos of the (huge) MultiDark simulation (A. Klypin, *et al.*, 2014).

Halo Data set	Mass range [log $M_\odot/h$]	$\bar{n}\,[(\mathrm{Mpc}/h)^{-3}]$	number count
Halo A	[13.2, 13.5]	1.44×10^{-4}	9.21×10^{6}
Halo B	[13.5, 15.7]	1.23×10^{-4}	7.90×10^{6}
Halo A + B	[13.2, 15.7]	2.67×10^{-4}	1.71×10^{7}



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Priors

We used flat prior for the cosmological parameters

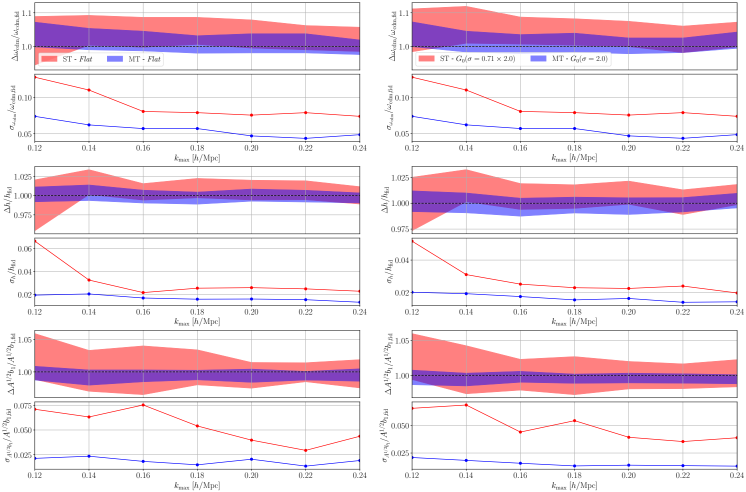
	Prior
ω_{cdm}	Flat $[0.095, 0.14]$
h	Flat $[0.6, 0.75]$
A	Flat $[1.49, 2.8]$

And both flat and Guassian priors for (some) of the bias and stochastic parameters

	Prior *Flat*	Prior $G_0(\sigma)$
b_1	Flat $[1.0, 2.2]$	
b_2	Flat $[-5.0, 5.0]$	Gauss.(0,σ)
$b_{\mathcal{G}_2}$	Flat $[-5.0, 5.0]$	Gauss(0,σ)
b_{Γ_3}	Flat $[-10.0, 10.0]$	Gauss(0,2σ)
$b_{\nabla^2\delta}$	Flat $[-5.0, 5.0]$	
c_0	Flat $[-5.0, 5.0]$	
c_2	Flat $[-5.0, 5.0]$	

Cosmological Constraints

Unbiased and stronger constraints!



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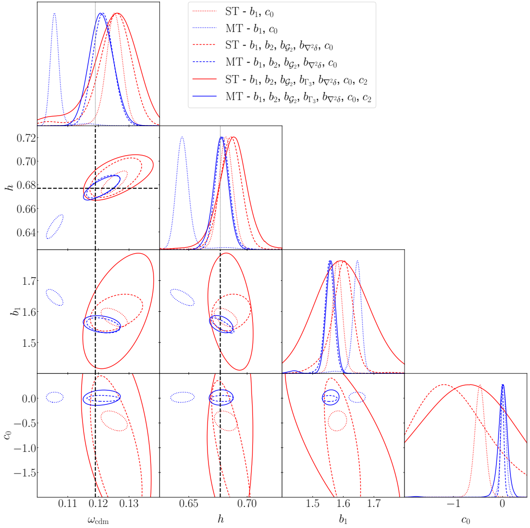
Model Complexity

The constraining power is weakly affected by the number of parameters!



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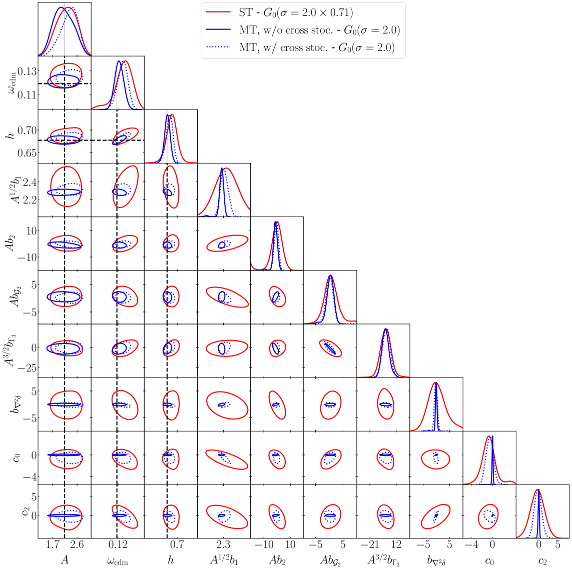
Stochastic cross-term

The cross stochastic term seems to not be very important.



