On the UV sensitivity of the power spectrum response function

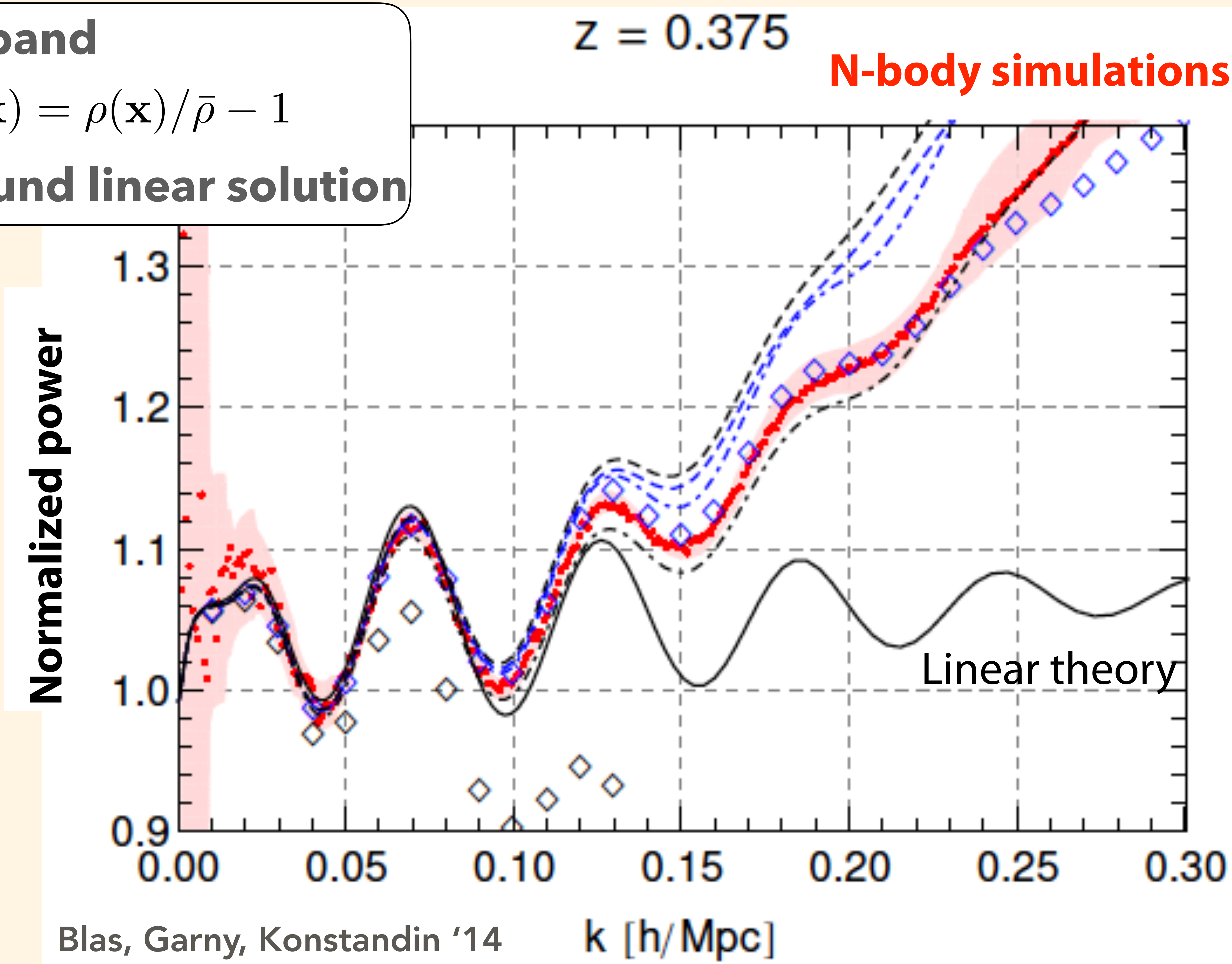
Takahiro Nishimichi, Atsushi Taruya (YITP),
Francis Bernardeau, Stephane Colombi (IAP),
Anaelle Halle (MPA)

PT in trouble

Expand

$$\delta(\mathbf{x}) = \rho(\mathbf{x})/\bar{\rho} - 1$$

around linear solution



Blas, Garny, Konstandin ‘14

PT in trouble

Expand

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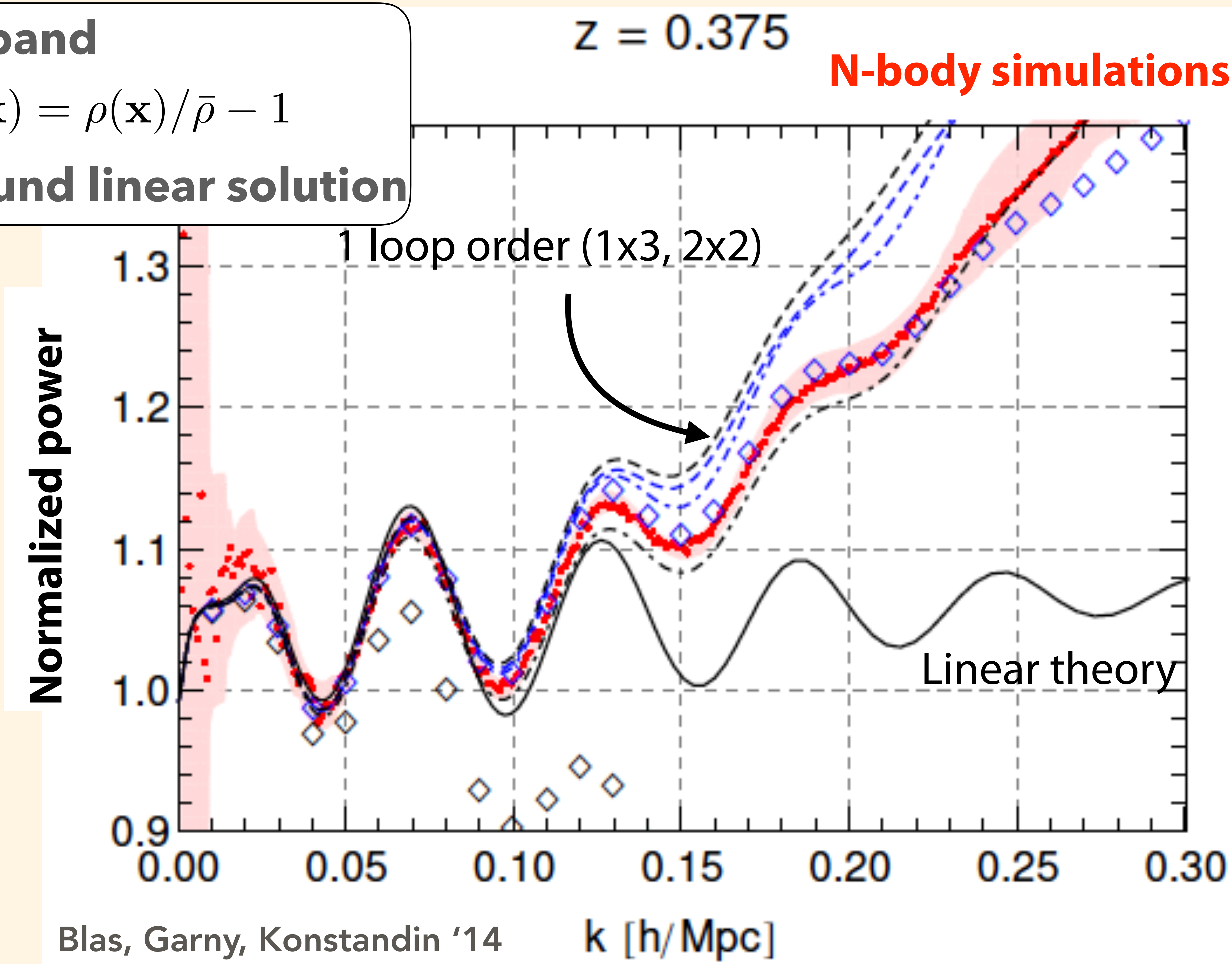

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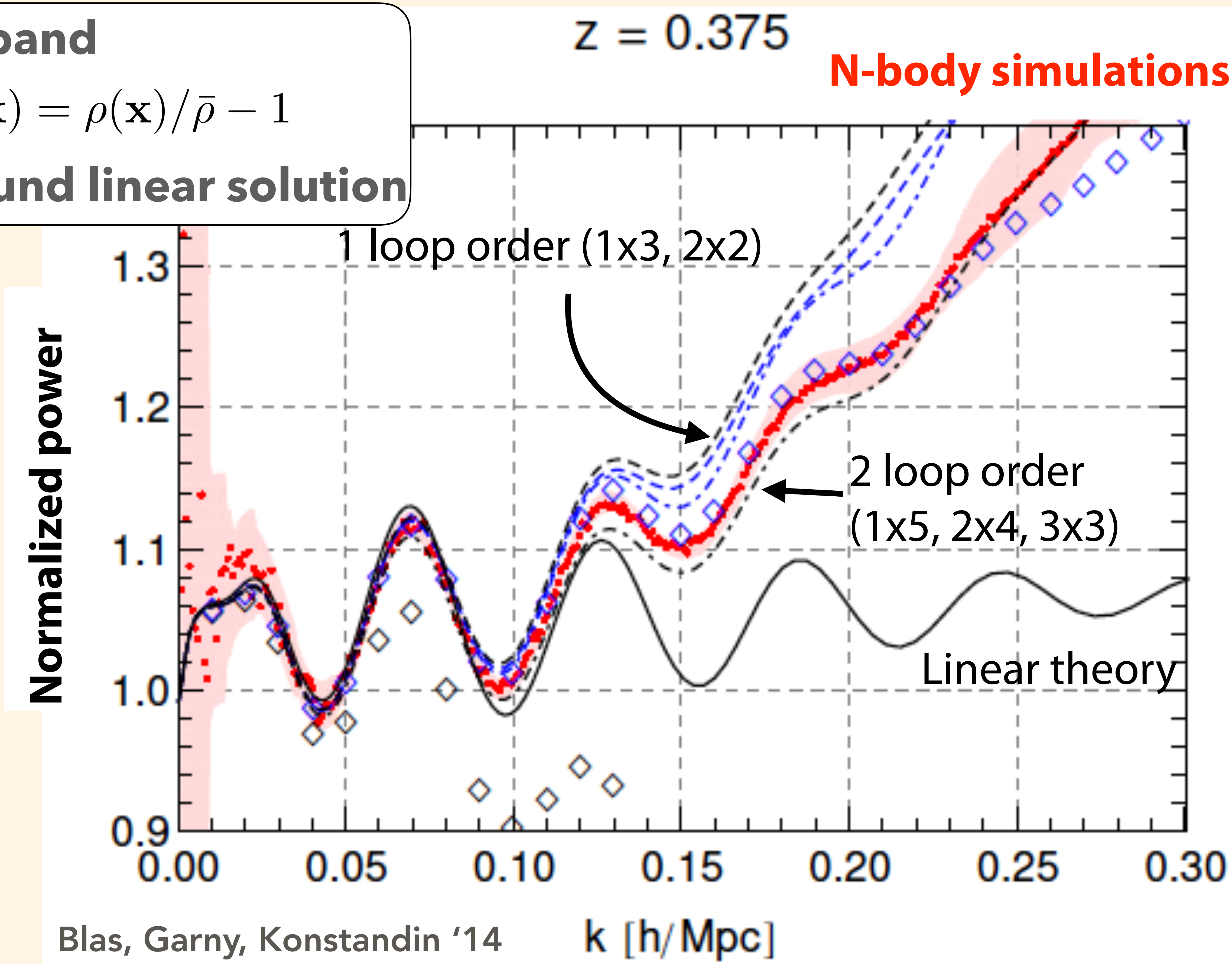

Blas, Garny, Konstandin '14

PT in trouble

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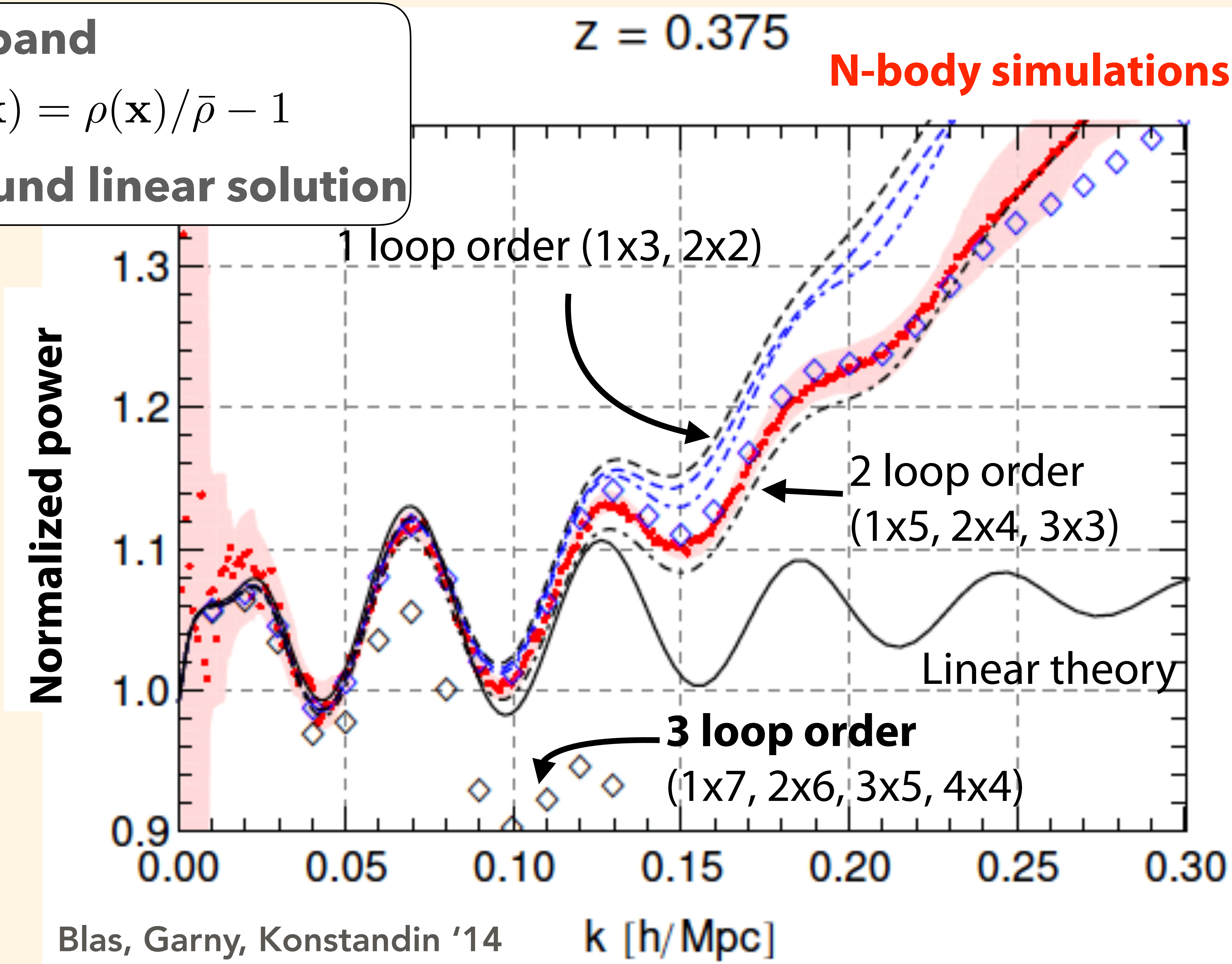

