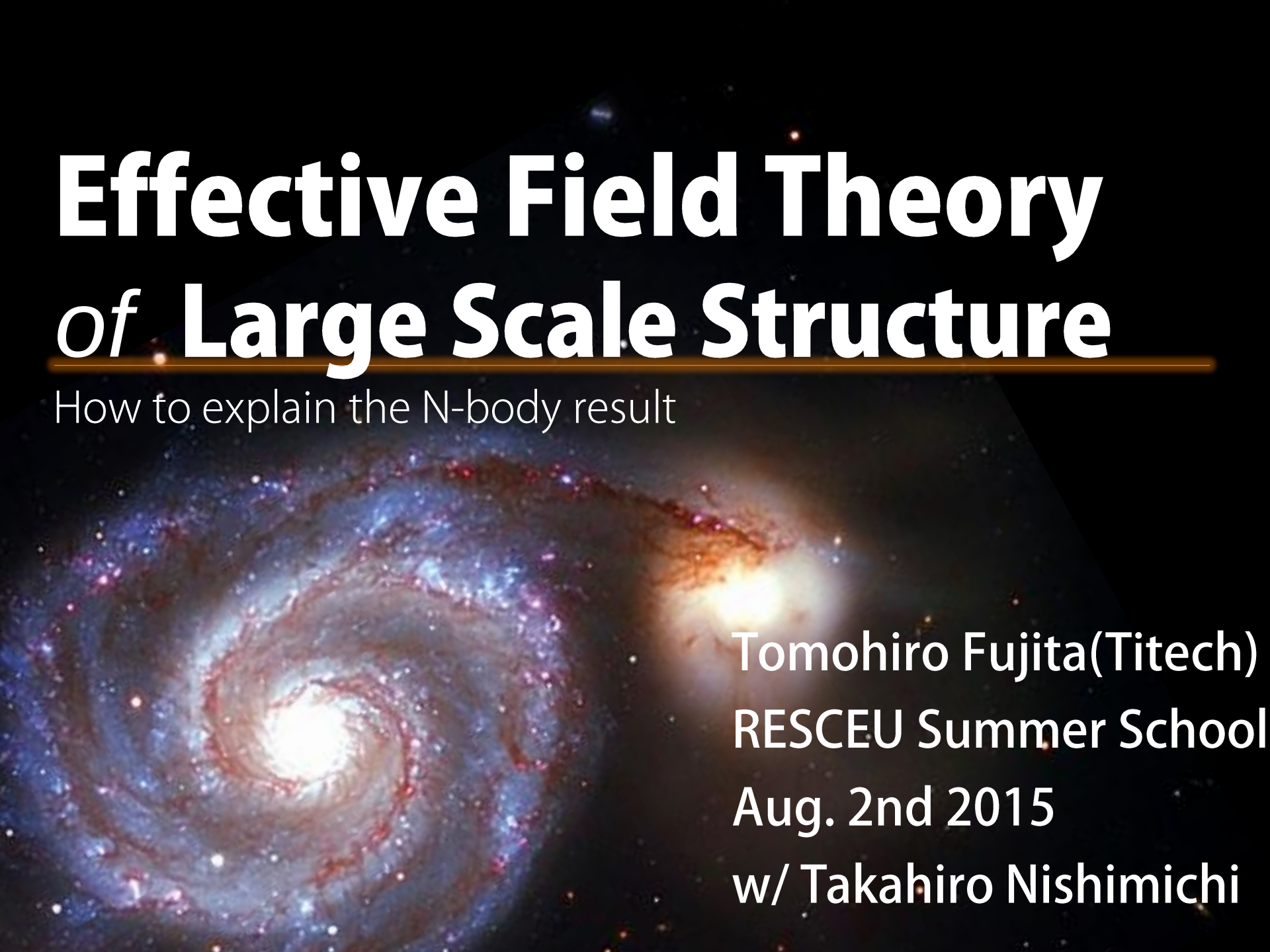
Effective Field Theory *of* Large Scale Structure

How to explain the N-body result



Tomohiro Fujita(Titech)