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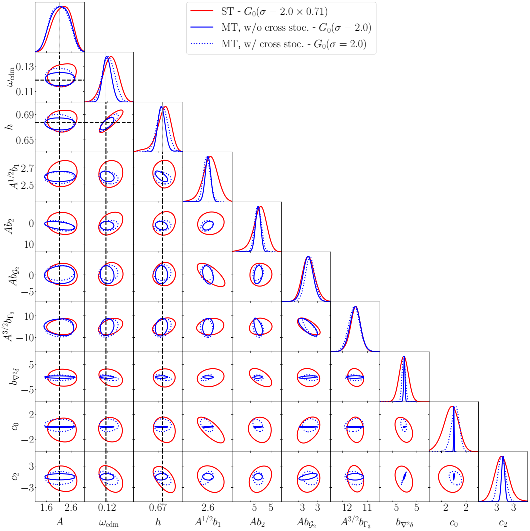
HOD Galaxies

More constraint for galaxies with populations with the similar b_1!



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Redshift Space EFT

The power spectra, for multi-tracer in redshift space, is given by [computed with CLASS-PT (Anton Chudaykin, Mikhail M. Ivanov, Oliver H.E. Philcox and Marko Simonović, 2020)]:

$P^{AB}(k) =$ Usual thing with symmetrized bias parameters where

$$P_{\rm ct}^{AB}(k,\mu) = \frac{k^2}{k_{\rm norm}^2} P_{\rm lin}(k) \left[Z_1^A \left(c_{{\rm ct},20}^B + c_{{\rm ct},22}^B \mu^2 + c_{{\rm ct},24}^B \mu^4 + c_{{\rm ct},44}^B \frac{k^2}{k_{\rm norm}^2} \mu^4 + \right.\right.$$
$$\left.\left. + \; c_{{\rm ct},26}^B \mu^6 + c_{{\rm ct},46}^B \frac{k^2}{k_{\rm norm}^2} \mu^6 \right) + A \leftrightarrow B \right] ,$$

and

$$P_{\varepsilon^A \varepsilon^B}(k,\mu) \quad = \quad \frac{1}{\sqrt{\bar{n}_A \bar{n}_B}} \left[c_{{\rm st},00}^{AB} + c_{{\rm st},20}^{AB} \frac{k^2}{k_{\rm norm}^2} + c_{{\rm st},22}^{AB} \frac{k^2}{k_{\rm norm}^2} f \mu^2 \right] .$$

$$\Big\{ b_1^A,\, b_2^A,\, b_{\mathcal{G}_2}^A,\, b_{\Gamma_3}^A,\, c_{{\rm ct},20}^A,\, c_{{\rm ct},22}^A,\, c_{{\rm ct},24}^A,\, c_{{\rm ct},26}^A,\, c_{{\rm ct},44}^A,\, c_{{\rm ct},46}^A,\, c_{{\rm st},00}^{AA},\, c_{{\rm st},02}^{AA},\, c_{{\rm st},22}^{AA},$$
$$b_1^B,\, b_2^B,\, b_{\mathcal{G}_2}^B,\, b_{\Gamma_3}^B,\, c_{{\rm ct},20}^B,\, c_{{\rm ct},22}^B,\, c_{{\rm ct},24}^B,\, c_{{\rm ct},26}^B,\, c_{{\rm ct},44}^B,\, c_{{\rm ct},46}^B,\, c_{{\rm st},00}^{BB},\, c_{{\rm st},02}^{BB},\, c_{{\rm st},22}^{BB},$$
$$c_{{\rm st},00}^{AB},\, c_{{\rm st},02}^{AB},\, c_{{\rm st},22}^{AB} \Big\} - 29\,\text{parameters}$$

