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RESCEU/DENET summer school
@ Aso, Kumamoto

RegPTfast :
a fast computation of non-linear power spectrum from perturbation theory

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In collaboration with
Francis Bernardeau, Martin Crocce, Roman Scoccimarro

Contents

- A new improved treatment of perturbation theory (PT) based on Bernardeau et al.('08) is developed and applied to a precision modeling of baryon acoustic oscillations.

→ **Regularized PT (RegPT)**

- Based on the RegPT formalism, a new and efficient scheme to accelerate the calculation of non-linear power spectrum is presented.

→ **RegPTfast**

Introduction

Large-scale structure as a key to pursue precision cosmology

Baryon acoustic oscillation (**BAO**) & redshift distortion (**RD**)

⟶ dark energy / cosmological test of gravity

fundamental statistics

Galaxy power spectrum $P(k)$ / correlation function $\xi(r)$

Need a precision modeling for future/on-going surveys

big issues

Reducing or controlling the non-linear systematics :

- gravitational clustering
- redshift distortions
- galaxy biasing

➡ Forward modeling based on perturbation theory (PT)

Perturbation theory approach

key point

For the scales accessible to future/on-going galaxy surveys,
annoying non-linear systematics are *rather mild*

- Perturbative treatment regarding the density field δ as small expansion parameter
- Bottom-up construction of a precision model starting with well-defined physical basis

gravitational clustering → redshift distortions → galaxy biasing

Closure theory — TNS model — in progress

AT & Hiramatsu ('08)
AT, Nishimichi, Saito & Hiramatsu ('09)
AT, Nishimichi & Saito ('10)
Nishimichi & AT ('11)

However, Bottle neck for practical application: gravitational clustering

an improved PT treatment involves time-consuming multi-dimensional integrals (~ a day), currently not relevant for global parameter search

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In this talk,
a new improved PT treatment of gravitational clustering, capable of accelerating the power spectrum calculations (--> **RegPT**)

However, Bottle neck for practical application: gravitational clustering

an improved PT treatment involves time-consuming multi-dimensional integrals (~ a day), currently not relevant for global parameter search

Regularized PT (RegPT)

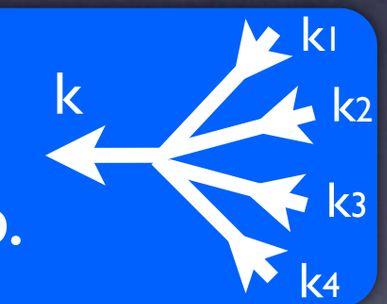
- Alternative non-perturbative formulation to deal with non-linear gravitational clustering developed by Bernardeau et al. ('08)
- Standard PT expansion is re-organized by multi-point propagators

multi-point correlations btw. initial & evolved density fields

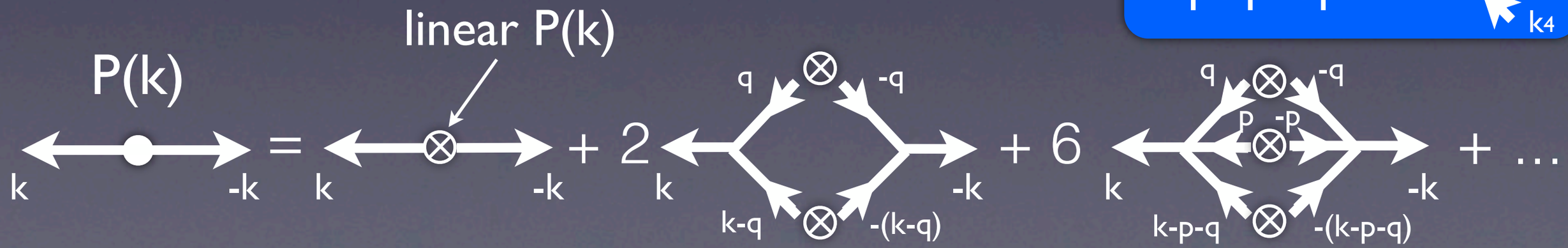
c.f. in RPT by Crocce & Scoccimarro ('06ab, '08), standard PT expansion is re-organized by power spectrum, one-point propagator, vertex function

Ex.

4-pt prop.