RESCEU Summer School

Aug. 2nd 2015

w/ Takahiro Nishimichi

Plan of Talk

1. Introduction

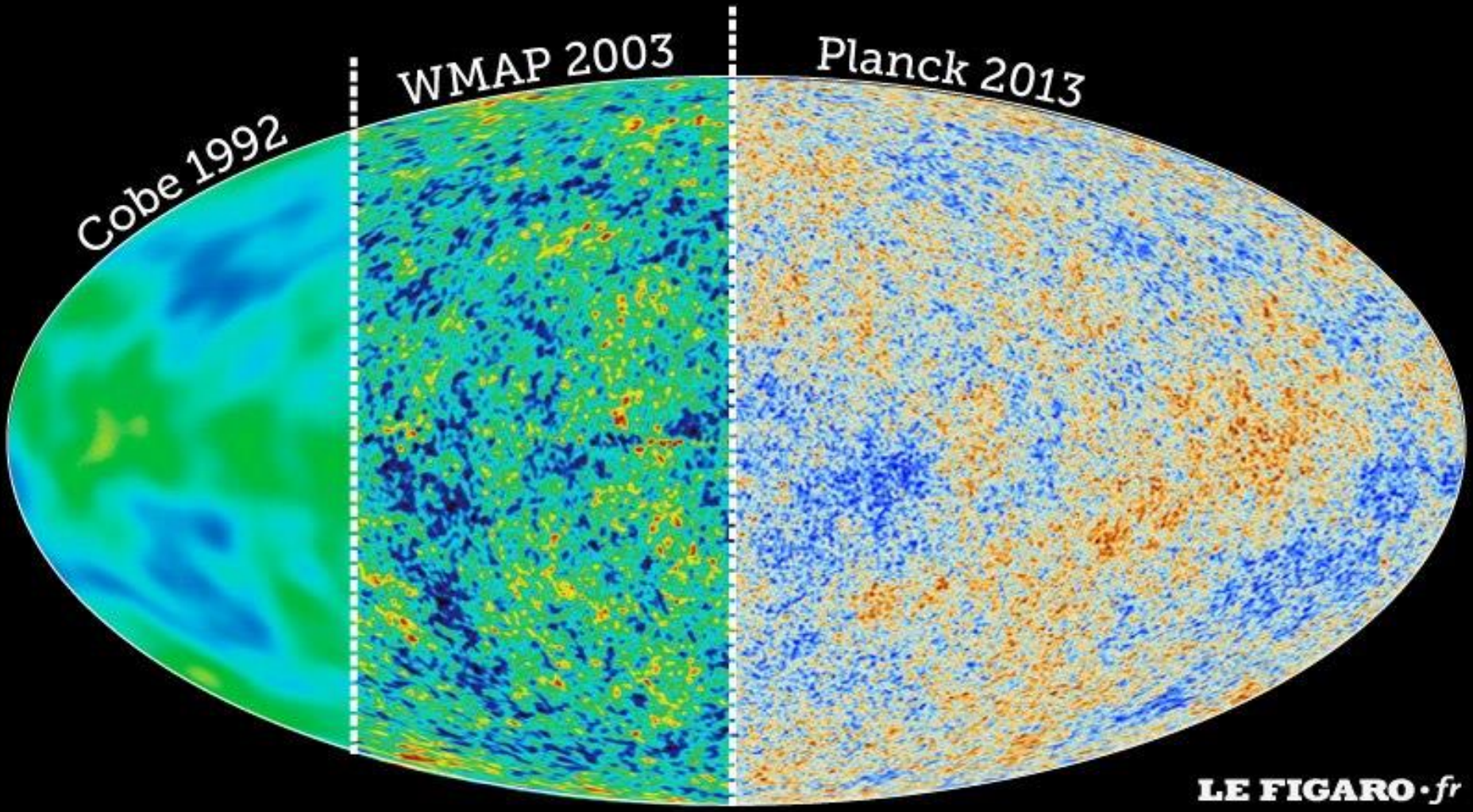
2. SPT

3. EFT

4. Response Function

5. Conclusion

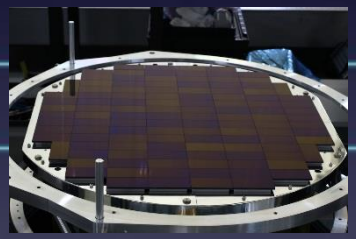
Golden age of CMB:



Golden age of Galaxy Survey

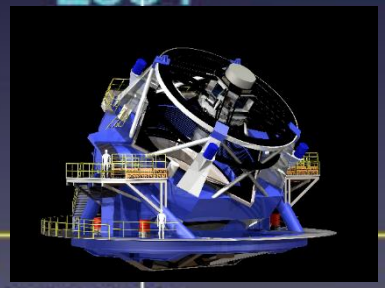
2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

imaging



DES
HSC

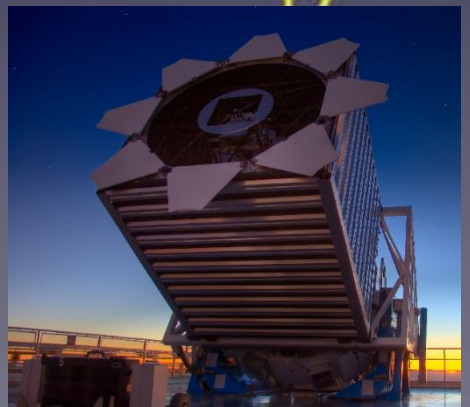
LSST

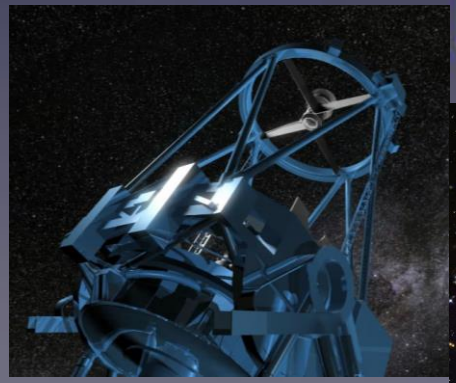


SDSS/BOSS

spectroscopy

PFS





Euclid

WFIRST?

Olympic Tokyo

Fight against

Nonlinearity

©Dark Sky Simulations

CMB: OK with linear pert.

LSS: δ grows on small scale

We need a theory to deal with Nonlinearity

List of papers about EFTofLSS

Pioneer work

- *Cosmological Non-Linearities as an Effective Fluid*
  Baumann et al. [JCAP 1207 (2012) 051]
- *The Effective Field Theory of Cosmological Large Scale Structures*
  Carrasco et al. [JHEP 1209 (2012) 082]

Development

- *The 2-loop matter power spectrum and the IR-safe integrand*
  Carrasco et al. [JCAP 1407 (2014) 056]
- *The Effective Field Theory of Large Scale Structures at Two Loops*
  Carrasco et al. [JCAP 1407 (2014) 057]
- *On the Renormalization of the Effective Field Theory of Large Scale Structures*
  Pajer et al. [JCAP 1308 (2013) 037]
- *Effective field theory of dark matter and structure formation: Semianalytical results*
  Hertzberg [Phys.Rev. D89 (2014) 4, 043521]
- *The Lagrangian-space Effective Field Theory of Large Scale Structures*
  Porto et al. [JCAP 1405 (2014) 022]
- *The One-Loop Matter Bispectrum in the Effective Field Theory of Large Scale Structures*
  Angulo et al. [arXiv:1406.4143]
- *The IR-resummed Effective Field Theory of Large Scale Structures*
  Senatore & Zaldarriaga [JCAP 1502 (2015) 02, 013]
- *The EFT of Large Scale Structures at All Redshifts: Analytical Predictions for Lensing*
  Foreman et al. [arXiv:1503.01775]
- *On the reach of perturbative methods for dark matter density fields*
  Baldauf et al. [arXiv:1507.02255]
- *The Effective Field Theory of Large Scale Structure at Two Loops: the apparent scale dependence of the speed of sound*
  Baldauf et al. [arXiv:1507.02256]
- *Precision Comparison of the Power Spectrum in the EFTofLSS with Simulations*
  Foreman et al. [arXiv:1507.05326]

Application

- *Bias in the Effective Field Theory of Large Scale Structures*
  L. Senatore [arXiv:1406.7843]
- *Redshift Space Distortions in the Effective Field Theory of Large Scale Struct*
  Senatore et al. [arXiv:1409.1225]
- *Analytic Prediction of Baryonic Effects from the EFT of Large Scale Structure*
  Lewandowski et al. [JCAP 1505 (2015) 05, 019]
- On the Statistics of Biased Tracers in the Effective Field Theory of Large Sca
  Angulo et al. [arXiv:1503.08826]

Plan of Talk

1. Introduction

2. SPT

3. EFT

4. Response Function

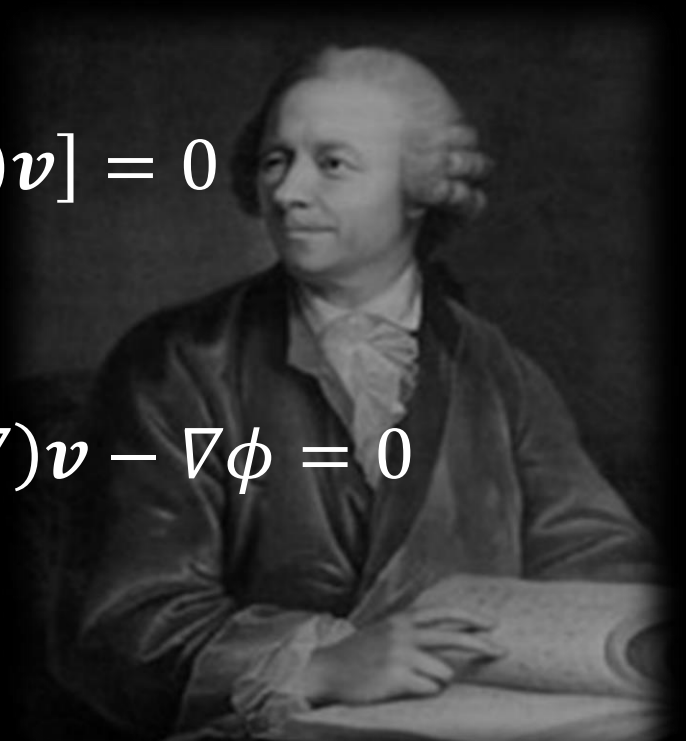
5. Conclusion

SPT = standard perturbation theory

assumes DM dynamics is approximated by pressureless fluid & solves fluid eqs. perturbatively.