Galaxy Catalogue

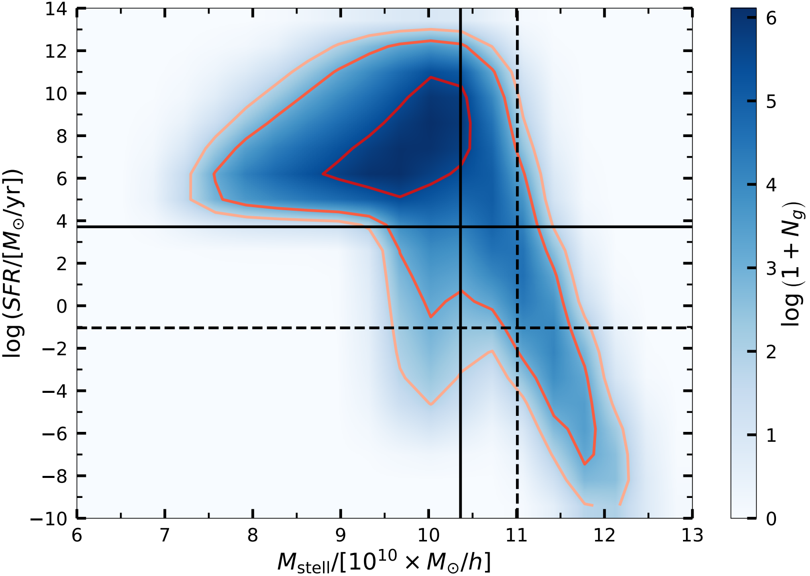
The galaxy catalogues were generated from BACCO using the SHAMe method (S. Contreras, *et al.*, 2020).

Galaxy set	SFR $[M_\odot/\mathrm{yr}]$	$\bar{n}\,[(\mathrm{Mpc}/h)^{-3}]$
A	$\gtrsim 10^{-4}$	0.0015
B	$\lesssim 10^{-4}$	0.0015
$A+B$		0.0030
Galaxy set	SFR $[M_\odot/\mathrm{yr}]$	$\bar{n}\,[(\mathrm{Mpc}/h)^{-3}]$
A	$\gtrsim 10^{-1}$	0.00015
B	$\lesssim 10^{-1}$	0.00015
$A+B$		0.00030

We assumed a Gaussian covariance (thanks to Enea di dio)

$$\mathrm{Cov}\left[P_\ell^{AB}(\boldsymbol{k}), P_{\ell'}^{CD}(\boldsymbol{k}')\right] = \frac{(2\ell+1)(2\ell'+1)}{2V_s}\frac{\delta_D(k-k')}{k^2} \sum_{\ell_1\ell_2\ell_3}(-1)^{\ell_2}(2\ell_3+1)\begin{pmatrix}\ell_1 & \ell_2 & \ell_3\\ 0 & 0 & 0\end{pmatrix}^2\begin{pmatrix}\ell & \ell' & \ell_3\\ 0 & 0 & 0\end{pmatrix}^2 \left[P_{\ell_1}^{AC}(k)\,P_{\ell_2}^{BD}(k) + (-1)^{\ell'}P_{\ell_1}^{AD}(k)\,P_{\ell_2}^{BC}(k)\right].$$

Galaxy Catalogue



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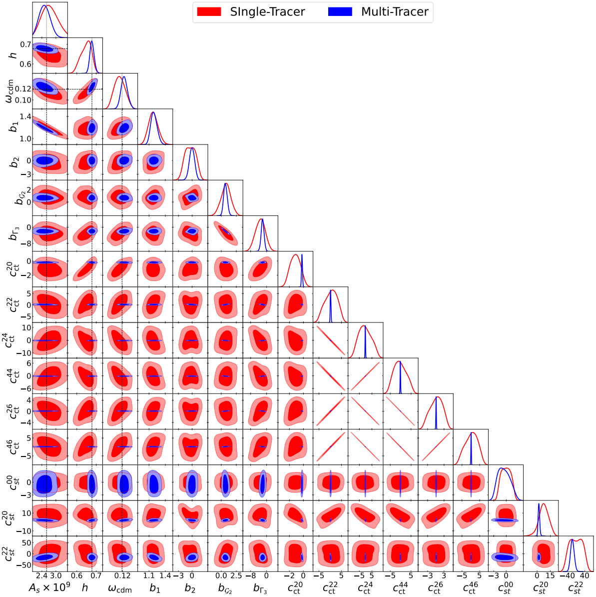
Comparison in Redshift Space



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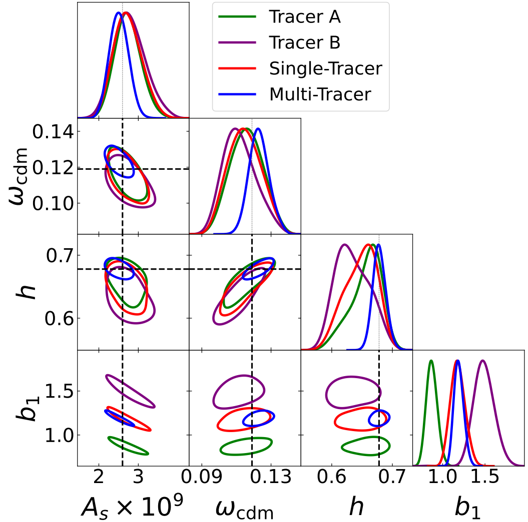
Comparison in Redshift Space