Diagramatic representation for P(k) in RegPT



Analytic expression

Up to 2-loop order

$$P(k;\eta) = \left[\Gamma^{(1)}_{\rm reg}(k;\eta)\right]^2 P_0(k) + 2\int \frac{d^3\boldsymbol{q}}{(2\pi)^3}\left[\Gamma^{(2)}_{\rm reg}(\boldsymbol{q},\boldsymbol{k}-\boldsymbol{q};\eta)\right]^2 P_0(q)P_0(|\boldsymbol{k}-\boldsymbol{q}|)$$
$$+ 6\int \frac{d^6\boldsymbol{p}d^3\boldsymbol{q}}{(2\pi)^6}\left[\Gamma^{(3)}_{\rm reg}(\boldsymbol{p},\boldsymbol{q},\boldsymbol{k}-\boldsymbol{p}-\boldsymbol{q};\eta)\right]^2 P_0(p)P_0(q)P_0(|\boldsymbol{k}-\boldsymbol{p}-\boldsymbol{q}|)$$

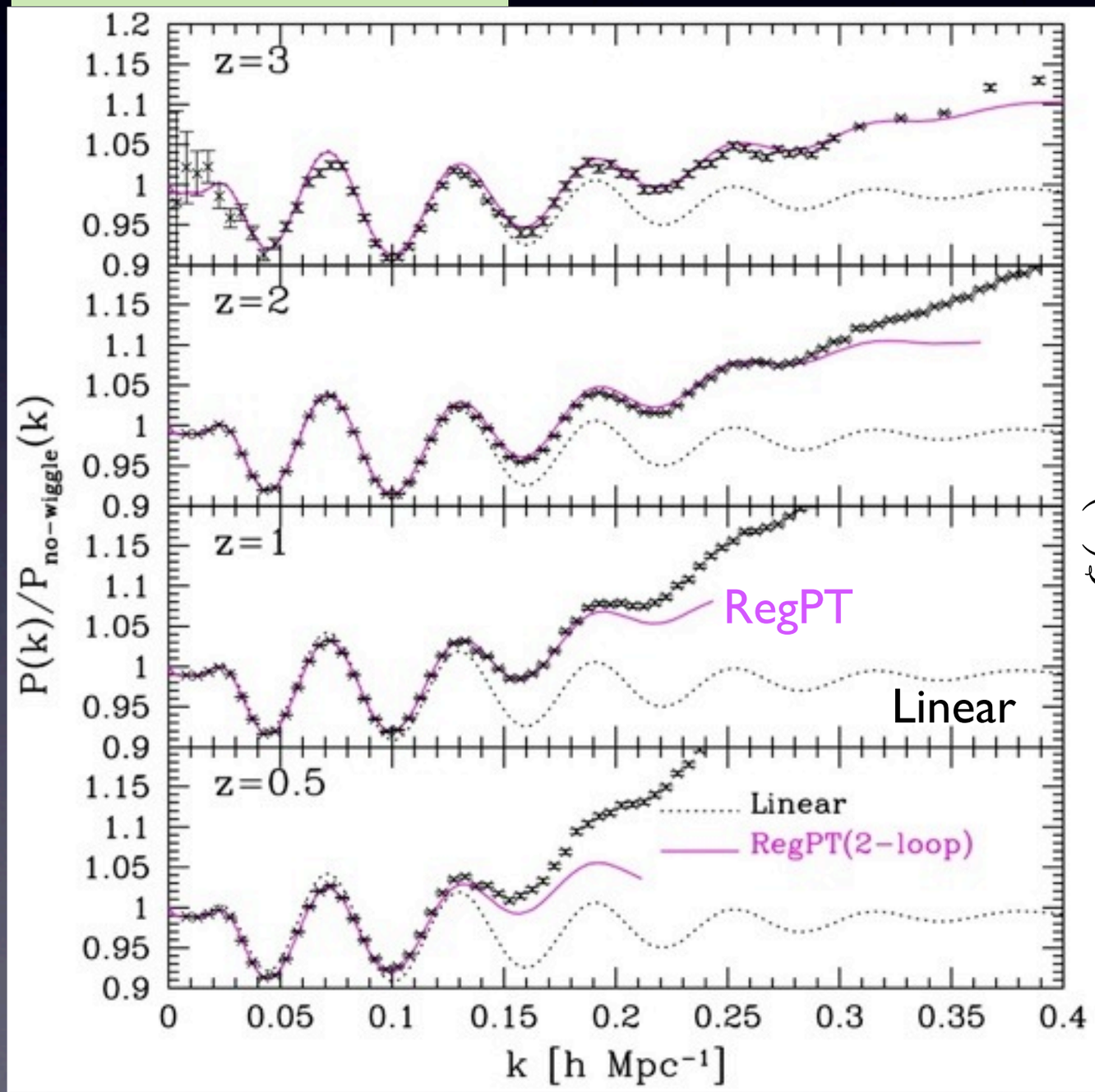
- Linear power spectrum $P_0(k)$
- Multi-point propagator $\Gamma^{(n)}_{\rm reg}$
  - UV property (k >>1) is analytically known $\left(\Gamma^{(n)}_{\rm reg} \to \Gamma^{(n)}_{\rm tree}\, e^{-k^2\sigma^2_{\rm v,lin}}\right)$
  - IR behavior (k<<1) is successfully described by standard PT calculations, and a precision can be improved perturbatively

