Gauging the Reaction: a New Framework for Non-Linear Clustering in ΛCDM and Beyond

Matteo Cataneo
University of Edinburgh

Cosmology from Home
20/8/2020

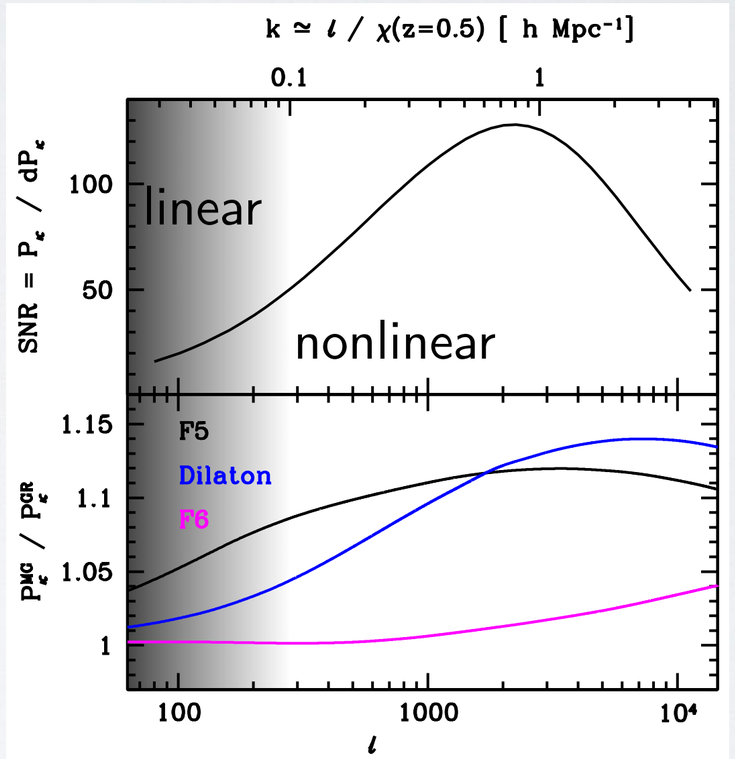
arXiv: 1812.05594 arXiv: 1906.02742 arXiv: 1909.02561 arXiv: 2005.12184

In collaboration with: Alex Barreira, Benjamin Bose, Sownak Bose, JD Emberson, Benjamin Giblin, Joachim Harnois-Deraps, Catherine Heymans, Derek Inman, Baojiu Li, Lucas Lombriser, Alex Mead, Ben Moews, Qianli Xia

Why Going Nonlinear?

1%

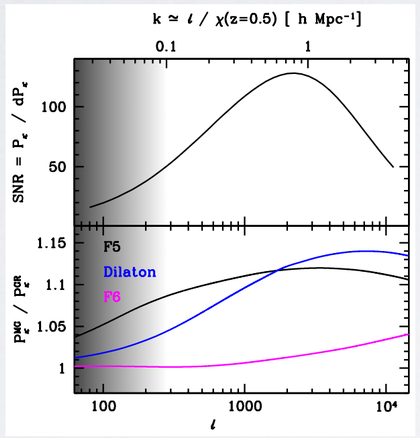
Precision of future LSS measurements



Heymans & Zhao 2018

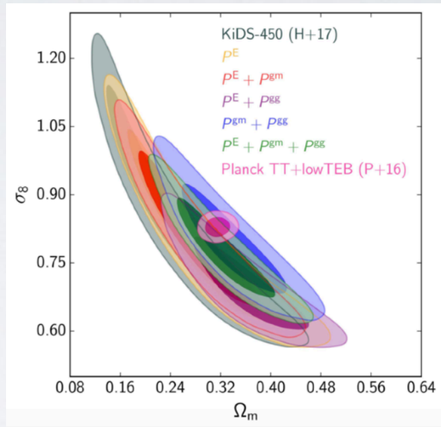
A Cosmologist's Wish List

Predictions...