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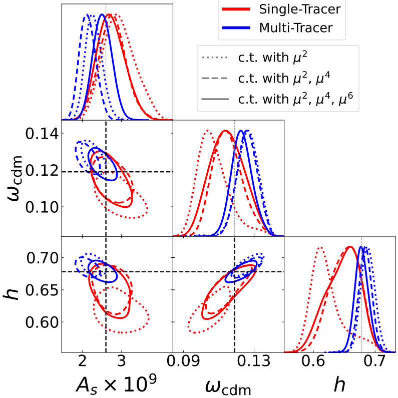
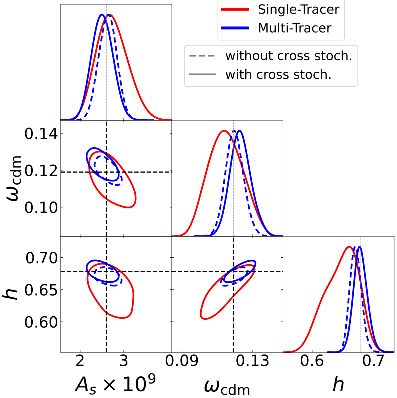
Model Complexity

Higher order μ-terms are important for multi-tracer but the cross stochastic terms are not.





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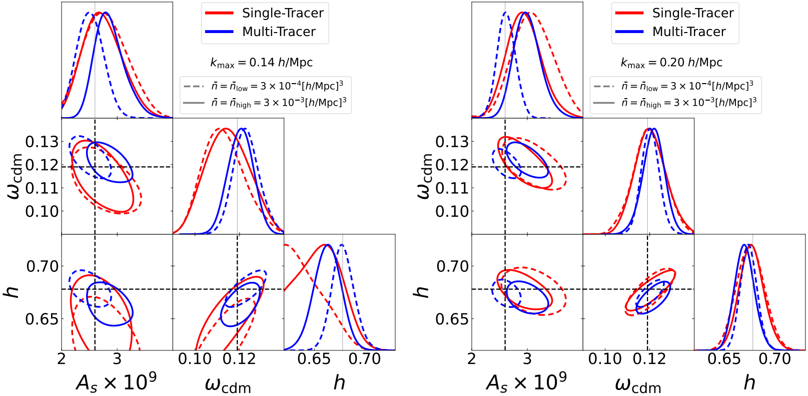
Shot Noise Impact

We can not go to deeply on non-linear scales if the shot noise is to small.



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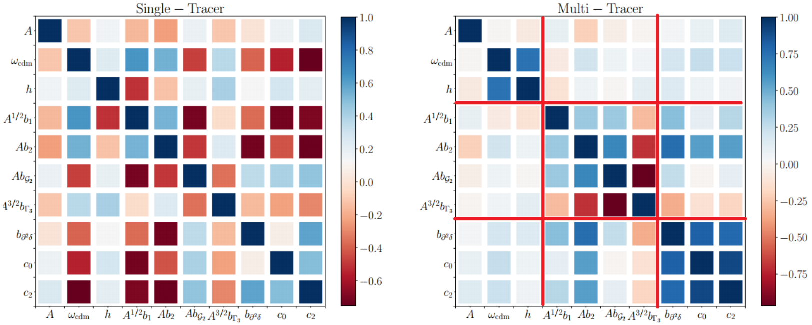
Conclusion

Multi-tracer block diagonalize the correlation matrix of parameters!



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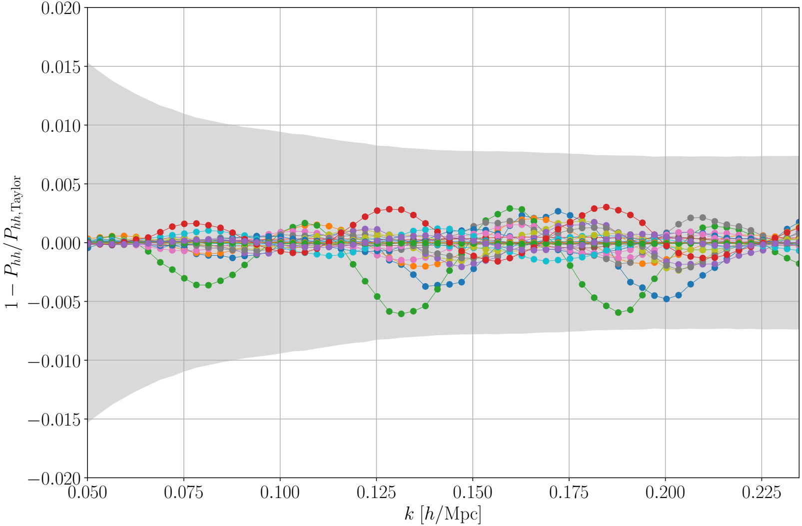
Taylor



