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:

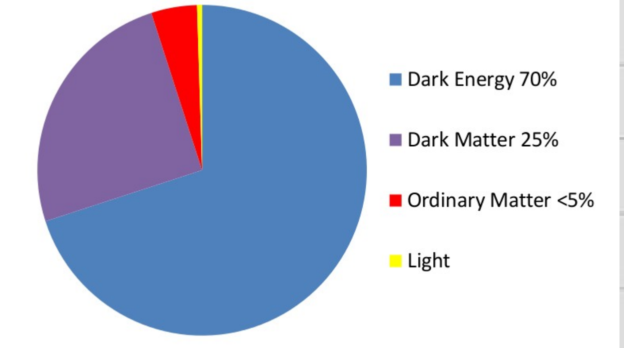
GR + ΛCDM

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

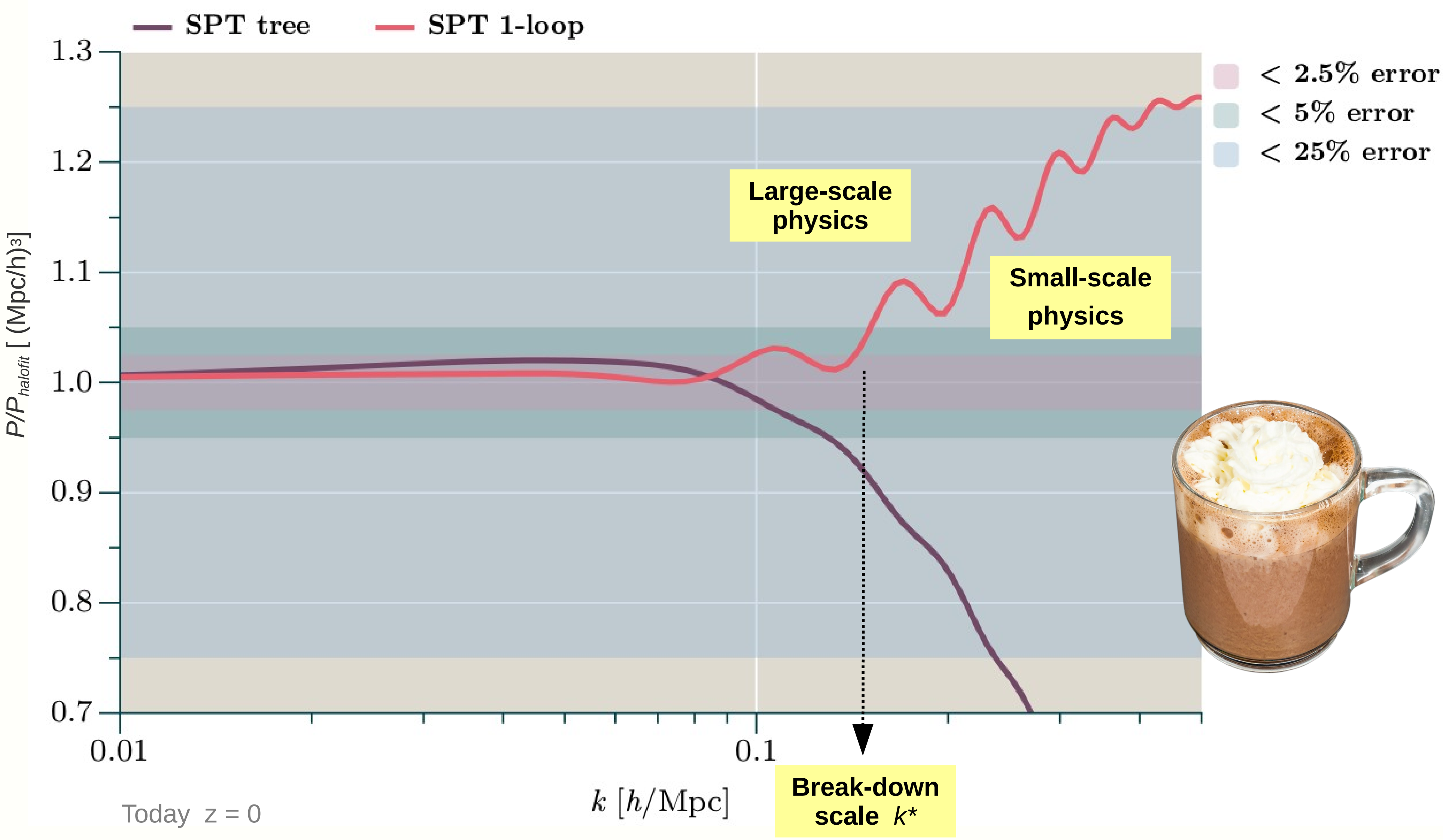
Perturbative solution:

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

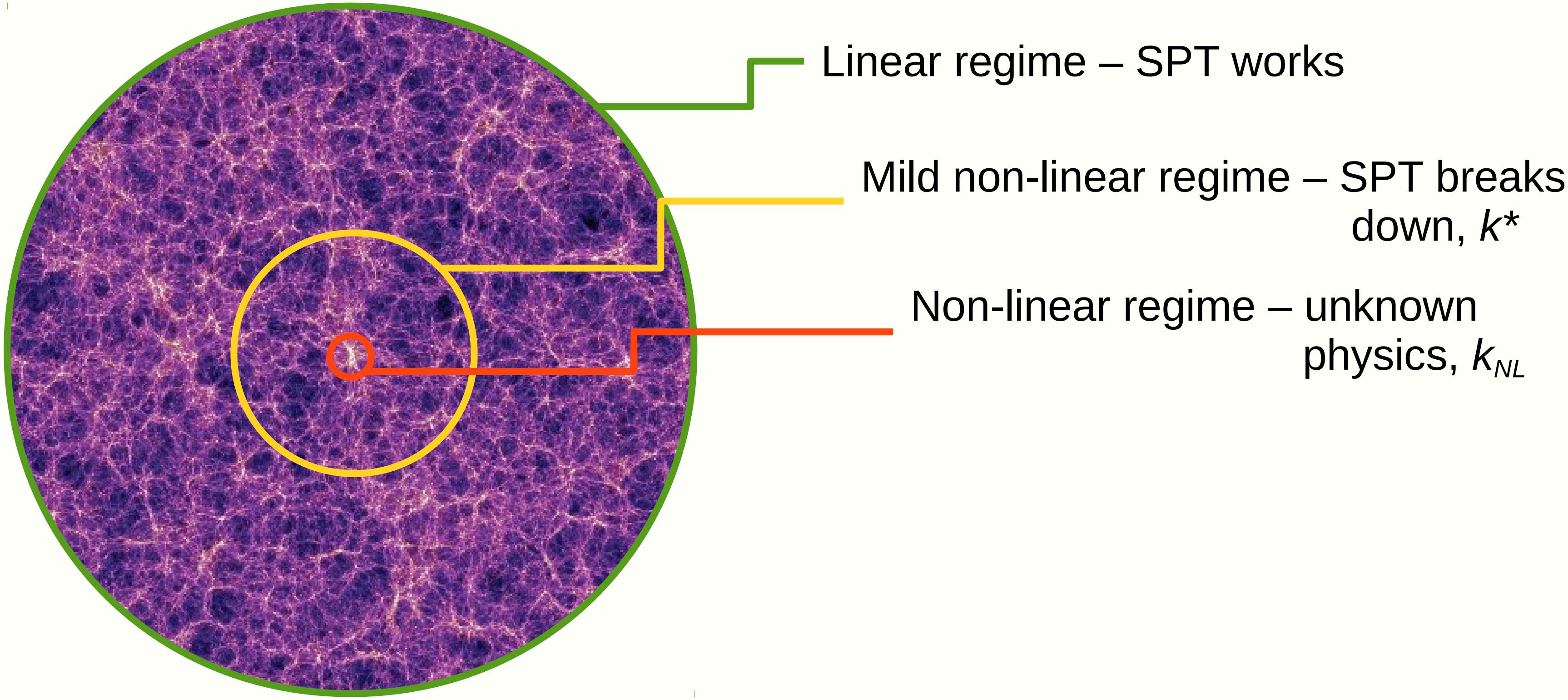
2Point correlation function

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

Standard Perturbation Theory – Predictions vs data



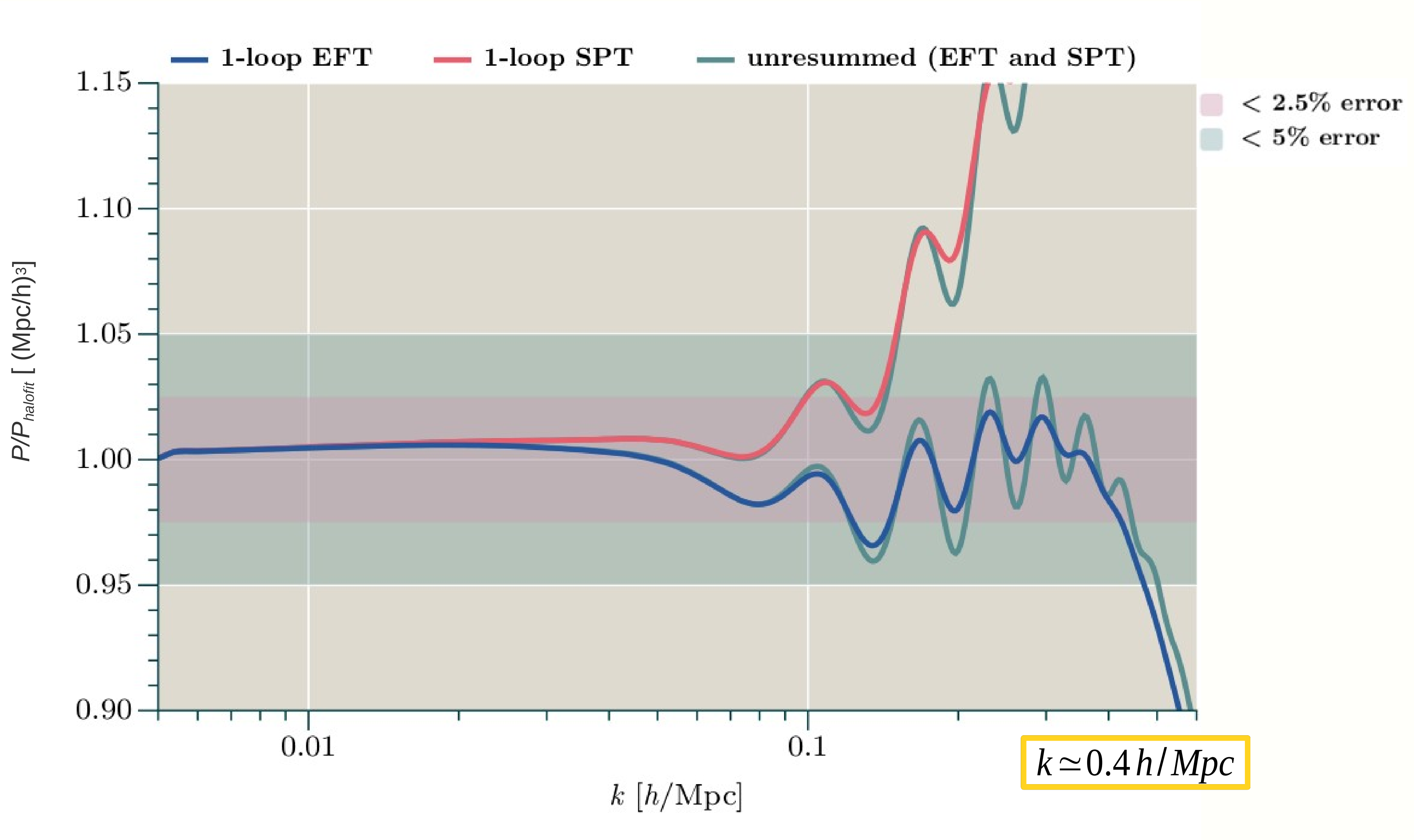
Effective Field Theory – *Small-scale physics*



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

COUNTER-TERM
Nbody simulations

Effective Field Theory – *Predictions vs data*



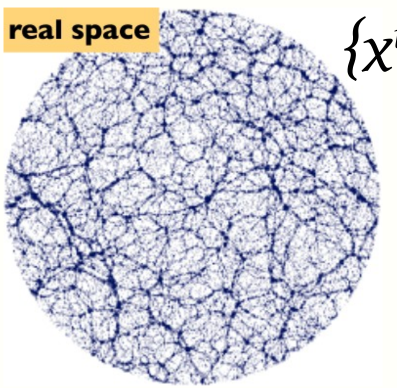
$k \simeq 0.4\, h/Mpc$

… but this is not the whole story

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

Galaxy surveys:

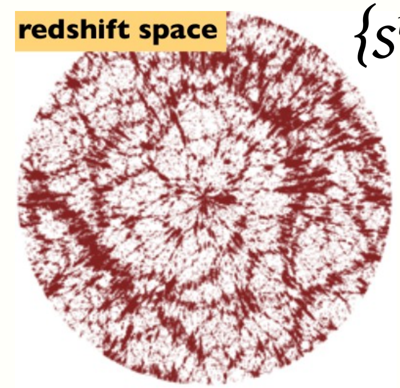
- Infer distances by measuring redshift → **redshift-space distortions**
- The measured power spectra depend on the angle of the **line of sight,** $\mu = \hat{k}\cdot\hat{r}$.



$\{x^i\}$

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

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



$\{s^i\}$

Fourier space

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

$[f]_{\underline{k}} \equiv$ *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 $P_{s,11}(k,\mu,z)\ ,\ P_{s,22}(k,\mu,z)\ ,\ P_{s,13}(k,\mu,z)\ldots$

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

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

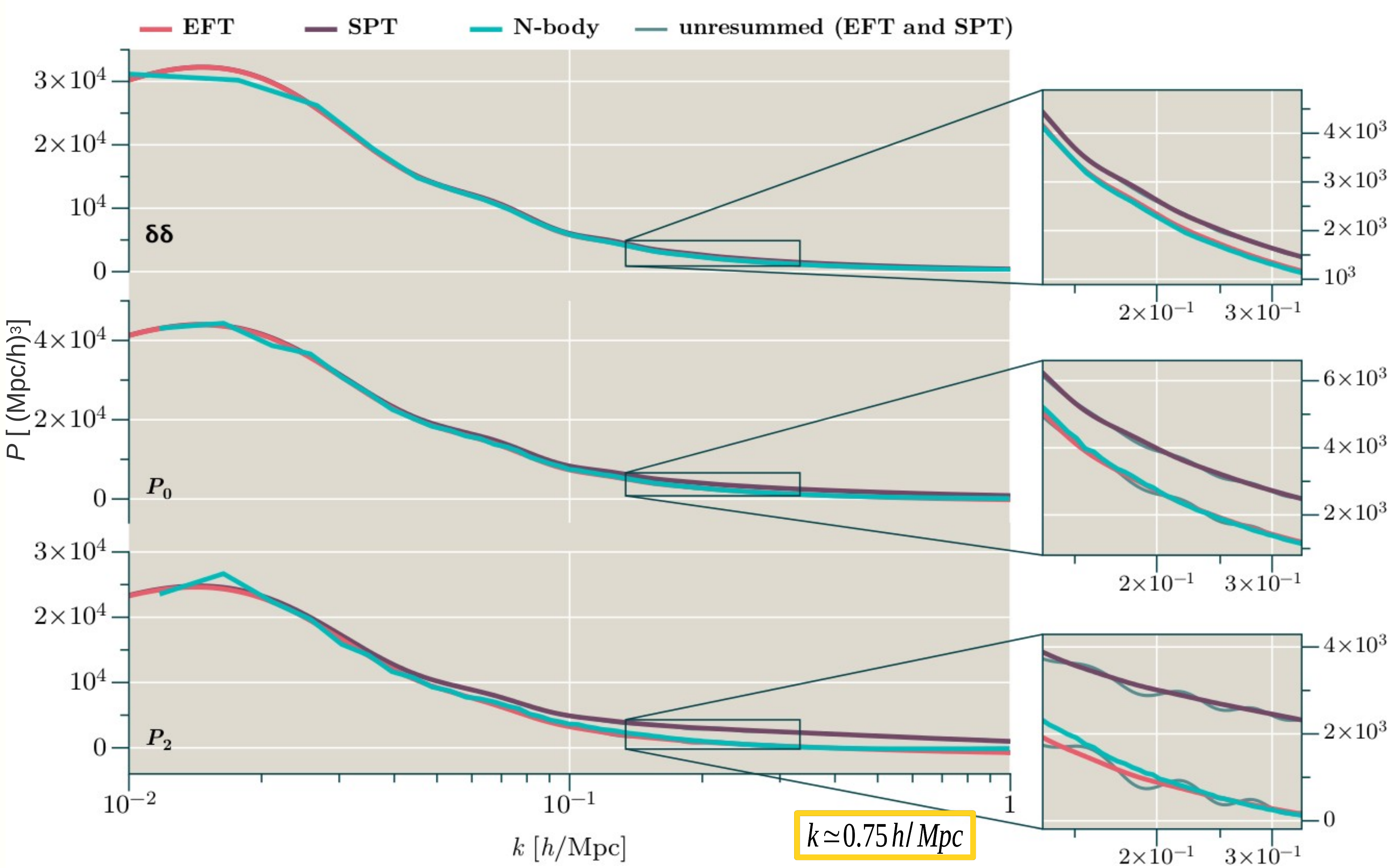
$$\frac{d_{\delta,0}}{k_{NL}^2}=1.88\,Mpc^2/h^2$$