Blas, Garny, Konstandin '14

PT in trouble

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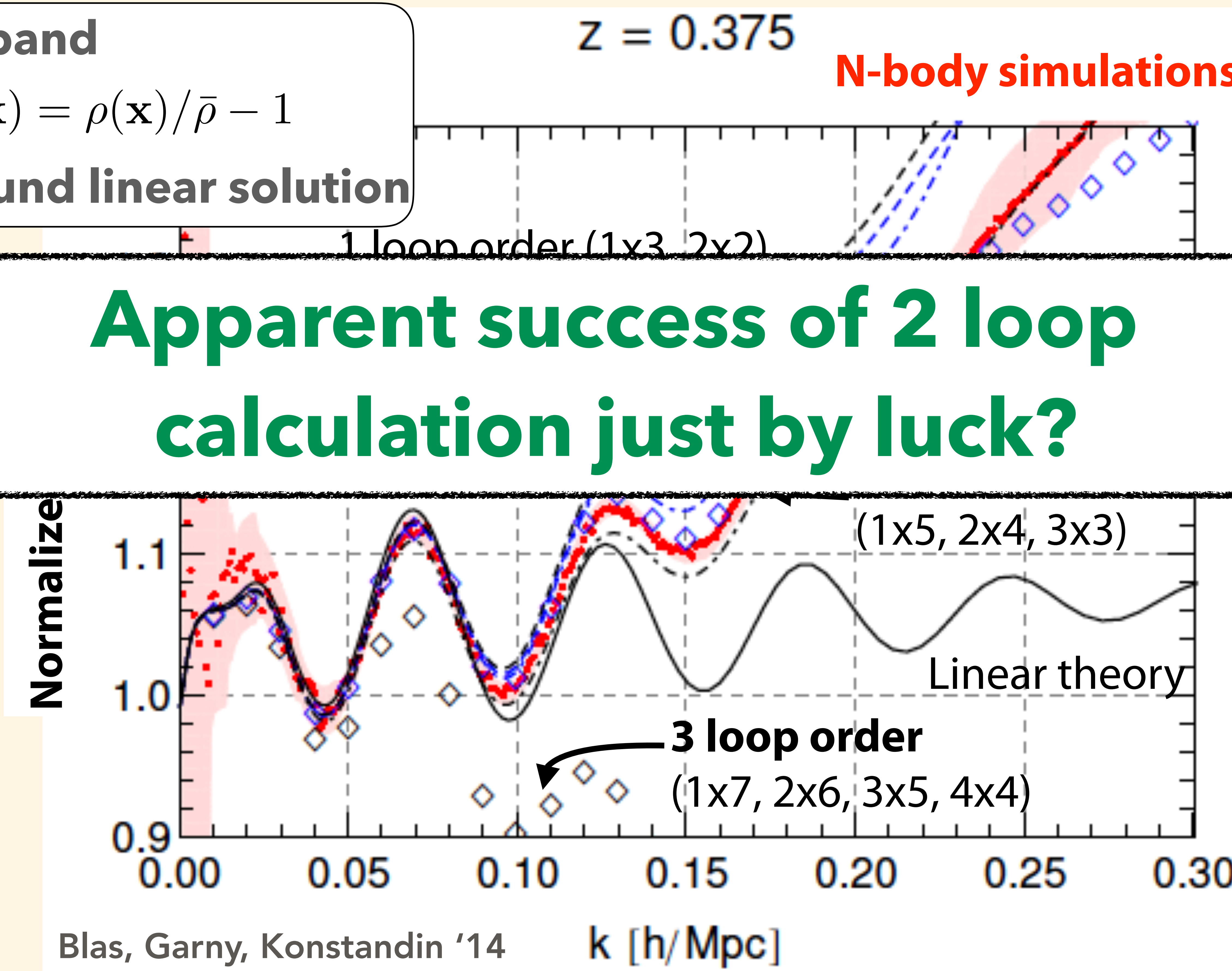
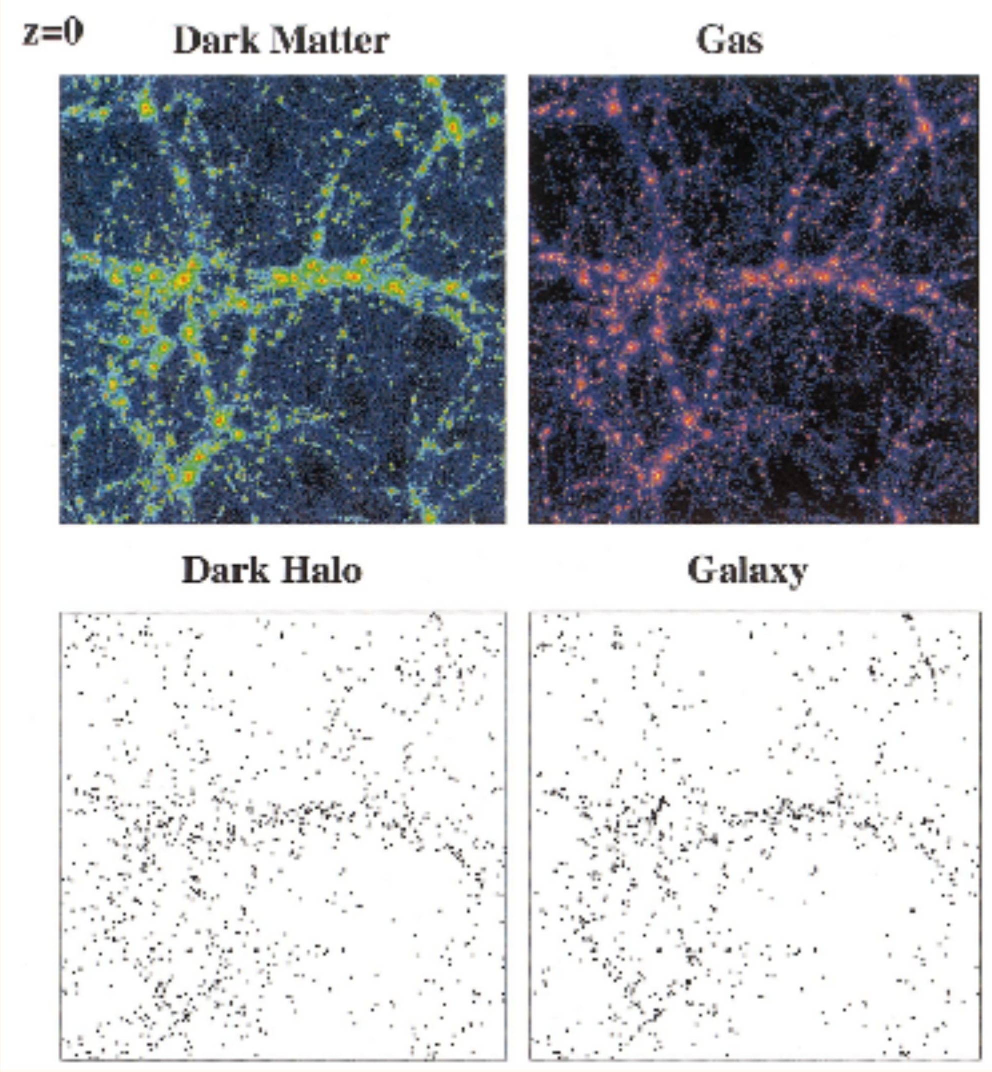


Blas, Garny, Konstandin '14

Apparent success of 2 loop calculation just by luck?

PT in trouble

- Luminous things are "tracers" of the underlying matter field (Kaiser '84)
- No first-principle analytical approach available (but hydro sims)
- Have to introduce many (really many!!) nuisance parameters?



Yoshikawa+'01

The Galaxy Power Spectrum and Bispectrum in Redshift Space

Vincent Desjacques, Donghui Jeong, Fabian Schmidt

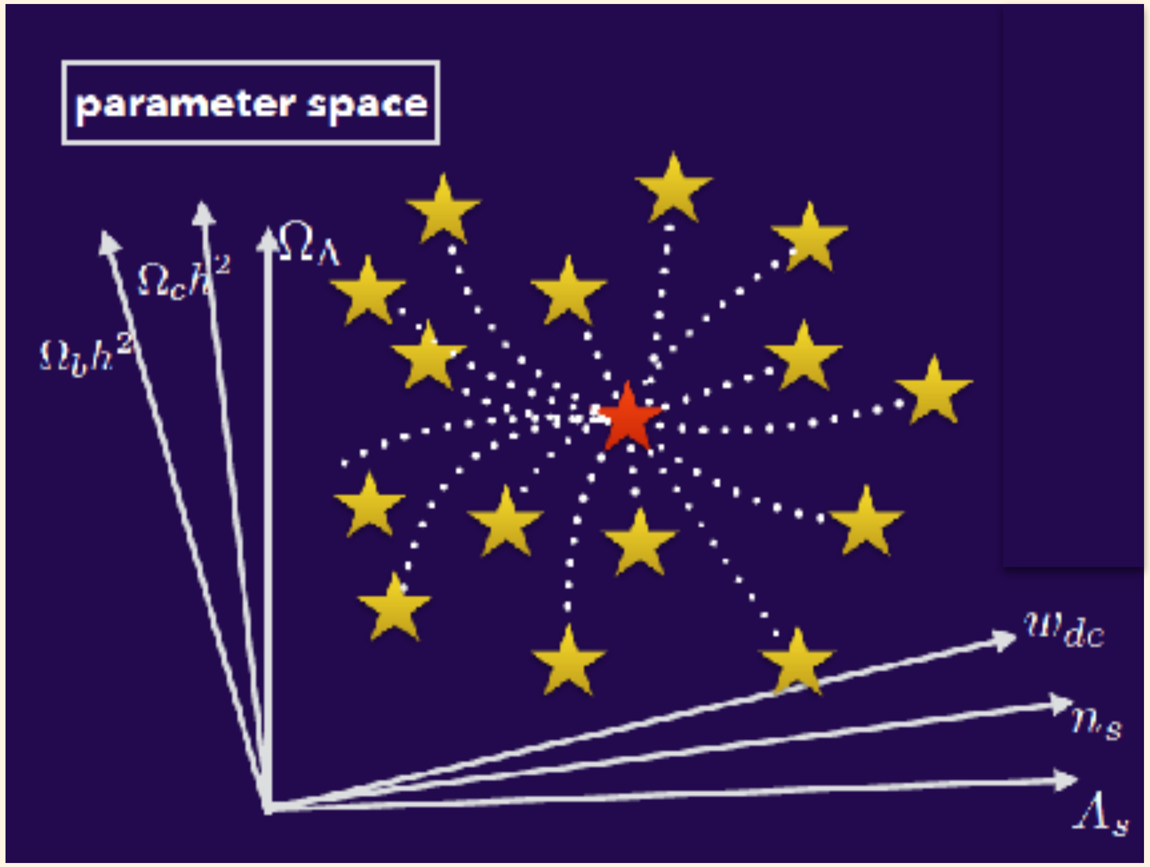
(Submitted on 11 Jun 2018)

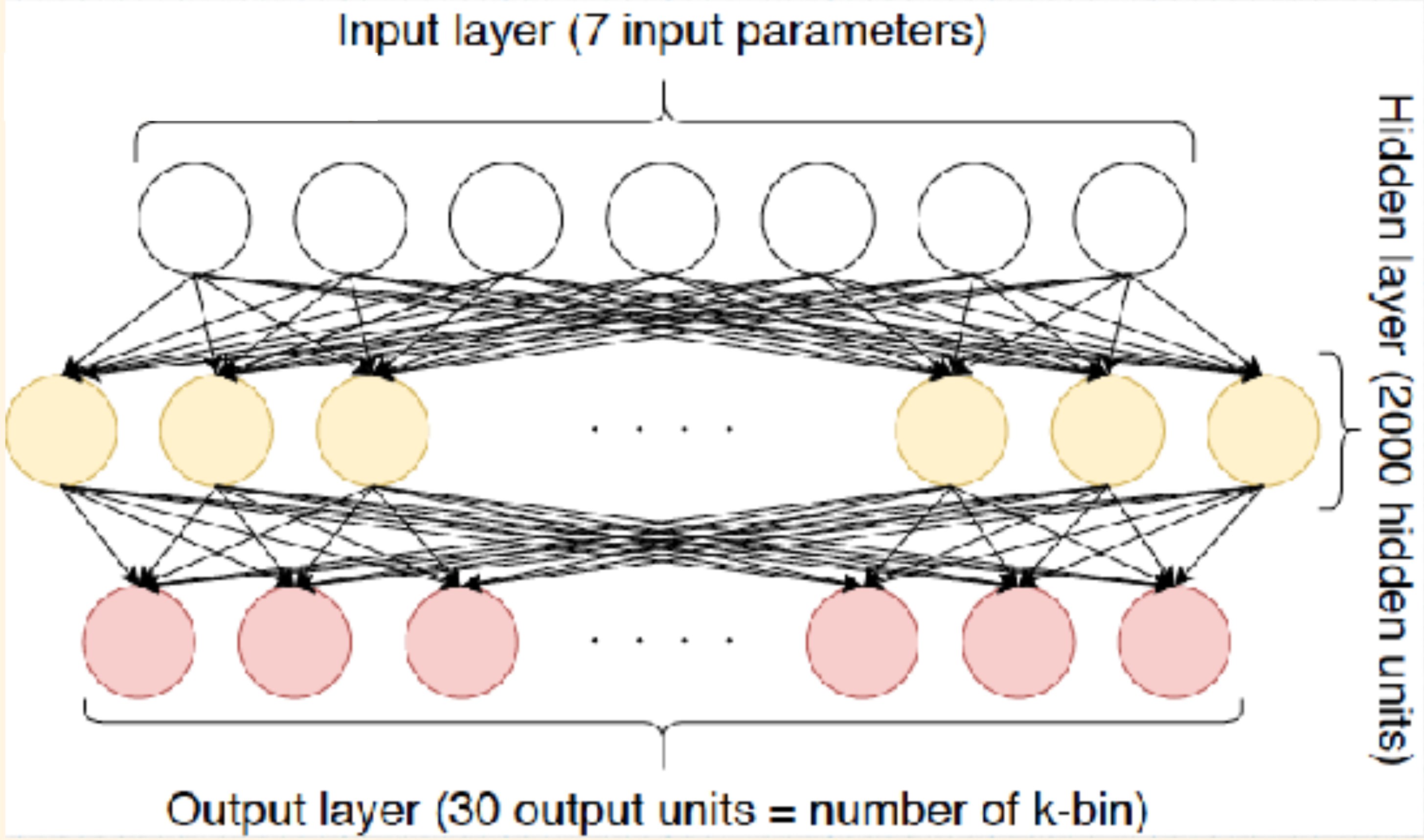
We present the complete expression for the next-to-leading (1-loop) order galaxy power spectrum and the leading-
space in the general bias expansion, or equivalently the effective field theory of biased tracers. We consistently includ
selection effects. These are degenerate with many, but not all, of the redshift-space distortion contributions, and hav
before. Moreover, we show that, in the framework of effective field theory, a consistent bias expansion in redshift spa
contributions. Physical arguments about the tracer sample considered and its observational selection have to be used
contributions. In summary, the next-to-leading order galaxy power spectrum and leading-order galaxy bispectrum i
described by 22 parameters, which reduces to 11 parameters if selection effects can be neglected. All contributions t
in terms of 28 independent loop integrals.

