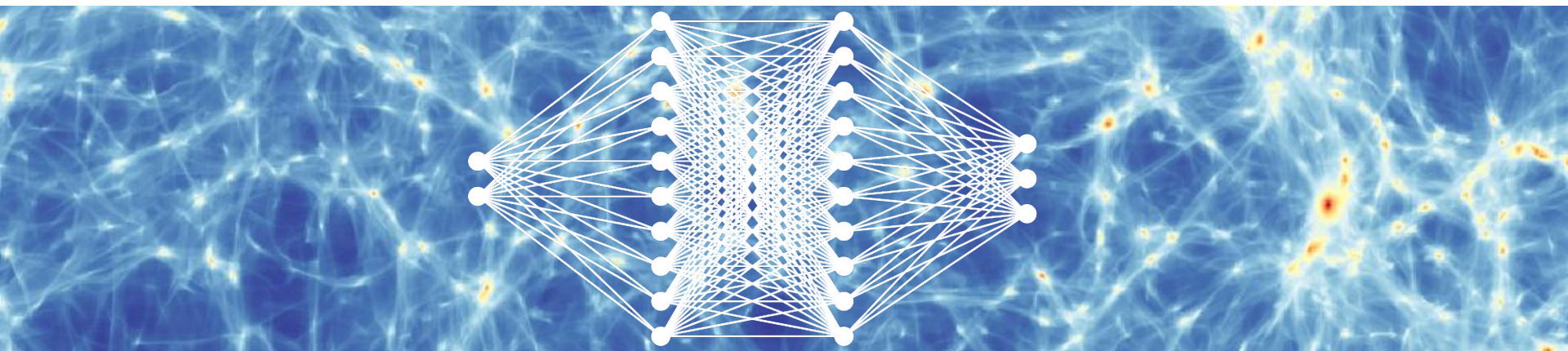


Describing galaxy clustering to small scales for upcoming galaxy surveys





The BACCO flavour of the hybrid Lagrangian bias expansion

This talk: real space and emulation

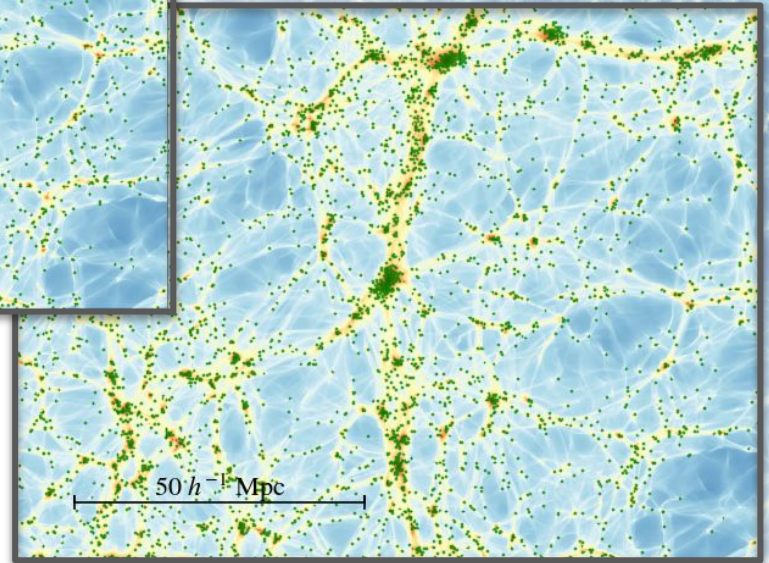
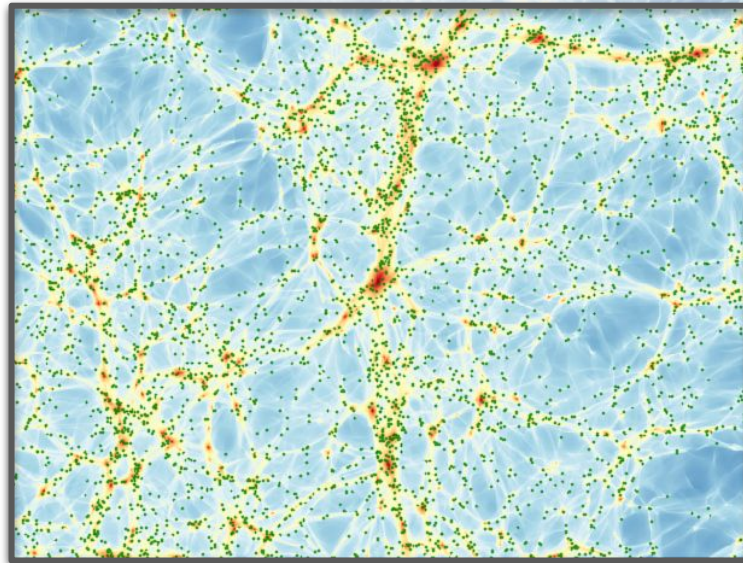
Francisco Maion: Intrinsic Alignments

Marcos Pellejero: extensions to redshift space and Gaussian bias

Galaxy clustering(s)

