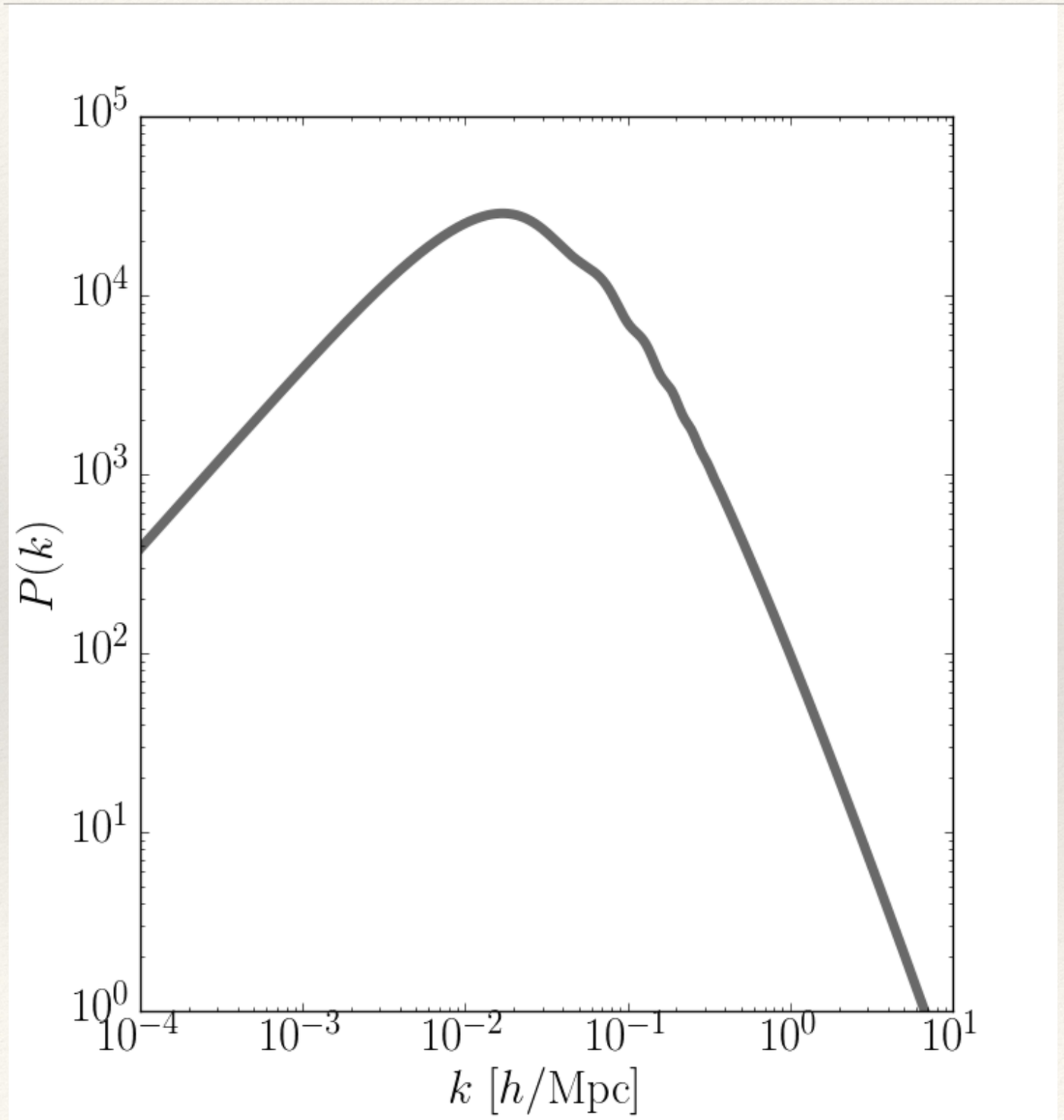
Benjamin Giblin, Postdoc, Uni. Edinburgh
with Matteo Cataneo, Ben Moews and Catherine Heymans

Non-Linear Matter Power Spectra Predictions for Arbitrary Cosmologies

CoSyne, IAP
11th Dec 2019

arXiv:1906.02742
MNRAS 490, 4

The workhorse of cosmology



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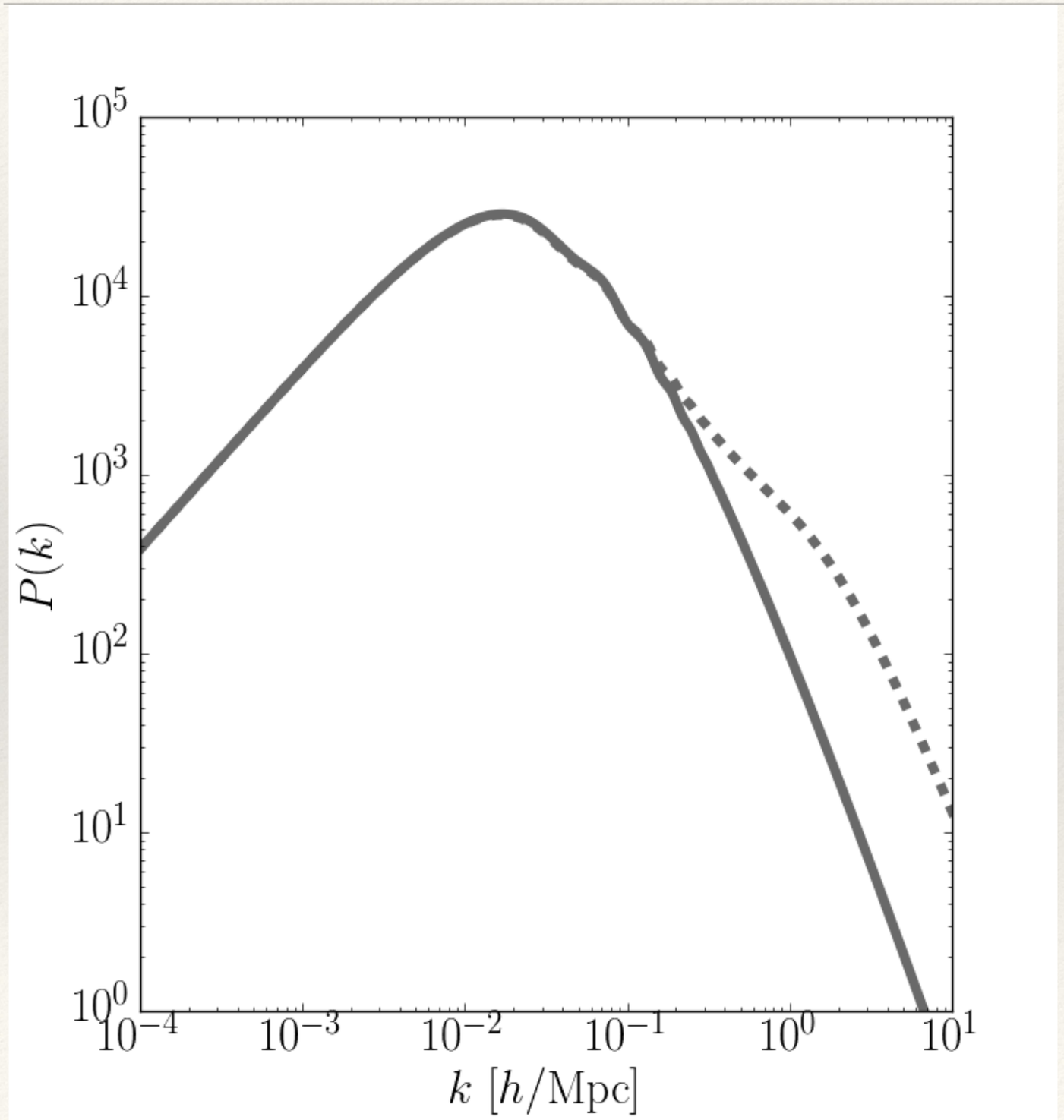
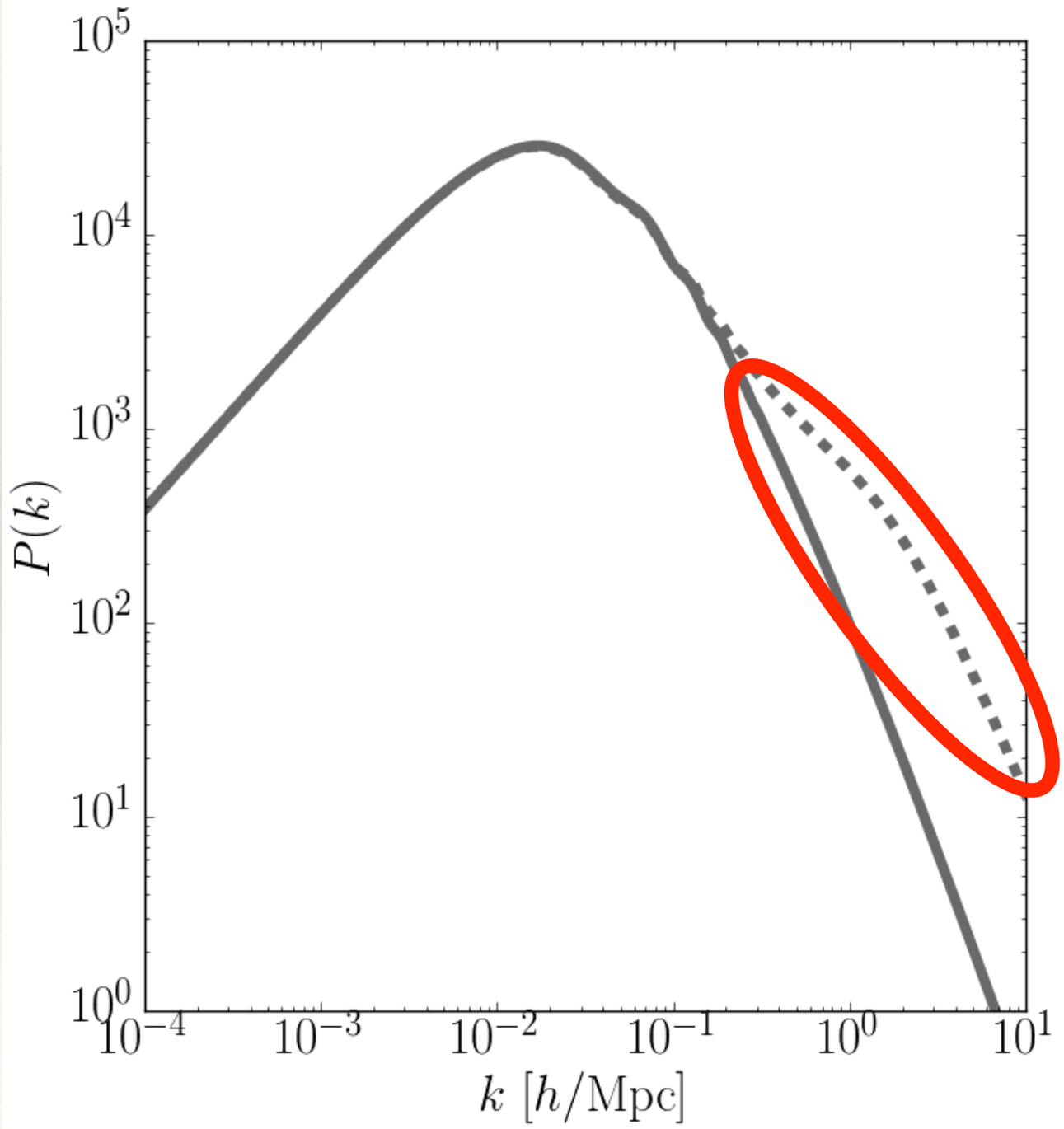


