Effective Field Theory

IN A NUTSHELL

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The motivation of this work...

* Large-scale structures
* Galaxy surveys

Challenges:

- Description of galaxy distribution
- Small-scale physics
- Line-of-sight effects
- Large-scale phenomena
- Others (open discussion)

MENÜ

* Matter power spectrum
  * Perturbation Theory
  * Effective Field Theory
  * Redshift-space mapping
  * IR-resummation

* Halo power spectrum

A tablespoon of bias models

DARK MATTER POWER SPECTRUM IN REDSHIFT SPACE

Standard Perturbation Theory – *Dark Matter*

My model:

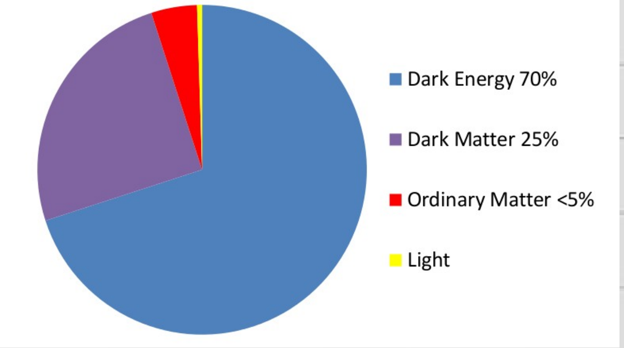
GR + ΛCDM

Flat, homogeneous, isotropic universe

Fluid components:

Energy density ρ

Pressure P



My calculations:

Fluid equations for dark matter

$$P=0$$
$$\rho=\rho_0+\delta\rho$$
$$\delta=\frac{\delta\rho}{\rho}$$

- Perfect fluid behaviour
- Non-relativistic limit
- Negligible vorticity

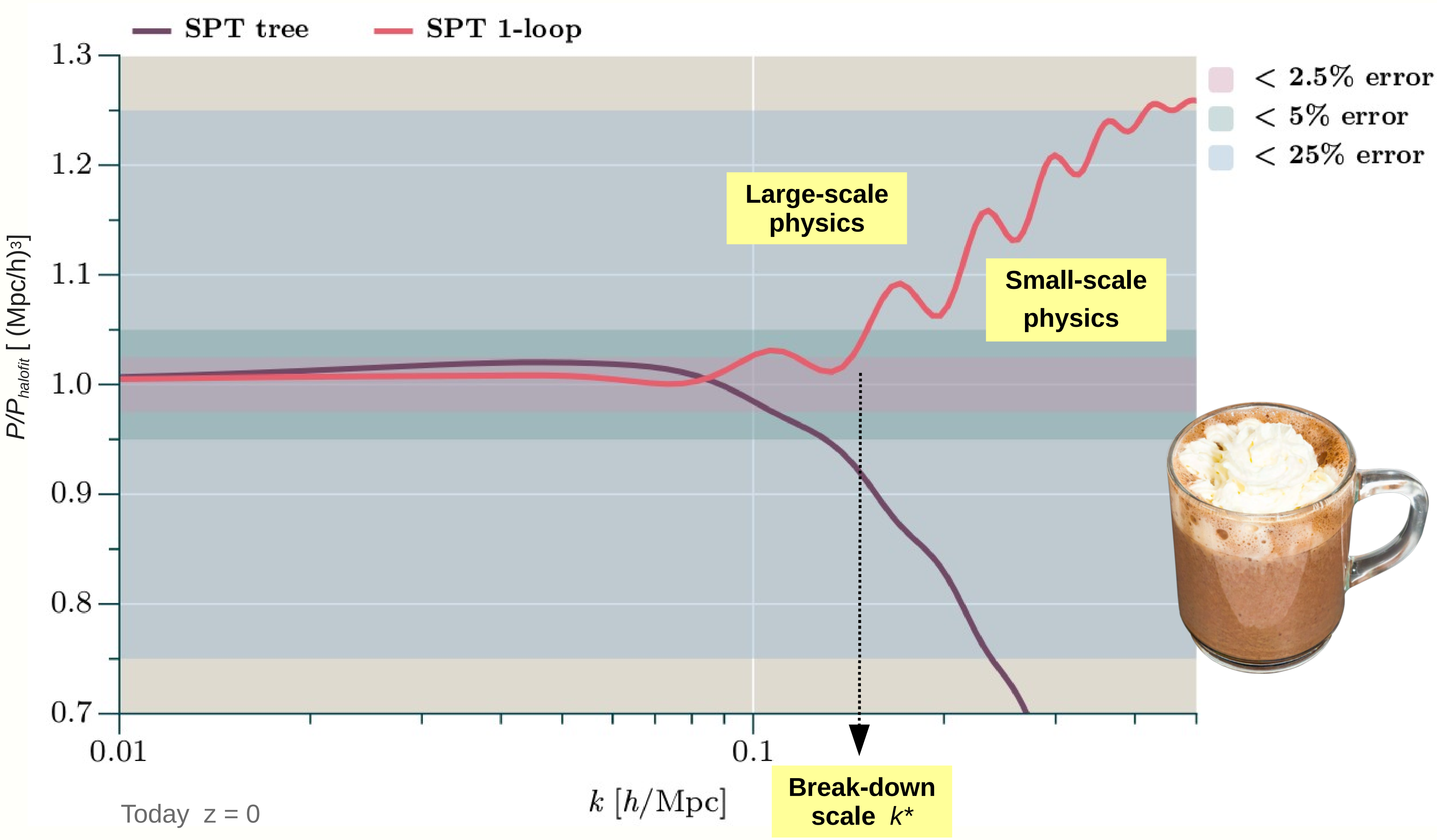
Perturbative solution:

$$\delta=\delta^{(1)}+\delta^{(2)}+\delta^{(3)}$$

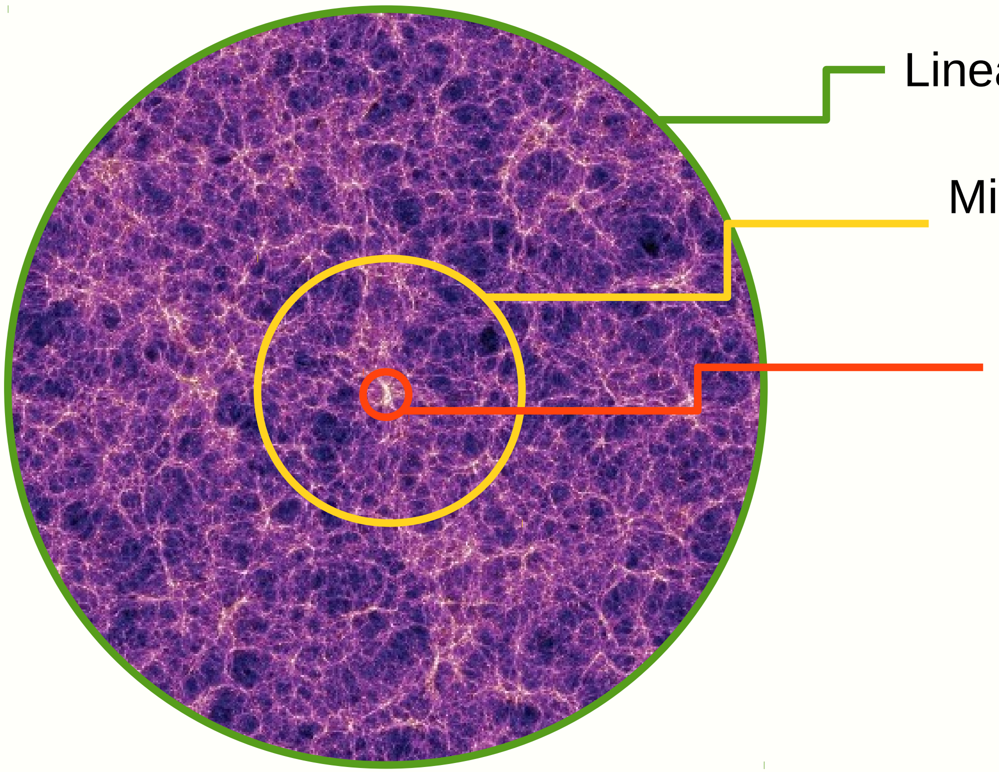
2Point correlation function

$$P^{SPT}_{1-loop}(k,z)=P_{11}(k,z)+P_{13}(k,z)+P_{22}(k,z)$$

Standard Perturbation Theory – Predictions vs data



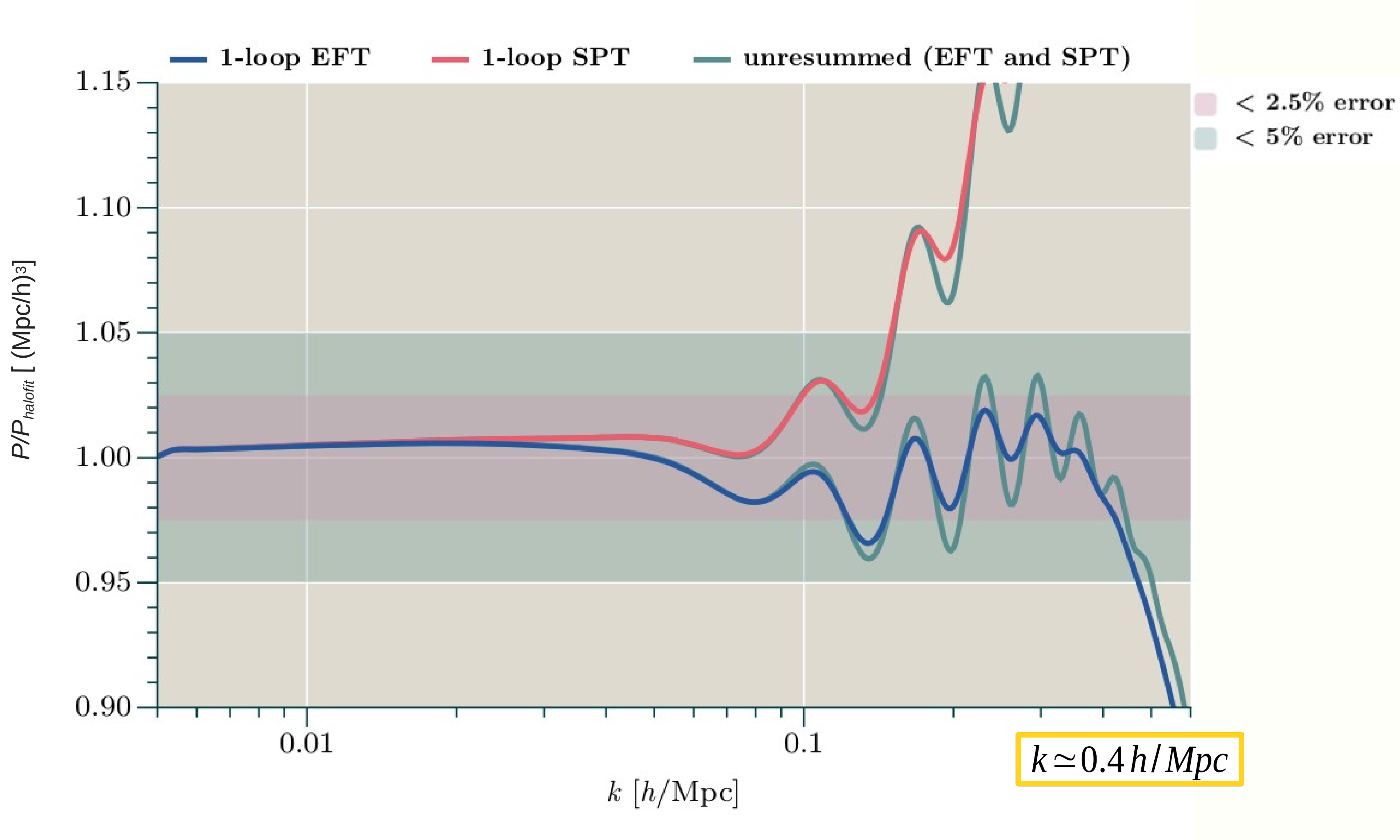
Effective Field Theory – Small-scale physics



$$\xi(r) \longrightarrow P_{\delta\delta}(k) \supseteq \int_{k_{IR}}^{k*} \mathrm{d}^3\mathbf{q} f(\mathbf{q}) g(\mathbf{q}, \mathbf{k}-\mathbf{q}) + \int_{k*}^{k_{NL}} \mathrm{d}^3\mathbf{q} f(\mathbf{q}) g(\mathbf{q}, \mathbf{k}-\mathbf{q}) = P^{\mathrm{SPT}}_{\mathrm{1\ loop}}(k) + \underbrace{\frac{c_\delta^2}{k_{NL}^2}} k^2 P_{\mathrm{lin}}(k)$$