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

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

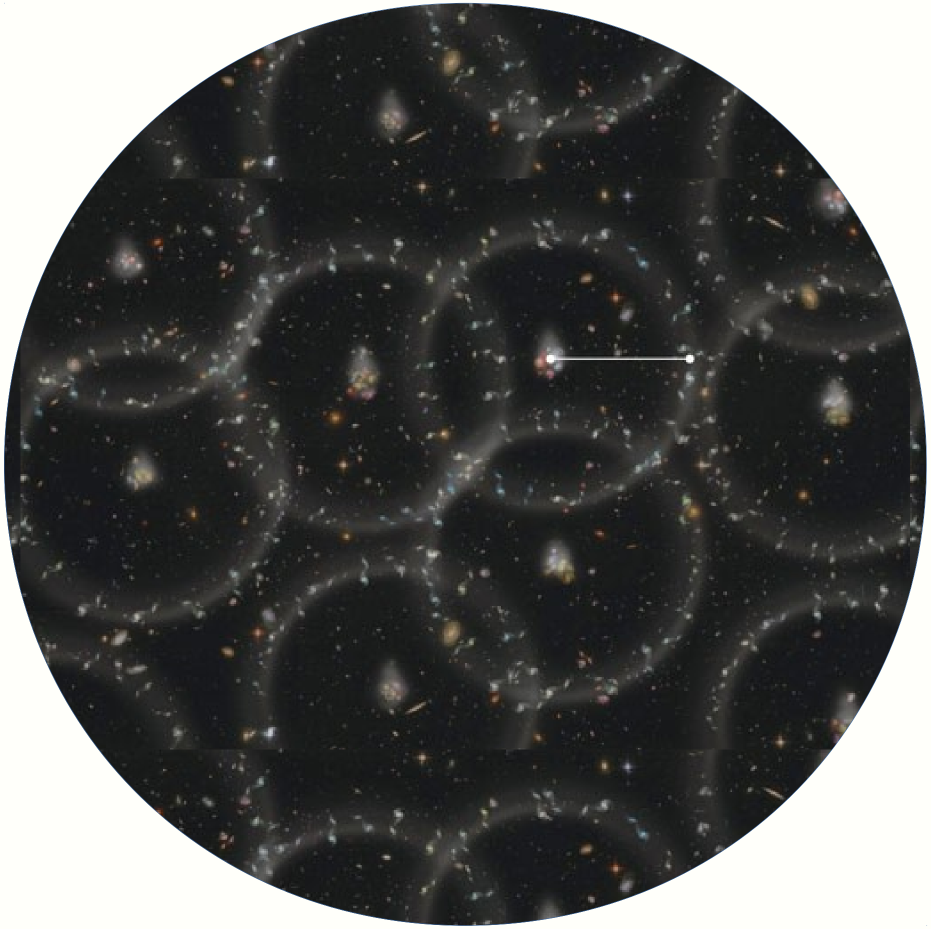
One **counter-term** per each multipole **(N-BODY SIMULATIONS)**

Redshift-space mapping – Prediction vs data



… what about the wiggles?