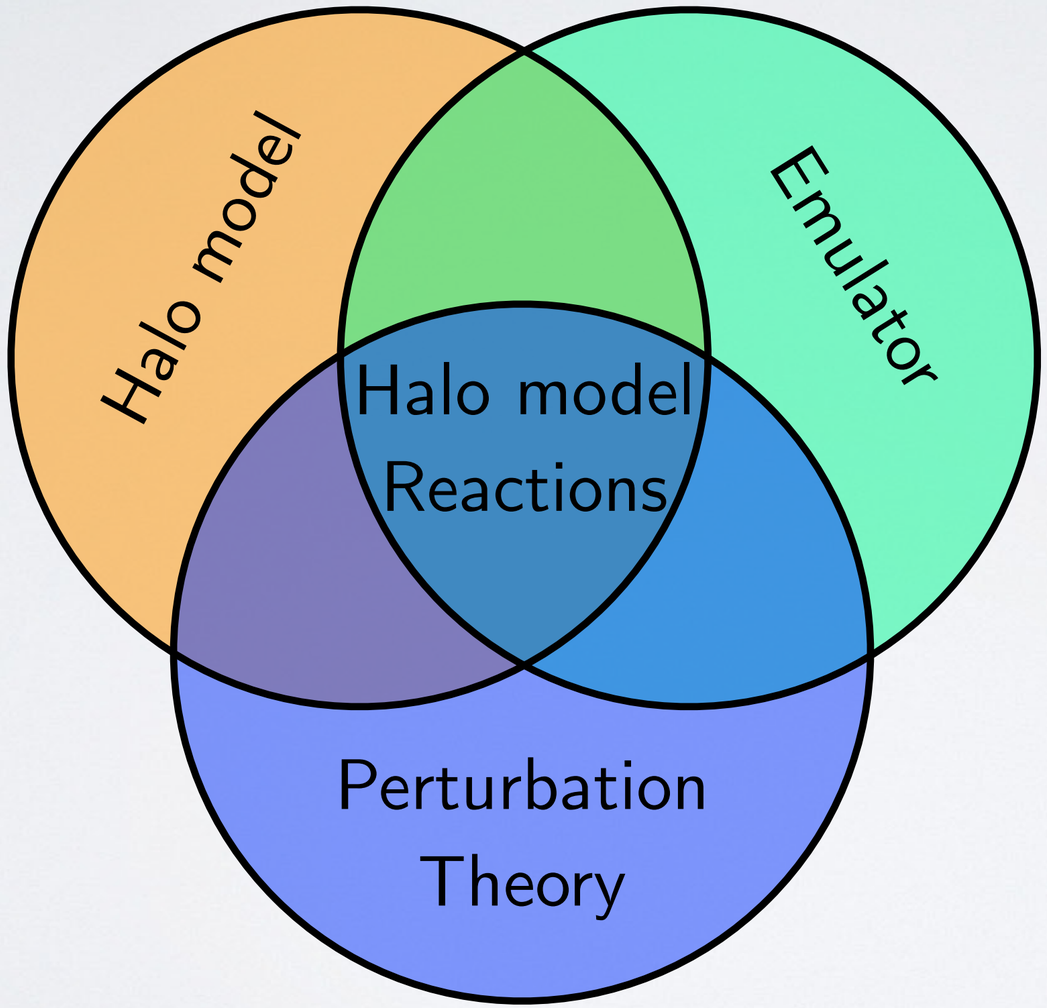


* Fast
* Accurate
* Flexible

$\mathrm{MG/DE},\ \mathrm{DM},\ m_\nu,\ N_{\mathrm{eff}}...$



The Best Of Three Worlds



* Fast
* Accurate
* Flexible

Halo Model Reactions

1) *Pseudo* cosmology

ΛCDM linear growth

&

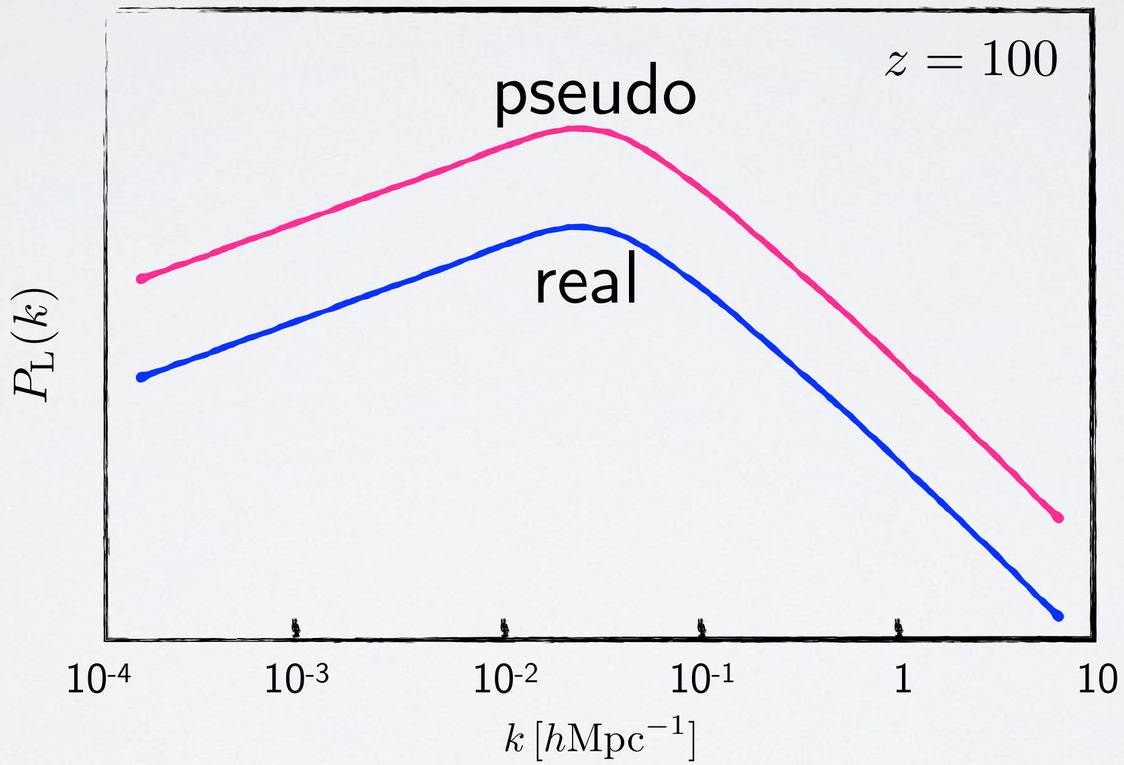
ICs adjusted to <u>match</u> the $P_{lin}(k,z_0)$ of

the non-standard$^{(*)}$ real cosmology

$^{(*)}$ non-standard = anything that is not a [flat + massless neutrino + ΛCDM] universe