The workhorse of cosmology

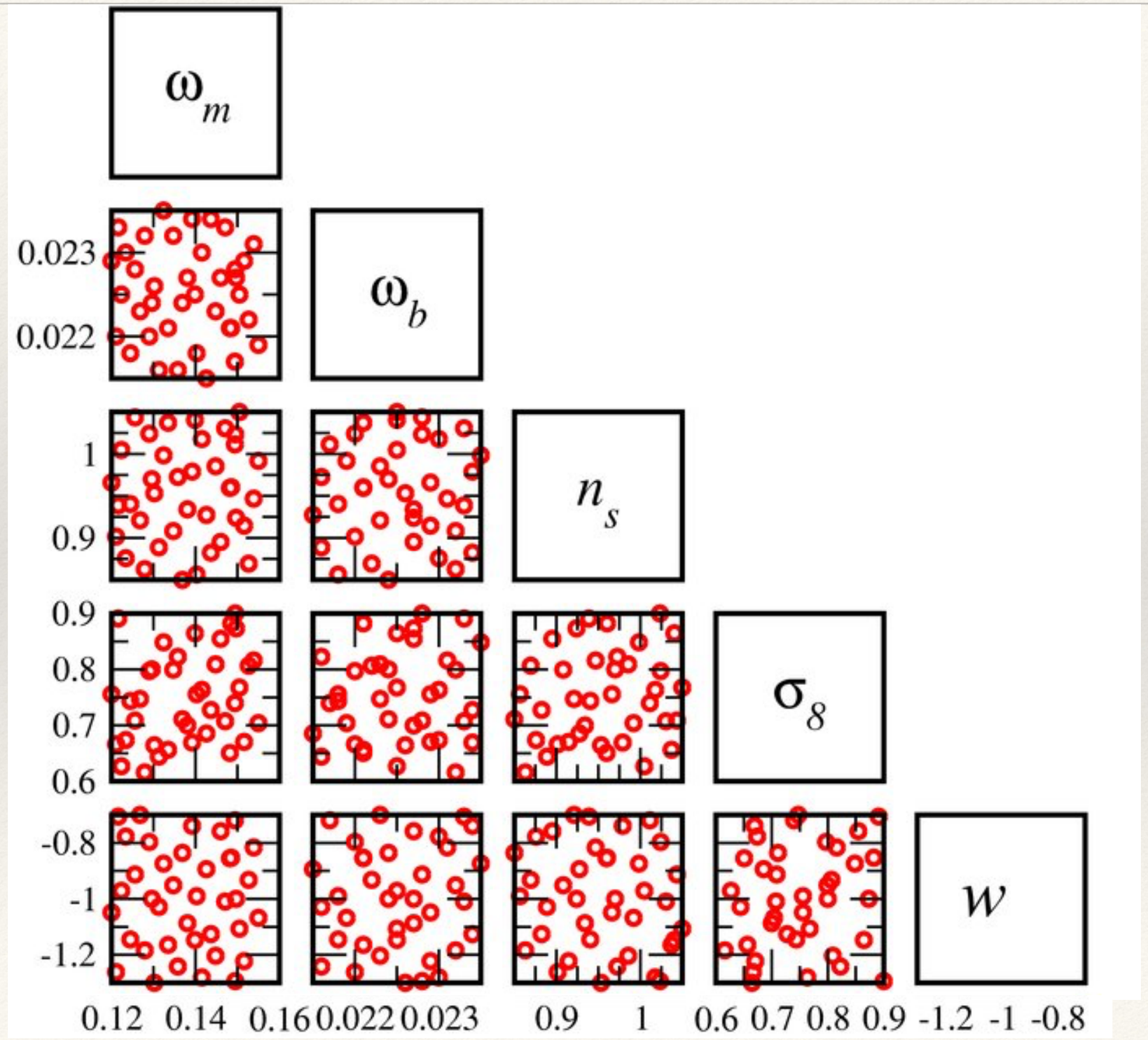


How to model the cosmology dependence of the $P_{NL}(k)$ with accuracies better than 1%?

- Simulations - too expensive!
- *Emulators*[2]

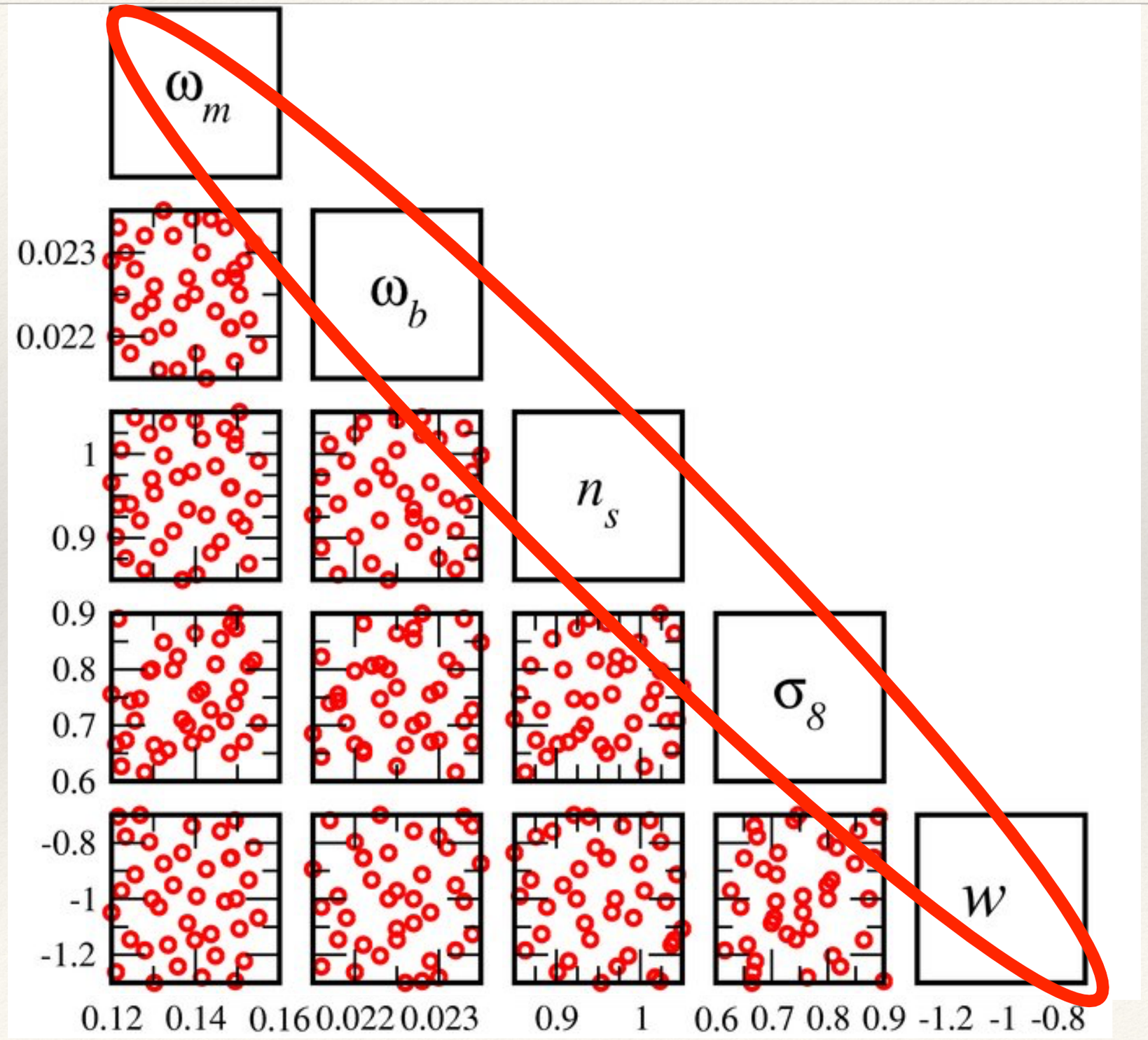
[2] e.g. Habib+07, Heitmann+09, Euclid Collaboration+18

Emulators



Heitmann+09

Emulators



Heitmann+09

NL modelling beyond ΛCDM

$$P(k,z) = P^{\rm pseudo}(k,z) \times R(k,z)$$

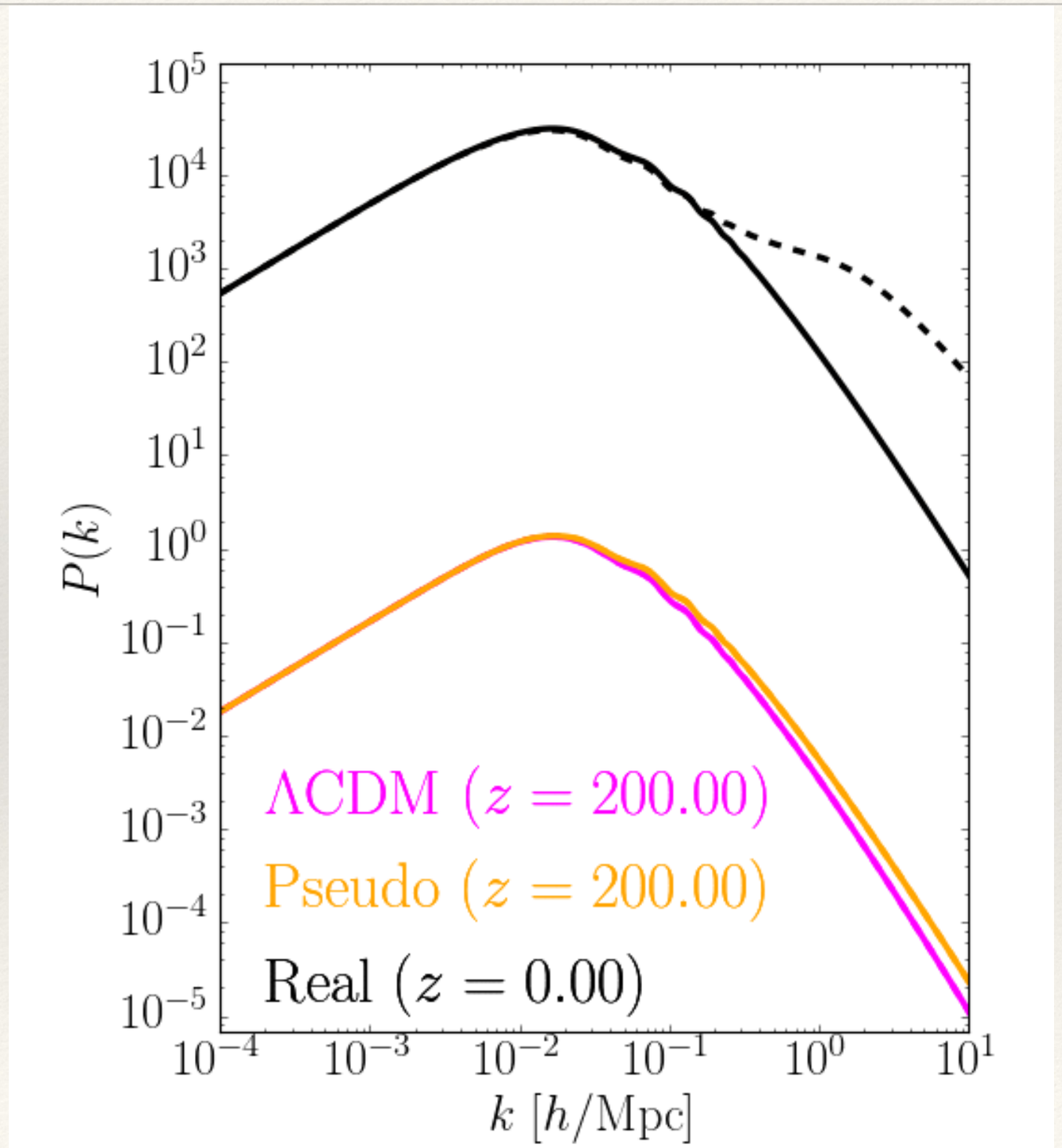
The full NL matter power spectrum in model of interest (e.g. f(R), wCDM, massive neutrinos)

Obtained by modifying the initial conditions in ***a ΛCDM simulation***

"Reaction function": From halo-model, cheap to compute

Cataneo et al. (2018)

What is the pseudo cosmology?