Time dependence is incorporated into propagators in a multiplicative way (no need to do the time-integration like RPT & Closure)

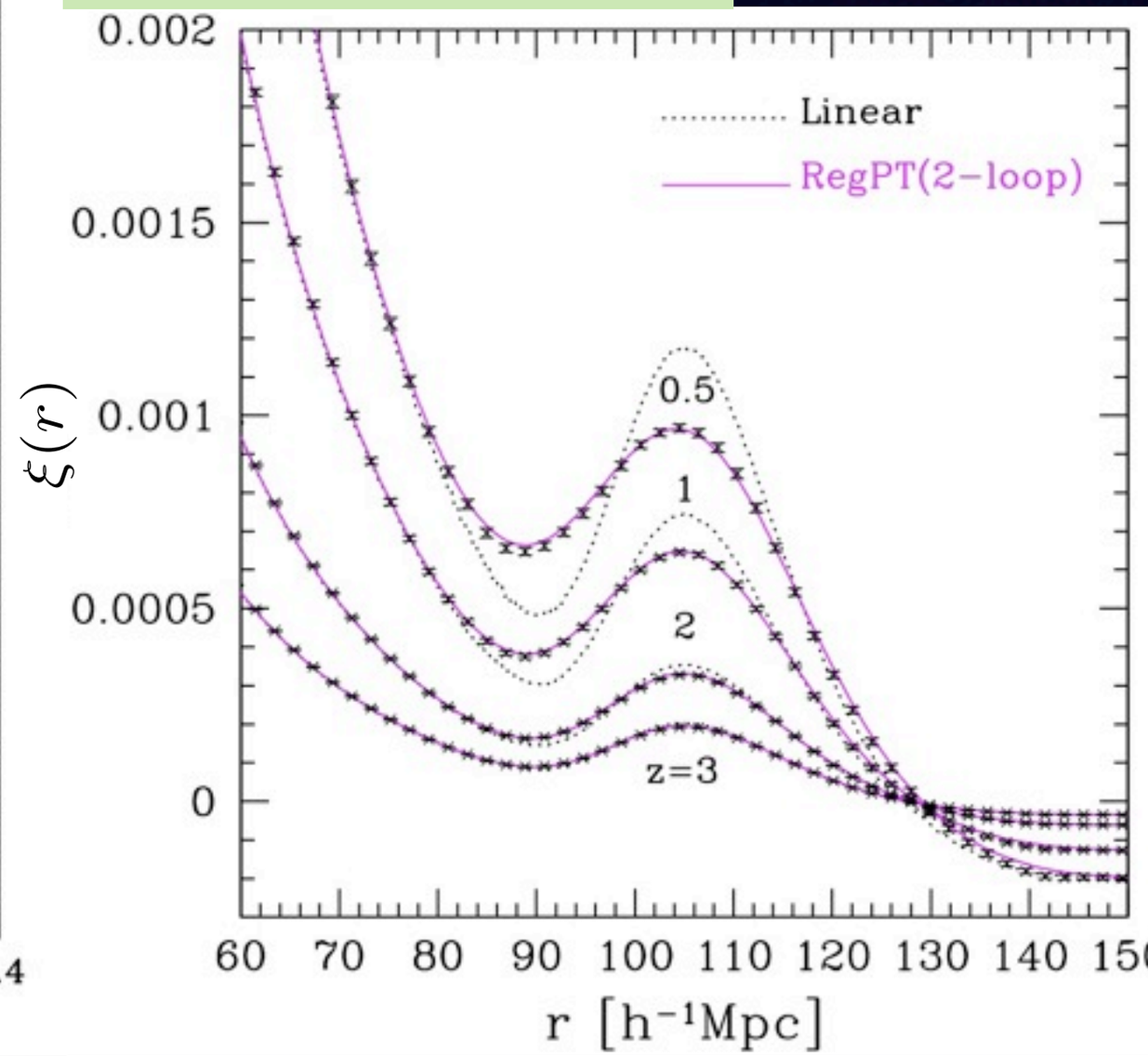
Comparison with N-body simulations