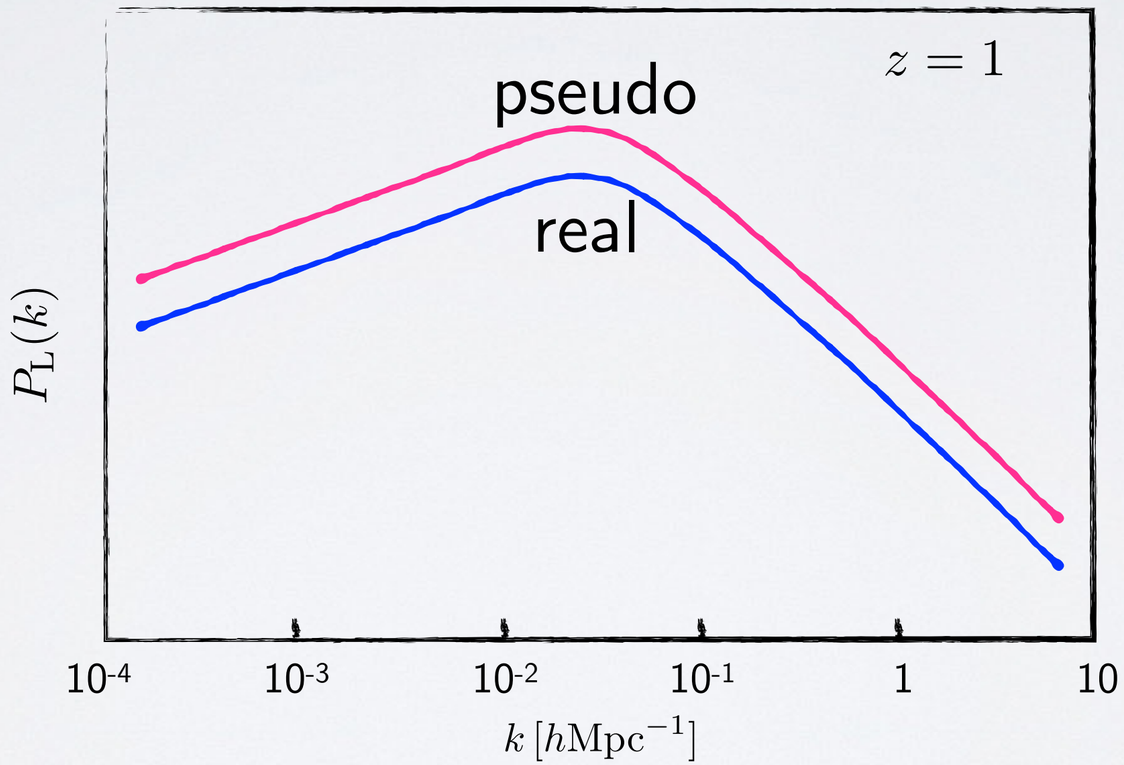
Halo Model Reactions

1) *Pseudo* cosmology



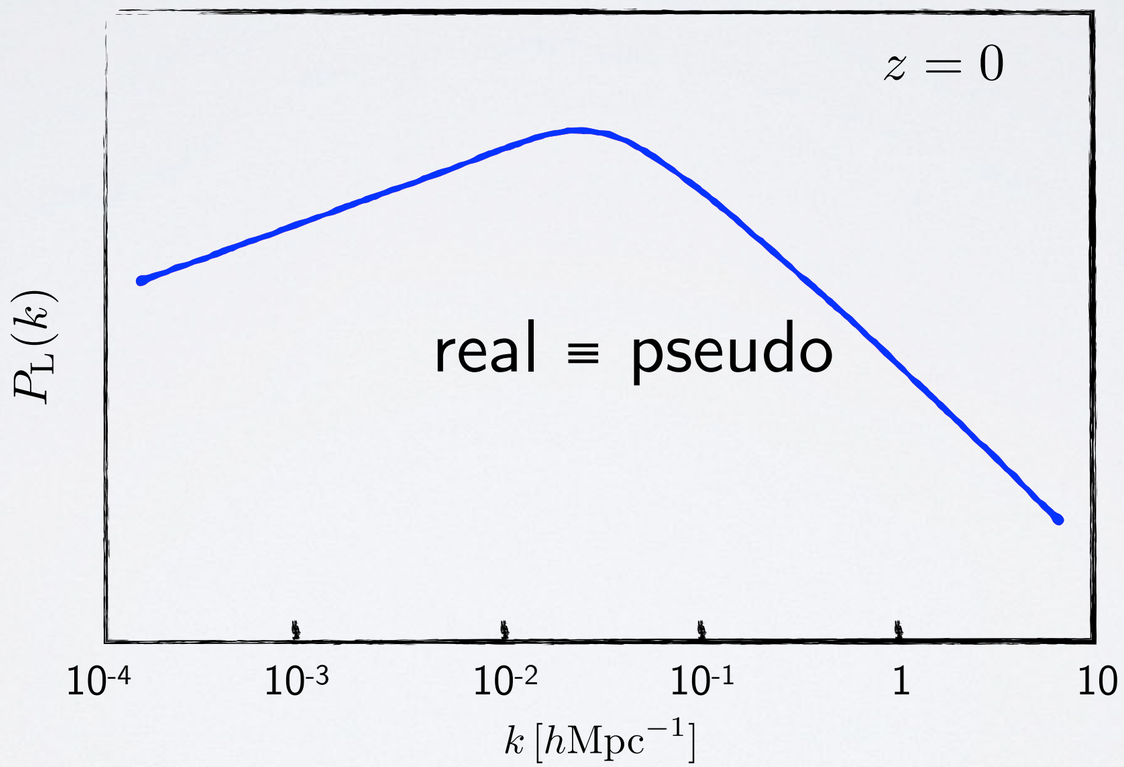
Halo Model Reactions

1) *Pseudo* cosmology



Halo Model Reactions

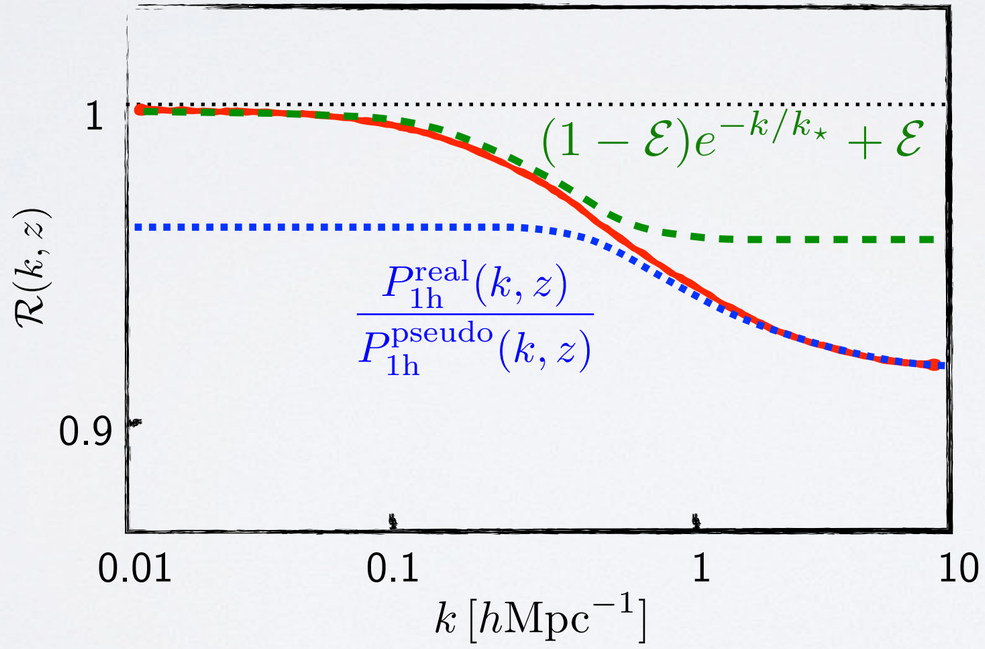
1) *Pseudo* cosmology



Halo Model Reactions

2) *Reaction*