Change galaxy
formation / selection:

very different galaxy
samples



Lagrangian Bias Expansion Model

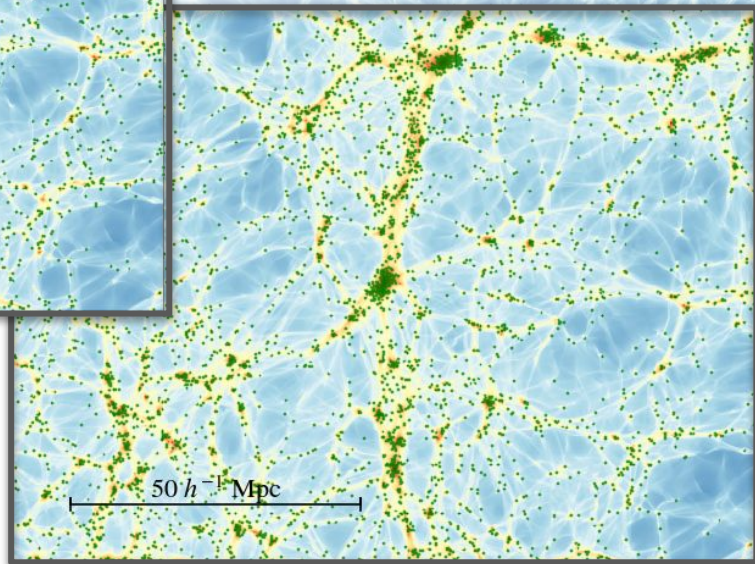
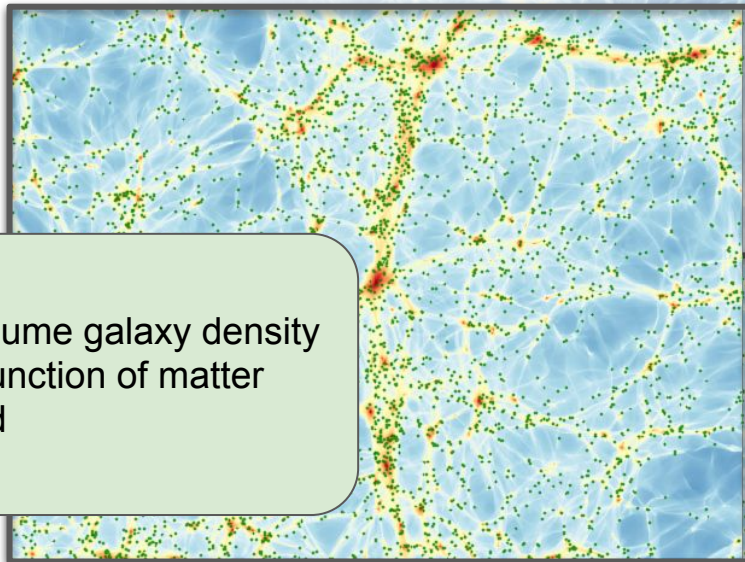
Change galaxy formation / selection:

very different galaxy samples

Assume galaxy density is function of matter field

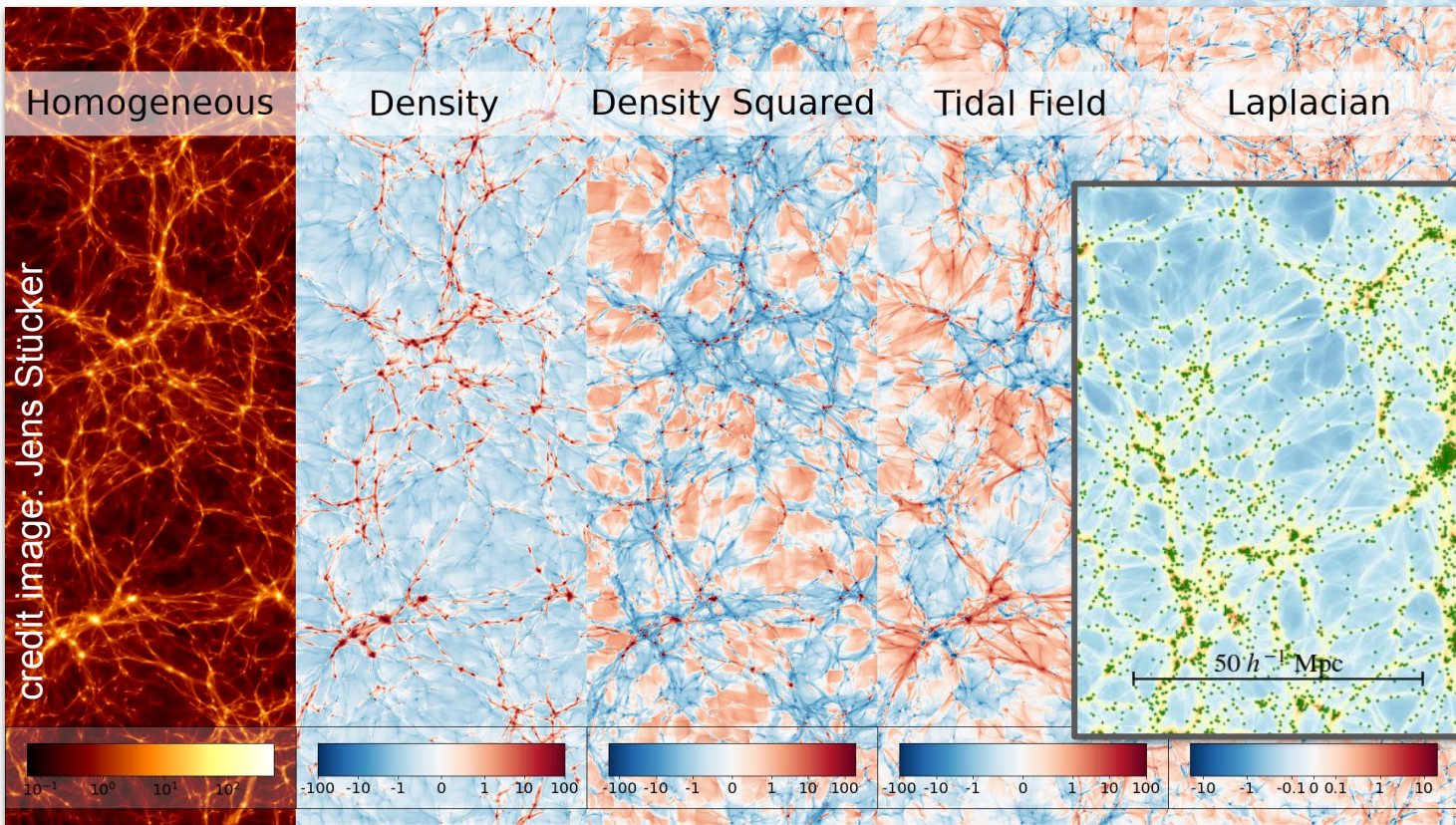
At 2nd order the ONLY terms that don't break symmetries are