NL modelling beyond ΛCDM

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NL modelling beyond ΛCDM

Can we **emulate** this part in a **model-independent** way?

$$P(k,z) = P^{\rm pseudo}(k,z) \times$$

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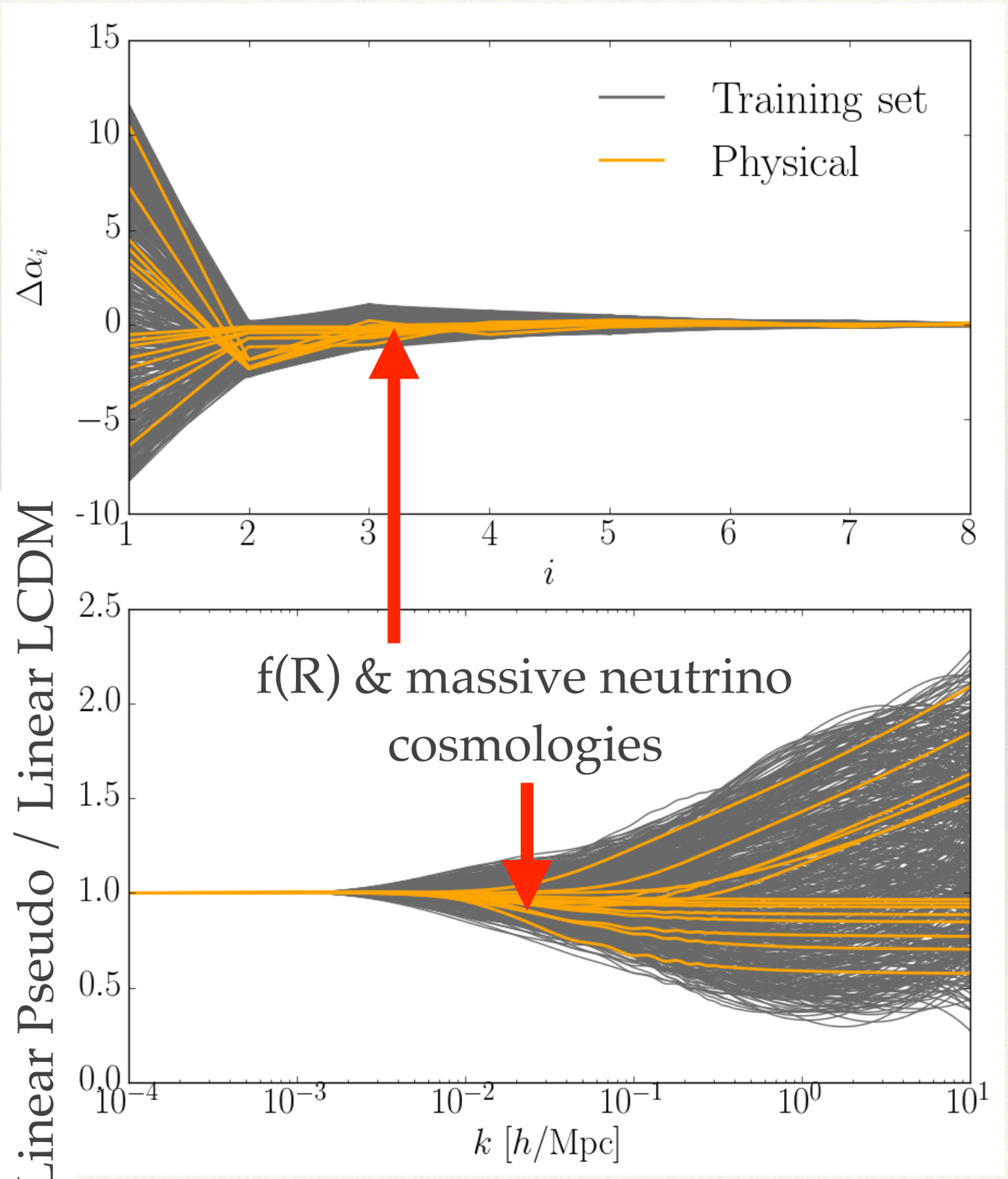
Model-independent parameterisation beyond ΛCDM