COUNTER-TERM
Nbody simulations

Effective Field Theory – *Predictions vs data*



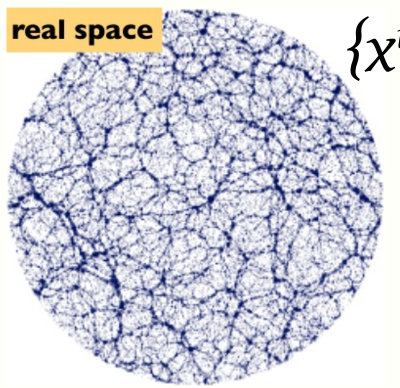
$k \simeq 0.4\, h/Mpc$

… but this is not the whole story

Redshift-space mapping – *Line-of-sight effects*

Galaxy surveys:

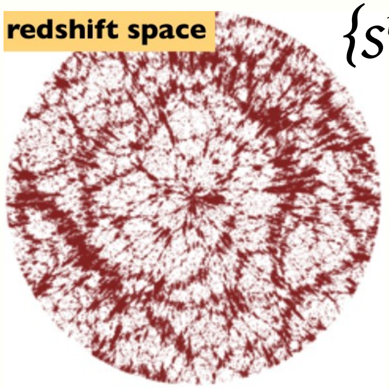
- Infer distances by measuring redshift → **redshift-space distortions**
- The measured power spectra depend on the angle of the **line of sight,** $\mu = \hat{k}\cdot\hat{r}$**.**



$\{x^i\}$

$$s^i = x^i + \hat{x}^i \hat{x}^j v_j$$

$$\rho(\underline{s})\, d^3\underline{s} = \rho(\underline{x})\, d^3\underline{x}$$