$$\delta_g(\mathbf{q}) = F(\delta, \delta^2, s^2, \nabla^2 \delta)$$



Lagrangian Bias Expansion Model

$$1 + b_1^L \delta(\mathbf{q}) + b_2^L \delta^2(\mathbf{q}) + b_{s^2}^L s^2(\mathbf{q}) + b_{\nabla^2 \delta}^L \nabla^2 \delta(\mathbf{q})$$



The BACCO hybrid lagrangian bias model

$$\delta_g(\mathbf{x}) = \int d^3 \mathbf{q} [1 + b_1^L \delta(\mathbf{q}) + b_2^L \delta^2(\mathbf{q}) + b_{s^2}^L s^2(\mathbf{q}) + b_{\nabla^2 \delta}^L \nabla^2 \delta(\mathbf{q})] \delta_D(\mathbf{x} - \mathbf{q} - \Psi)$$

$$P_{gg}(k) = \sum_{i,j} b_i b_j P_{ij}(k) + \frac{A_{sn}}{\bar{n}}$$

5 free parameters $b_1^L, b_2^L, b_{s^2}^L, b_{\nabla^2 \delta}^L, A_{sn}$

The BACCO hybrid lagrangian bias model

$$\delta_g(\mathbf{x}) = \int d^3 \mathbf{q} [1 + b_1^L \delta(\mathbf{q}) + b_2^L \delta^2(\mathbf{q}) + b_{s^2}^L s^2(\mathbf{q}) + b_{\nabla^2 \delta}^L \nabla^2 \delta(\mathbf{q})] \delta_D(\mathbf{x} - \mathbf{q} - \Psi)$$

$$P_{gg}(k) = \sum_{i,j} b_i b_j P_{ij}(k) + \frac{A_{sn}}{\bar{n}}$$

5 free parameters $b_1^L, b_2^L, b_{s^2}^L, b_{\nabla^2 \delta}^L, A_{sn}$

The BACCO **hybrid** lagrangian bias model

$$\delta_g(\mathbf{x}) = \int d^3 \mathbf{q} [1 + b_1^L \delta(\mathbf{q}) + b_2^L \delta^2(\mathbf{q}) + b_{s^2}^L s^2(\mathbf{q}) + b_{\nabla^2 \delta}^L \nabla^2 \delta(\mathbf{q})] \delta_D(\mathbf{x} - \mathbf{q} - \Psi)$$

from simulations - fully nonlinear

$$P_{gg}(k) = \sum_{i,j} b_i b_j P_{ij}(k) + \frac{A_{sn}}{\bar{n}}$$

5 free parameters $b_1^L, b_2^L, b_{s^2}^L, b_{\nabla^2 \delta}^L, A_{sn}$

The workhorse: cosmology rescaling

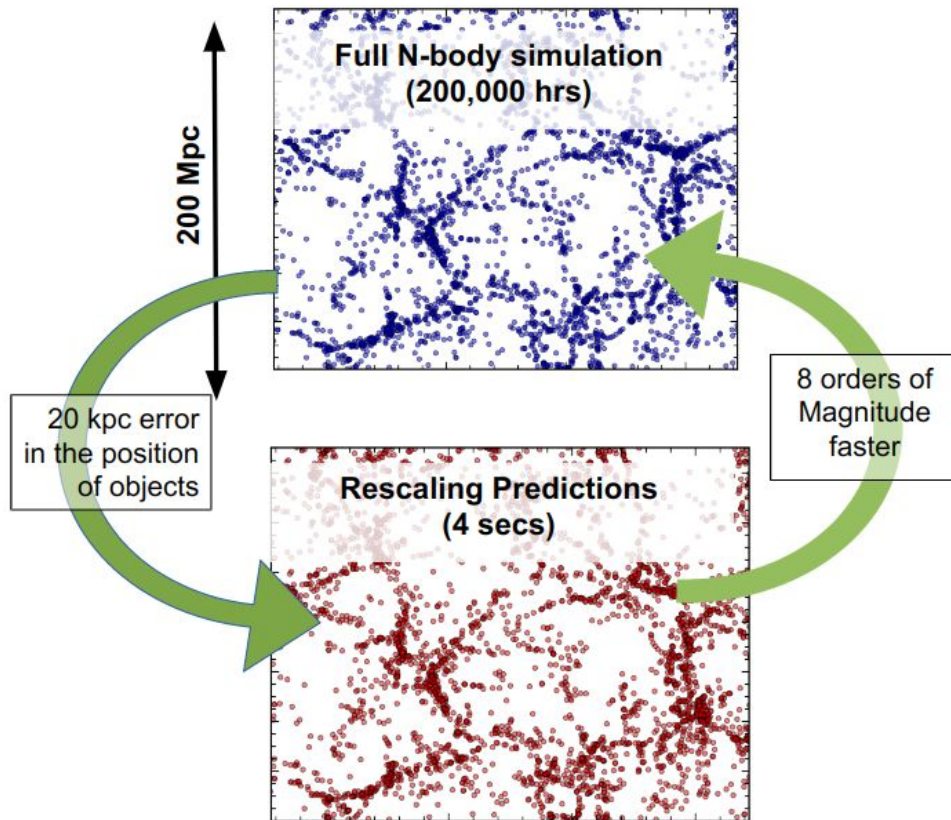
Apply time and space transformations to **change the cosmology** of a N-body simulation