$$\boldsymbol{\pi} = \{\boldsymbol{\pi}^{\Lambda}, \Delta\boldsymbol{\alpha}\}$$

"Baseline" LCDM parameters
$\{\omega_{\rm m}, \omega_{\rm b}, h, n_s, A_s\}$

Parameters describing departures from the baseline ΛCDM

Constructing training & trial sets



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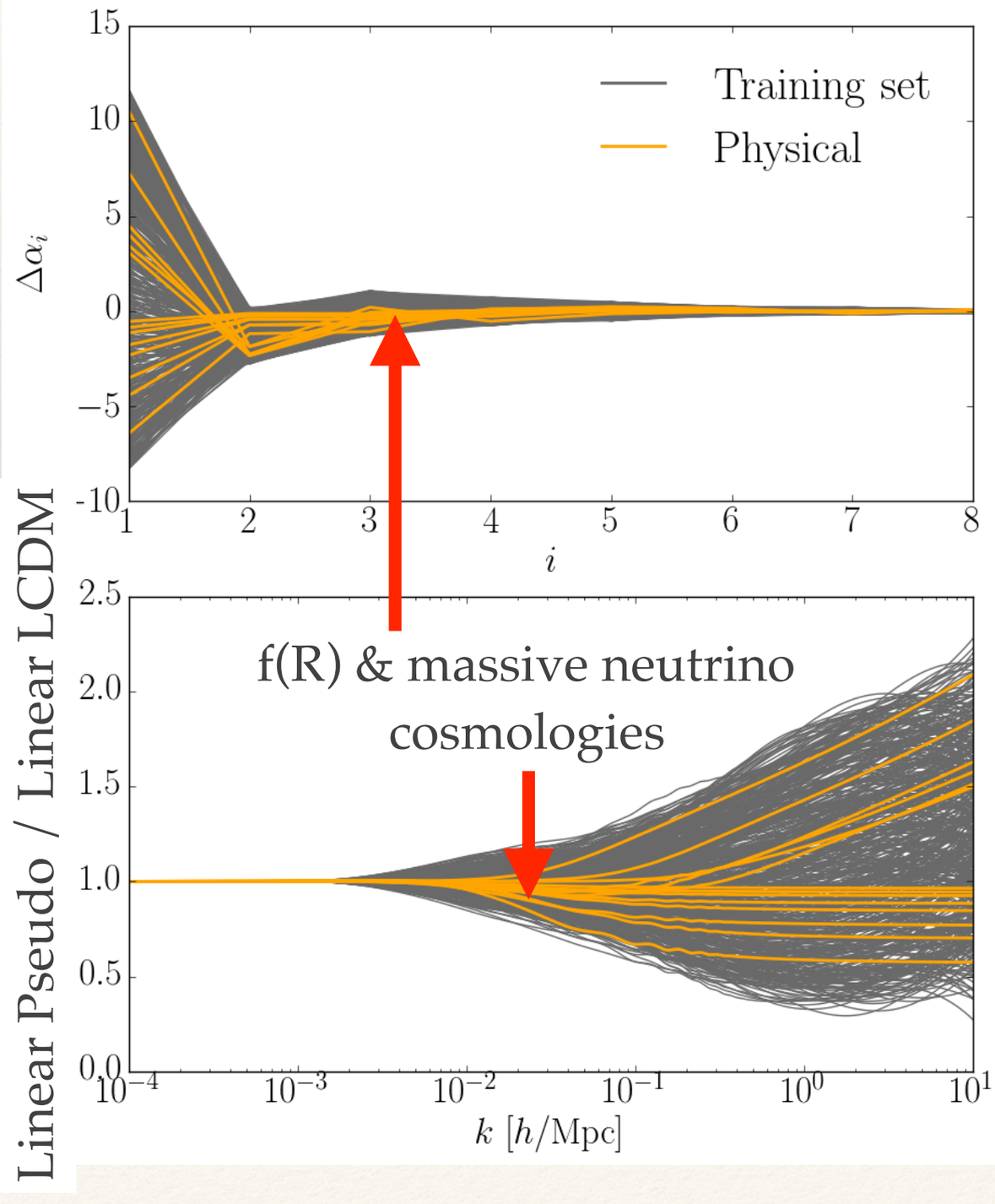
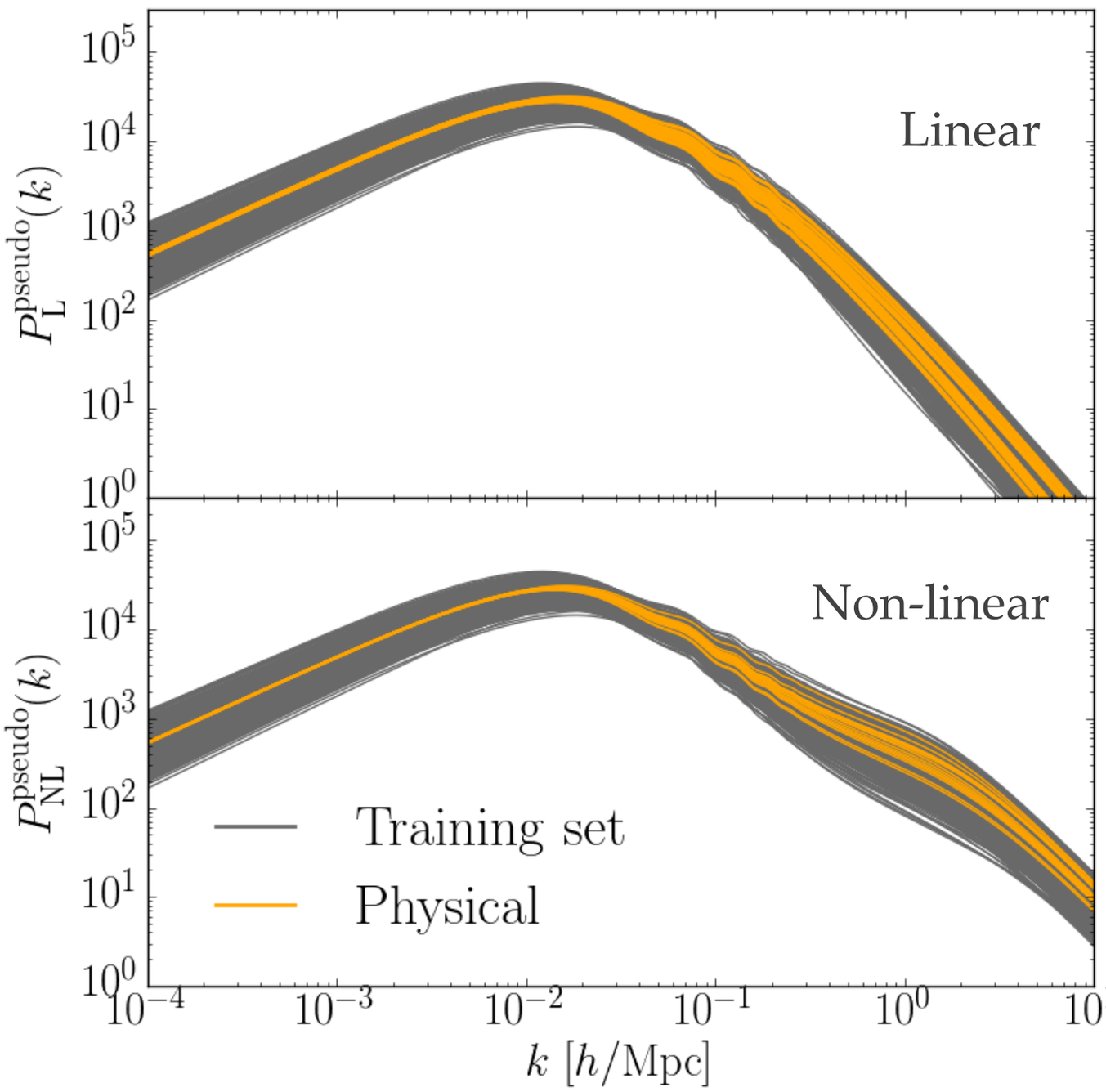
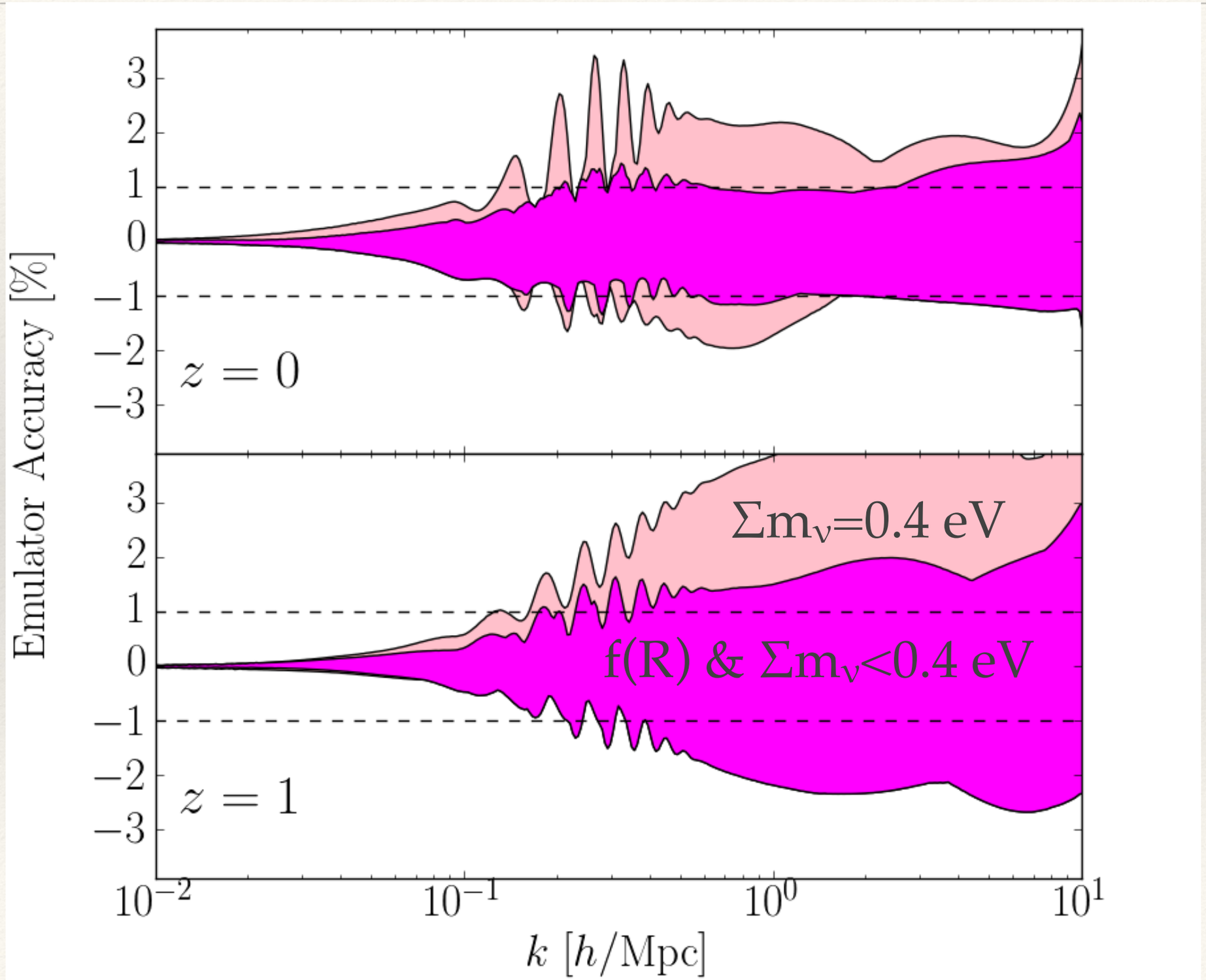
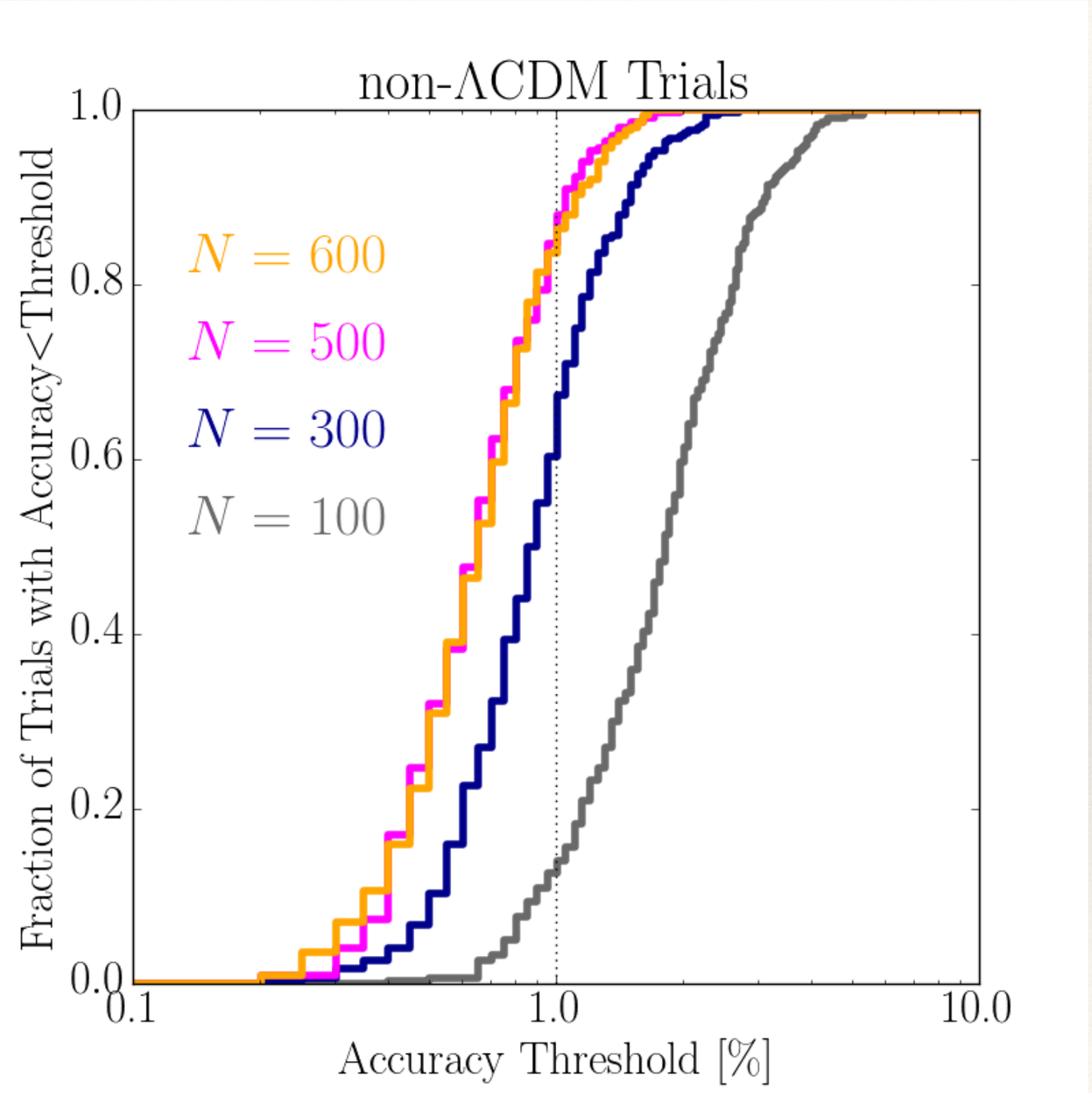




Results for f(R) gravity and massive neutrinos



Results for arbitrary cosmologies



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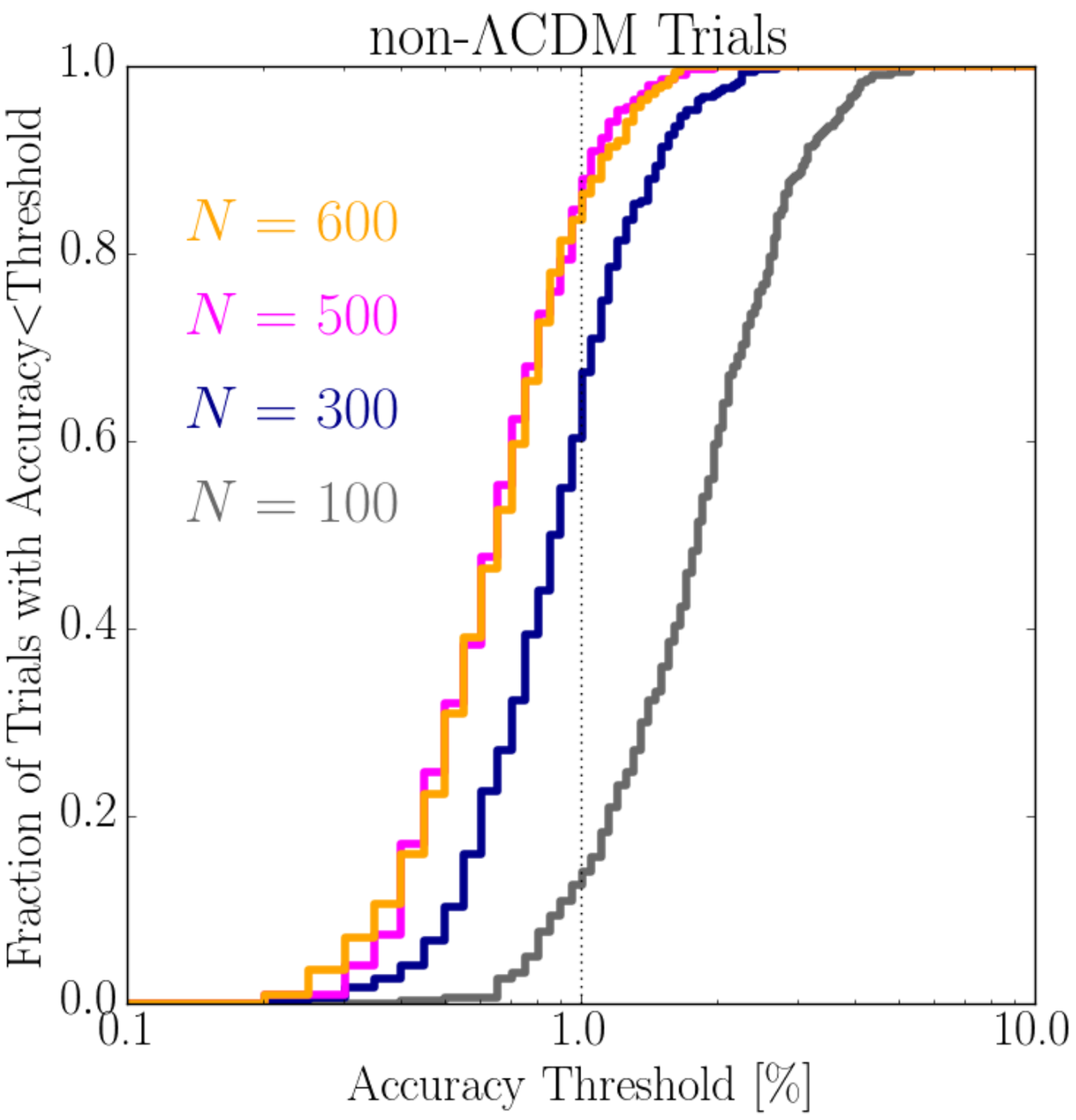