Give up using PT?

TN+'18 arXiv:1811.09504
3+ years effort
101 wCDM cosmologies
Lensing + clustering of HOD galaxies **Dark Quest**

- Simulation based "emulators"
  - Yosuke's talk this afternoon: halos in redshift space





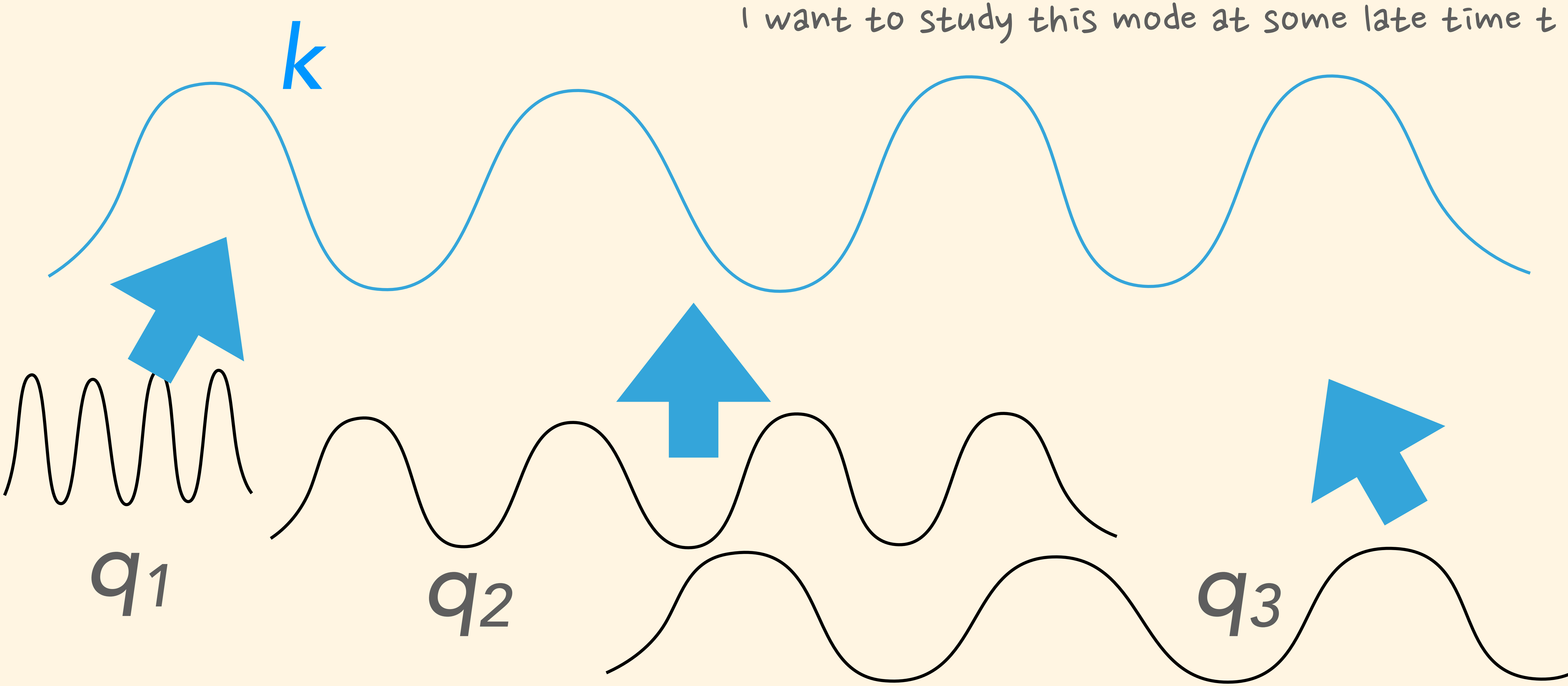
- Hybrid approaches
  - Understand where, when and how PT breaks down
  - Empirical remedies if available

System-level response function

$$K(k,q) = q\,\frac{\delta P_{nl}(k)}{\delta P_{lin}(q)}$$

TN, Bernardeau, Taruya '16

I want to study this mode at some late time t



what is the impact from wave mode q at the initial time t_0?