Continuity eq. $\delta' + \nabla \cdot [(1+\delta)\boldsymbol{v}] = 0$

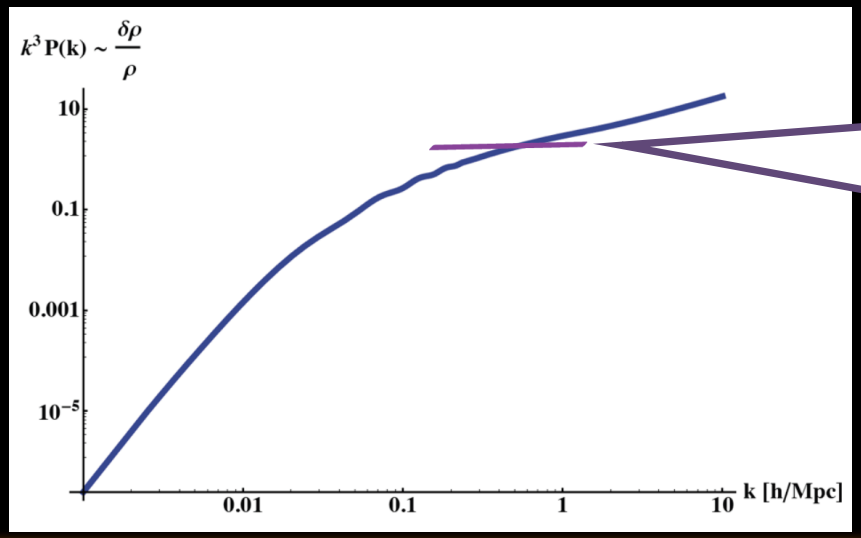
Euler eq. $\boldsymbol{v}' + \mathcal{H}\boldsymbol{v} + (\boldsymbol{v}\cdot\nabla)\boldsymbol{v} - \nabla\phi = 0$



We can solve the EoMs perturbatively

$$\delta = \delta_1 + \delta_2 + \delta_3 \cdots$$

SPT relies on perturbation of $\delta \ll 1$



$\delta > 1$
on smaller scales

SPT fails on smaller scales, $k \gtrsim 0.1h\mathrm{Mpc}^{-1}$

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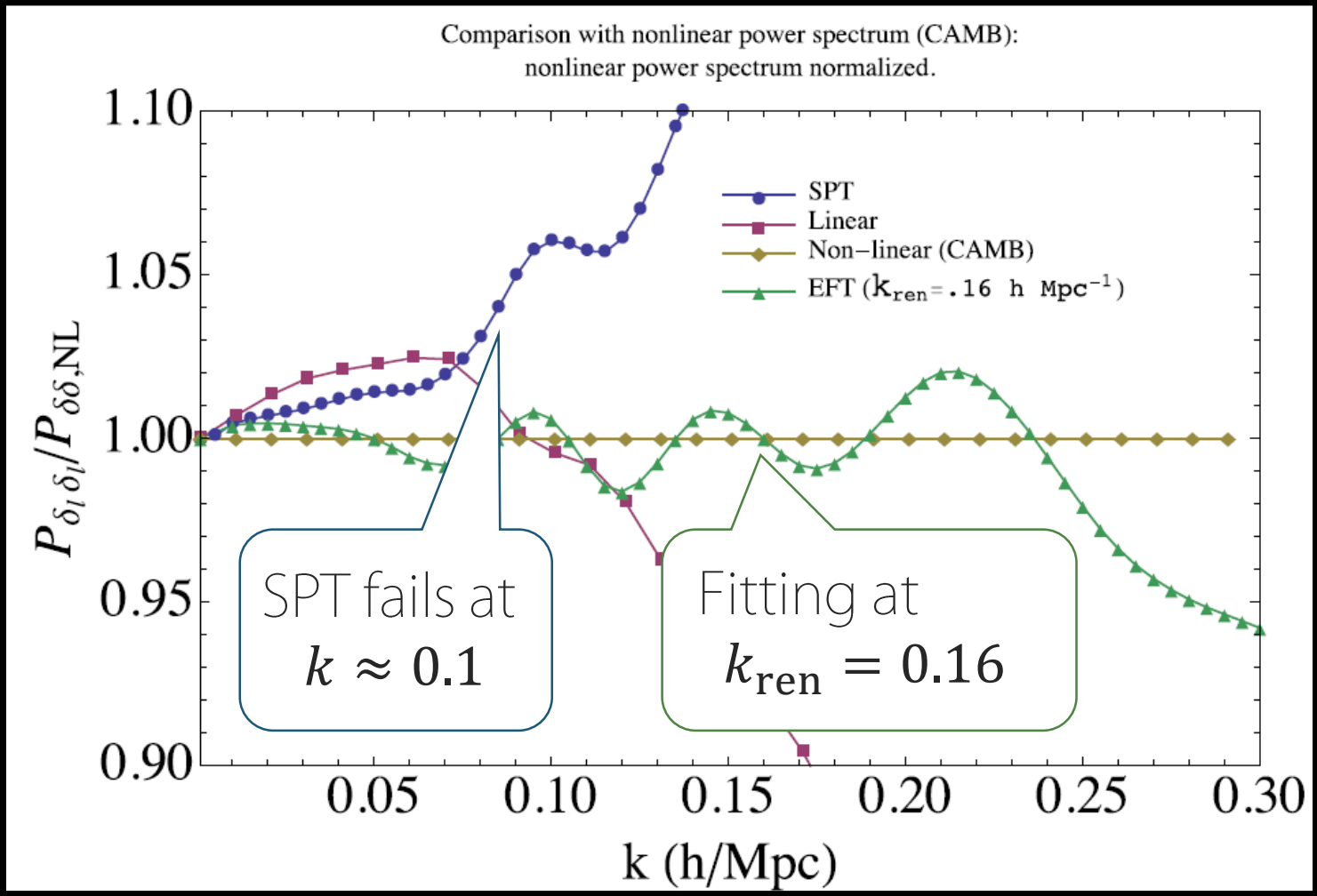
EFT = effective field theory

$\approx$ SPT + fitting parameter

Parameter is fixed s.t. $P_{\delta}(k_{\mathrm{ren}})$ in EFT of LSS agrees with observed or simulated $P_{\delta}(k_{\mathrm{ren}})$.