$$\mathcal{R}(k,z) \equiv \frac{P_{\rm NL}^{\rm real}(k,z)}{P_{\rm NL}^{\rm pseudo}(k,z)} = \frac{[(1-\mathcal{E})e^{-k/k_\star}+\mathcal{E}]P_{\rm L}^{\rm real}(k,z) + P_{\rm 1h}^{\rm real}(k,z)}{P_{\rm L}^{\rm real}(k,z) + P_{\rm 1h}^{\rm pseudo}(k,z)}$$

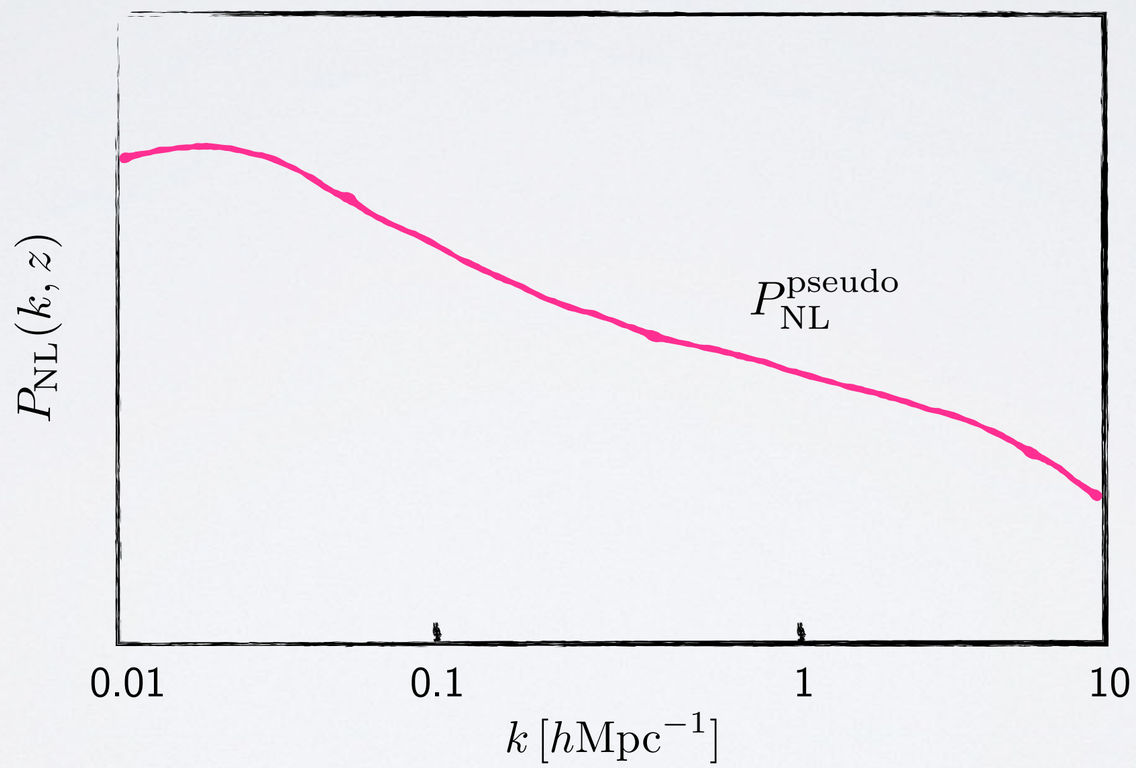


$$\mathcal{E} \equiv \frac{P_{\rm 1h}^{\rm real}(k\to 0)}{P_{\rm 1h}^{\rm pseudo}(k\to 0)}$$