Validated for:

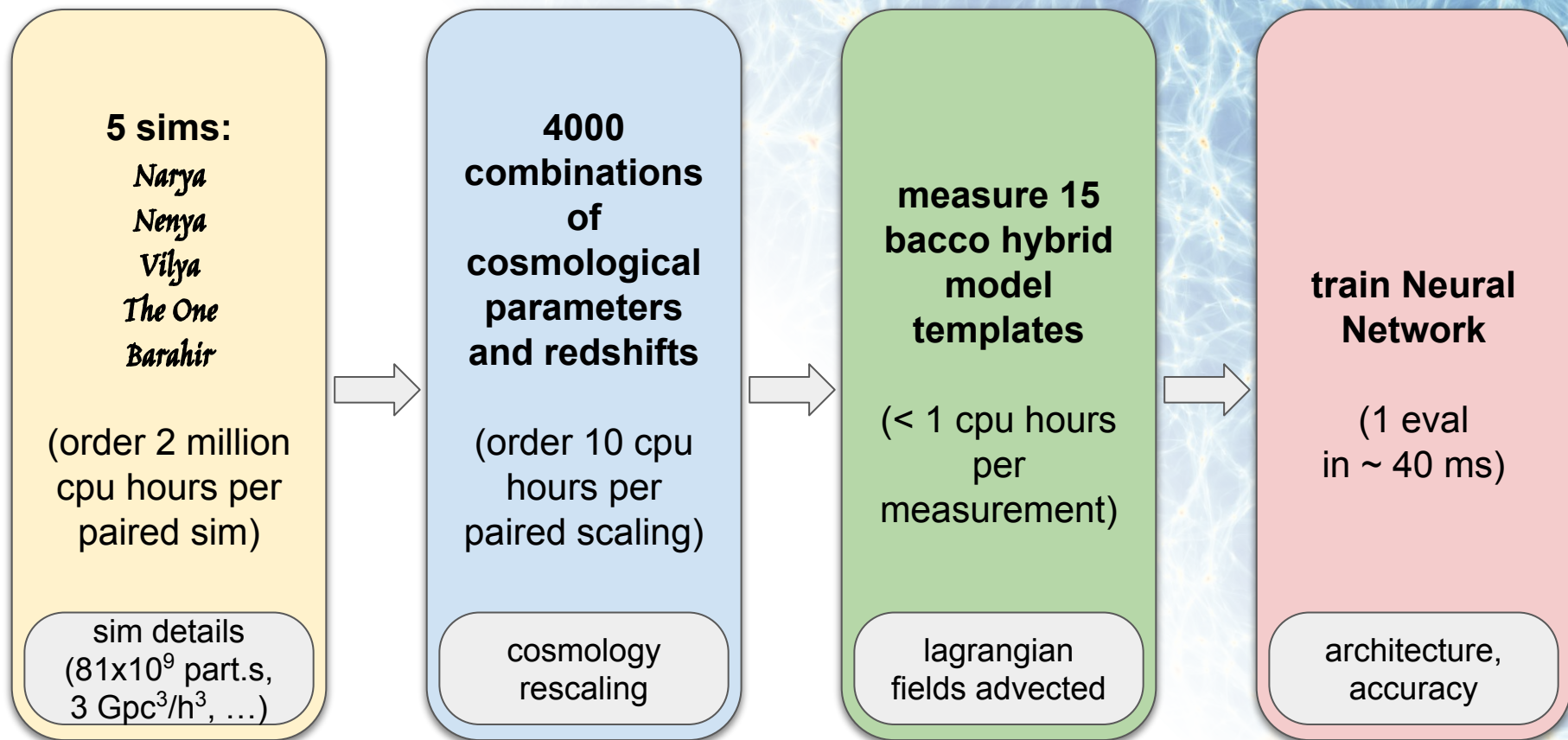
- real/redshift-space
- correlation function/power spectra
- 3-point correlation functions
- (sub)halo mass function
- abundance of voids
- different redshifts/cosmologies

Obtain **thousands** of simulations, running only a **handful**

Angulo & White (2010), MZ et al (2019), Contreras, MZ, et al (2020), Angulo, MZ, et al (2020), Ondaro-Mallea, MZ, et al (2021), López-Cano, MZ, et al (2022)