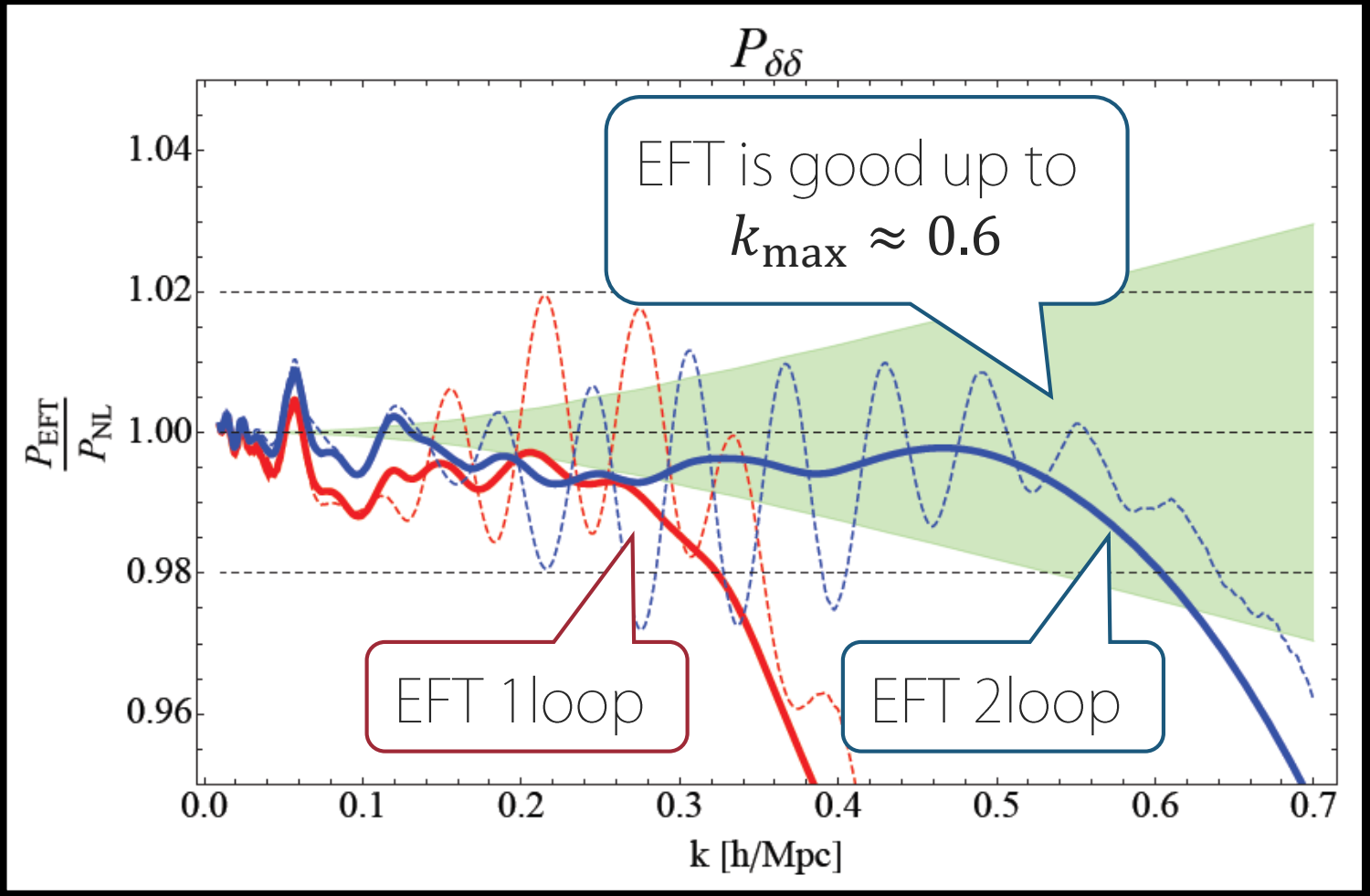
EFT prediction is consistent with $P_{\mathrm{N-body}}$ up to much smaller scale than SPT.

1loop result of EFT



- *The Effective Field Theory of Cosmological Large Scale Structures*
  Carrasco et al. [JHEP 1209 (2012) 082]

2loop result of EFT+IR resummation

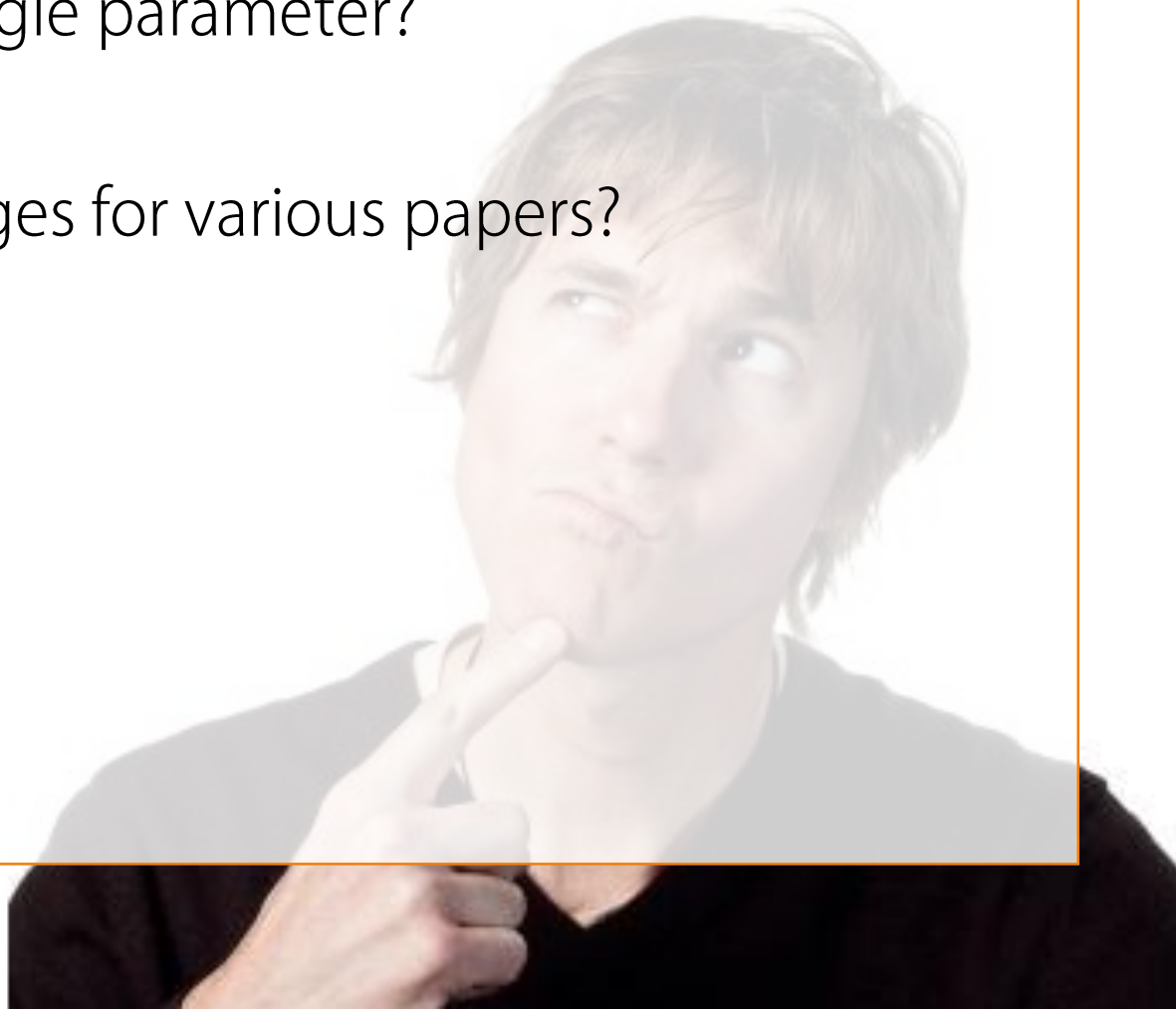


The IR-resummed Effective Field Theory of Large Scale Structures
Senatore & Zaldarriaga [JCAP 1502 (2015) 02, 013]

Questions

- Is non-linear dynamics of DM really described by adding a single parameter?