$$\mathcal{R}_{\rm HM}(k_0|k_\star) = \mathcal{R}_{\rm SPT}(k_0)$$

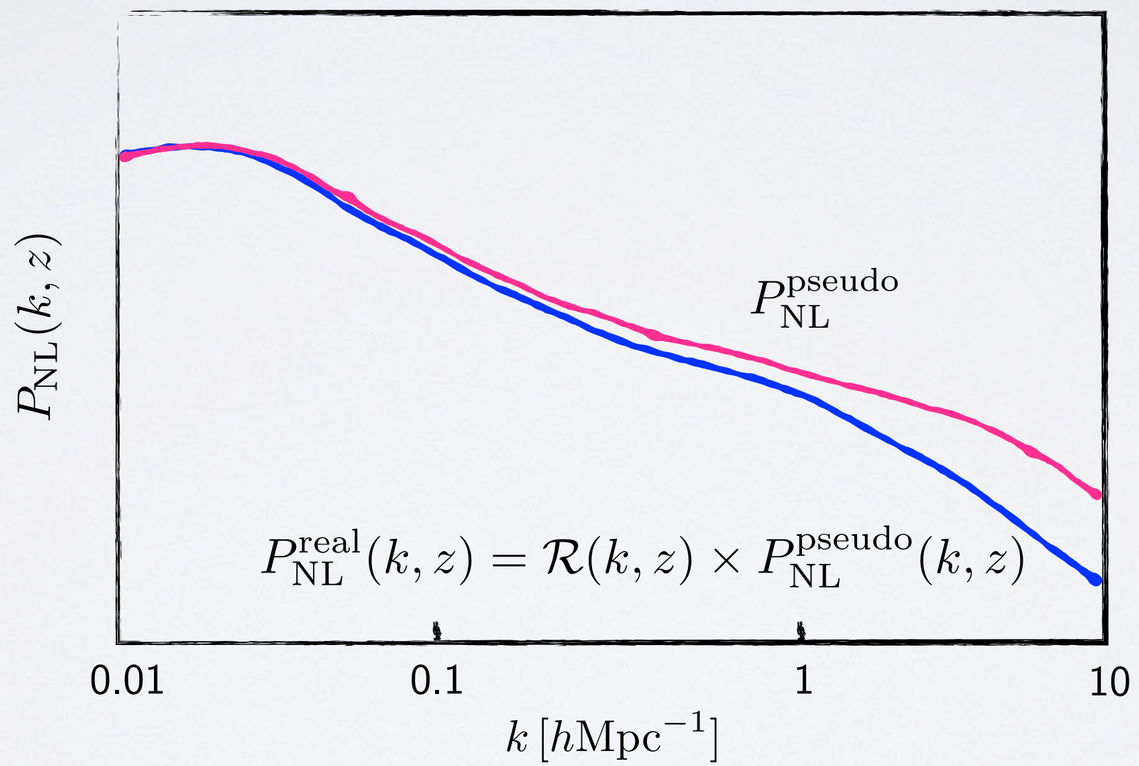
Halo Model Reactions

3) Power spectrum

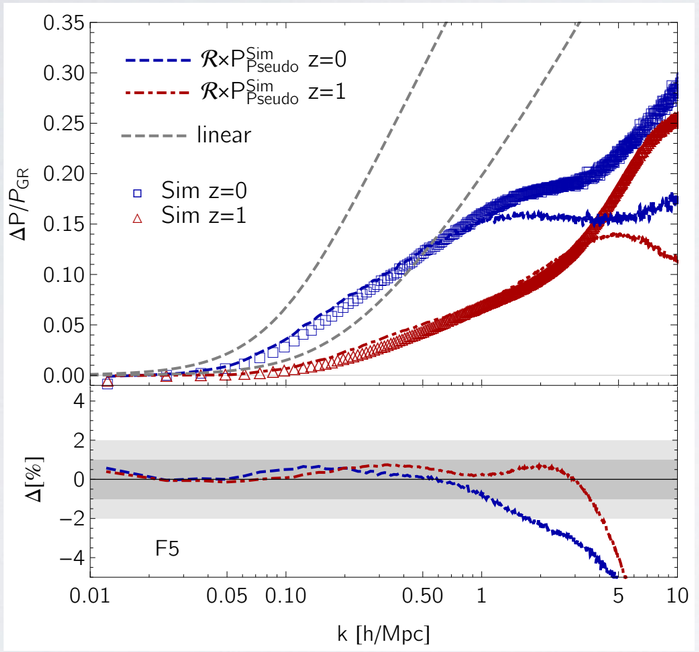


Halo Model Reactions

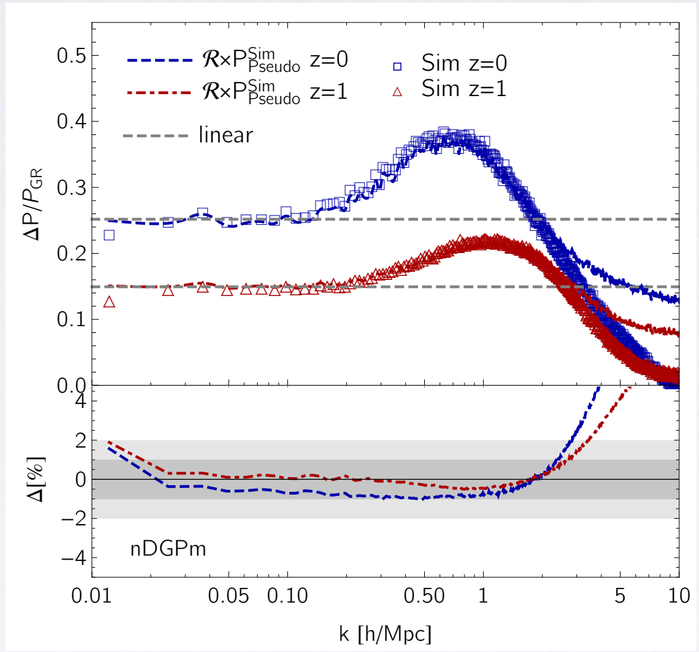
3) Power spectrum



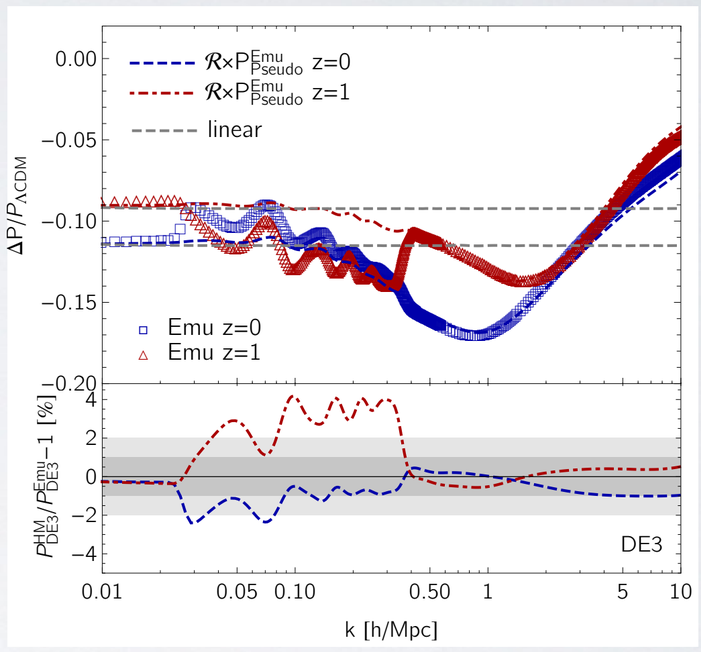
Modified gravity & Dark energy



f(R) gravity



nDGP

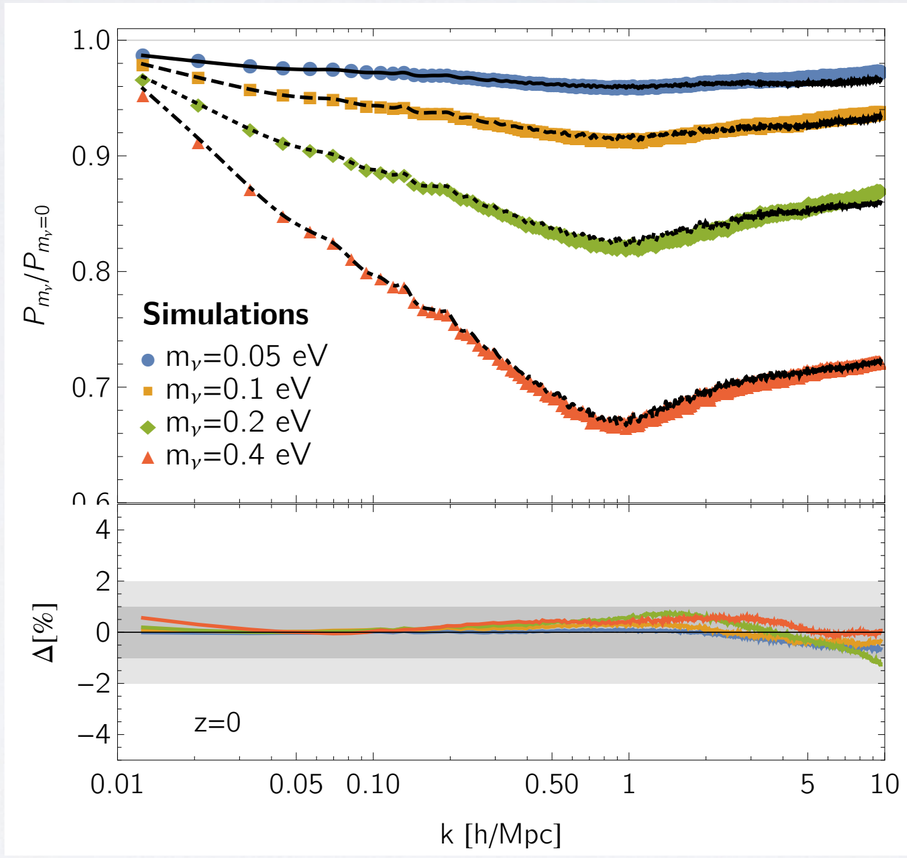


(w_0=-1 w_a=0.5)

Cataneo+ 2019

Massive Neutrinos

- Neutrinos assumed to cluster only linearly