$\{s^i\}$

Fourier space

$$\begin{aligned}[\delta_s]_{\underline{k}} = [\delta]_{\underline{k}} &- \frac{i}{H}(\underline{k}\cdot\hat{\underline{r}})[\hat{\underline{r}}\cdot\underline{\upsilon}]_{\underline{k}} - \frac{i}{H}(\underline{k}\cdot\hat{\underline{r}})[\hat{\underline{r}}\cdot\underline{\upsilon}\,\delta]_{\underline{k}} \\ &+ \frac{1}{2!\,H^2}(\underline{k}\cdot\hat{\underline{r}})^2[(\hat{\underline{r}}\cdot\underline{\upsilon})^2]_{\underline{k}} + \frac{1}{2!\,H^2}(\underline{k}\cdot\hat{\underline{r}})^2[(\hat{\underline{r}}\cdot\underline{\upsilon})^2\delta]_{\underline{k}} \\ &+ \frac{i}{3!\,H^3}(\underline{k}\cdot\hat{\underline{r}})^3[(\hat{\underline{r}}\cdot\underline{\upsilon})^3]_{\underline{k}} + O(4) \quad .\end{aligned}$$

$[f\,]_{\underline{k}} \equiv$ *Fourier transform*

Figures by SDSS and eBOSS survey 2018

Redshift-space mapping – Power spectrum

1. Compute the 2-point correlation function

2. Get all contributions to the power spectrum $P_{s,11}(k,\mu,z)$, $P_{s,22}(k,\mu,z)$, $P_{s,13}(k,\mu,z)$...

3. Perform the Legendre decomposition

$$P_{s,l}(k,z) = \frac{2l+1}{2}\sum_{n=0}^{3}\int_{-1}^{1}\mu^{2n}\mathscr{L}_l(\mu)P_{2n,s}(k,z)$$

$\mathscr{L}_l(\mu)$ *Legendre polynomials*

l=0, 2 and ***4*** modes

4. Apply the effective field theory method

$$\frac{d_{\delta,0}}{k_{NL}^2} = 1.88\,Mpc^2/h^2$$

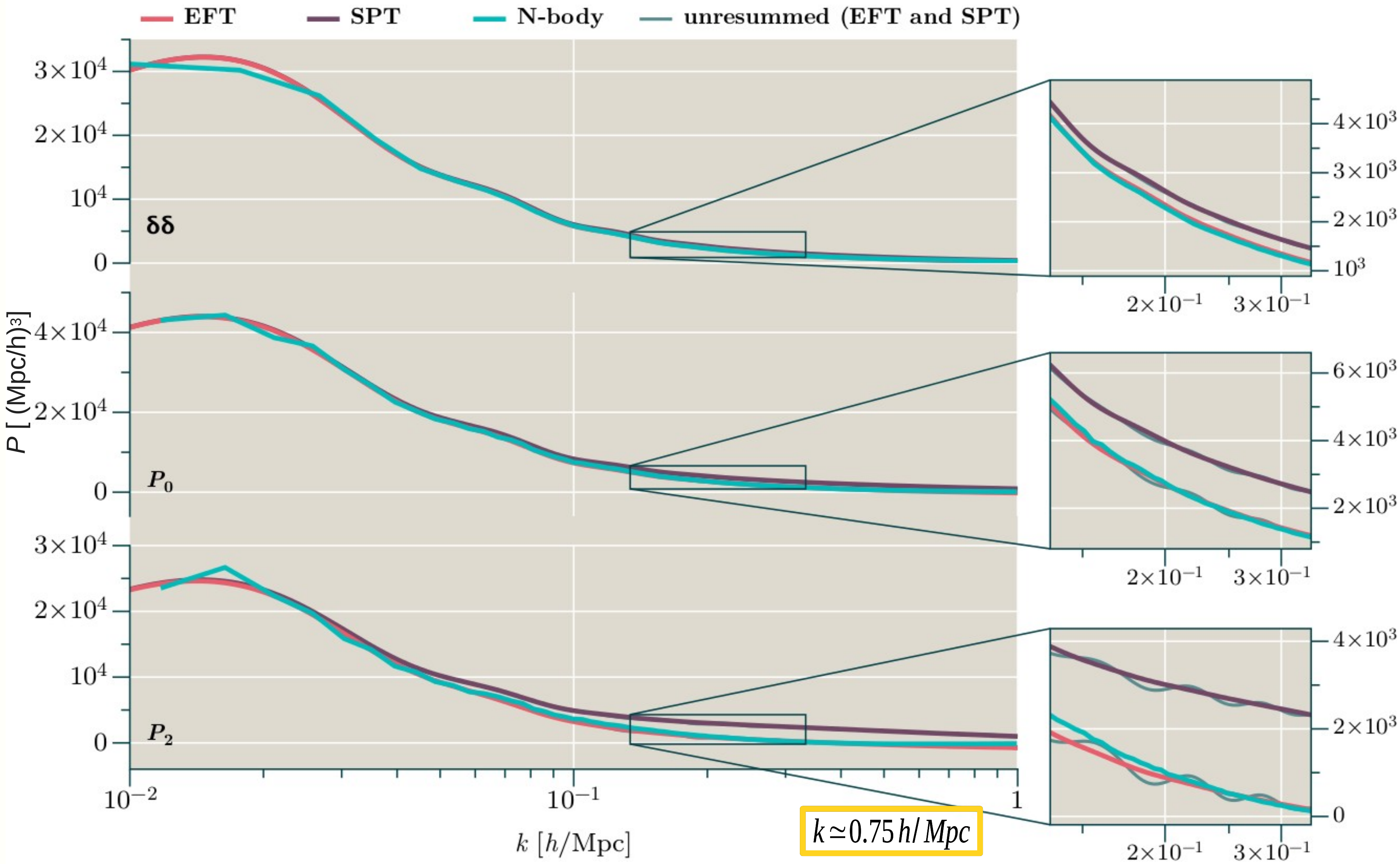
$$\frac{d_{\delta,2}}{k_{NL}^2} = 15.8\,Mpc^2/h^2$$