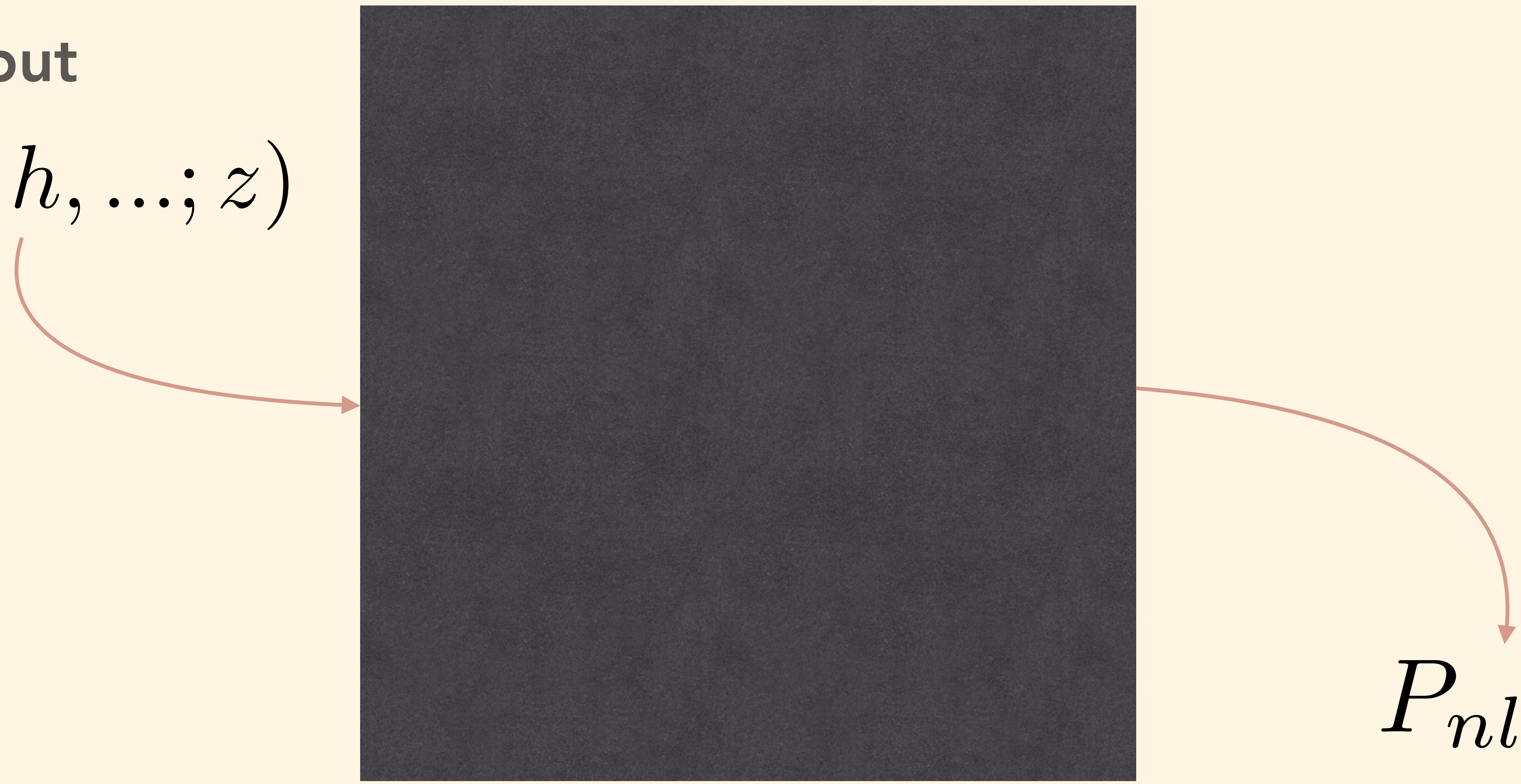
System-level response function

TN, Bernardeau, Taruya '16

large scale structure gravitational evolution

Input

$$(\Omega_m, h, ...; z)$$

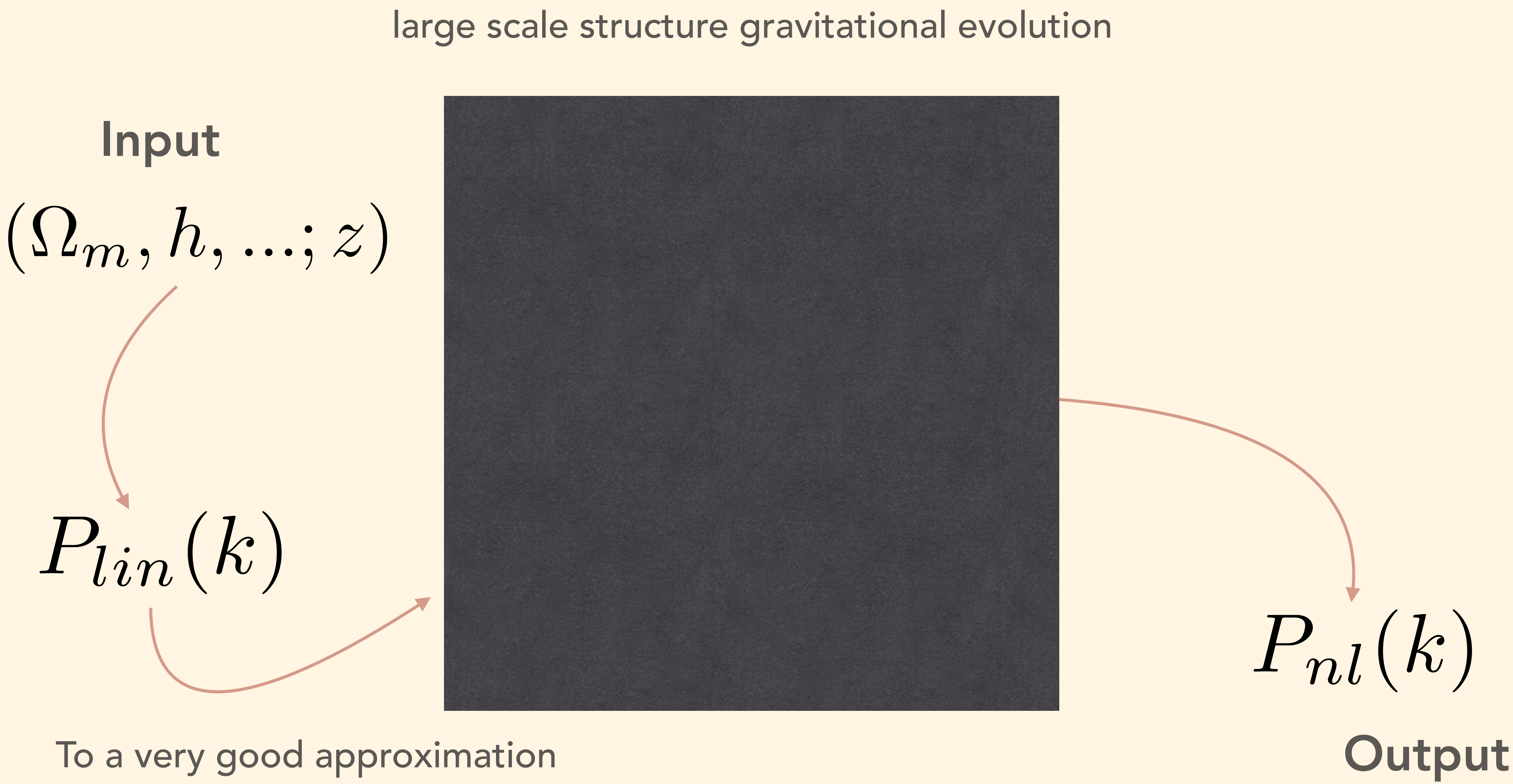


$$P_{nl}(k)$$

Output

System-level response function

TN, Bernardeau, Taruya '16



System-level response function

TN, Bernardeau, Taruya '16

Input

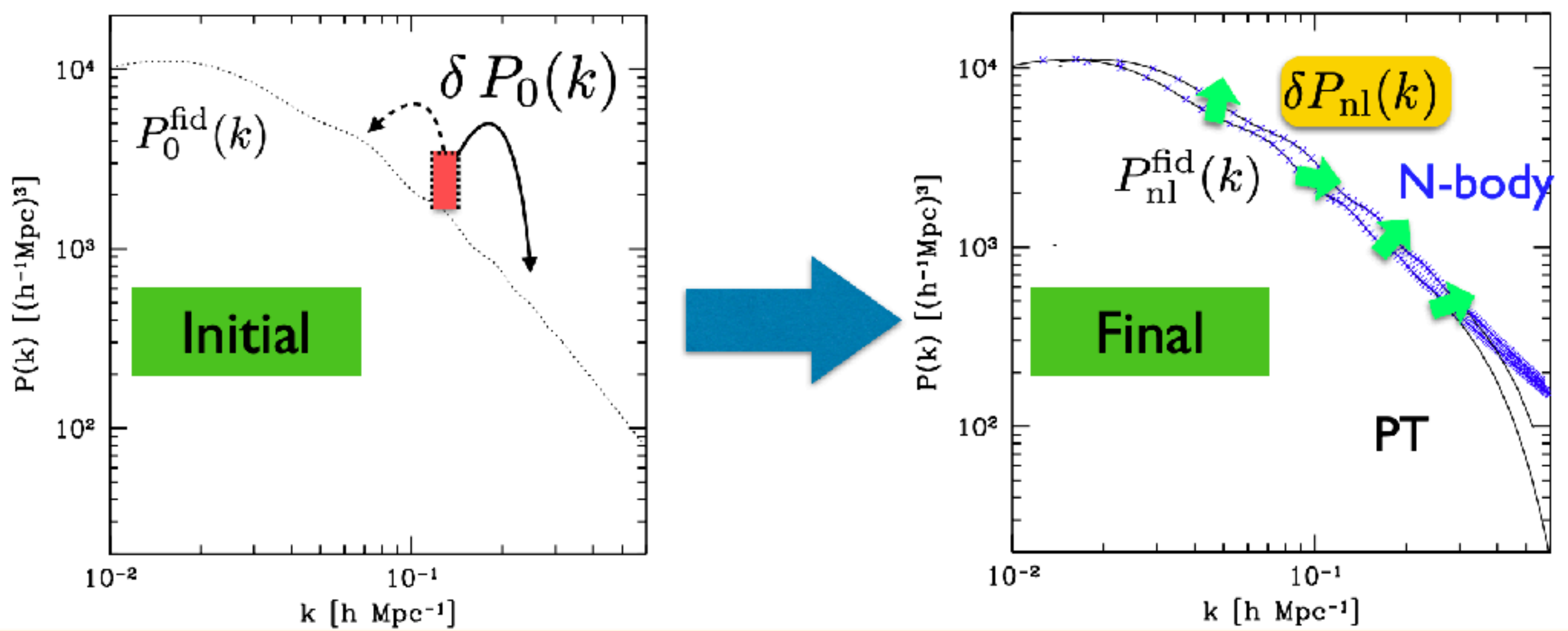
$$P_{lin}(k)$$

Nonlinear growth

Output

$$P_{nl}(k)$$

$$K(k,q) = q\,\frac{\delta P_{nl}(k)}{\delta P_{lin}(q)}$$



System-level response function

TN, Bernardeau, Taruya '16

Input

$P_{lin}(k)$

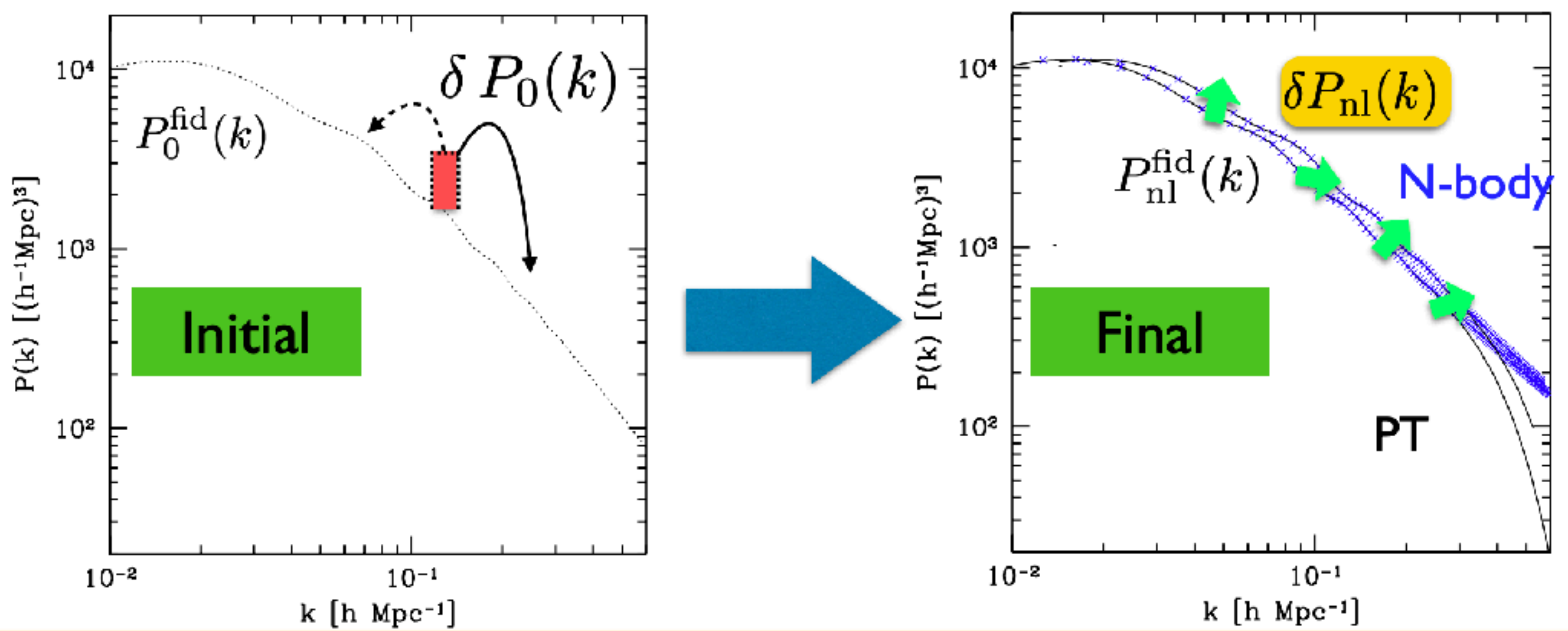
$+\delta P_{lin}(k)$

Nonlinear growth

Output

$P_{nl}(k)$

$$K(k,q) = q\,\frac{\delta P_{nl}(k)}{\delta P_{lin}(q)}$$



System-level response function

TN, Bernardeau, Taruya '16

Input

$P_{lin}(k)$

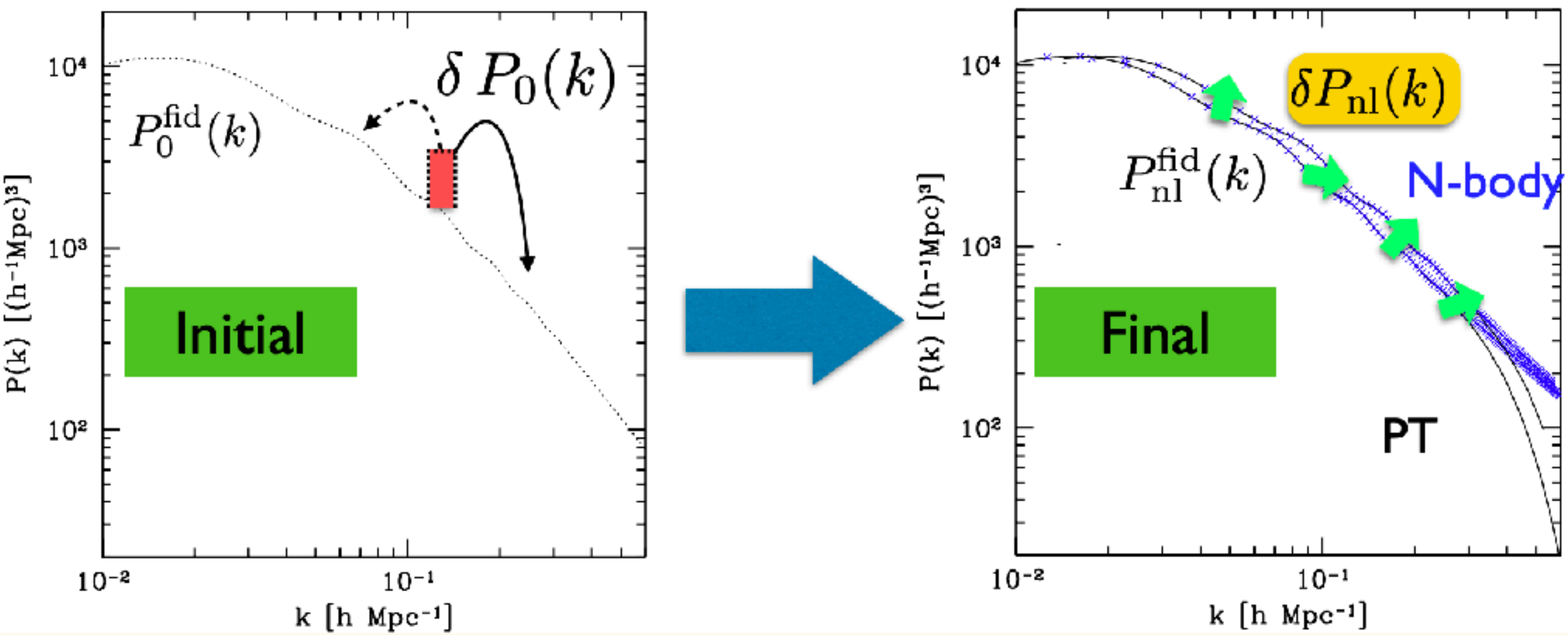
$+\delta P_{lin}(k)$

Nonlinear growth

Output

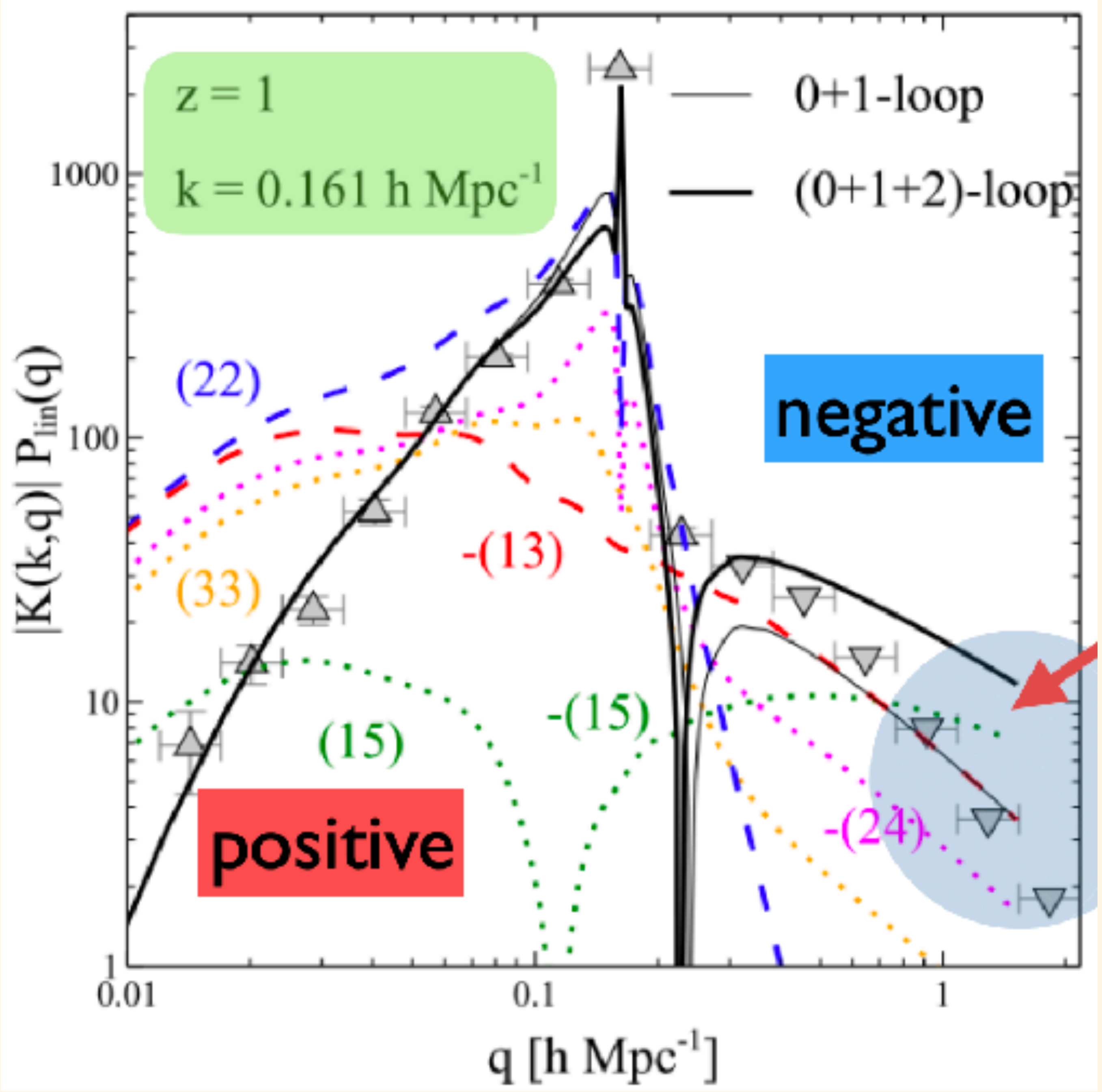
$P_{nl}(k)$ $+\delta P_{nl}(k)$

$$K(k,q) = q\,\frac{\delta P_{nl}(k)}{\delta P_{lin}(q)}$$



Response function: first look

$$K(k,q) = q\,\frac{\delta P_{nl}(k)}{\delta P_{lin}(q)}$$



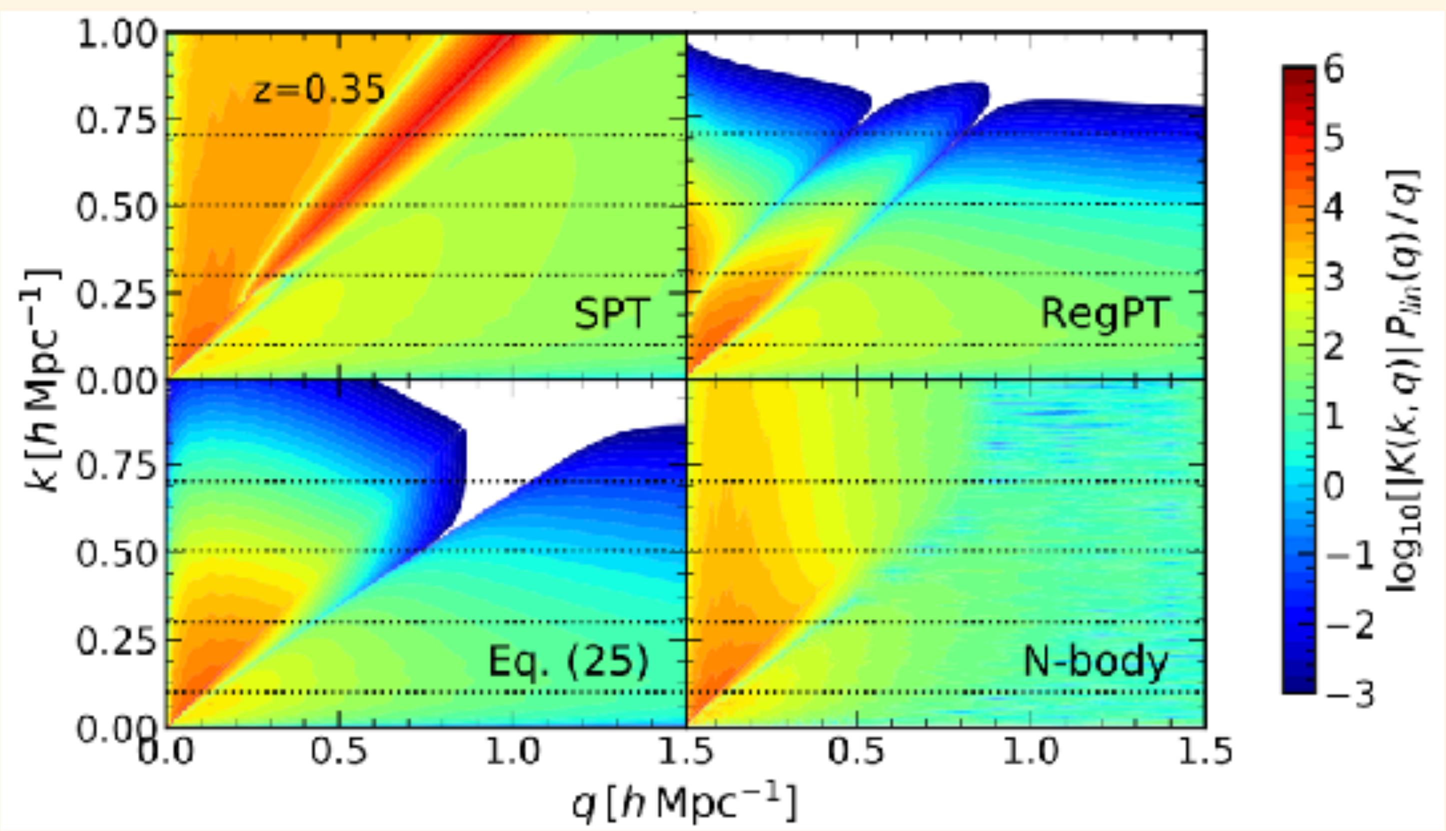
TN, Bernardeau, Taruya '16