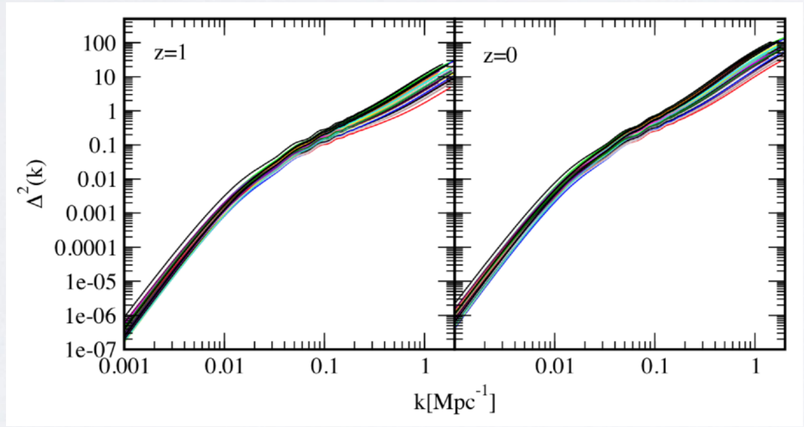
Cataneo+ 2020

Absolute Calibration of *Pseudo* Cosmologies

Pseudo cosmology: ΛCDM cosmology with ICs adjusted to match the non-standard *real* cosmology $P_{lin}(k,z_0)$

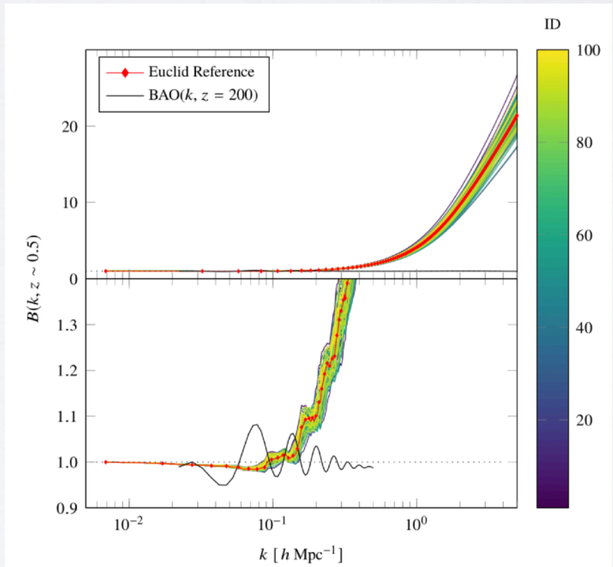
$$\boldsymbol{\pi}_\Lambda = \{\omega_\mathrm{b}, \omega_\mathrm{m}, h, n_s, A_s\}$$

CosmicEmu



Lawrence+ 2010

EuclidEmulator



Knabenhans+ 2019

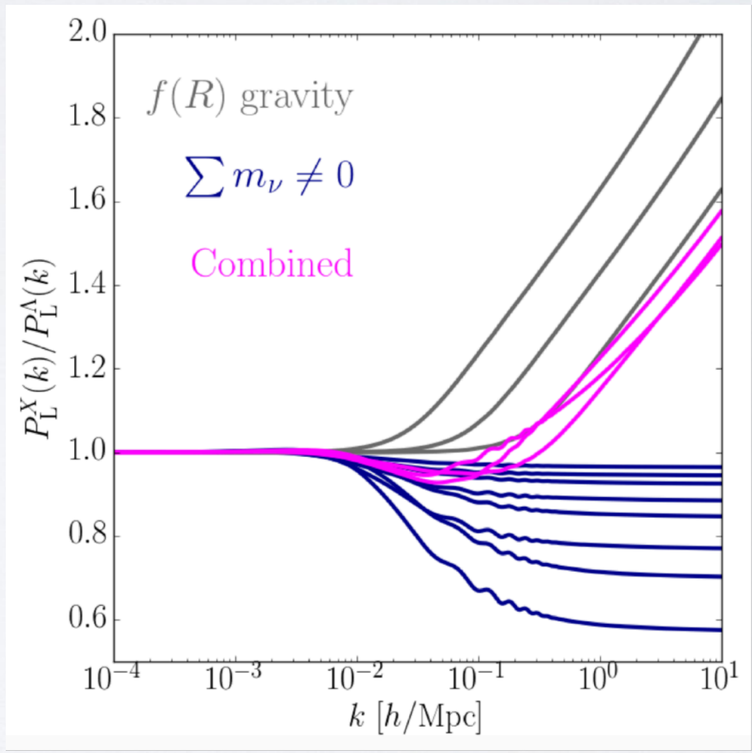
Absolute Calibration of *Pseudo* Cosmologies