- Why $k_{\mathbf{max}}$ changes for various papers?



Change of $k_{\max}$ $P_\delta(z=0)$

Carrasco et al. [JHEP 1209 (2012) 082]	$k_{\max}^{1loop} = 0.24h\mathrm{Mpc}^{-1}$
Carrasco et al. [JCAP 1407 (2014) 057]	$k_{\max} = 0.6h\mathrm{Mpc}^{-1}$
Senatore&Zaldarriaga [JCAP1502(2015)02,013]	$k_{\max} \sim 0.6h\mathrm{Mpc}^{-1}$
Foreman&Senatore [arXiv: 1503.01775]	$k_{\max} = 0.6h\mathrm{Mpc}^{-1}$
Baldauf et al. [arXiv: 1507.02256]	$k_{\max} \approx 0.3h\mathrm{Mpc}^{-1}$
Foreman et al. [arXiv:1507.05326]	$k_{\max} = 0.34h\mathrm{Mpc}^{-1}$

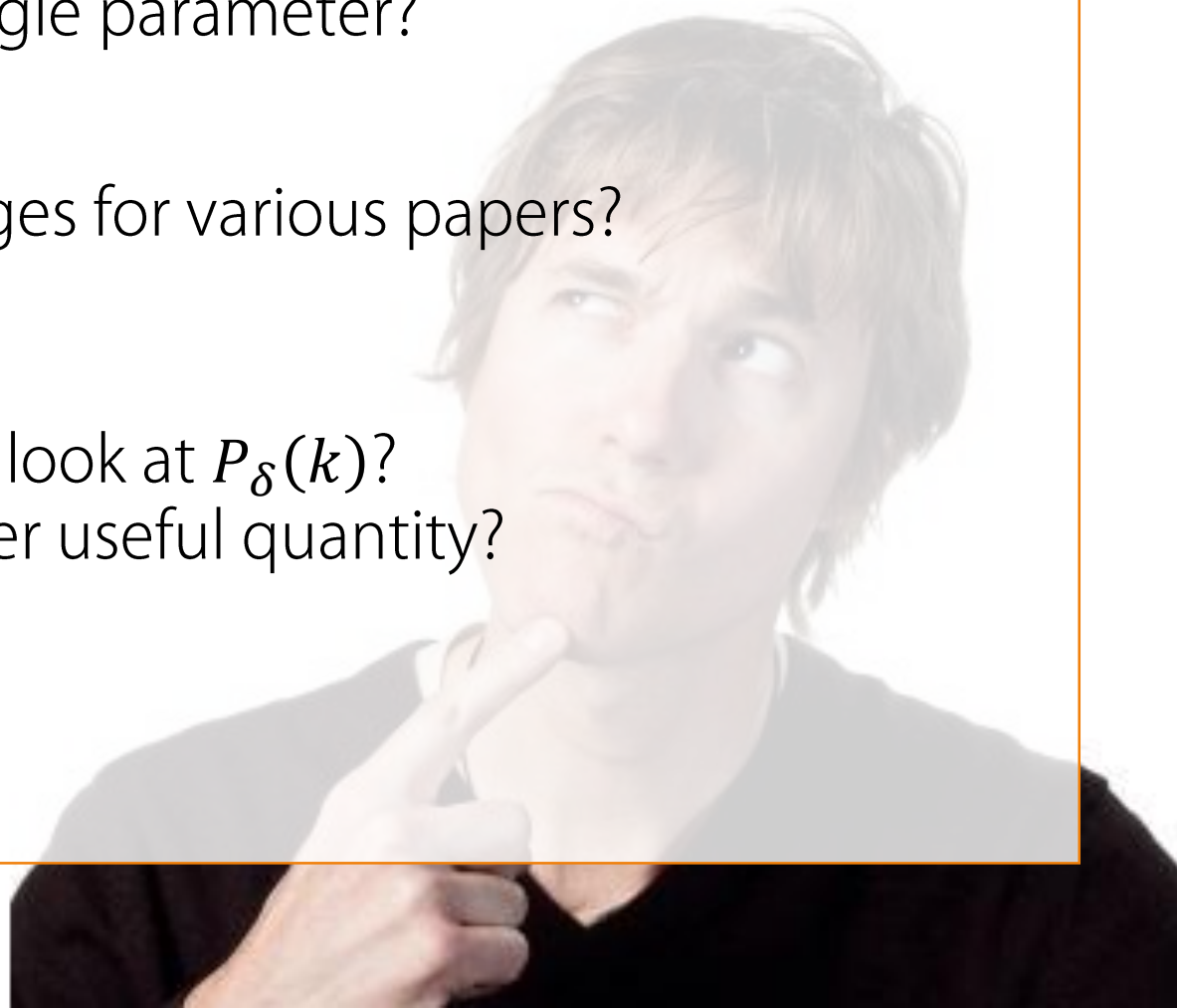
We found EFT describes the correct nonlinear dynamics up to $\boldsymbol{k \approx 0.3}$

Questions

- Is non-linear dynamics of DM really described by adding a single parameter?

- Why $k_{\mathbf{max}}$ changes for various papers?

- Is it sufficient to look at $P_{\delta}(k)$?
  Is there any other useful quantity?