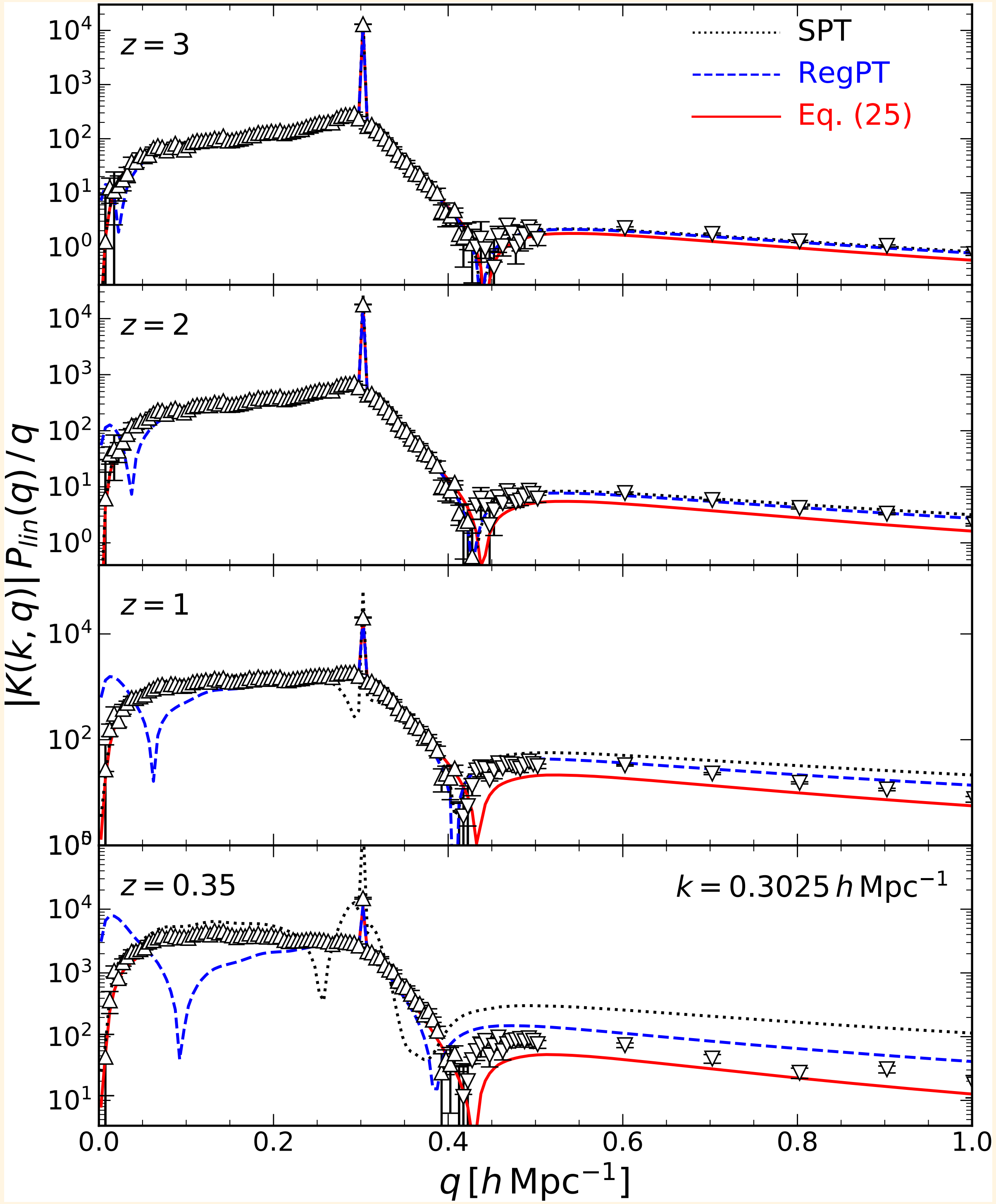
- Overall feature well captured by PT
- PT >> N-body @ high q
- This is where exactly PT breaks down
  - "UV does not propagate to IR"
- Mechanism?
  - Merely truncation of PT at a finite order?
  - Some more fundamental issue in the formalism?

Response function: fine structure

TN, Bernardeau, Taruya '17

- 1,400 runs of N=512^3 sims to study fine structures of the response function
- Vs 2-loop calculation based on different schemes (SPT/RegPT)
- New phenomenological model introduced





Practical usage? Reconstruction

- From the definition of a functional derivative

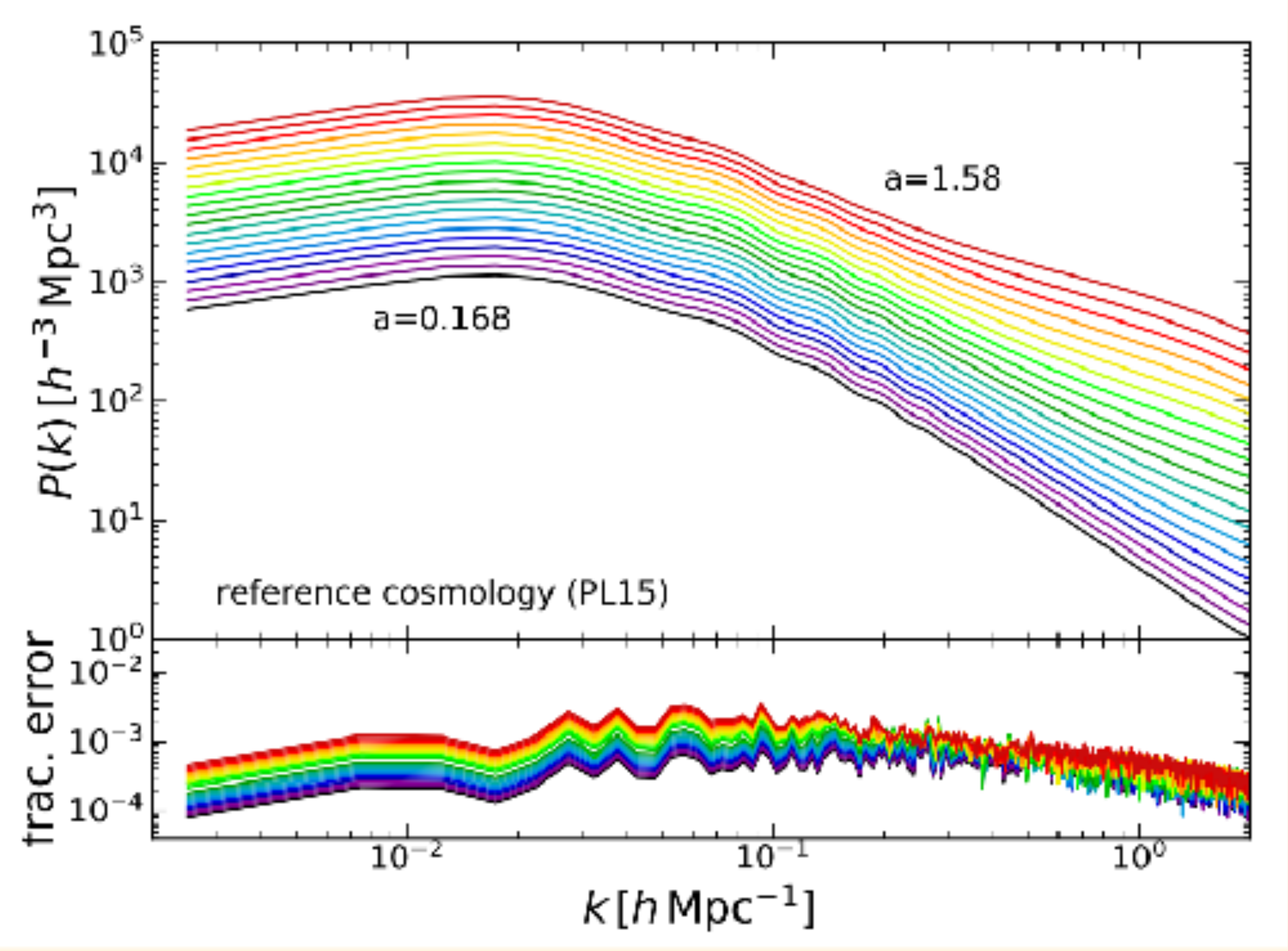
$$P_{\rm nl}(k;\boldsymbol{p}_1) \approx P_{\rm nl}(k;\boldsymbol{p}_0) + \int {\rm d}\ln q\, K(k,q) \times \left[P_{\rm lin}(q;\boldsymbol{p}_1) - P_{\rm lin}(q;\boldsymbol{p}_0)\right],$$

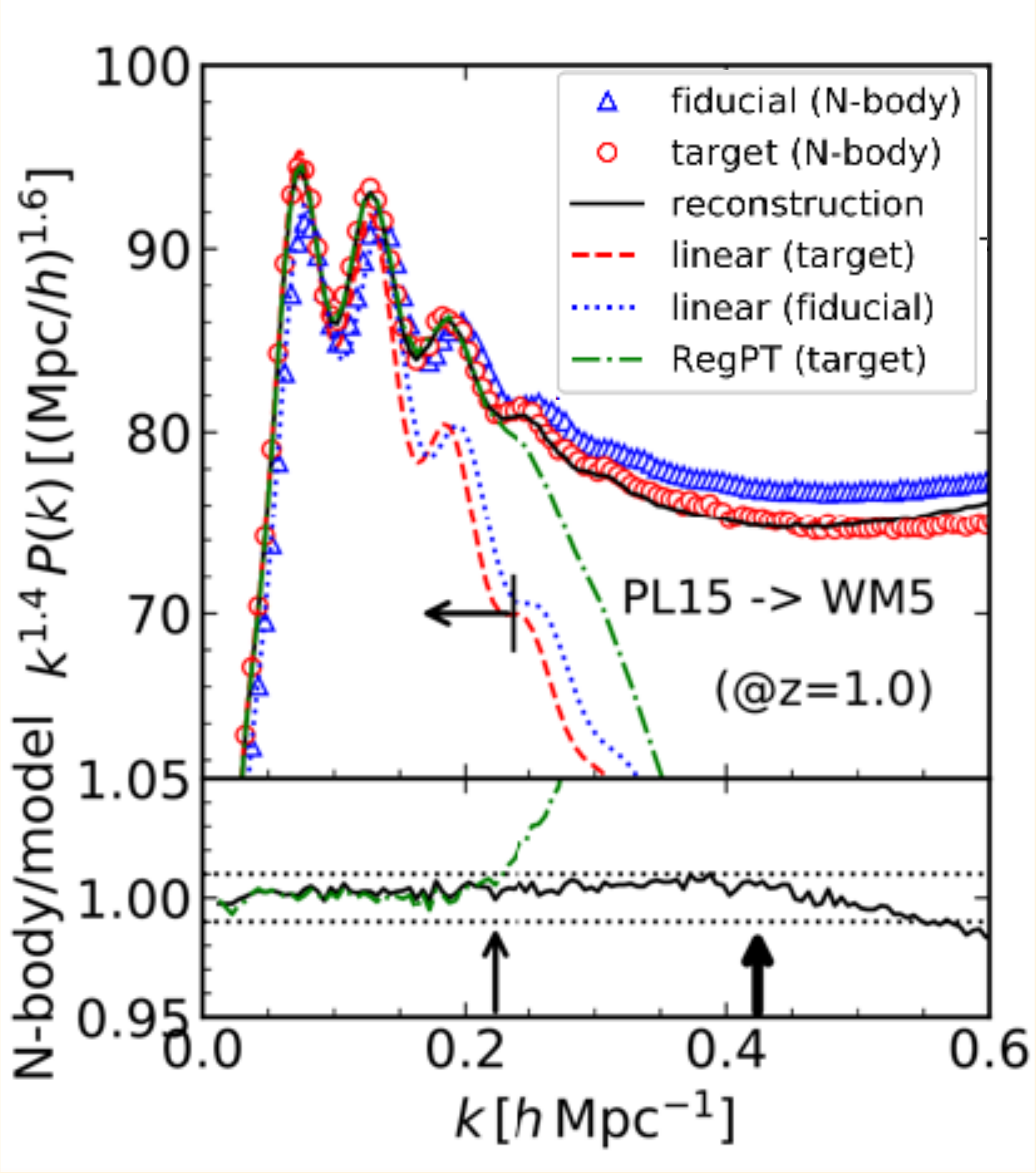
- Use this to predict P_{nl} for cosmological model $\mathbf{p}_1$ given P_{nl} for another model $\mathbf{p}_0$

A simple implementation

$$P_{\rm nl}(k;\boldsymbol{p}_1) \approx P_{\rm nl}(k;\boldsymbol{p}_0) + \int {\rm d}\ln q\, K(k,q) \times \left[P_{\rm lin}(q;\boldsymbol{p}_1) - P_{\rm lin}(q;\boldsymbol{p}_0)\right],$$