Pseudo cosmology: ΛCDM cosmology with ICs adjusted to match the non-standard *real* cosmology $P_{lin}(k,z_0)$

$$\boldsymbol{\pi}_\Lambda = \{\omega_\mathrm{b}, \omega_\mathrm{m}, h, n_s, A_s\}$$

$$+$$

$$\boldsymbol{\pi}_\mathrm{X} = \left\{f_{R0}, \sum m_\nu, \cdots\right\}$$



Giblin, Cataneo et al 2019

(Quasi-)Model-independent shape reconstruction

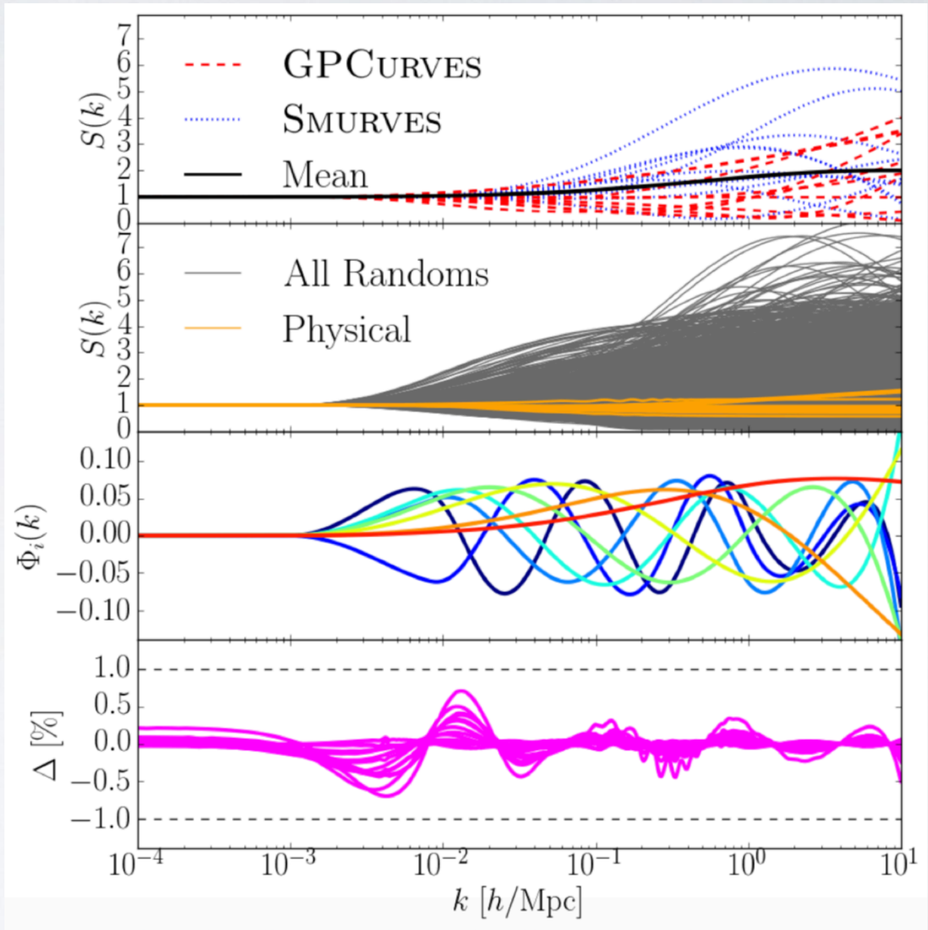
$$S\left(k,z;\boldsymbol{\pi}_\Lambda,\Delta\boldsymbol{\alpha}\right) \equiv \frac{P_{\rm L}^{\rm pseudo}\left(k,z;\boldsymbol{\pi}_\Lambda,\boldsymbol{\pi}_{\rm X}\right)}{P_{\rm L}^{\Lambda}\left(k,z;\boldsymbol{\pi}_\Lambda\right)}$$