$$\frac{d_{\delta,4}}{k_{NL}^2} = 6.43\,Mpc^2/h^2$$

$$P_{s,l}(k,z) = P_{s,l}^{SPT} - 2D(z)^2\frac{d_{\delta_s,l}}{k_{NL}^2}k^2\widetilde{P}_l(k)$$

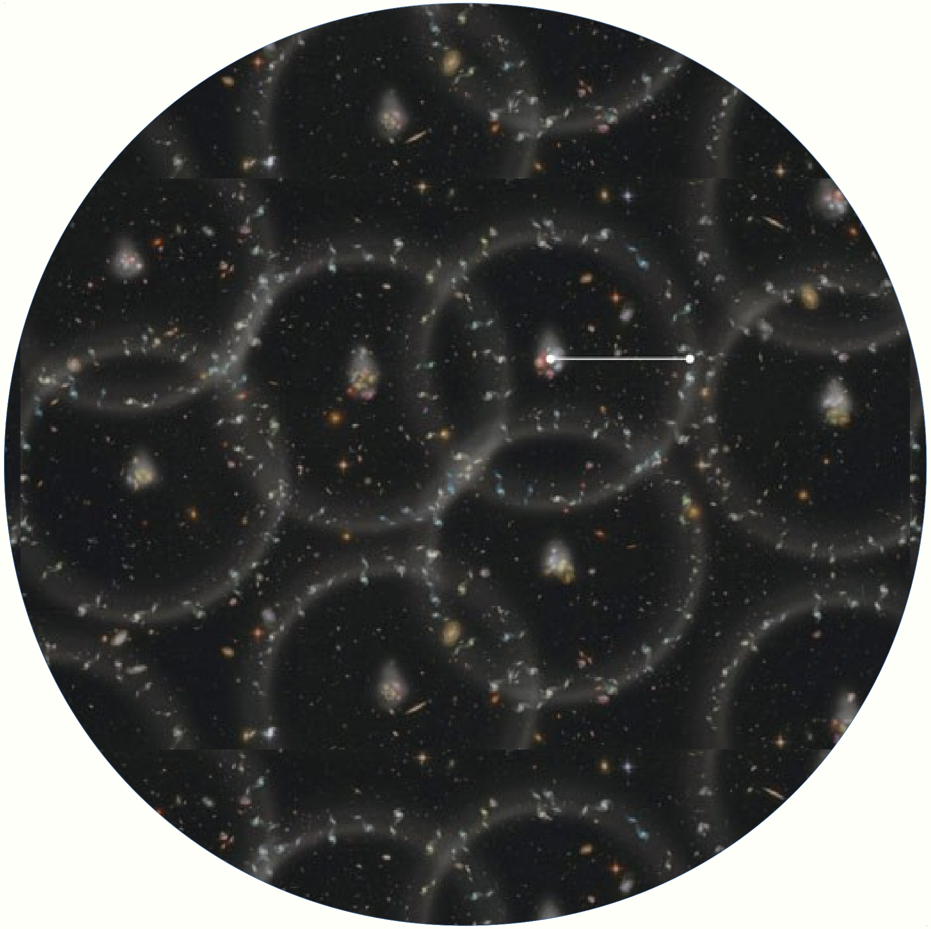
One **counter-term** per each multipole **(N-BODY SIMULATIONS)**