P(k) template from sims for PLANCK15 cosmology

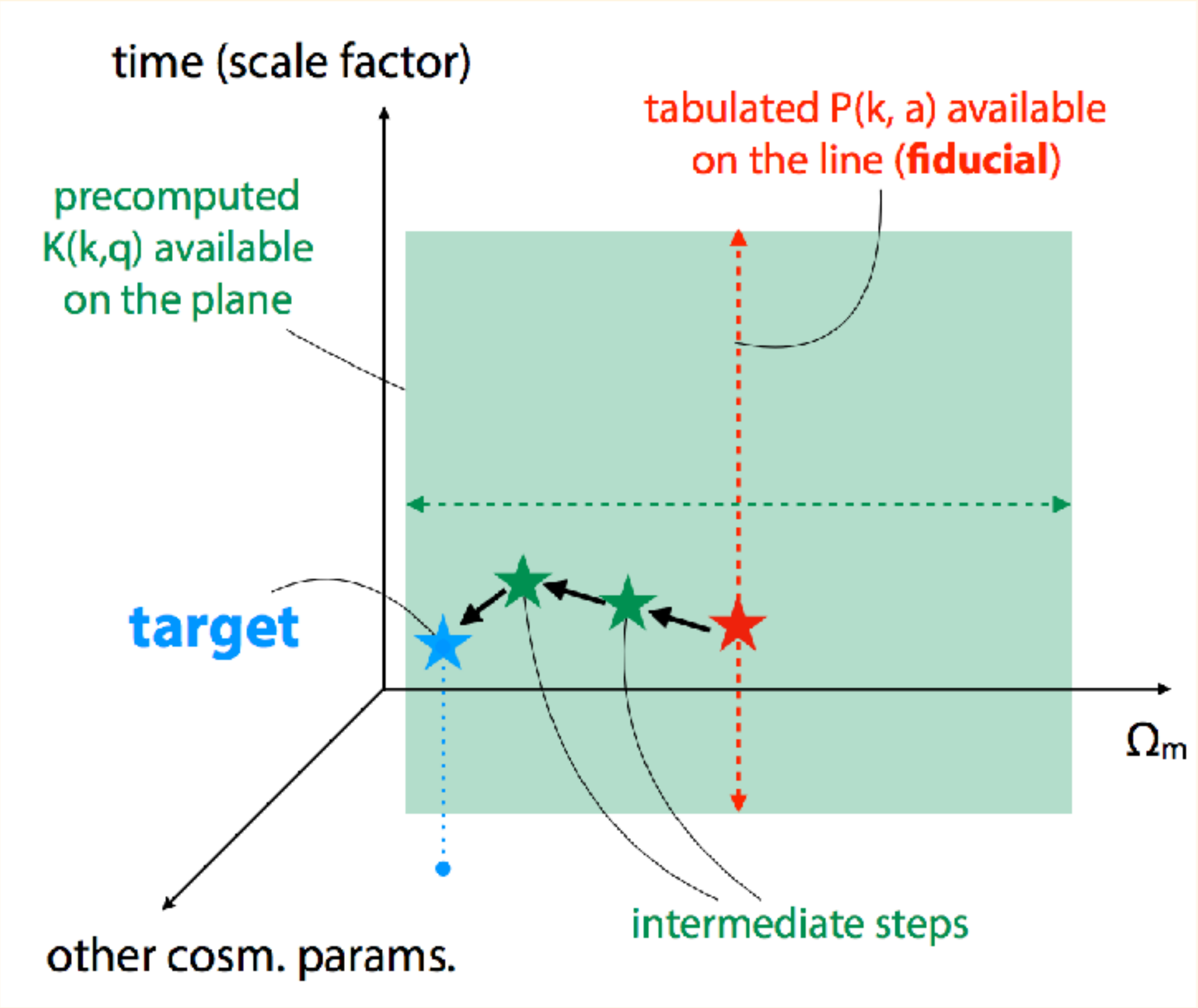




- Double the reliable k range from the pure RegPT prediction

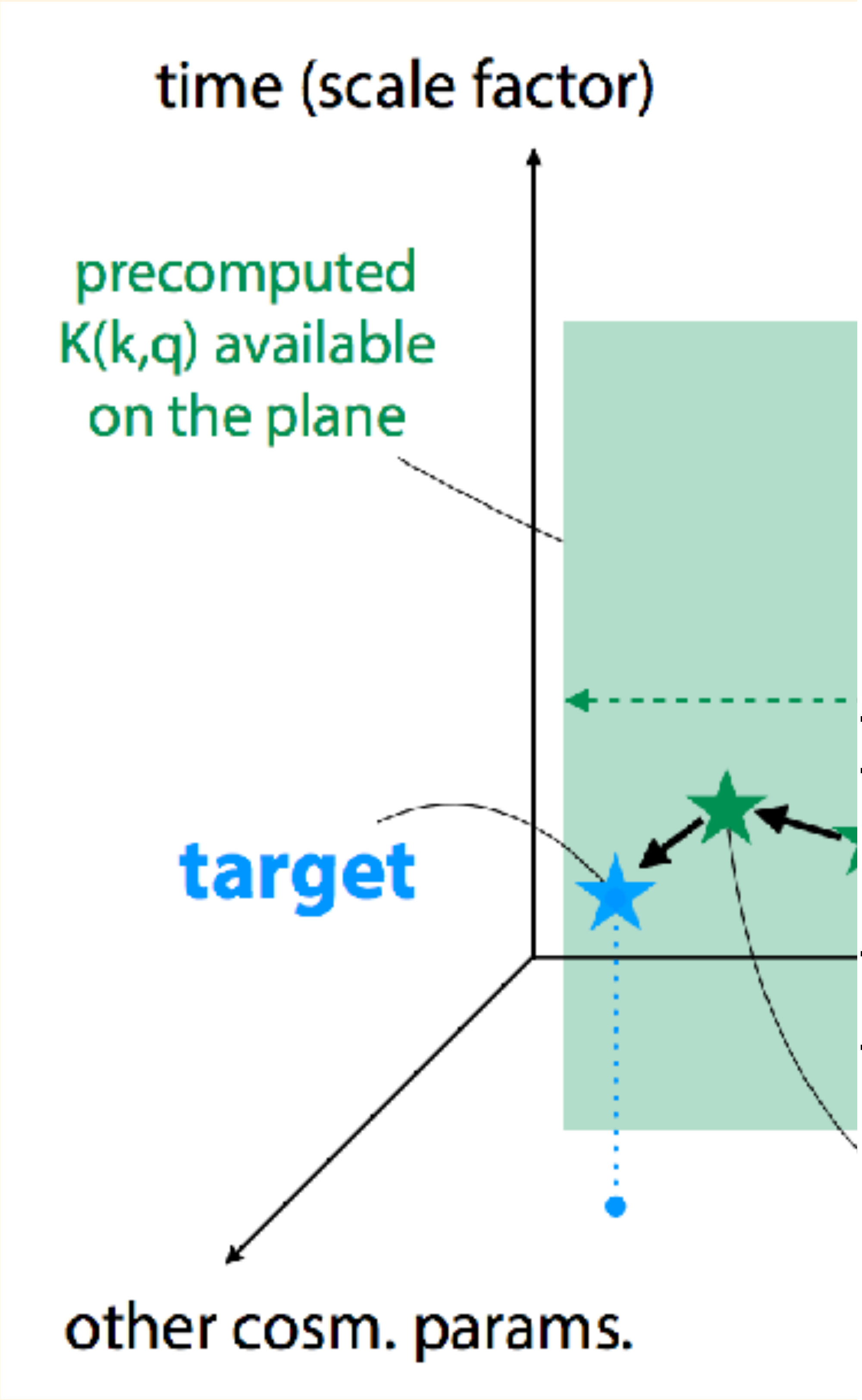
More extreme models

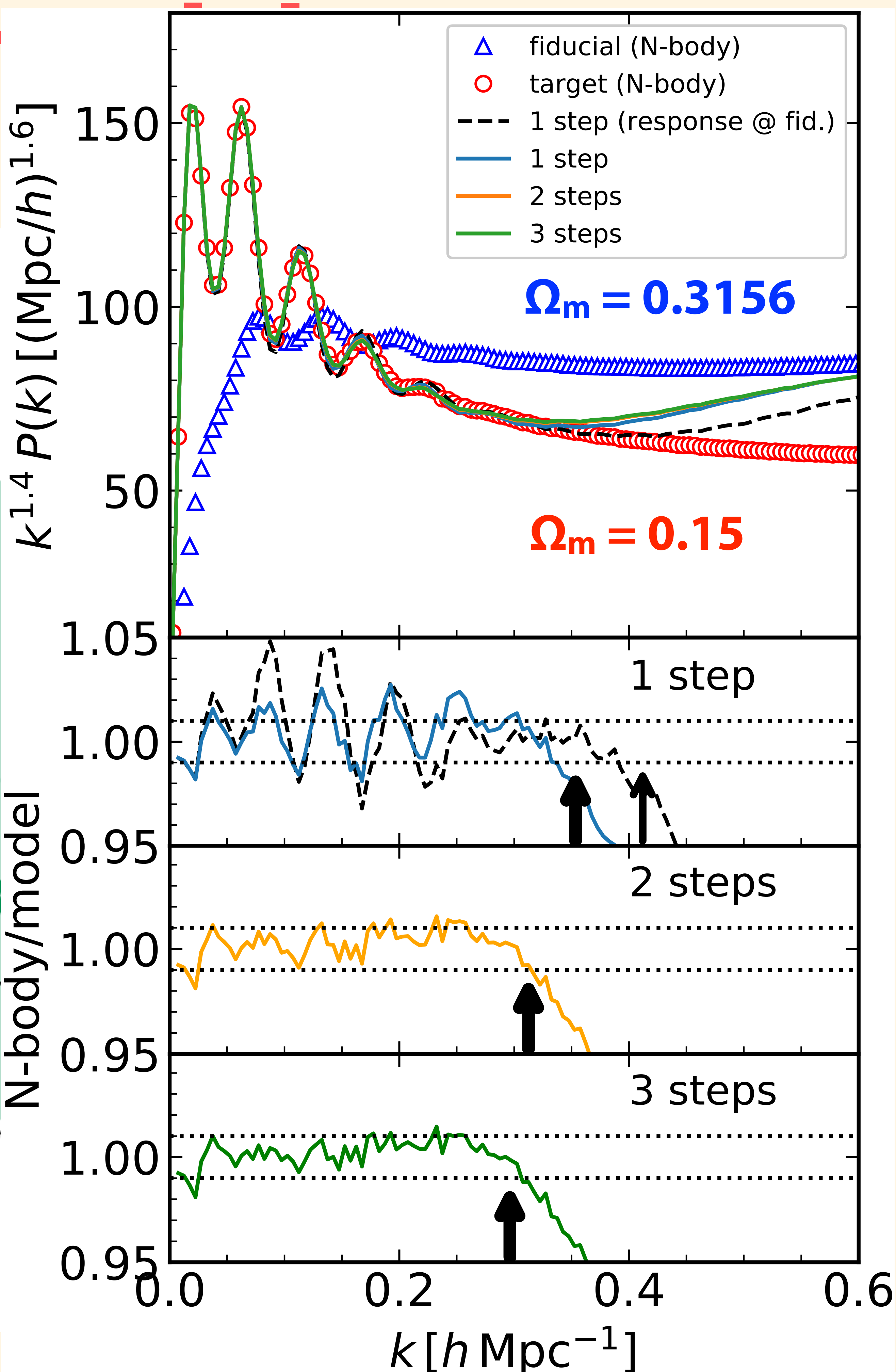
- Employ multi-steps



More extreme r

- Employ multi-steps

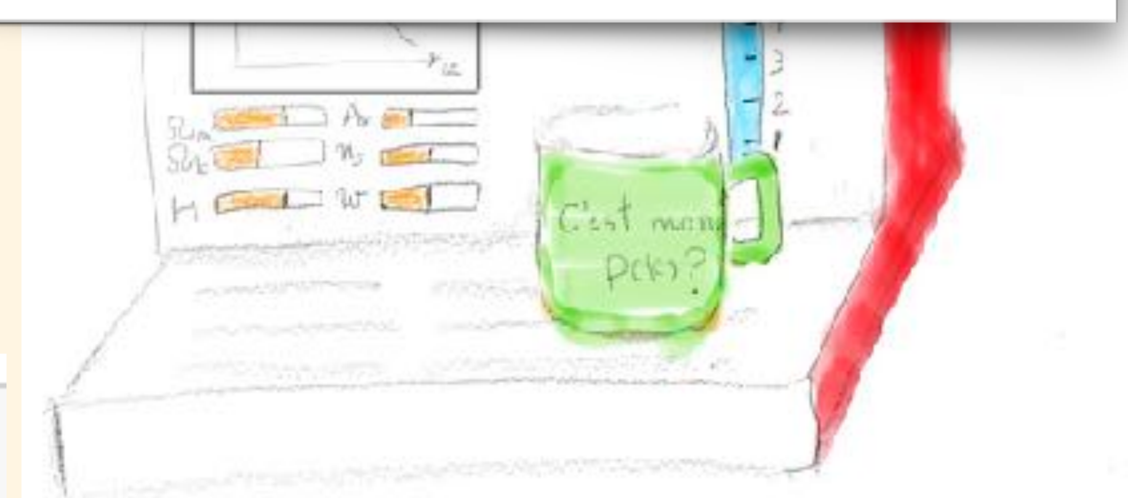




RESPRESSO Python package available!


```
In [7]: respresso_obj.find_path()
```

```
In [9]: kwave = respresso_obj.get_kinternal()
        pnl_rec = respresso_obj.reconstruct()
```



http://www-utap.phys.s.u-tokyo.ac.jp/~nishimichi/public_codes/respresso/

RESPRESSO Python package available!

(Rapid and Efficient SPectrum calculation based on RESponSe functiOn)

```
In [1]: %pylab inline
        import respresso

In [3]: respresso_obj = respresso.respresso_core()

        Hello. This is RESPRESSO.
        Load precomputed data files...
        RESPRESSO ready.

In [6]: respresso_obj.set_target(plin_target_spl)

In [7]: respresso_obj.find_path()

In [9]: kwave = respresso_obj.get_kinternal()
        pnl_rec = respresso_obj.reconstruct()
```

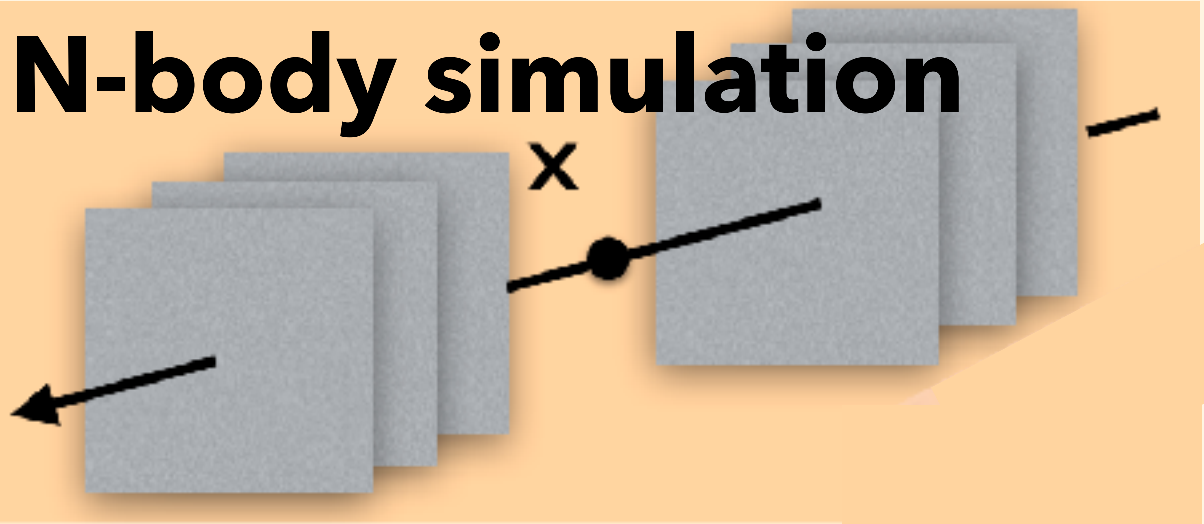
http://www-utap.phys.s.u-tokyo.ac.jp/~nishimichi/public_codes/respresso/