N-body simulations by T.Nishimichi

Power spectrum



Correlation function



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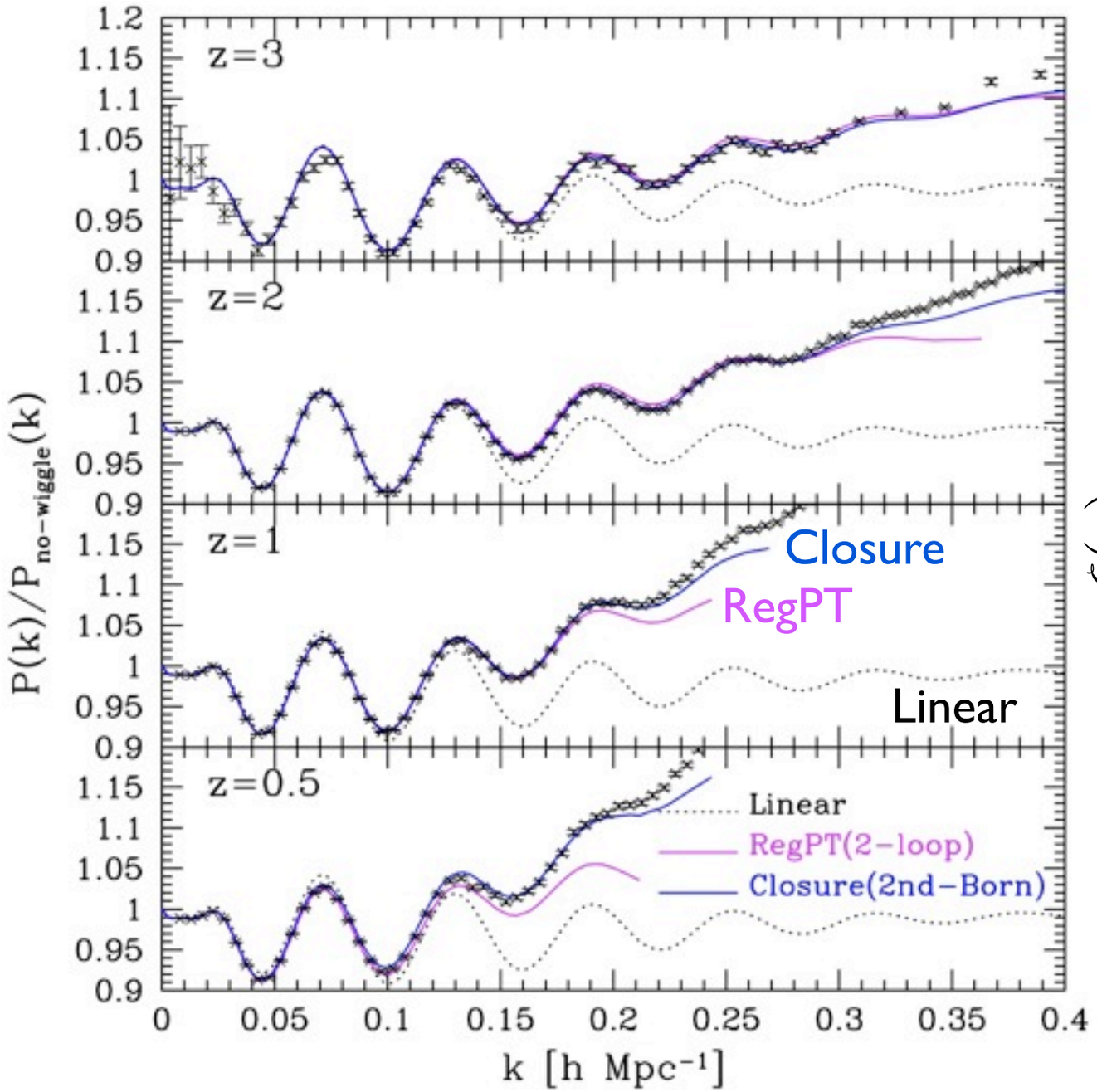