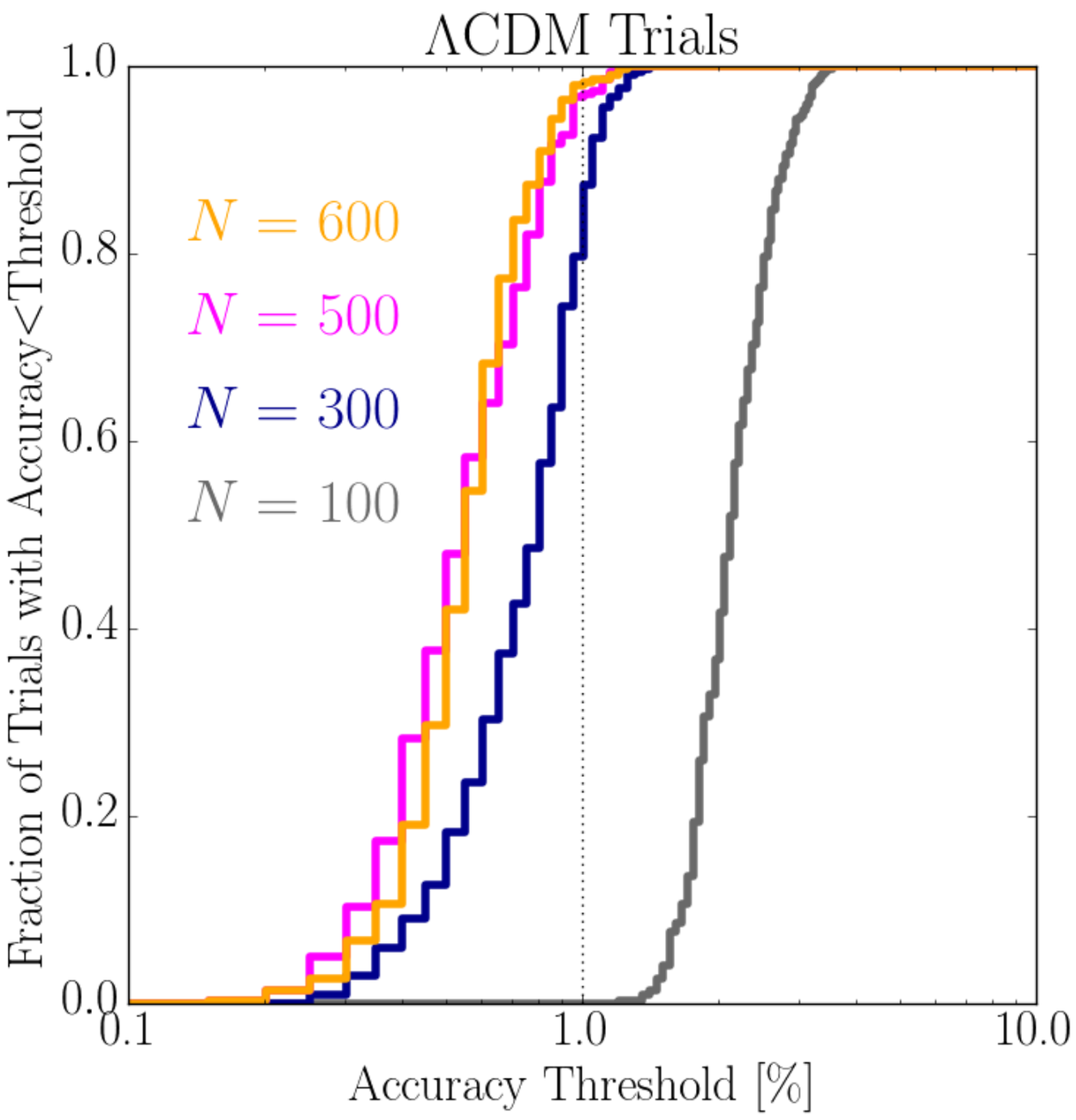

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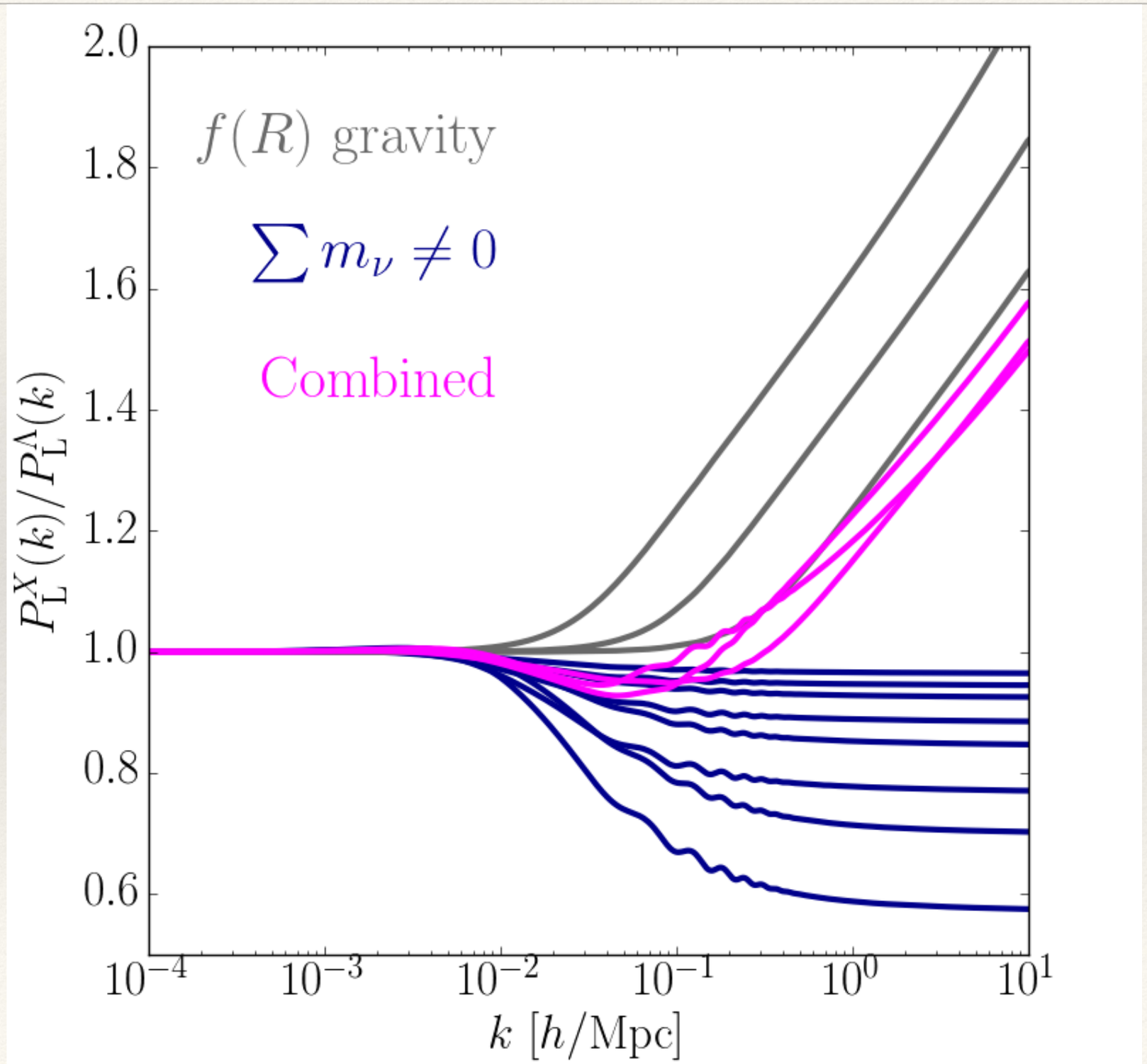
Summary

- This emulator combined with the reaction function (Cataneo+18) facilitates per cent level predictions of the non-linear matter power spectra for *arbitrary cosmologies*.
- We need 500(x2 - Angulo & Pontzen, 2016) **ΛCDM** N-body simulations for training.
- Potentially could be reduced with further optimisation of the training set (e.g. Rogers+19, Caron+19) or different emulation method (e.g. Euclid Collaboration+18).
- Could potentially be used to model baryonic physics with minimal modification.

The many flavours beyond ΛCDM



What is the reaction function?

$$R(k,z) = \frac{P^{\rm real}(k,z)}{P^{\rm pseudo}(k,z)}$$

By definition, unity on linear scales…

Using the halo model:

$$R(k,z) = \frac{P^{\rm real}_{2h}(k,z) + P^{\rm real}_{1h}(k,z)}{P^{\rm pseudo}_{2h}(k,z) + P^{\rm pseudo}_{1h}(k,z)}$$

… on non-linear scales, equal to ratio of 1-halo terms…

…the ratio damps inaccuracies in the halo model at the transition between 2 terms…

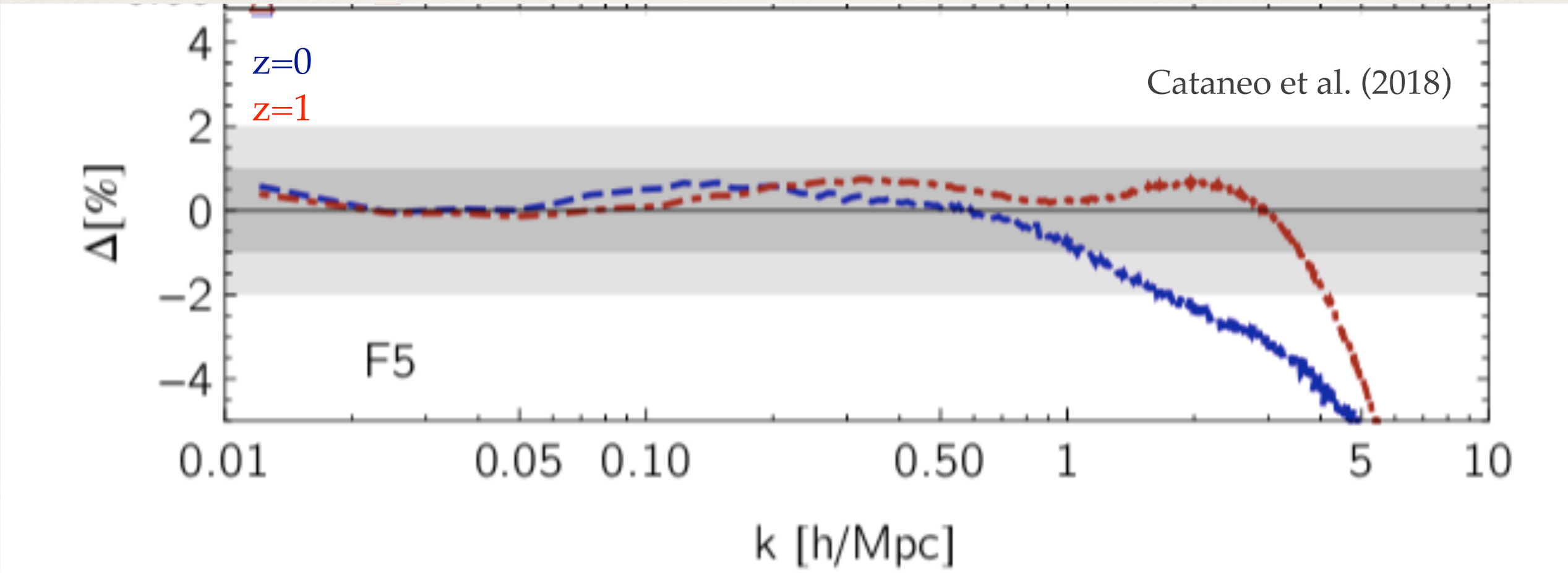
Parameters from SPT

$$R(k,z) = \frac{\left[(1-\epsilon)e^{-k/k_*} + \epsilon\right] P^{\rm real}_{\rm L}(k,z) + P^{\rm real}_{1h}(k,z)}{P^{\rm pseudo}_{\rm L}(k,z) + P^{\rm pseudo}_{1h}(k,z)}$$