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

$$\boldsymbol{\pi}_{\rm X}=\left\{f_{R0},\sum m_\nu,\cdots\right\}$$

$$\downarrow$$

$$\Delta\boldsymbol{\alpha}$$

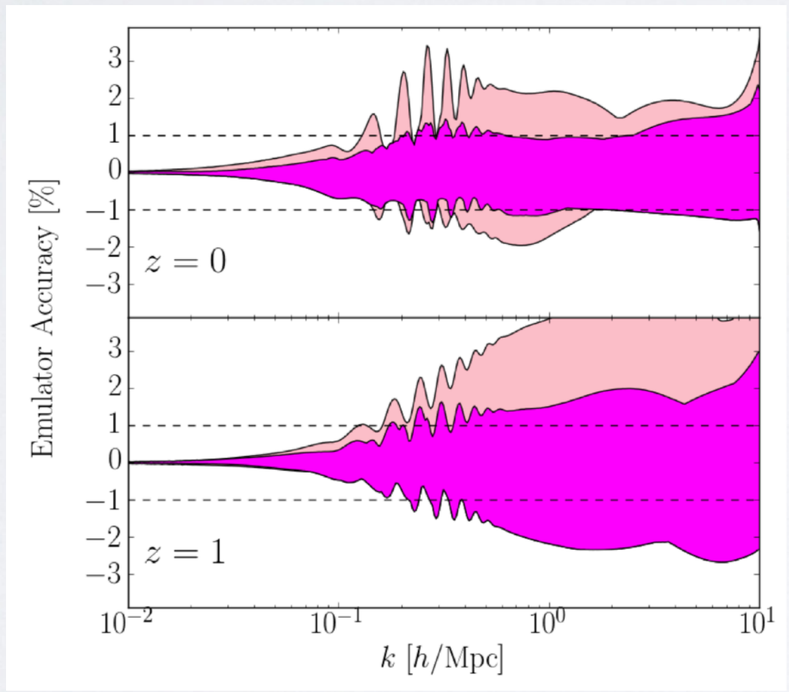


Giblin, Cataneo et al 2019

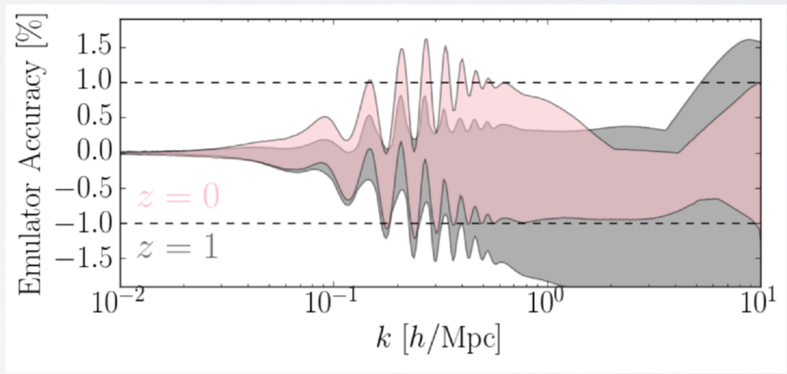
Pseudo Cosmology Emulator

$N_{\rm nodes} = 500$; 13 params; Gaussian Process

f(R) gravity, m_ν and combinations

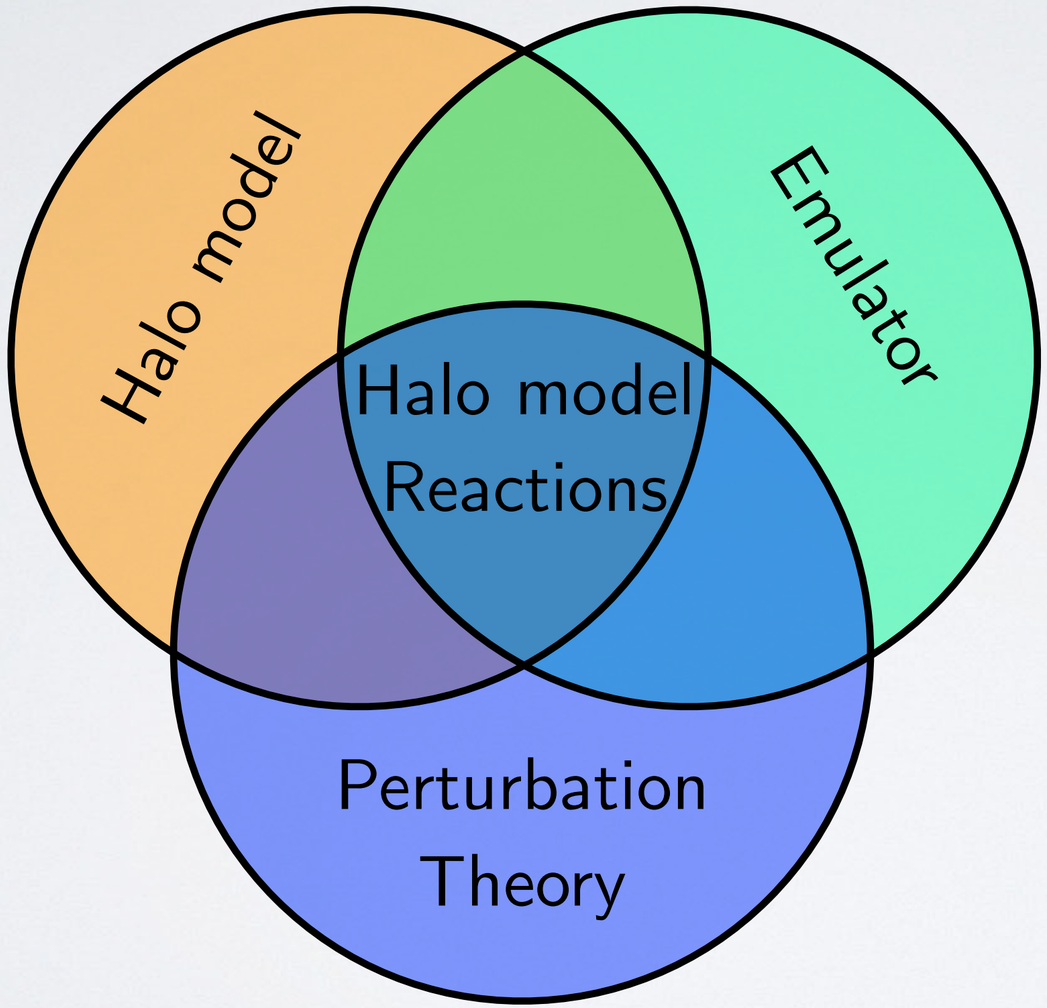


$\Delta N_{\rm eff} = +1$



Giblin, Cataneo et al 2019

The Best Of Three Worlds



* Fast
* Accurate
* Flexible

ReACT

- C++ library & Python wrapper (pyReACT)
- Fast (0.3 sec/redshift) —> likelihood analyses
- Modularised —> easy to add models and to modify
- Current version: Hu-Sawicki f(R) gravity, nDGP and w0waCDM
- Coming up: massive neutrinos
- Download it @ https://github.com/nebblu/ReACT

Bose, Cataneo, Tröster et al 2020

Summary & Outlook

- Halo model reaction framework
  - ☑ Fast (`ReACT`)
  - ☑ Accurate (≲1% for k < 1 h/Mpc)
  - ☑ Flexible (many ΛCDM extensions)
- Strong link between halo properties and matter clustering

- Improve highly NL regime in MG/DE (1 < k Mpc/h < 10)
- *Pseudo* emulator w/ simulations (SPCE, design optimisation...)
- Include baryonic physics; halo clustering
- Extend to (sub-class of) Horndeski theory
- Simultaneous treatment of different physics beyond vanilla ΛCDM