Redshift-space mapping – Prediction vs data



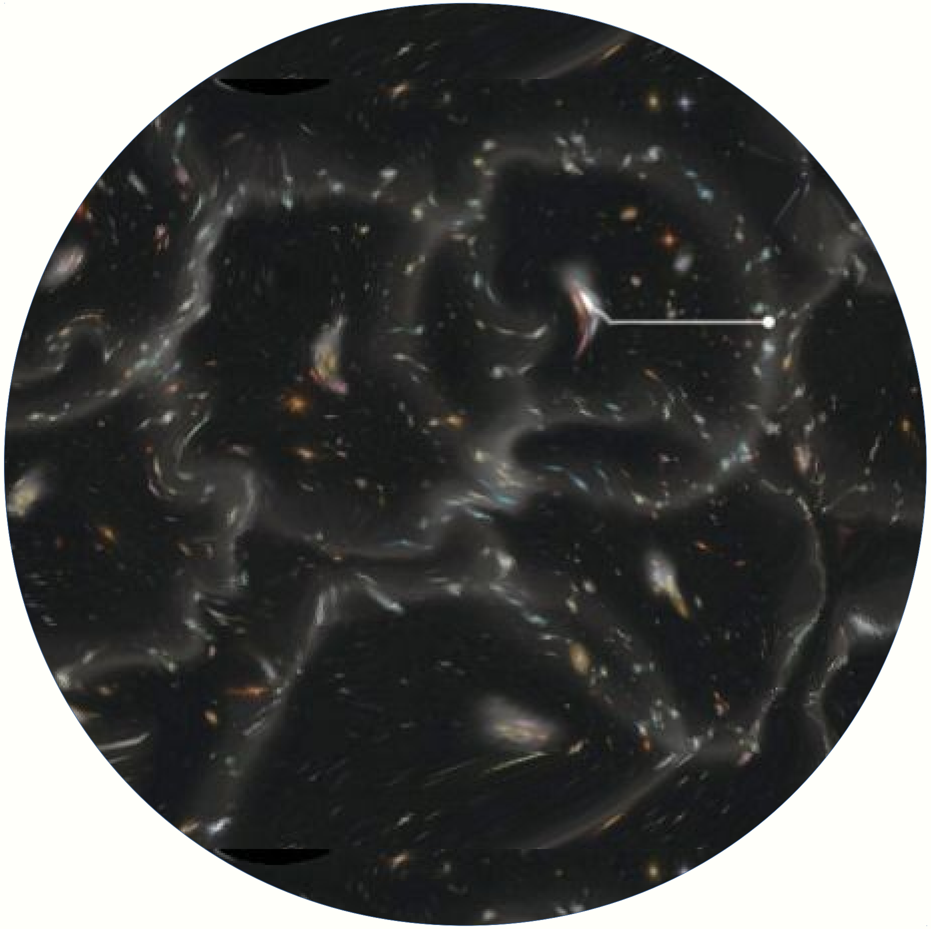
… what about the wiggles?

IR resummation – *Large-scale phenomena*



IR resummation – Lagrangian Perturbation

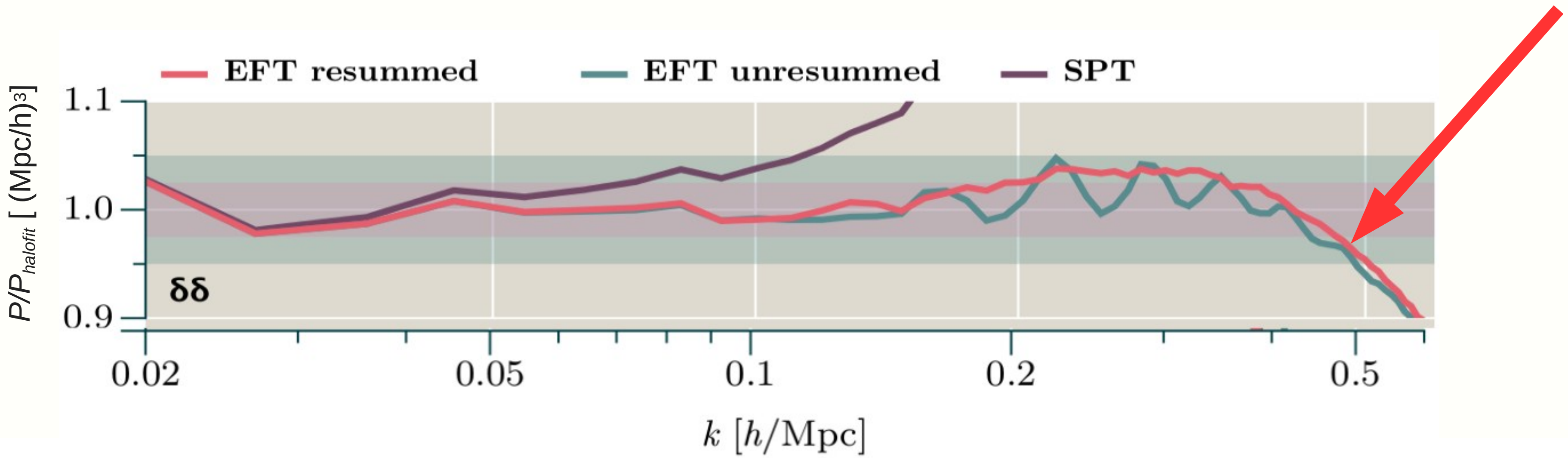
$$P^{IR}(k) = \int d^3 \underline{x}_q e^{-i\underline{k}\cdot\underline{x}_q} \mathcal{K}(\underline{k}, \underline{q}, \underline{\Psi}(\underline{q}))$$ ➜ $$P^{IR}(k) = P_{NW}(k) + \int d^3 \underline{x}_q e^{-i\underline{k}\cdot\underline{x}_q} \mathcal{K}_W(\underline{k}, \underline{q}, \underline{\boldsymbol{\Psi}}(\underline{q}))$$