IR resummation – Large-scale phenomena

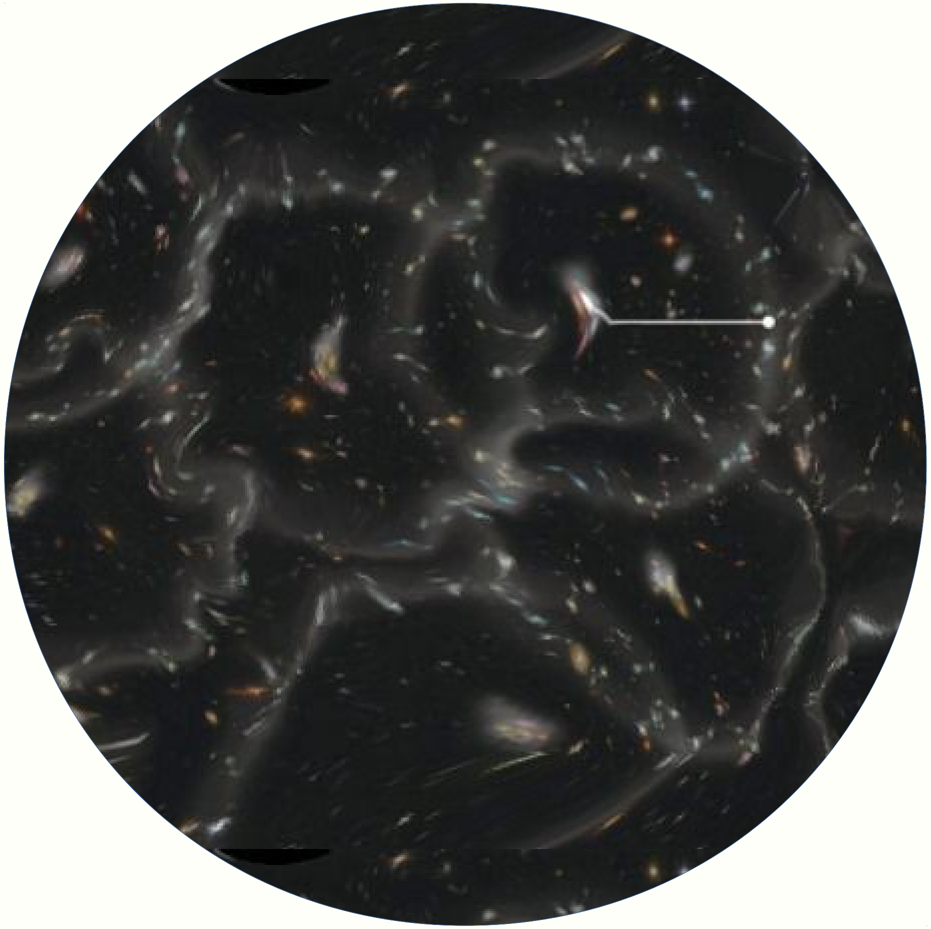


IR resummation – Lagrangian Perturbation

$$P^{IR}(k) = \int d^3 x_q \, e^{-i \underline{k} \cdot \underline{x}_q} \mathscr{K}(\underline{k}, \underline{q}, \underline{\Psi}(\underline{q}))$$