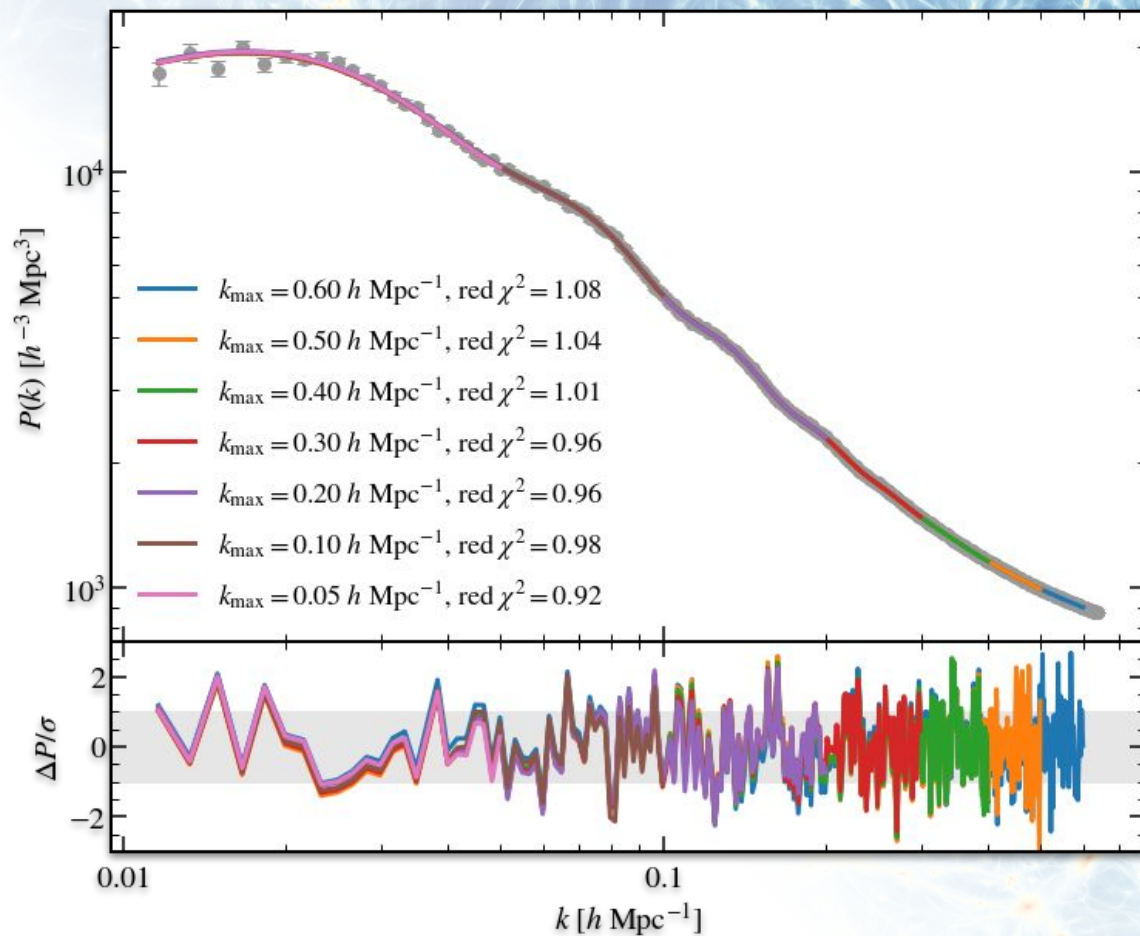
We rely on emulators



The BACCO hybrid lagrangian bias model

Euclid-like galaxies at $z \sim 1$

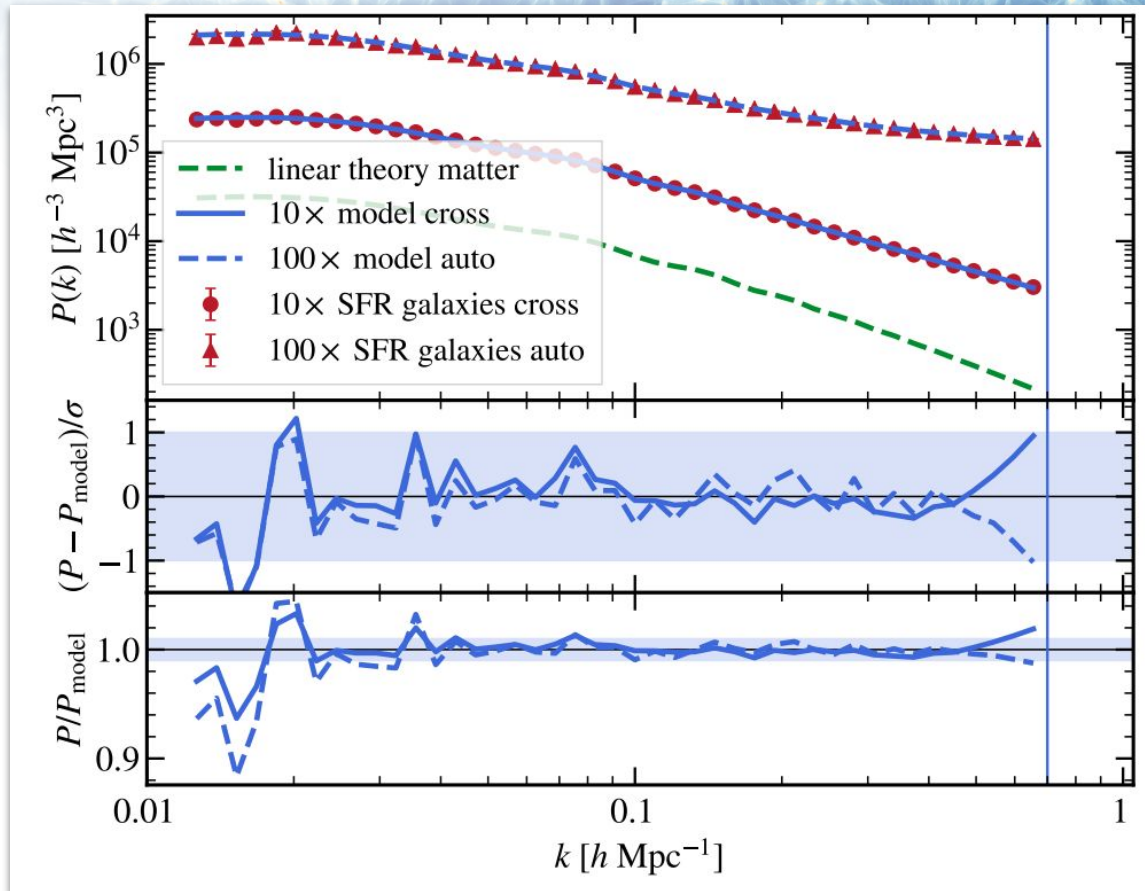
Gaussian errors
corresponding to volume of
Euclid $z \sim 1$ redshift bin