All details in Cataneo+18; arXiv:1812.05594

What is the reaction function?

f(R) Gravity



Model-independent parameterisation beyond ΛCDM

$$\boldsymbol{\pi} = \{\boldsymbol{\pi}^{\Lambda}, \Delta\boldsymbol{\alpha}\}$$

"Baseline" LCDM parameters

$\{\omega_{\rm m}, \omega_{\rm b}, h, n_s, A_s\}$

Parameters describing **departures** from the baseline ΛCDM

$$S(k,z) = 1 + \sum_{i=1}^{n_\Phi} \Phi_i(k,z)\Delta\alpha_i$$

"Shape" - ratio of non-ΛCDM and ΛCDM linear P(k,z)

Model-independent parameterisation beyond ΛCDM

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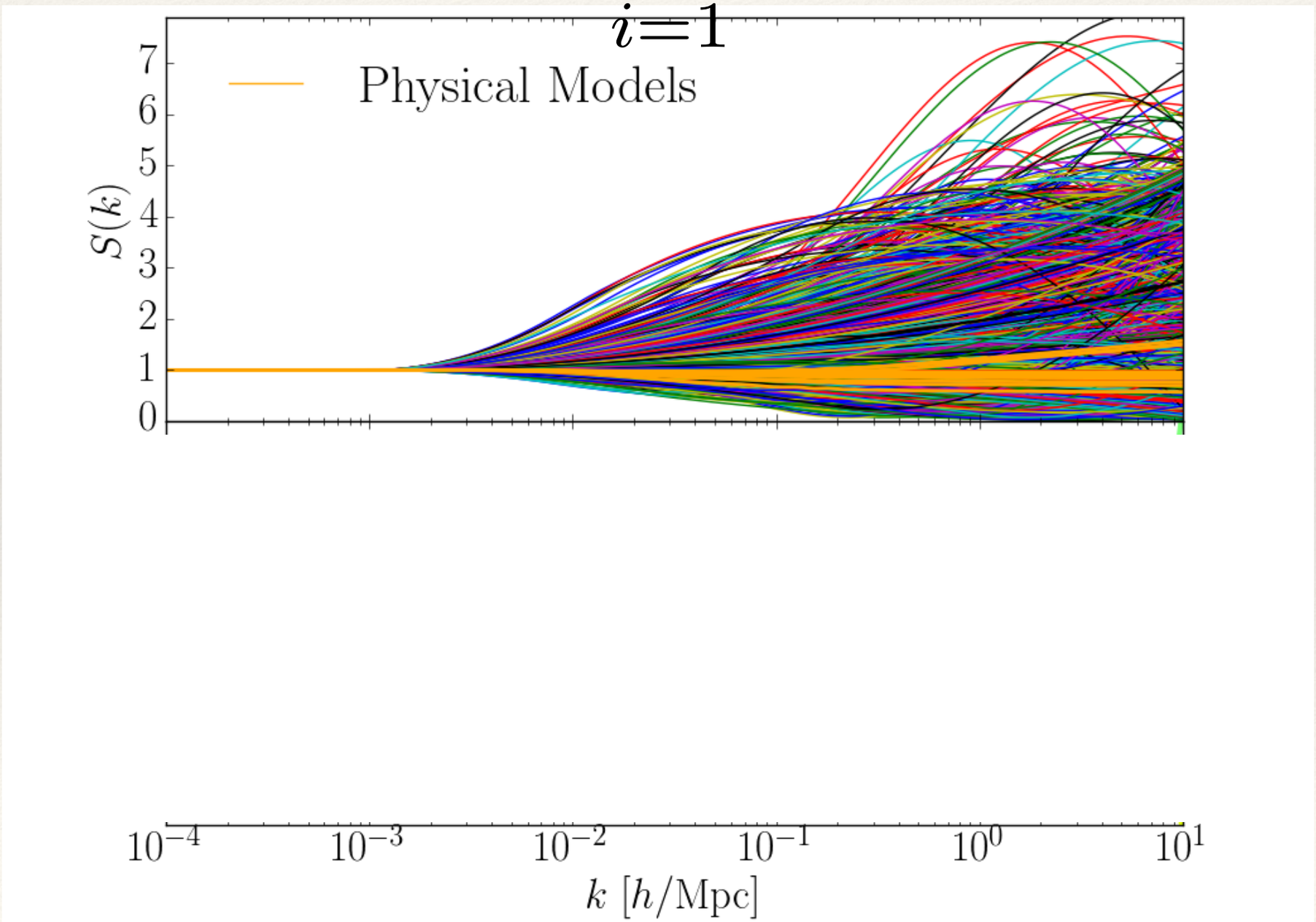

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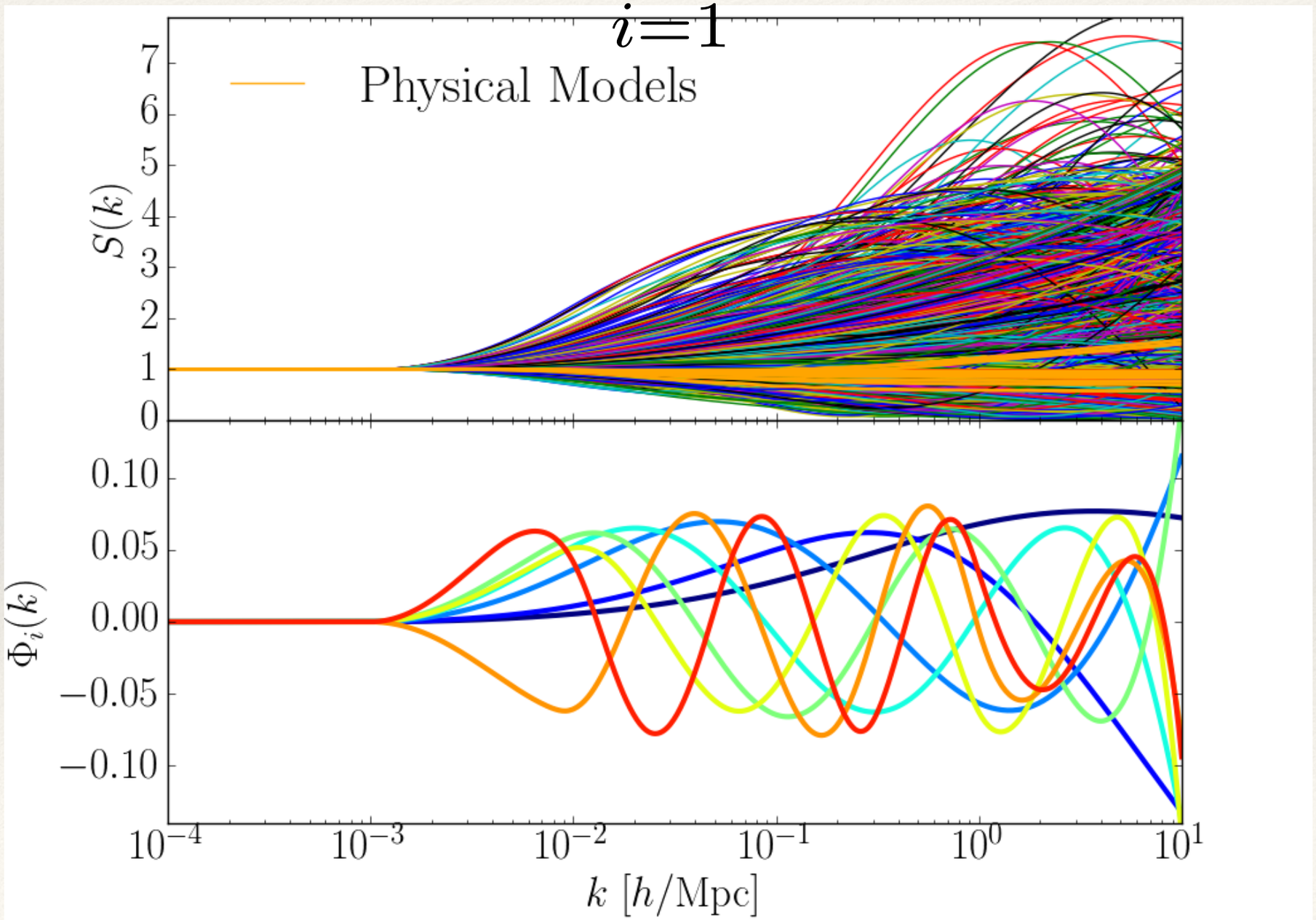
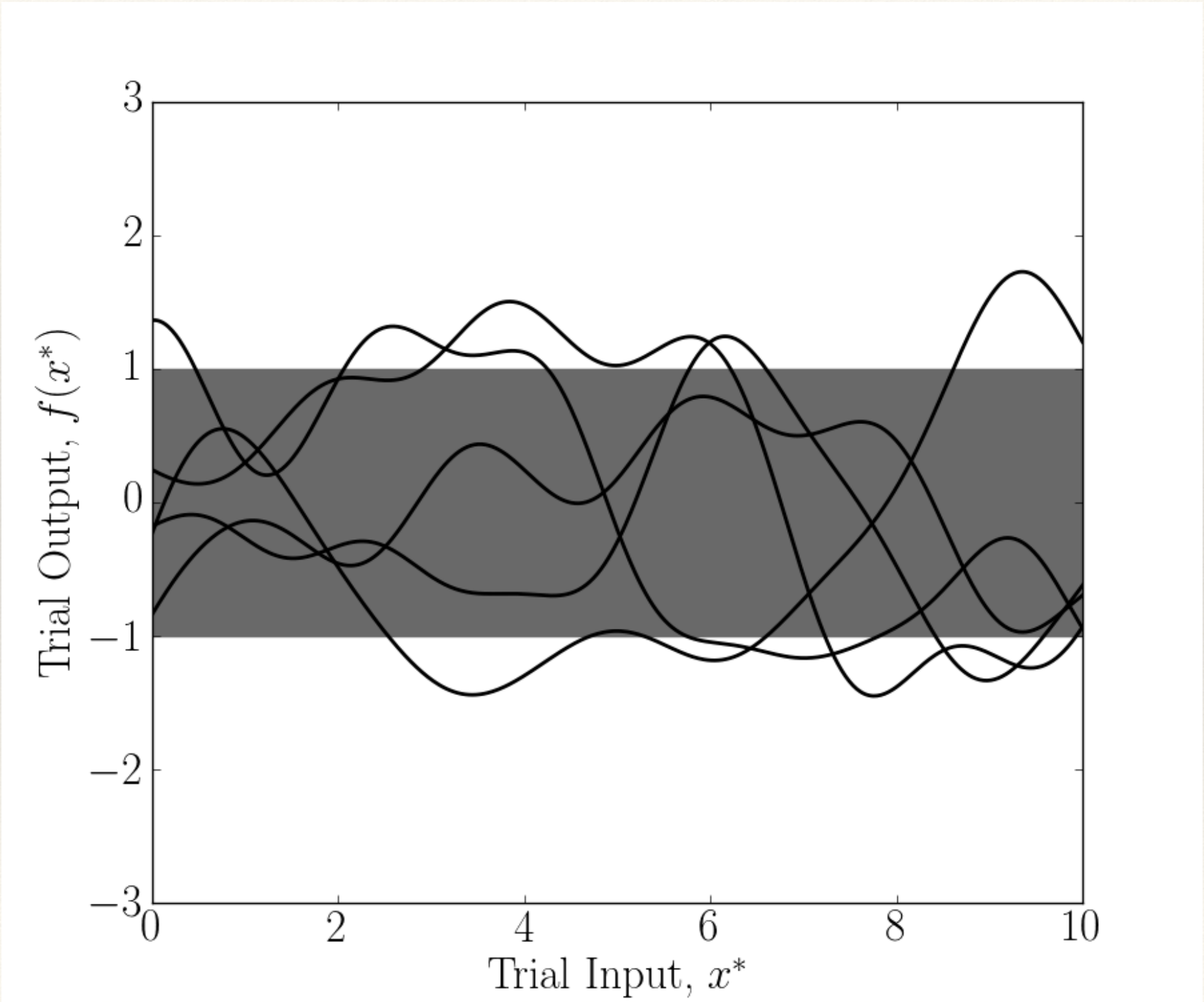