1D toy cosmology

Taruya & Colombi; Halle, TN et al. in prep

- Consider the dynamics in 1D expanding universe
  - Motion of equal mass "sheets"
  - Employ the linear dimensionless power spectrum same as in 3D
- Zel'dovich is an exact solution up to shell crossing
  - Can separate shell crossing on RF by comparing Zel'dovich and N-body
- **Adaptive smoothing**

N-body simulation



Zel'dovich = exact solution before shell crossing

Displacement Linear growth

$$x(q;\tau) = q + \psi(q) D_+(\tau)$$

$$\mathrm{v}(q;\tau) = \psi(q) \frac{dD_+(\tau)}{d\tau}$$

Adaptive smoothing

Apply a filter at an appropriate scale to each mass element to suppress the motion after the shell crossing

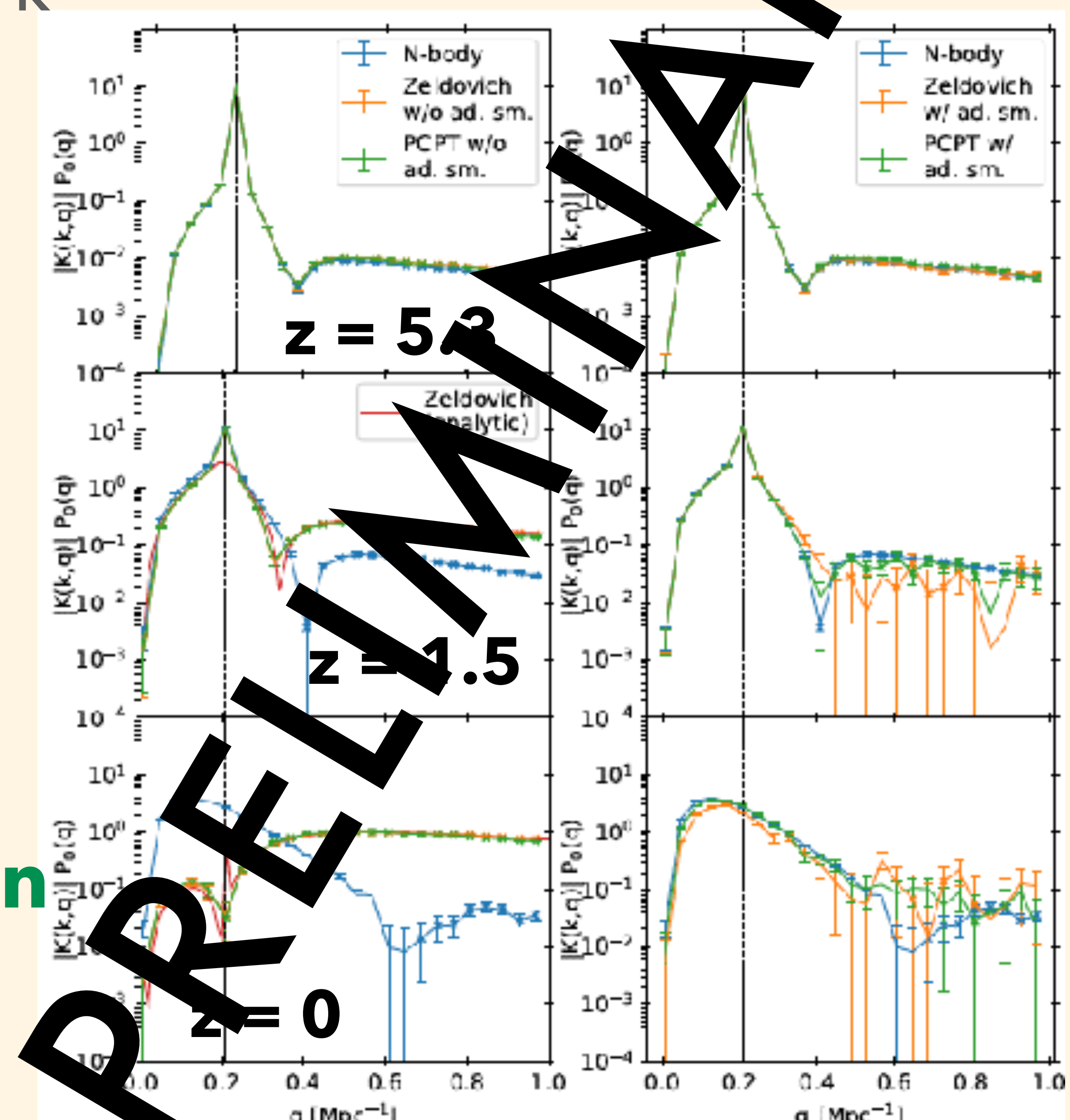
Response function in 1D

- Qualitatively similar overall structure to 3D
  - Widening around k = q with time
  - Change of sign at some scale on q>k
- Zel’dovich vs N-body
  - Though the former is a full-order solution, UV regime is totally different from N-body
  - Probably the UV sensitivity in PT in 3D is not due to the truncation at a finite order
- **With adaptive smoothing we can recover the RF measured in N-body**

Halle, TN et al. in prep

Adaptive smoothing

w/o **w/**



Implication to 3D? PINOCCHIO

- Implementation of the adaptive smoothing to 3D is not trivial
- There is one approximate dynamics following a similar spirit in the literature: **PINOCCHIO** (= *PIN pointing Orbital-Crossing Collapsed HIerarchical Objects: Monaco et al. 2002*)
- Originally (I believe) this is developed to generate a halo catalog and their merger tree quickly
- Compute displacement following Lagrangian PT with a filter at various scales
- Excursion set-like treatment to find the first barrier crossing to each mass element
- Determine shell crossing points under the local Ellipsoidal collapse approximation
- Group collapsed points
    - Filament or halo
- Follow the dynamics of 3LPT up to orbit crossing
- “Halo” particles -> force to follow the NFW profile

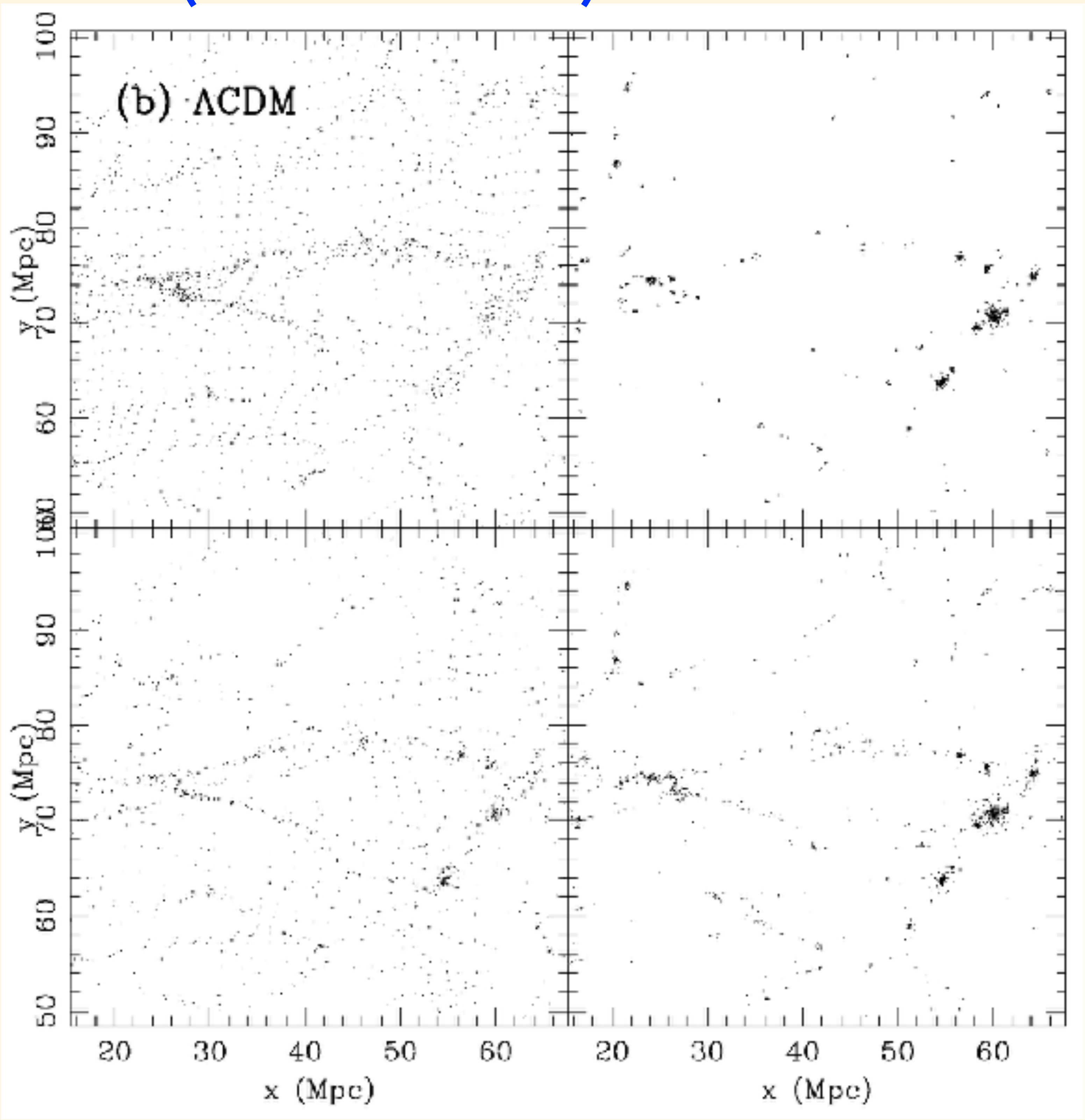
$$\phi(\vec{q}_0) \simeq \phi_0 + \phi_{,i}(\vec{q}_0)(\vec{q}-\vec{q}_0)_i + \phi_{,ij}(\vec{q}_0)(\vec{q}-\vec{q}_0)_{ij}$$