Fixed cosmology

8000 samples between haloes and SHAME galaxies with different cosmologies, redshifts, number densities, SHAME properties

Fits at fixed cosmology always accurate
(where $P / \text{Shot Noise} > 1.5$)



Fixed cosmology

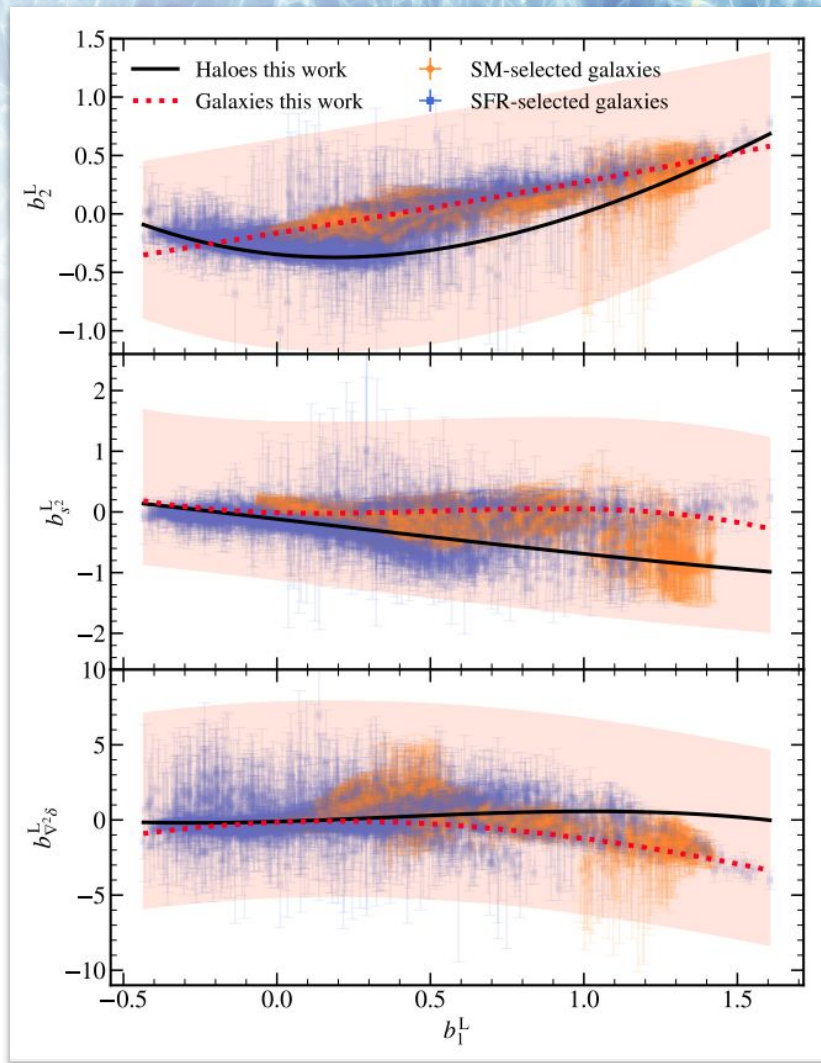
8000 samples between haloes and SHAME galaxies with different cosmologies, redshifts, number densities, SHAME properties