Gaussian Process Emulation



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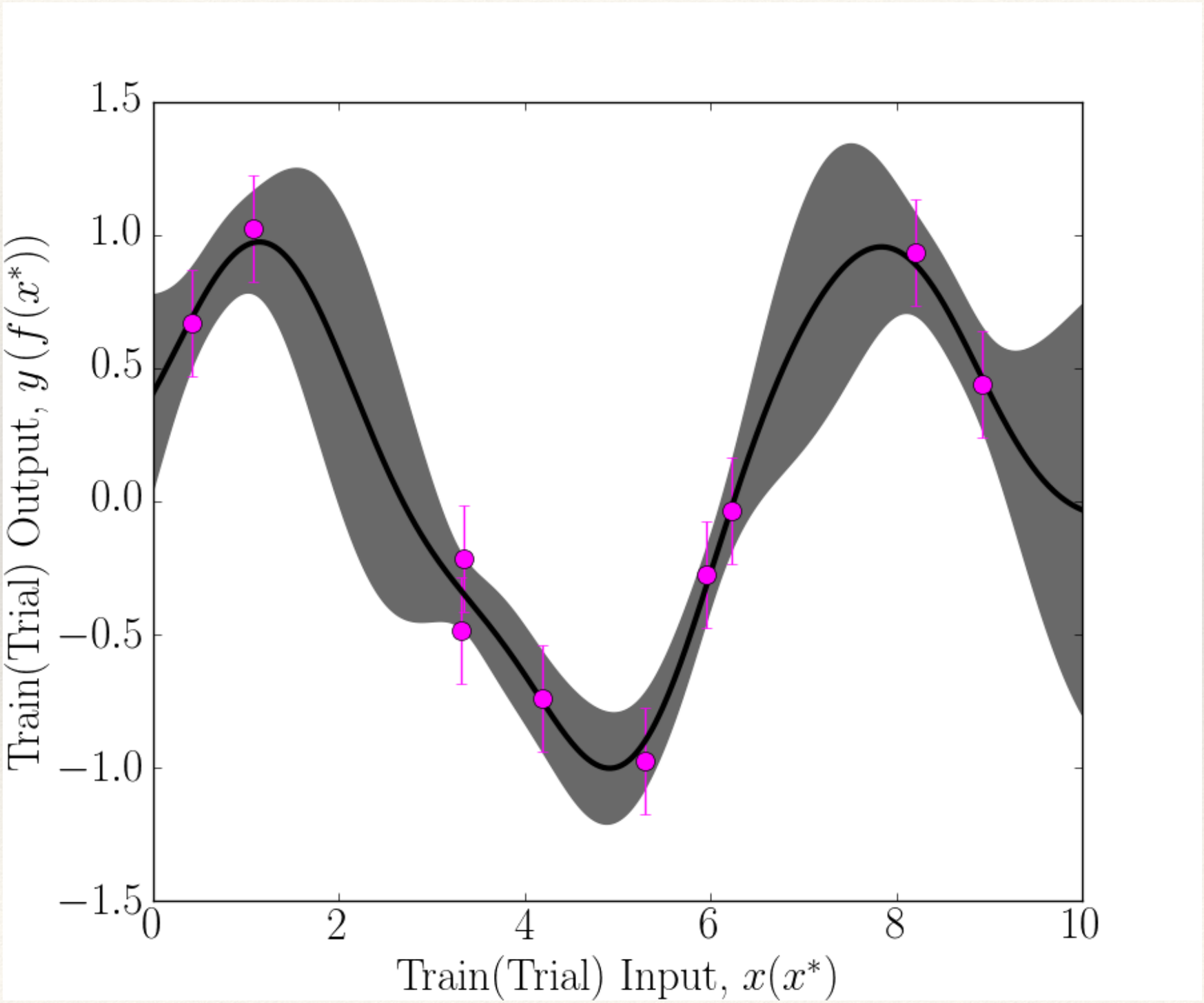
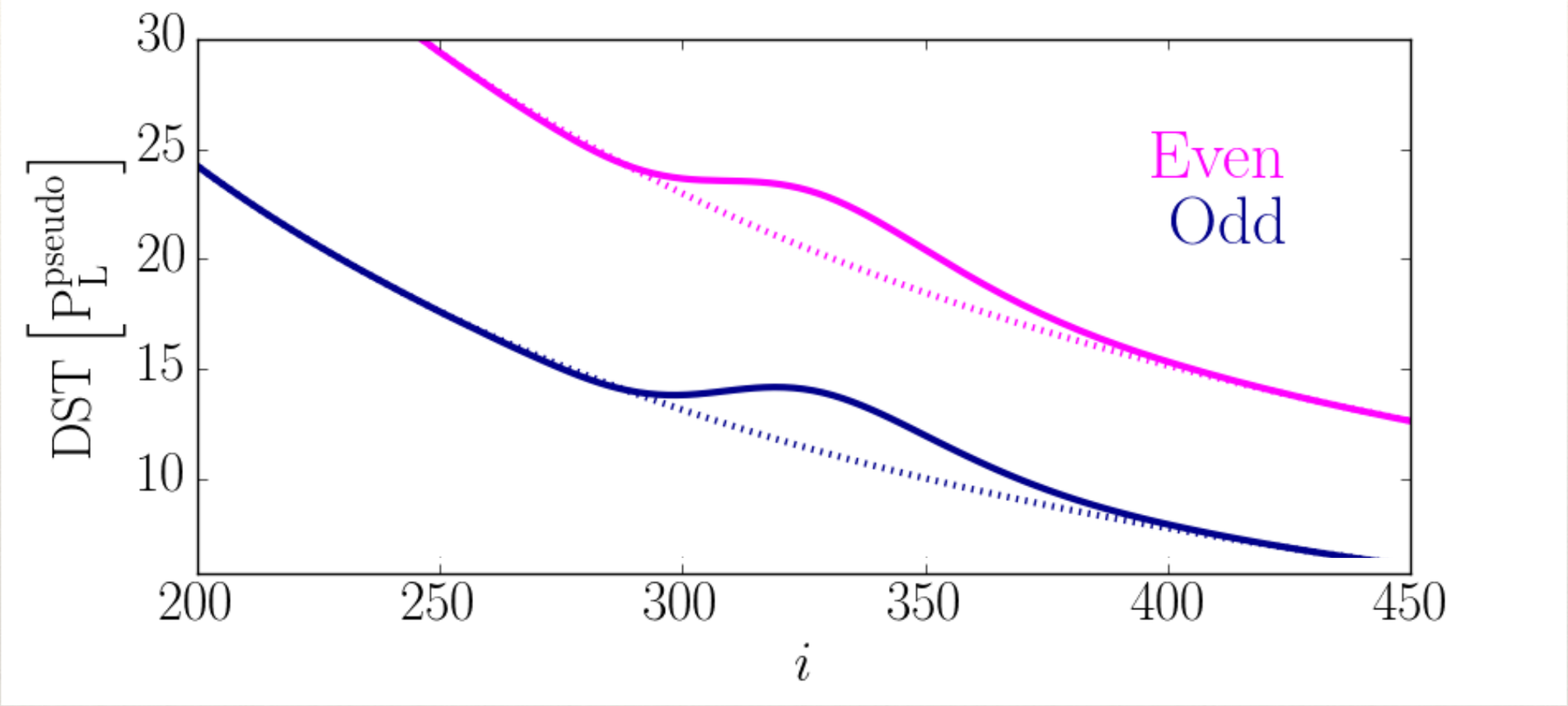


Modelling the BAO residual



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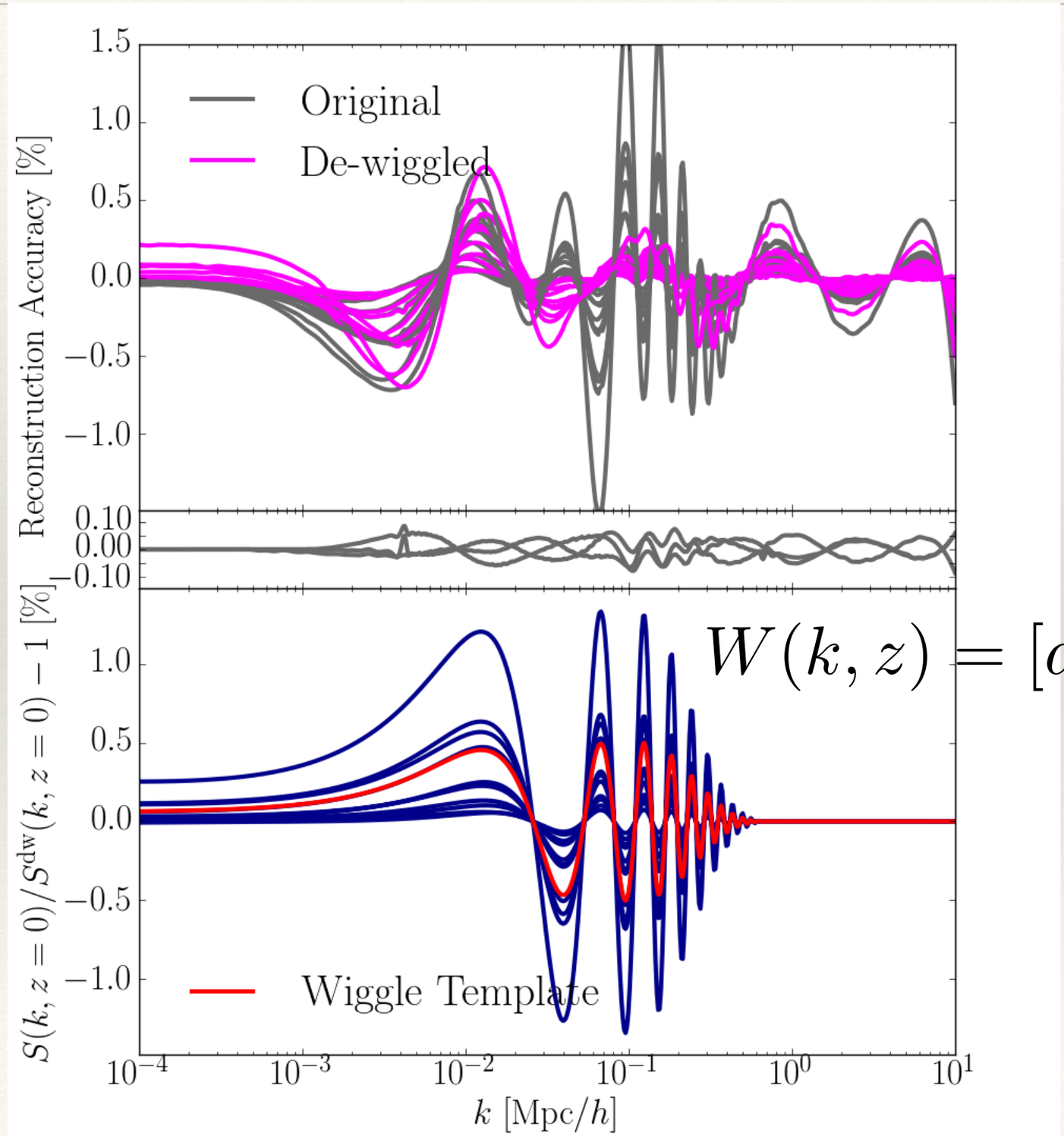