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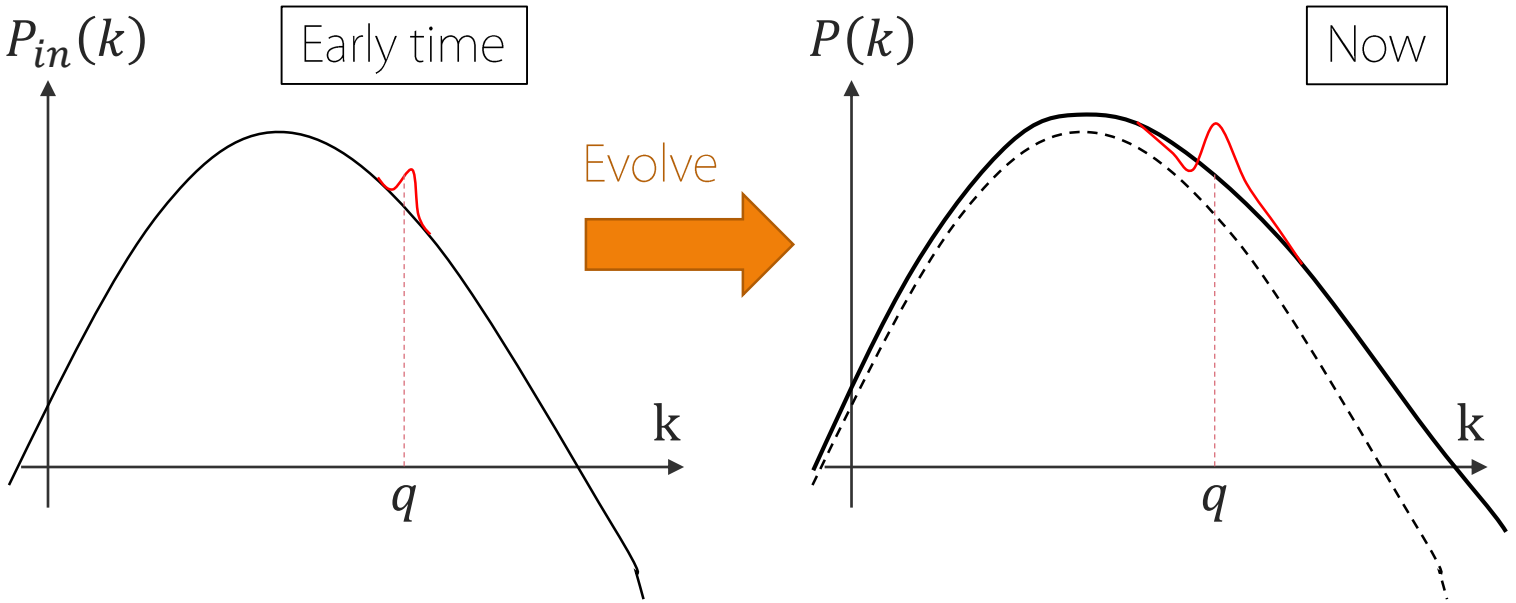
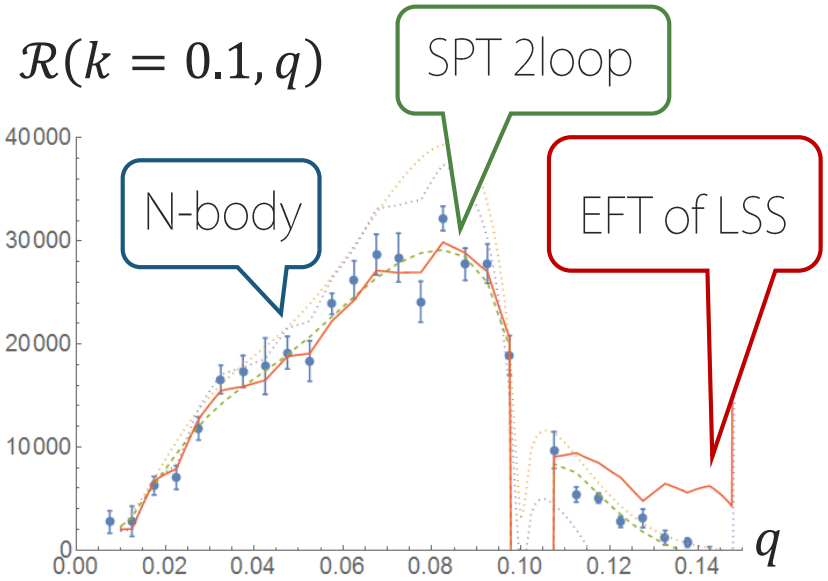
Response Function

$$\mathcal{R}(k,q) \equiv \frac{\delta P(k)}{\delta P_{11}(q)}$$

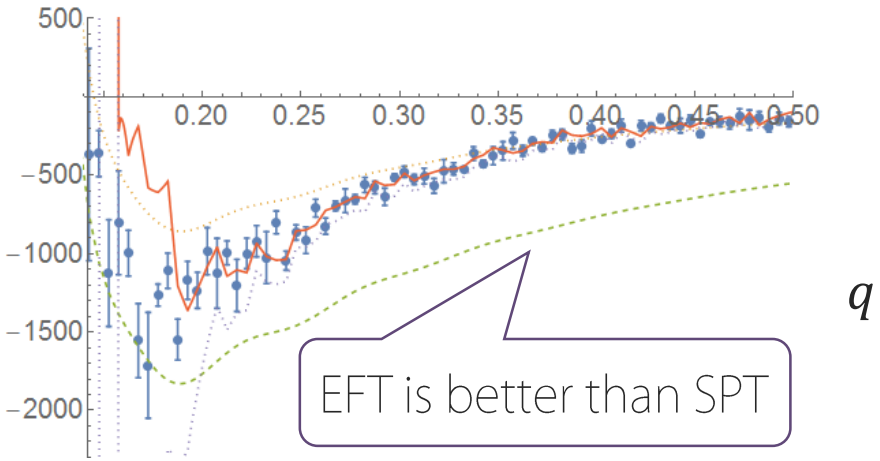
$\mathcal{R}$ indicates how resultant $P(k)$ changes,
if one perturbs the initial condition $P_{11}(q)$.