Fits at fixed cosmology always accurate
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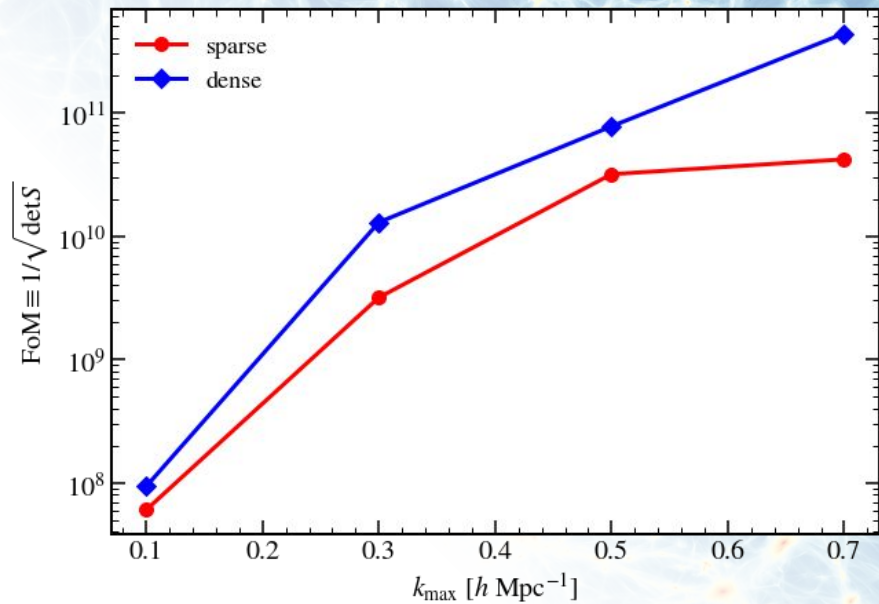
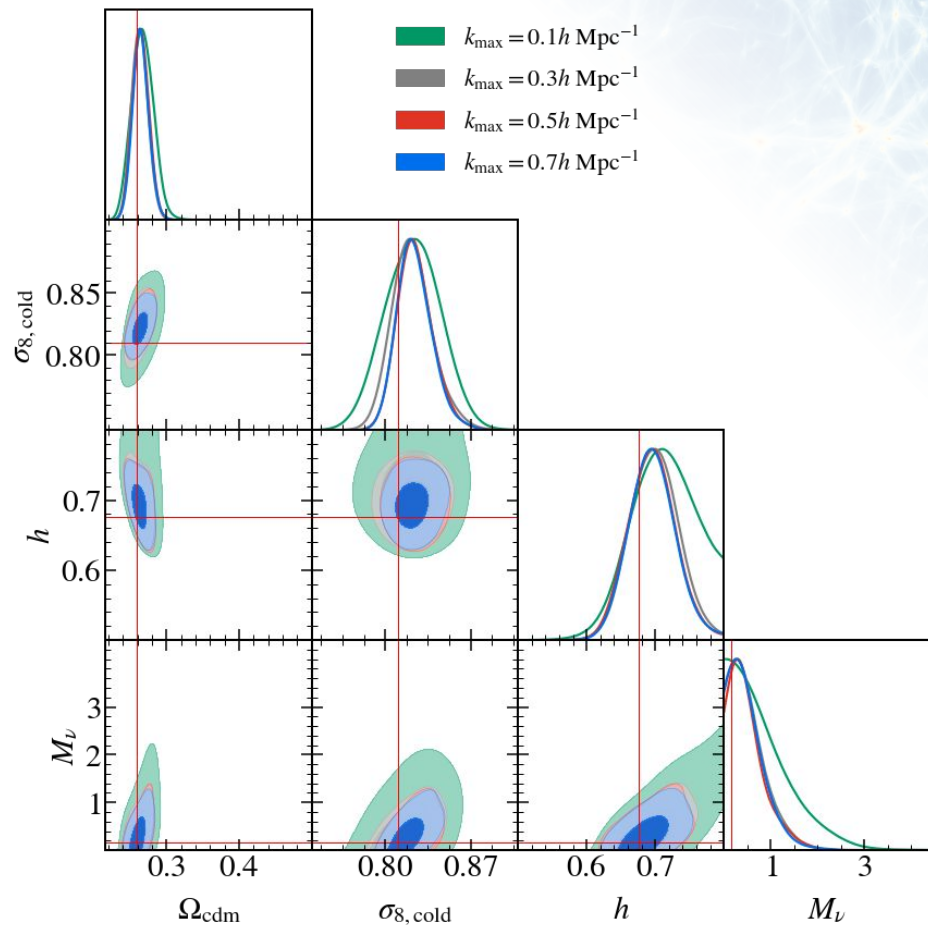
Coevolution relations for these bias parameters:

$$b_2(b_1) \quad b_{s^2}(b_1)$$

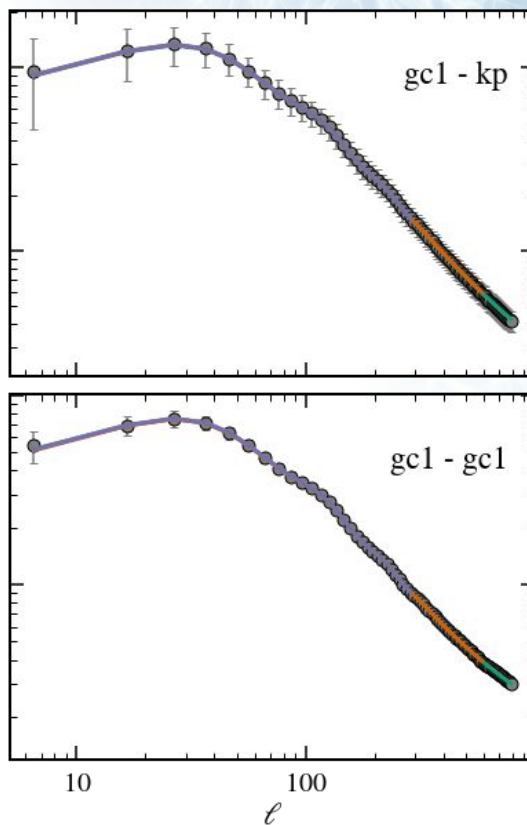
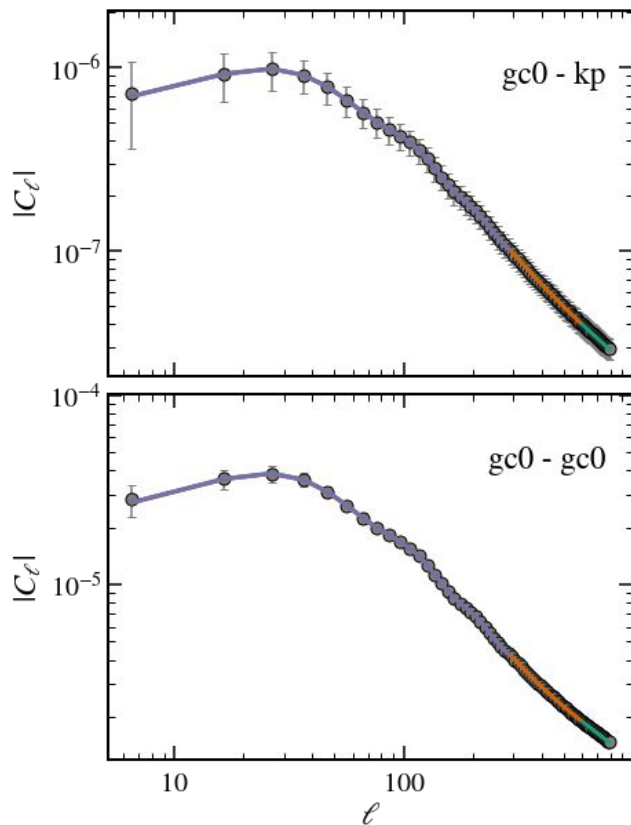
$$b_{\nabla^2 \delta}(b_1) \quad \text{!}$$



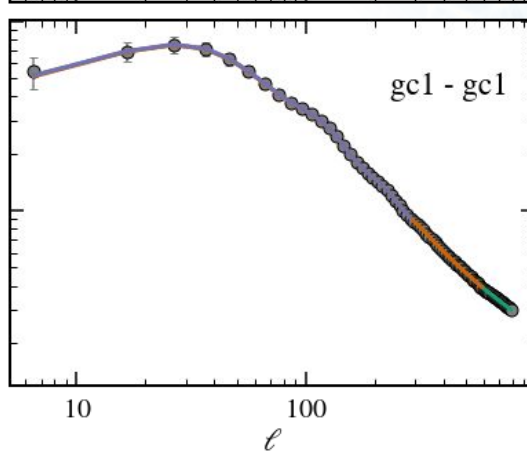
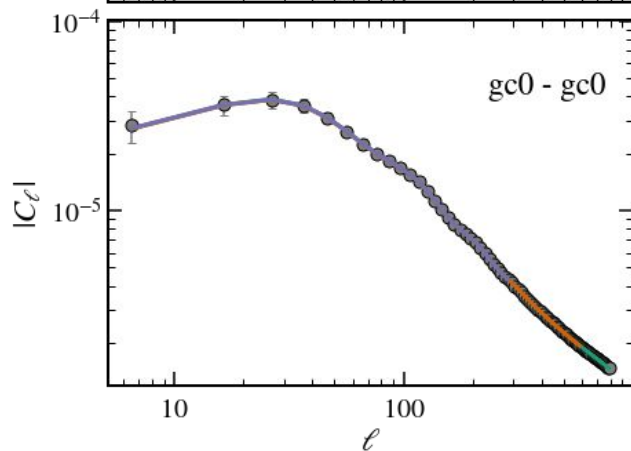
The BACCO hybrid lagrangian bias model



The BACCO hybrid lagrangian bias model



- $k_{\max} = 0.40 \text{Mpc}^{-1}, N_{\text{dof}} = 308, \chi^2 = 4.31$
- $k_{\max} = 0.30 \text{Mpc}^{-1}, N_{\text{dof}} = 228, \chi^2 = 1.95$
- $k_{\max} = 0.15 \text{Mpc}^{-1}, N_{\text{dof}} = 108, \chi^2 = 0.22$



Work in progress:

2x2point (and **3x2point** when combined with matter power spectrum + baryons emulator)

Reanalysis of current **weak lensing surveys** with nonlinear bias to small scales

baccoemu: a full suite of emulators

Nonlinear **matter** power spectrum

Baryon Correction Model (BCM)

Nonlinear templates for hybrid Lagrangian bias expansion in real space

Nonlinear templates for hybrid Lagrangian **bias** expansion in **redshift space**

Galaxy clustering from SHAMe models

Linear matter power spectrum (tot matter)

Linear matter power spectrum (cdm+b)

Linear matter power spectrum with **smear**ed **BAO** (cdm+b) in real and redshift space

Linear matter power spectrum **dewiggled** (cdm+b)

2LPT templates for hybrid Lagrangian **bias** expansion

As $\rightarrow \sigma_{8,\text{cold}}, \sigma_{8,\text{tot}}, \sigma_{12,\text{cold}}, \sigma_{12,\text{tot}}$