$$W(k,z) = [a + b\log_{10}(k)]\,T(k)$$

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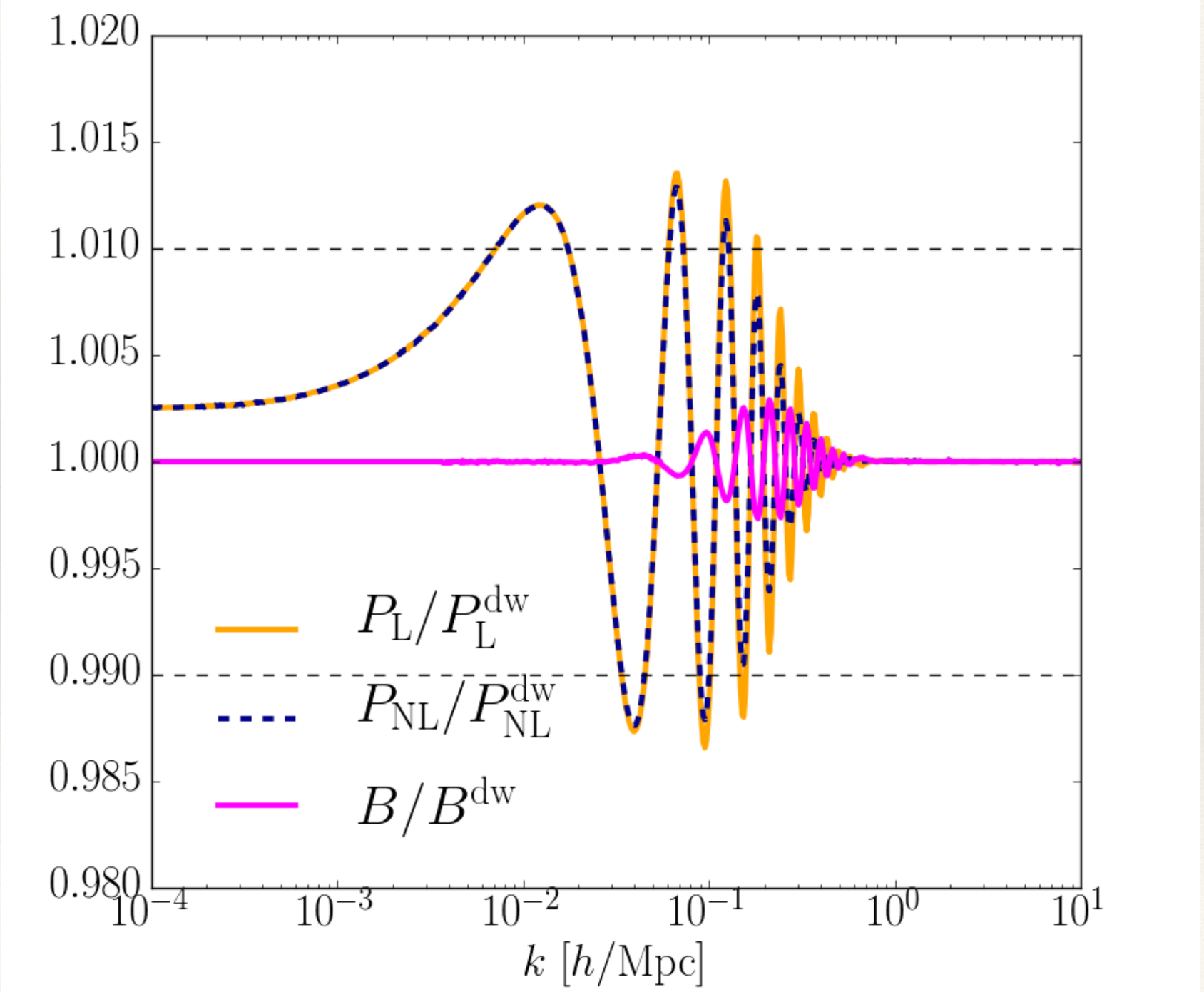

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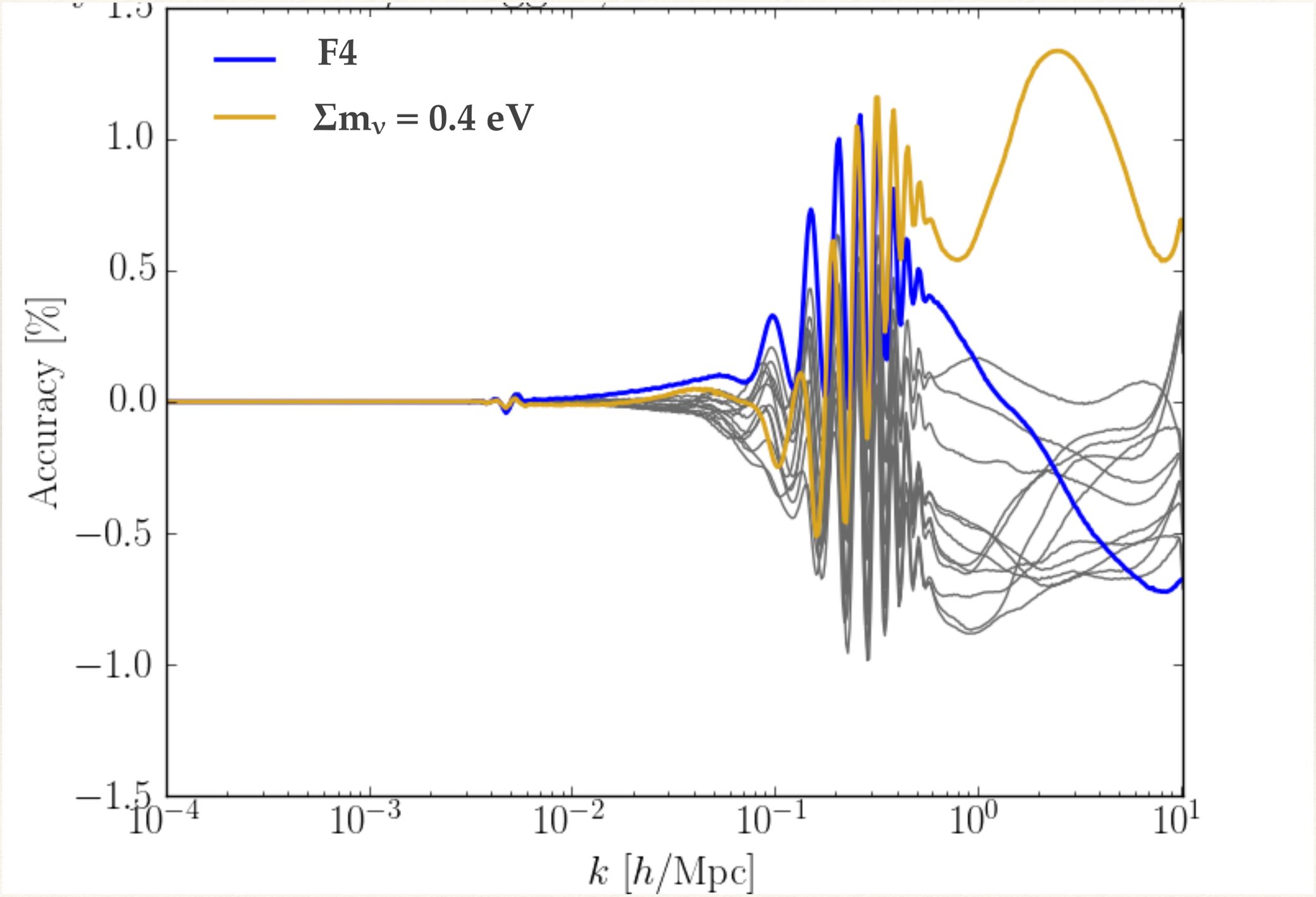
Modelling NL Stats Beyond ΛCDM



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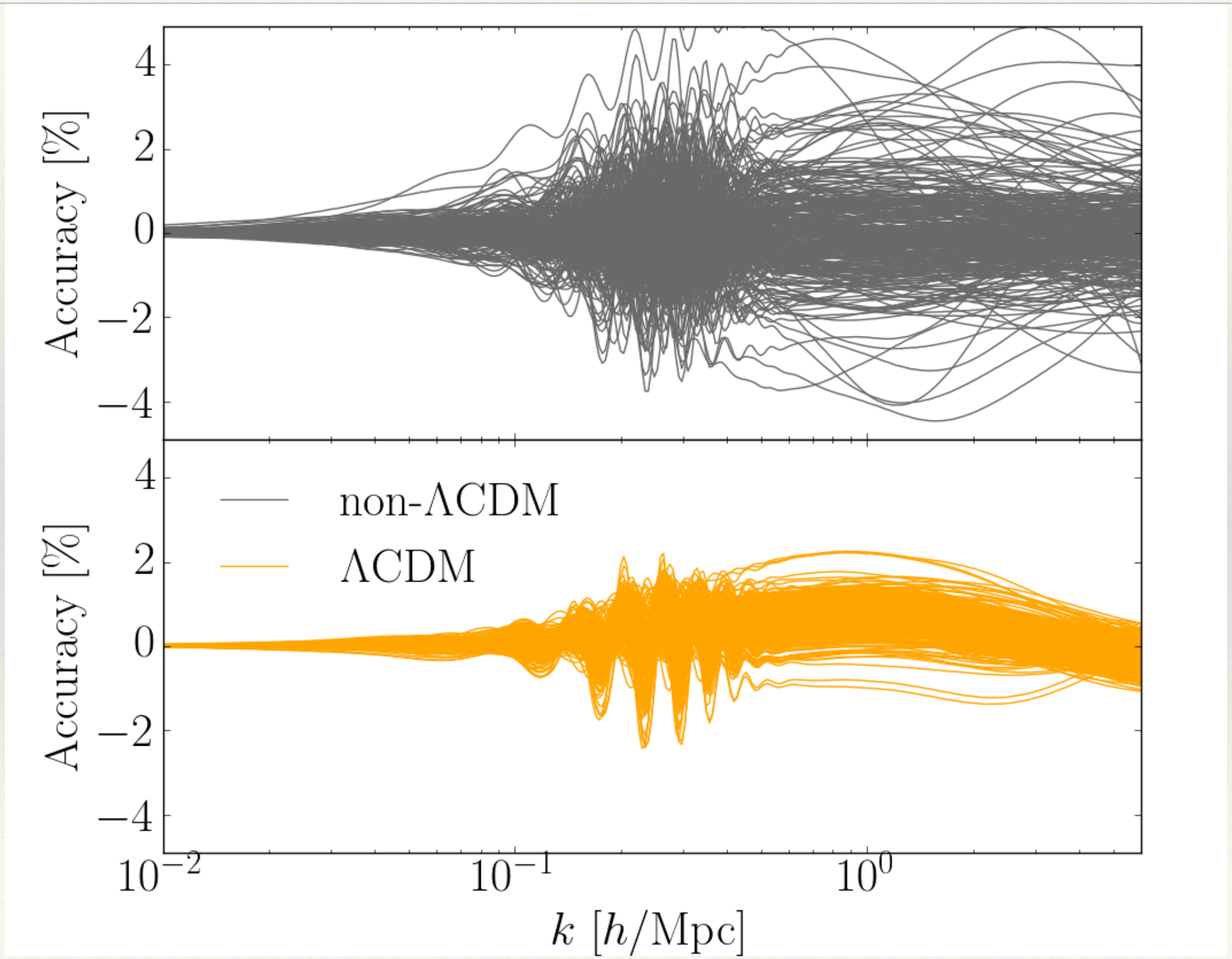

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Modelling NL Stats Beyond ΛCDM

Recipe for emulating $P^{\rm pseudo}(k)$

User inputs $P_L^M(k)$ for arbitrary model M and the 5 cosmological params for the matching $P_L^{\Lambda CDM}(k)$

A PCA breaks this into 8 numbers parameterising its deviations from ΛCDM

These are fed into a GPR Emulator which has been trained on how these numbers relate to $P_{NL}^N(k)$, where **N** is an ensemble of simulated models

$P_{NL}^M(k)$ returned to user

As long as M is contained by model ensemble **N**, the emulator provides accurate predictions for $P_{NL}^M(k)$ - it need not have been trained on Model M.