→

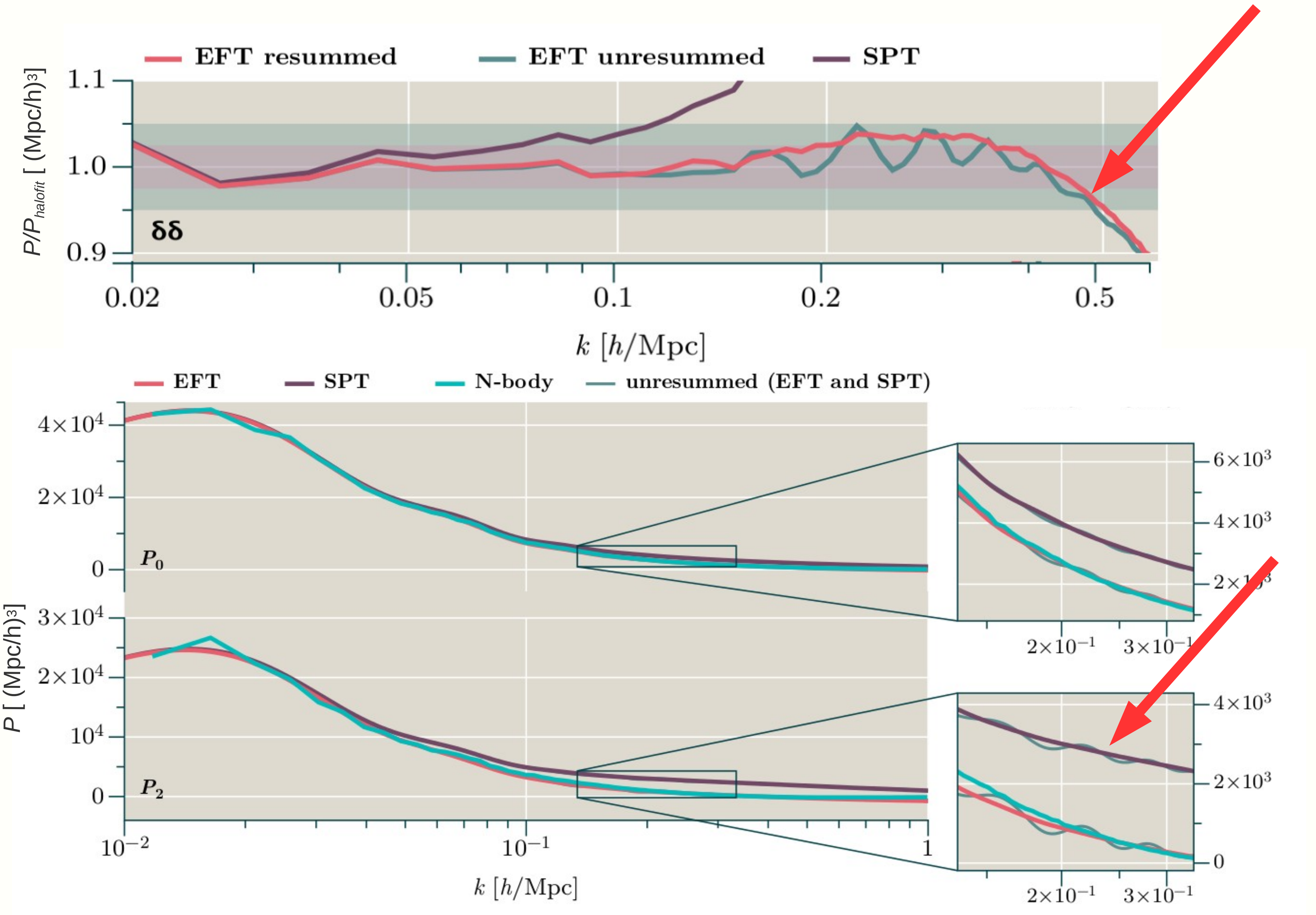
$$P^{IR}(k) = P_{NW}(k) + \int d^3 \underline{x}_q \, e^{-i \underline{k} \cdot \underline{x}_q} \mathscr{K}_W(\underline{k}, \underline{q}, \underline{\boldsymbol{\Psi}}(\underline{q}))$$



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

OSCILLATIONS ARE DAMPED

IR resummation – *Prediction vs data*



In summary –

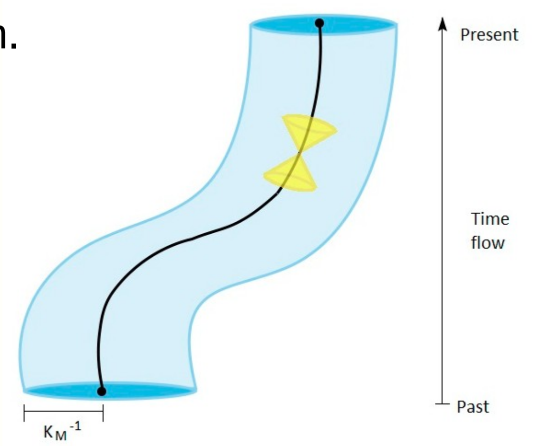
- Effective Field Theory in Real Space to deal with the issues encountered by the Standard Perturbation Theory: predictions are reliable for larger values of *k* since counter-terms parametrise small-scale physics.
- Real surveys provide observational data in redshift space so we need to translate every result into Redshift Space.
- Power Spectra given by surveys appear decomposed in their different Legendre multipoles.
- We decompose the redshift-space one-loop matter power spectrum in its monopole, cuadrupole and hexadecapole components.
- We fit one counter-term for each multipole by using N-body simulations.
- We apply the IR-resummation scheme.
- We compare our results with N-body simulations and see the success of the resummed predictions of EFToLSS in Redshift-Space and validity up to $k \simeq 0.75\, h/Mpc$.

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