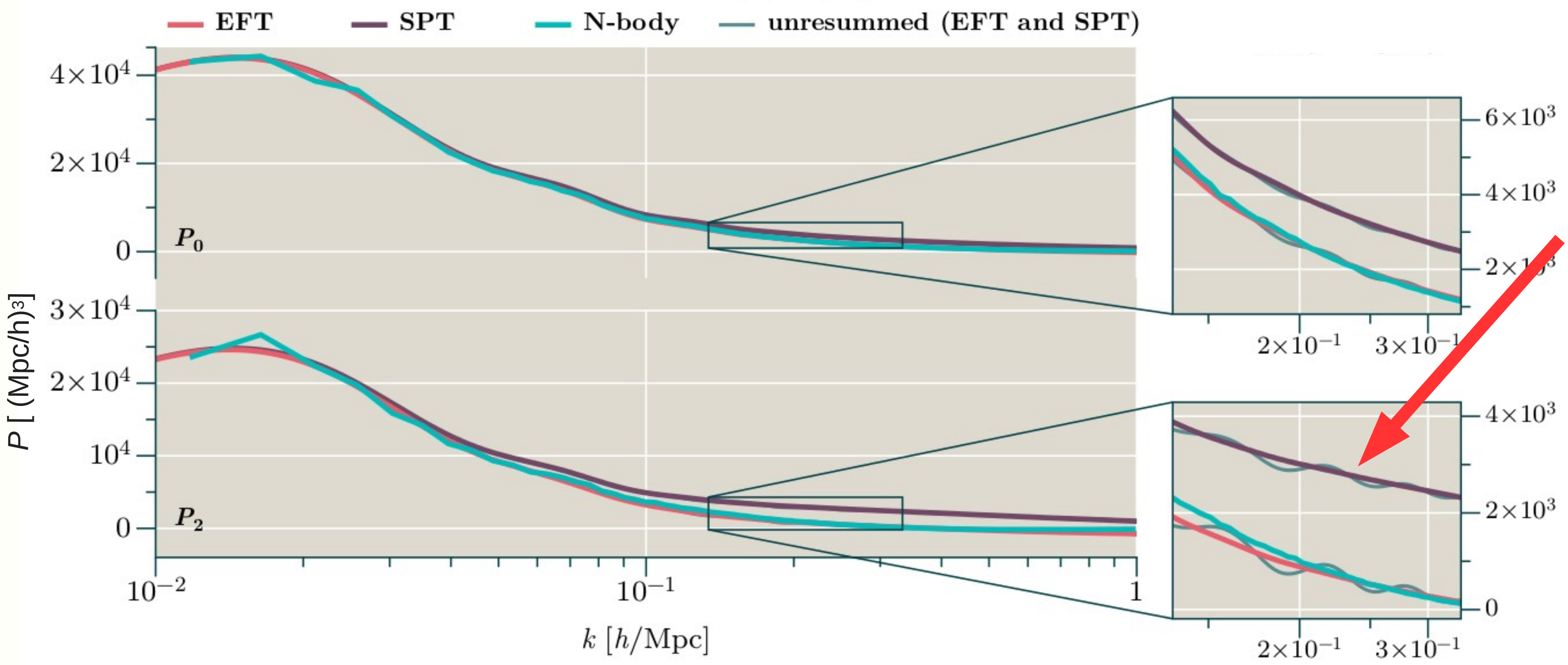


$$P^{IR}(k,z) = P_{NW}(k,z) + e^{\Sigma^2 k^2}\left(\Delta P_{1-loop,\,NW}(k,z) + \Sigma^2 k^2 \Delta P_{11,\,w}(k,z)\right)$$