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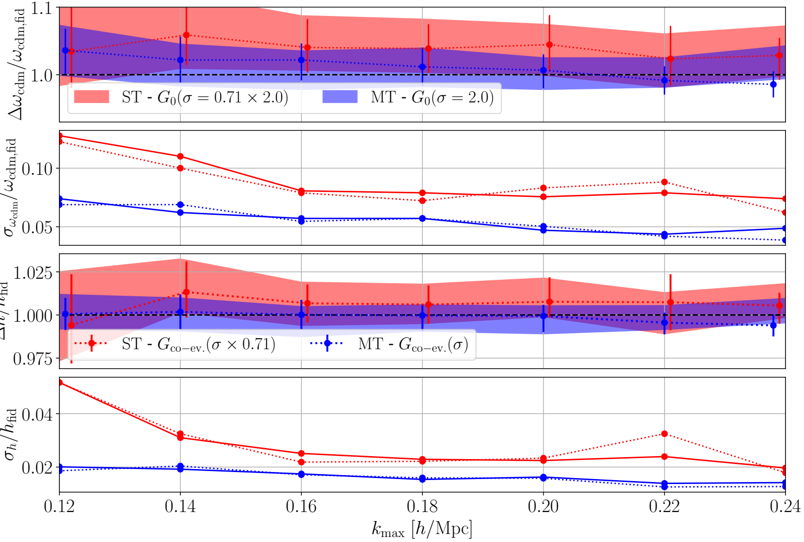
Co-evolution Relations



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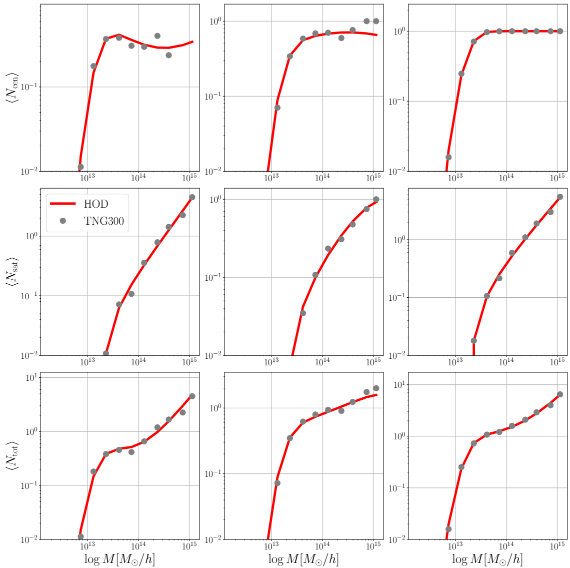
HOD



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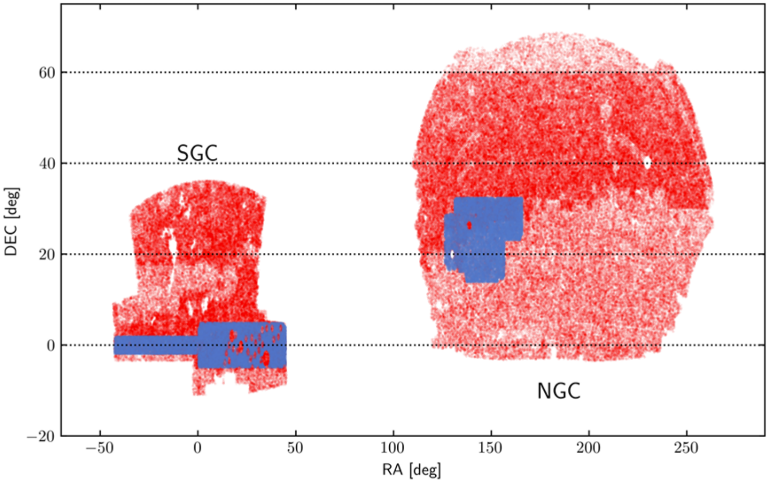
eBOSS Footprint



Ruiyang Zhao, *et al.*, 2023.