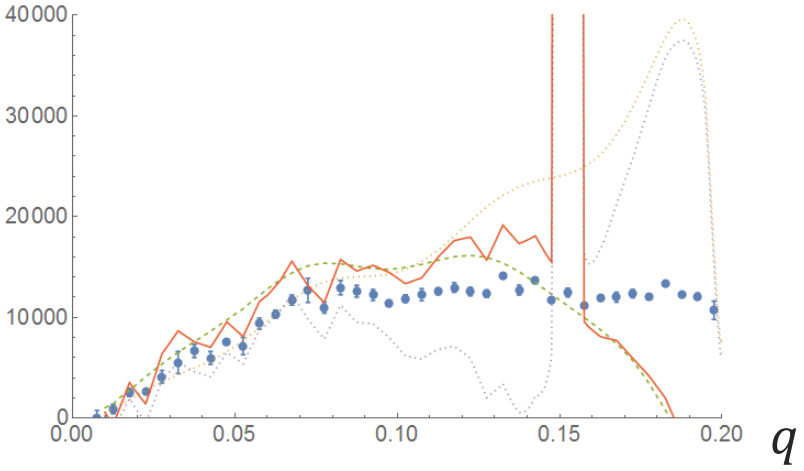
$\mathcal{R}(k=0.1,q)$



$\mathcal{R}(k=0.1,q)$

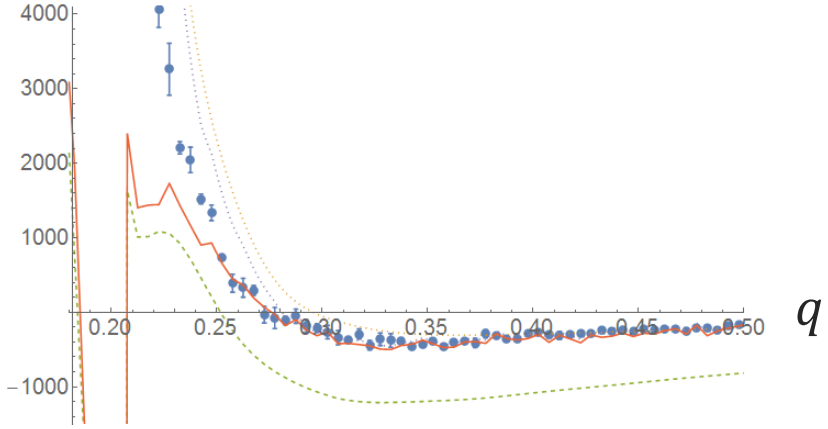


$\mathcal{R}(k=0.2,q)$

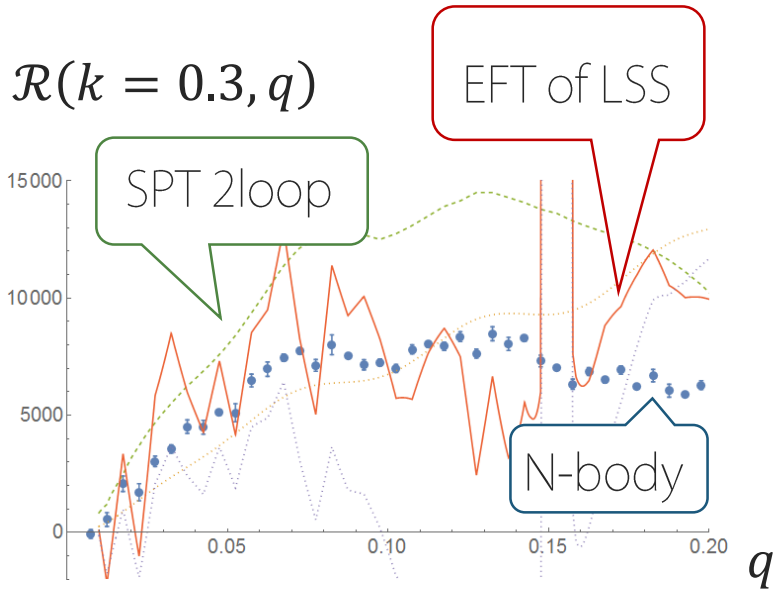


$\mathcal{R}(k=0.2,q)$

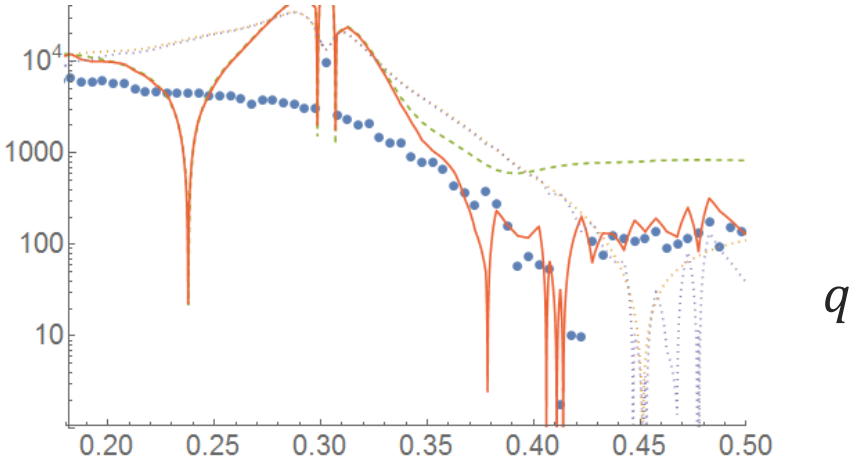
$k_{\mathrm{ren}}=0.15$



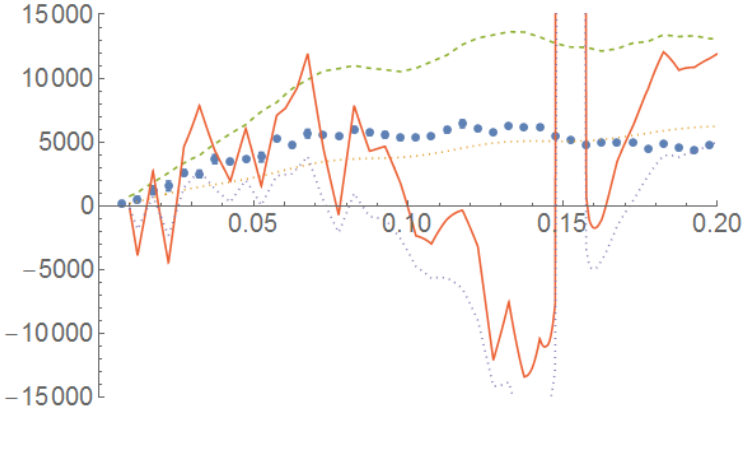
$\mathcal{R}(k=0.3,q)$



$\mathcal{R}(k=0.3,q)$

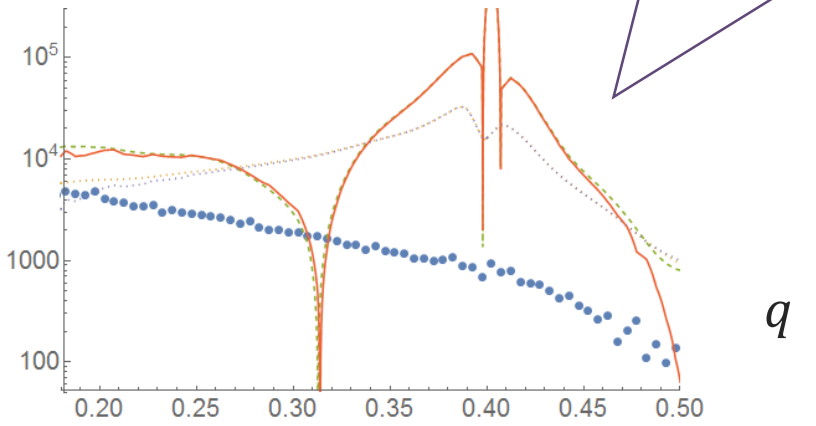


$\mathcal{R}(k=0.4,q)$



$\mathcal{R}(k=0.4,q)$

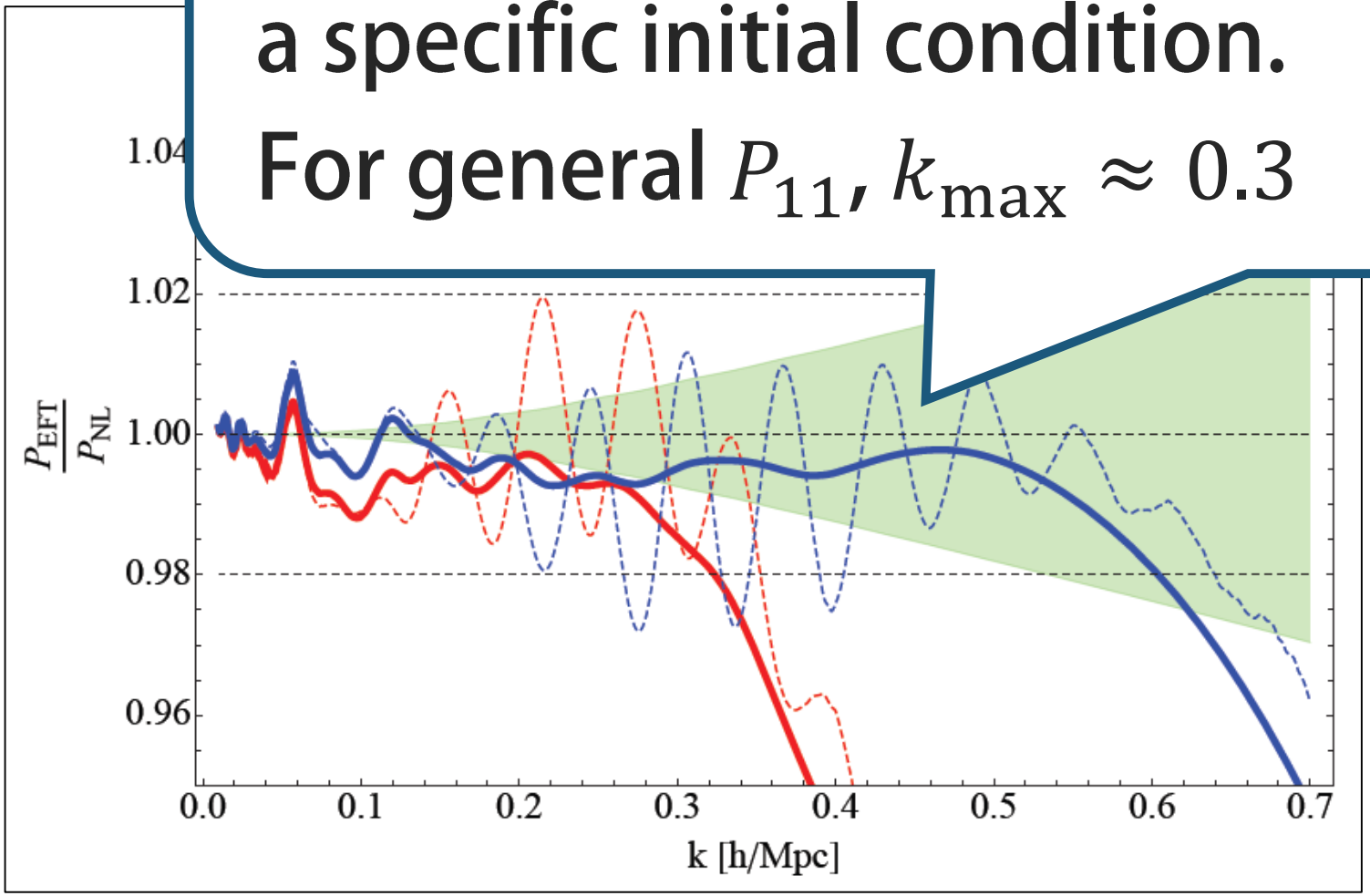
EFT fails to reproduce $\mathcal{R}_{NL}$



2loop r

It's an accidental success for a specific initial condition.

For general P_{11}, $k_{\max} \approx 0.3$