Bulk motion

deformation

Implication to 3D? PINOCCHIO

Filament (incl. sheets) Halo

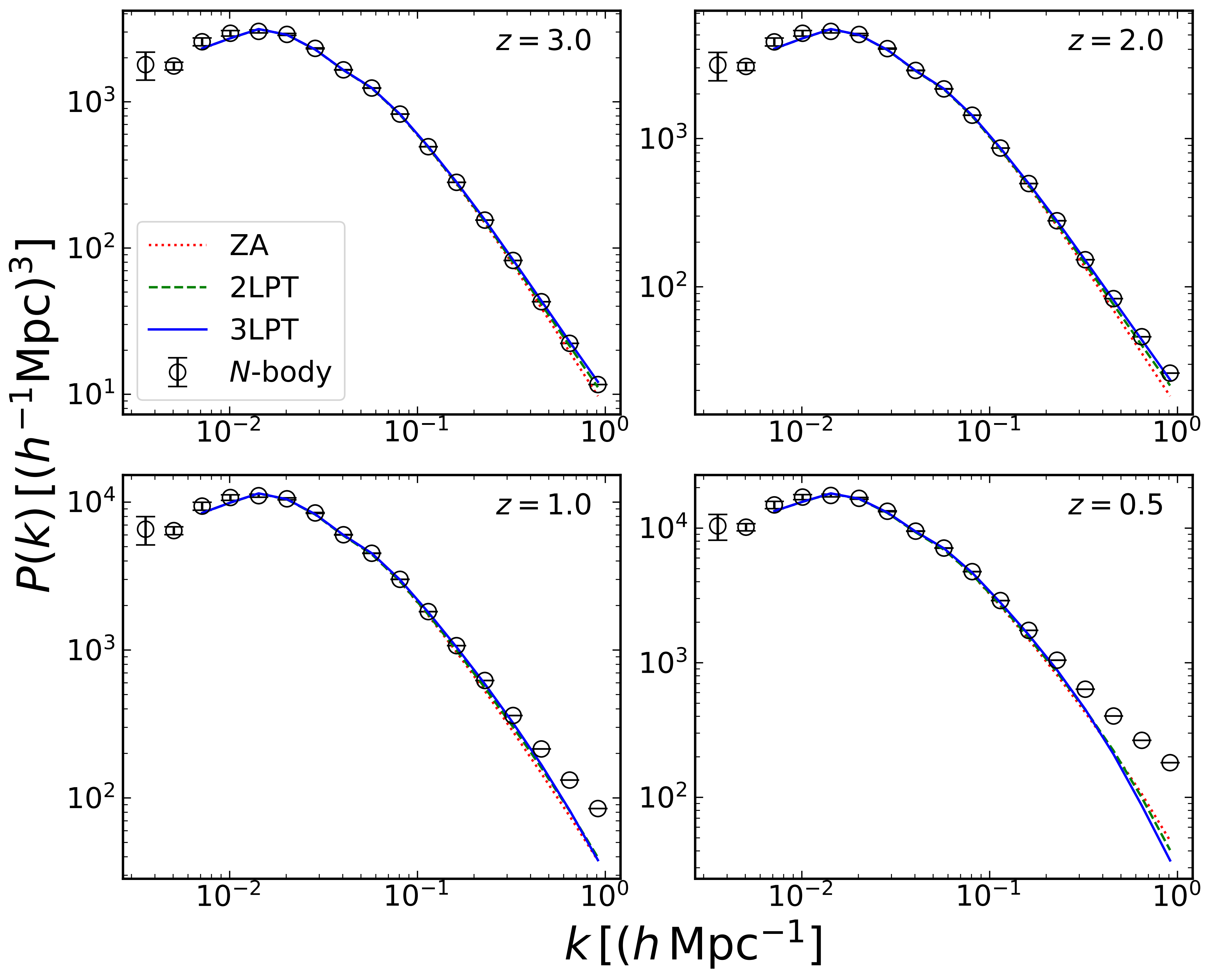


← N-body

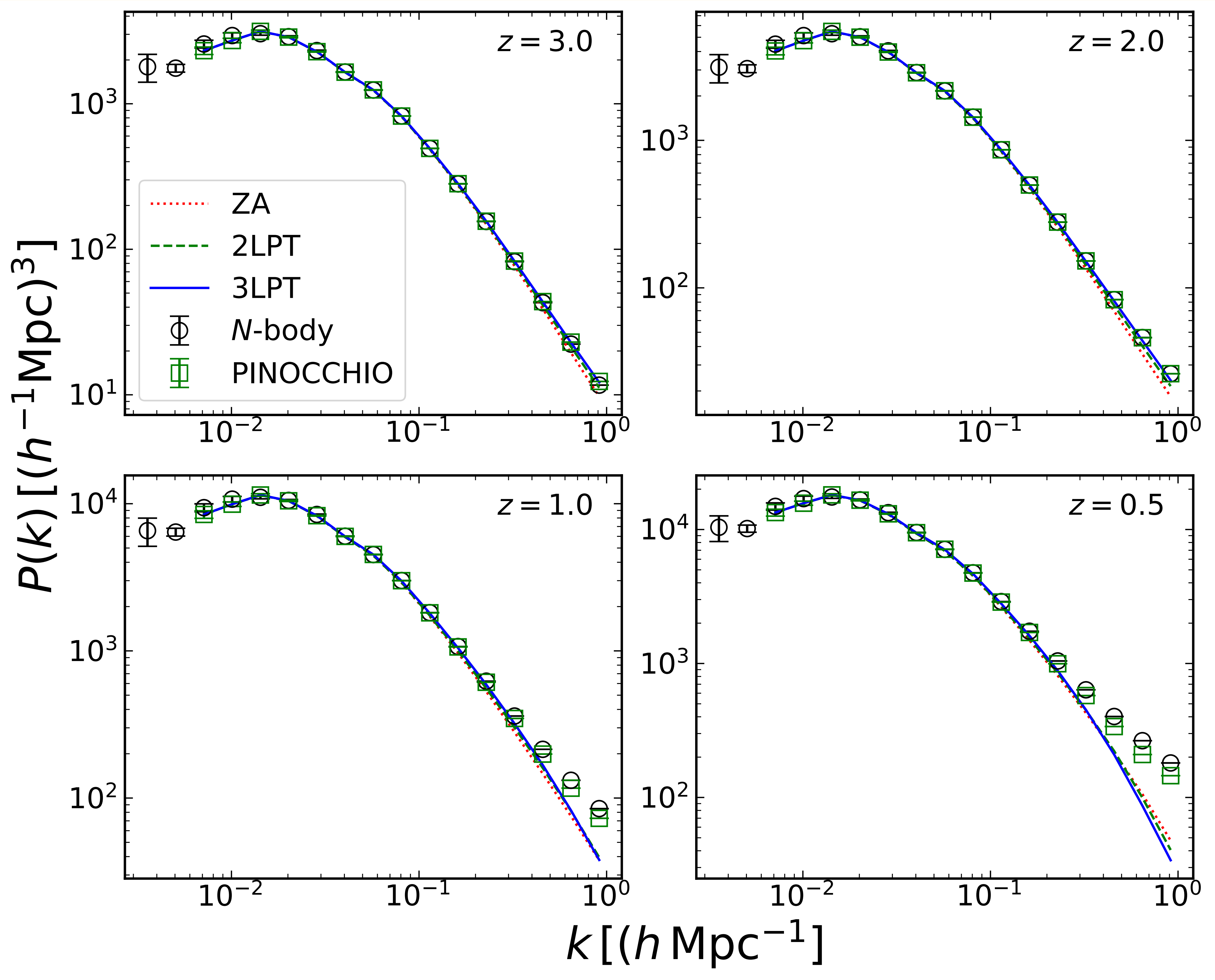
← PINOCCHIO

Monaco +'02

Power spectrum in LPT dynamics

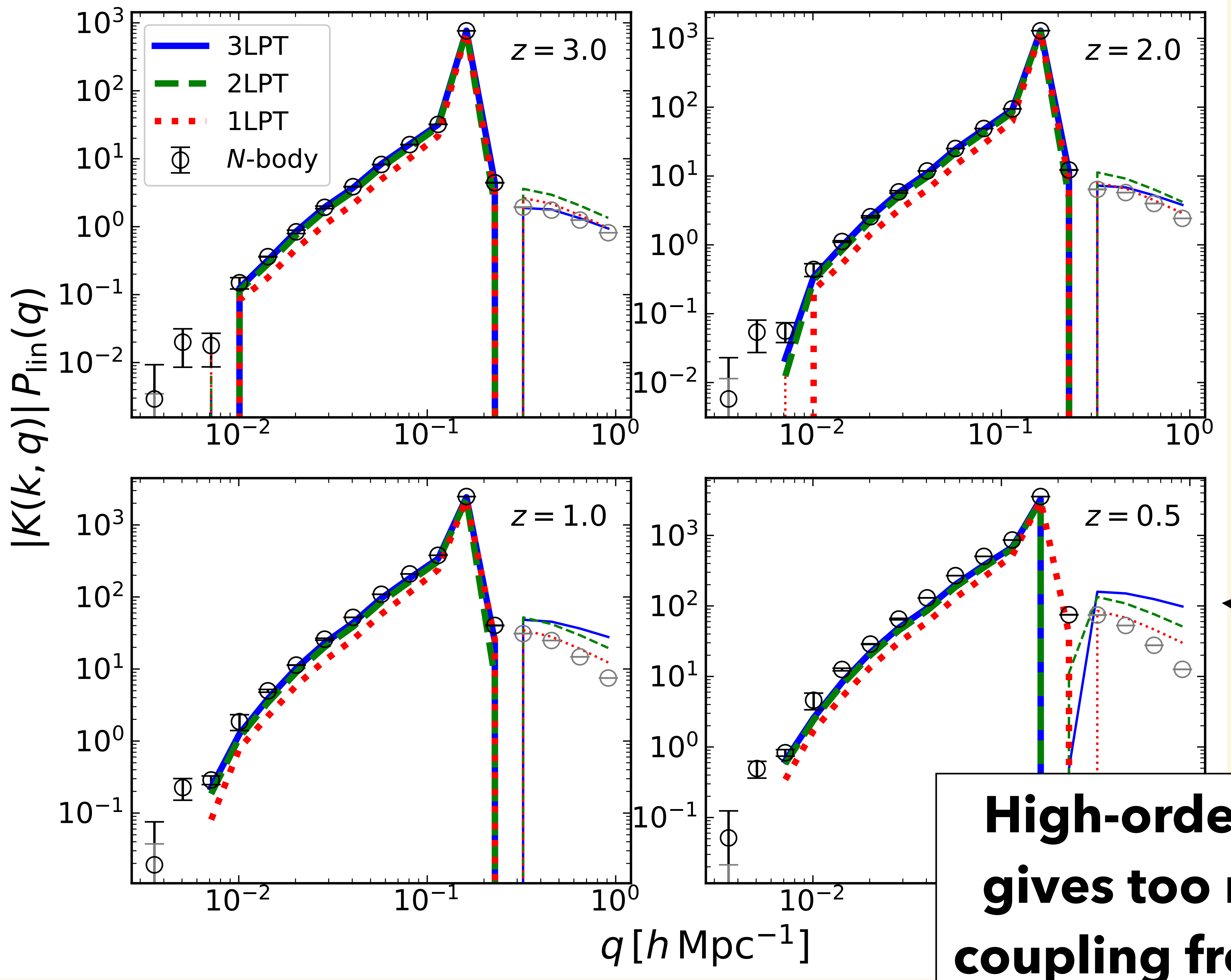


Power spectrum in LPT dynamics



Response function from LPT solutions

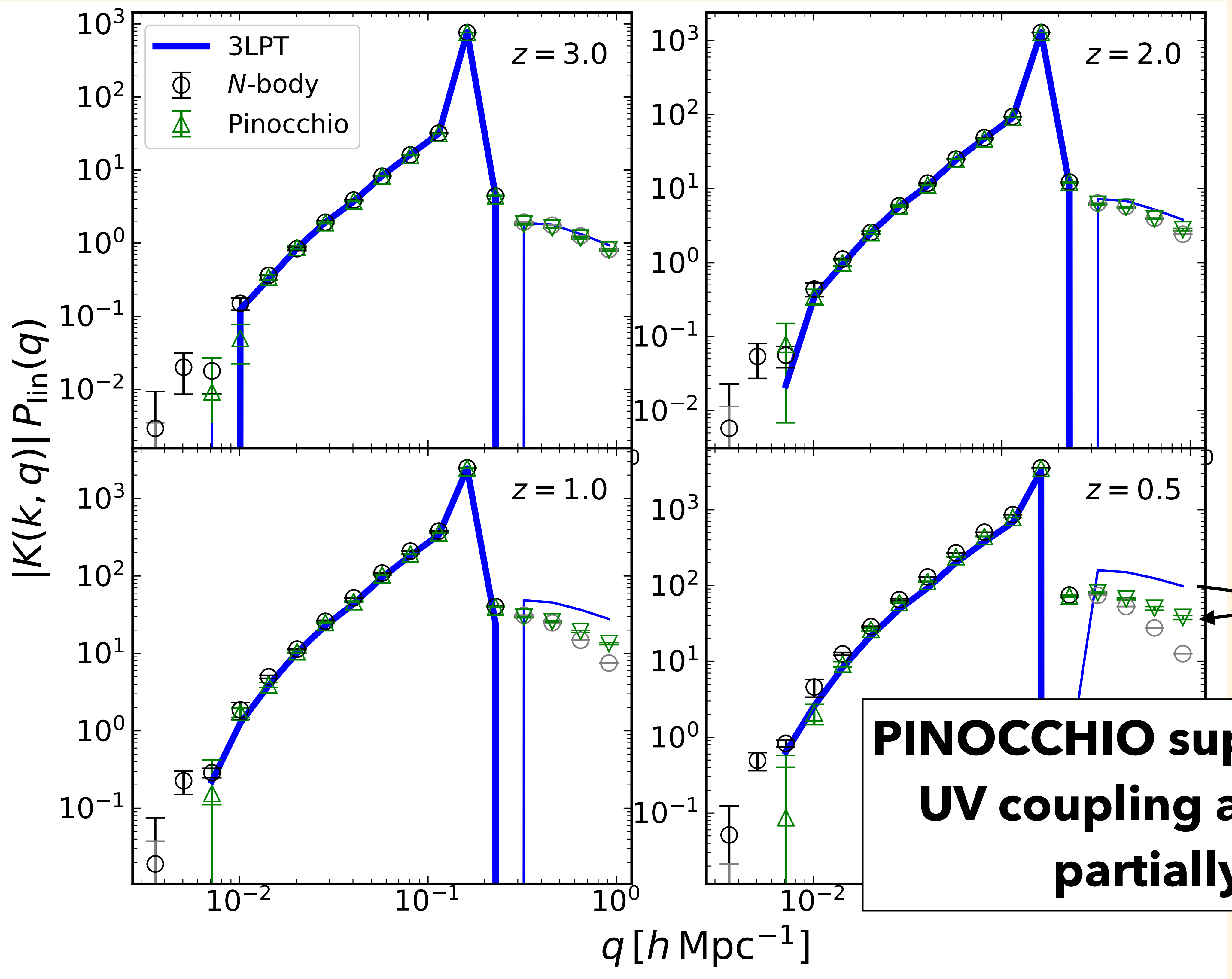
Halle, TN et al. in prep



High-order LPT gives too much coupling from UV

vs Pinocchio

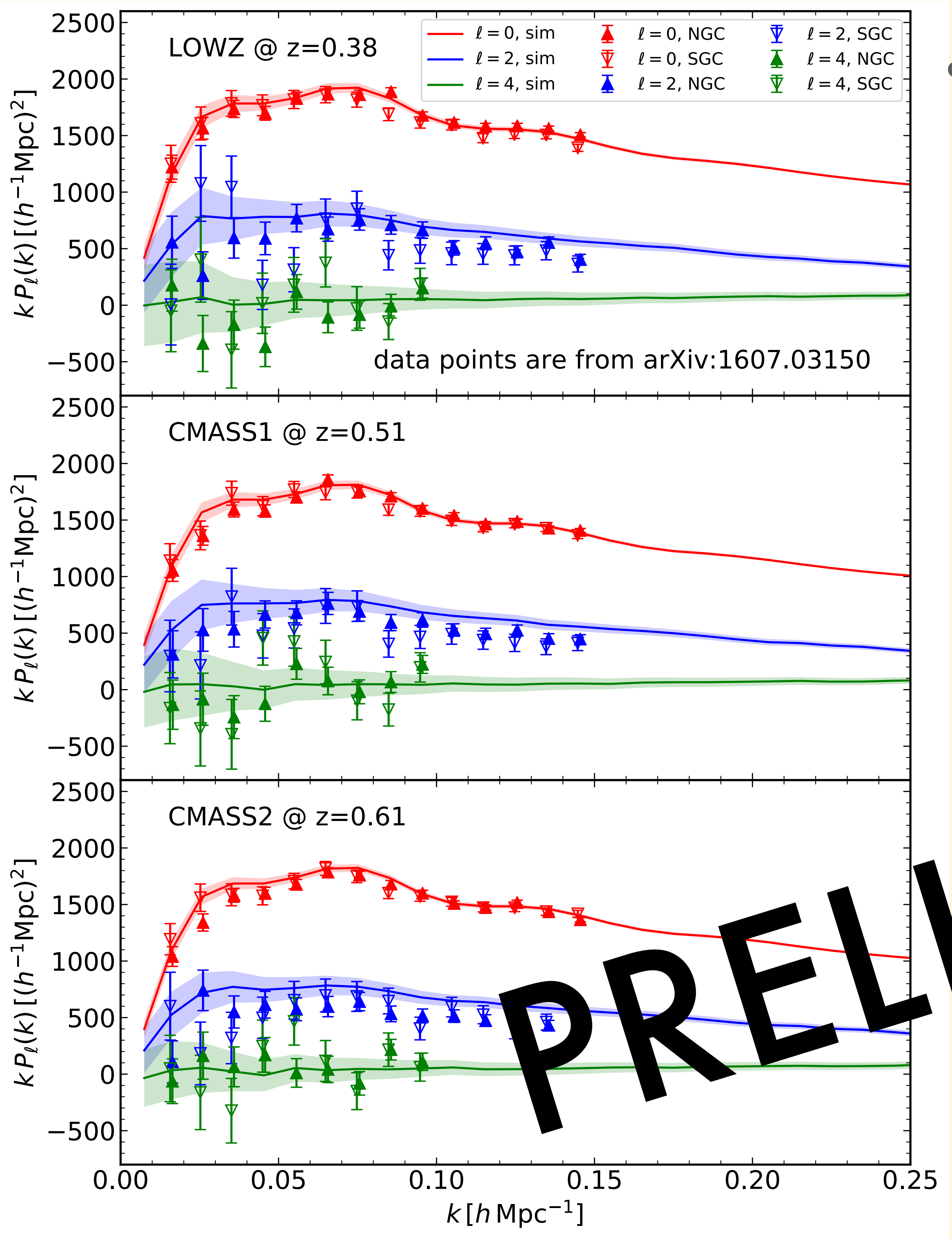
Halle, TN et al. in prep



PINOCCHIO suppresses UV coupling at least partially

PT challenge

TN, Takada, Senatore, Zaldarriaga++ in prep



PRELIMINARY

- Biased tracers in redshift space
  - http://www-utap.phys.s.u-tokyo.ac.jp/~nishimichi/data/PTchallenge/

Summary

- Something is wrong in PT expansion
  - **Response function** a new diagnostic
  - *Regularize the mode transfer from UV to IR*
- Simulation calibrated RF helpful for reconstruction: **RESPRESSO algorithm**
- 1D toy model
  - Full order solution (= Zel'dovich) exhibits the same problem
  - Adaptive smoothing to suppress the displacement after shell crossing is a key: breakdown of the single-streaming approximation is the root for this problem
- LPT dynamics in 3D
  - PINOCCHIO with NFW halo particles regularizes at least partly the problematic mode transfer from UV
  - What about filaments or sheets?