OSCILLATIONS ARE DAMPED

IR resummation – *Prediction vs data*



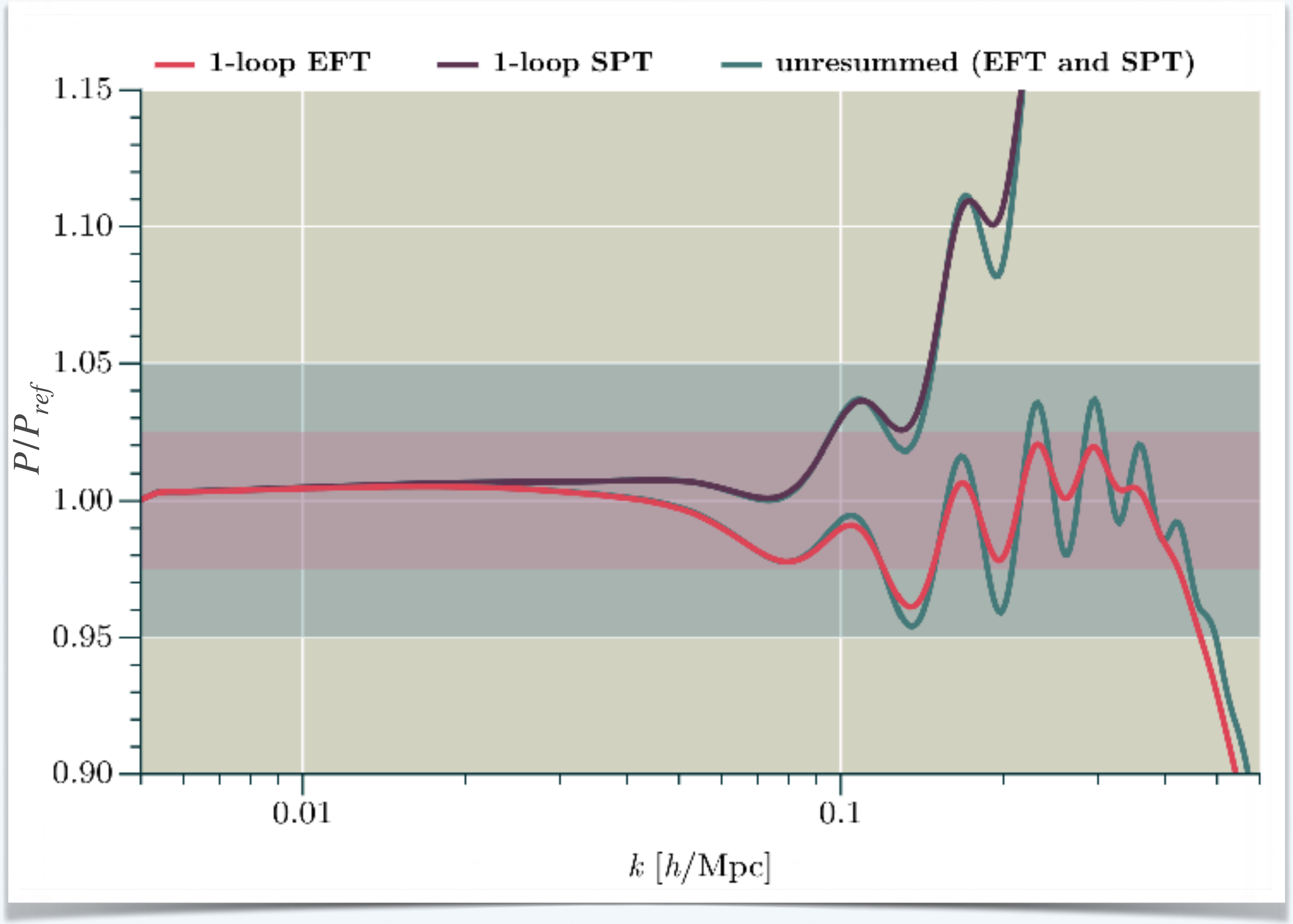


Effective Field Theory of Large Scale Structure

de la Bella et al. 2017
de la Bella et al. 2018

Linear regime SPT works.
Mild non-linear regime SPT breaks down.
Non-linear regime unknown description.

$$P_{EFT} = P_{SPT} - \underbrace{c^2 k^2 P_{11}}_{\text{counterterm}}$$



Traditionally

- One-loop power spectrum in standard perturbation theory
- Einstein-de Sitter approximation for growth functions
- Divergences from small-scale physics

New

- One-loop power spectrum in redshift space
- Most general bias model
- Full time dependence non-linear growth functions
- Novel analytical methods:
  - Split tensor and scalar loop integrals
  - Fabrikant's procedure for Bessel functions
- Counterterms:
  - Uniform notation and language
- Applied the Vlah et al. IR-resummation scheme in redshift space.

Application

- Redshift-space distortions
- Halo bias and WIZCOLA sims

Impact

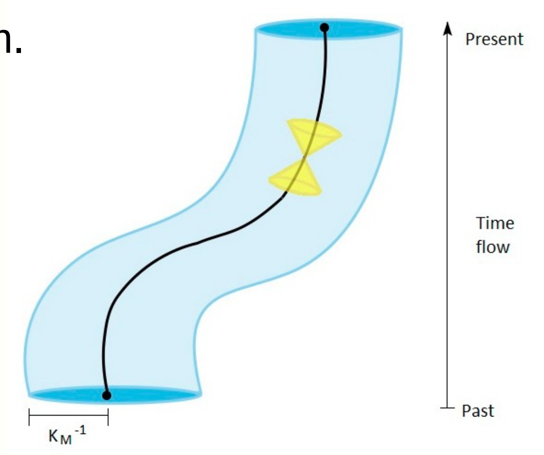
- Accuracy on smaller scales!

HALO POWER SPECTRUM IN REDSHIFT SPACE

Halo power spectrum – bias and redshift models

Understanding the appropriate level of modelling sophistication required to analyse present-day and near-future galaxy surveys.

- Impact of ***bias*** & ***redshift-space*** *models* on the halo power spectrum.
- We develop the most general bias model: **the advective bias model**.
- We use **EFT** to account for non-linear physics and use the **WizCOLA** simulation.
- Risk of **over-fitting**: Bayesian Information Criterion (**BIC**), WizCOLA ensemble average.



One-loop SPT
+
Coevolution bias

	BIC	Min χ2/dof	Δχ2(%)
Linear+ KaiserTree	11.1	1.1	1.8
Linear+Kaiser Halo	11.1	1.0	3.1
Coev+Kaiser Halo	16.6	1.0	3.2
Coev+SPT	16.6	1.0	2.3
Coev+EFT	44.2	1.1	6.9
M&Roy+ KaiserTree	27.6	1.0	2.8
Advect+SPT	38.7	1.1	5.1
Advect+EFT	66.4	1.2	6.0