The IR-resummed Effective Field Theory of Large Scale Structures
Senatore & Zaldarriaga [JCAP 1502 (2015) 02, 013]

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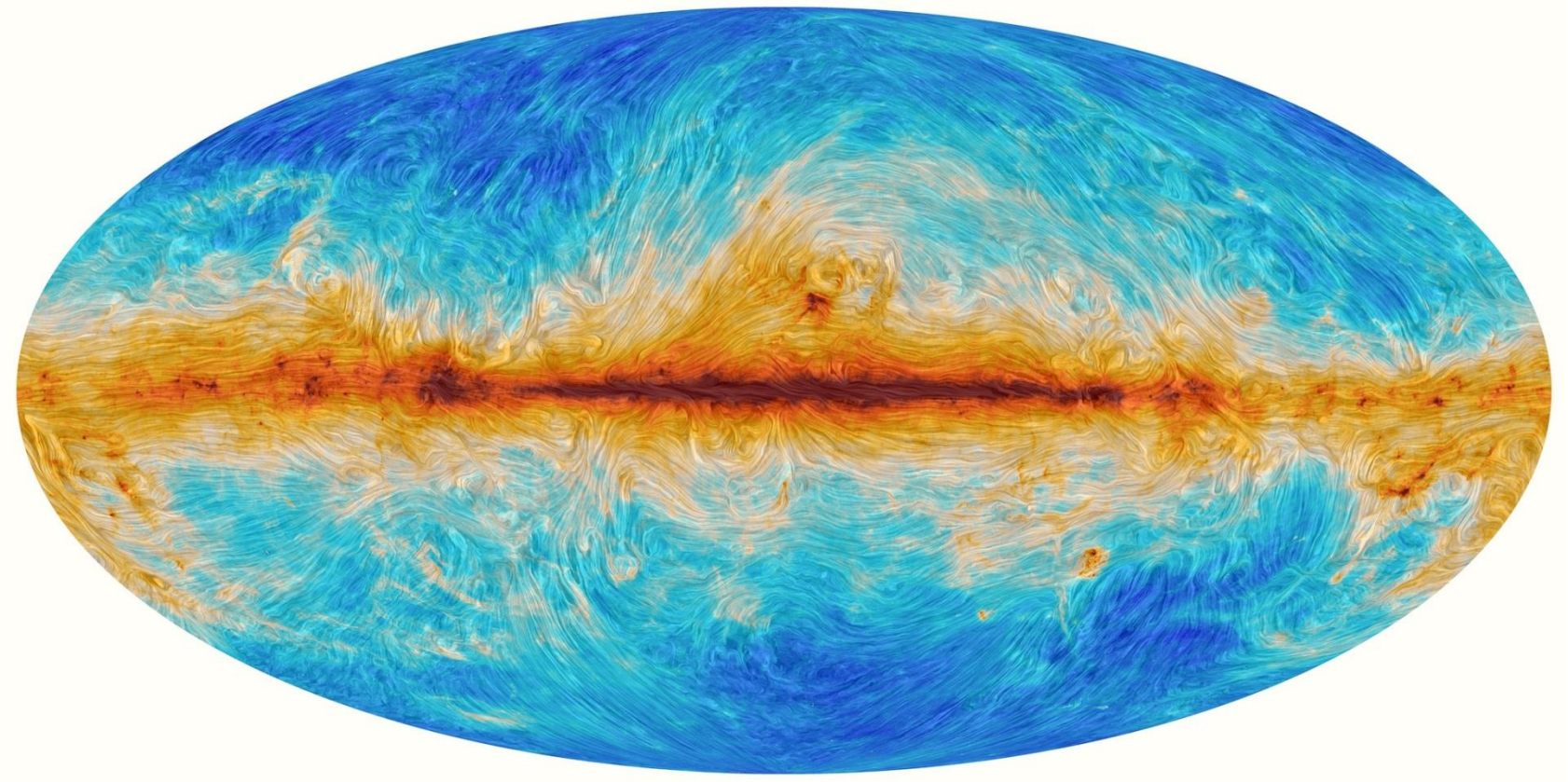
Conclusion

- To exploit upcoming galaxy surveys, we need to develop a theory to deal with non-linearity.
  EFT of LSS is a promising theoretical foundation.
- Even if a theory reproduces $P_\delta(k)$ for an initial condition, it does not guarantees the correct dynamics.
  The response function $\mathcal{R}$ is a powerful discriminator.
- $\mathcal{R}(k,q)$ in EFT of LSS shows that 2loop EFT is consistent with N-body simulation up to $k \approx 0.3h\mathrm{Mpc}^{-1}$.



Thank you!