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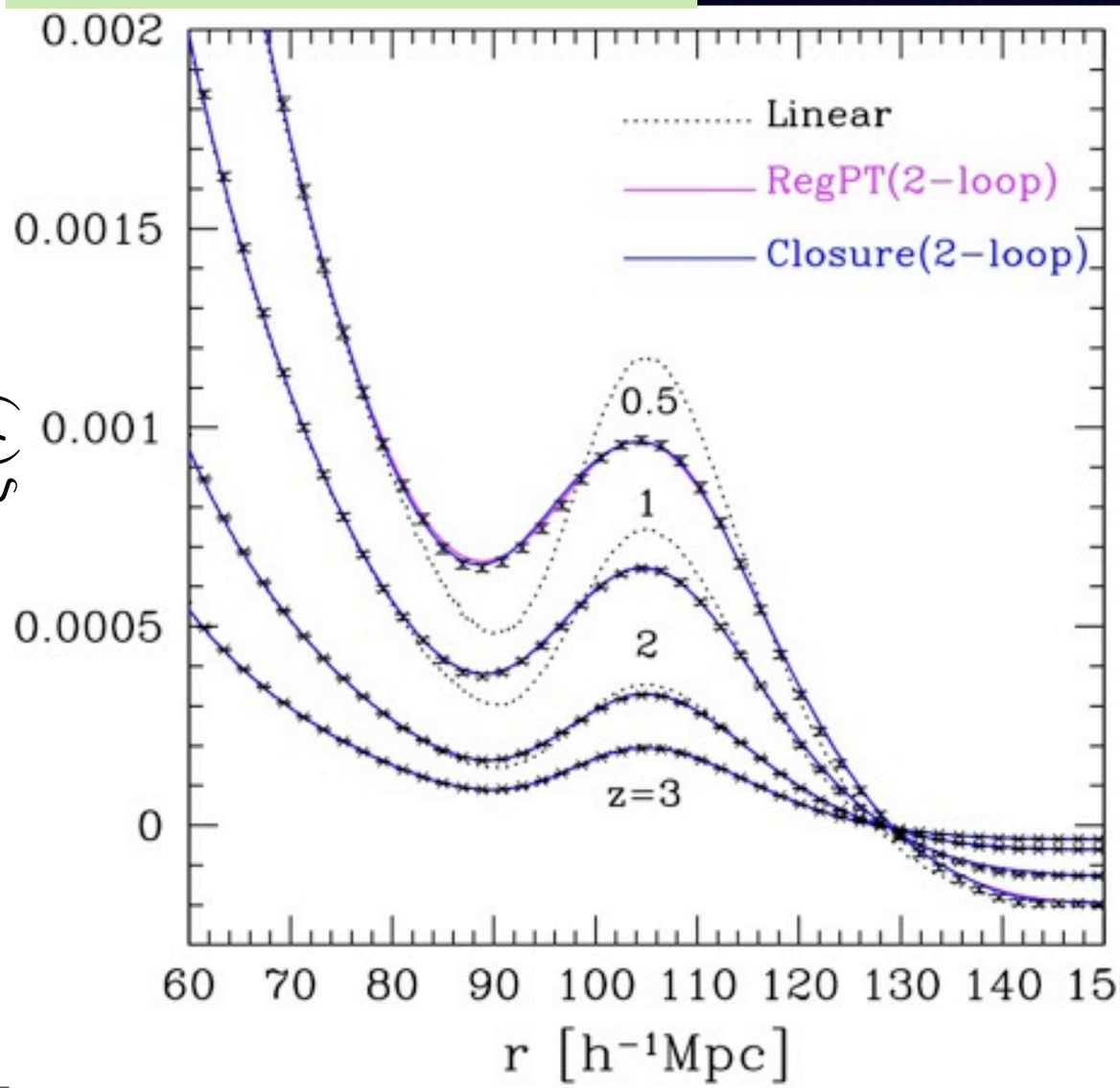


Accelerated power spectrum calculation

Given the data set for RegPT calculation in a fiducial cosmology,

An accelerated calculation of non-linear power spectrum
is possible for arbitrary target cosmological model (**RegPTfast**)

Assumption

Linear power spectrum in target model is close to the one in the fiducial model:

$$P_{0,\mathrm{target}}(k) = P_{0,\mathrm{fid}}(k) + \delta P_0(k)\,; \quad \delta P_0(k) \ll P_{0,\mathrm{fid}}(k)$$

perturbation

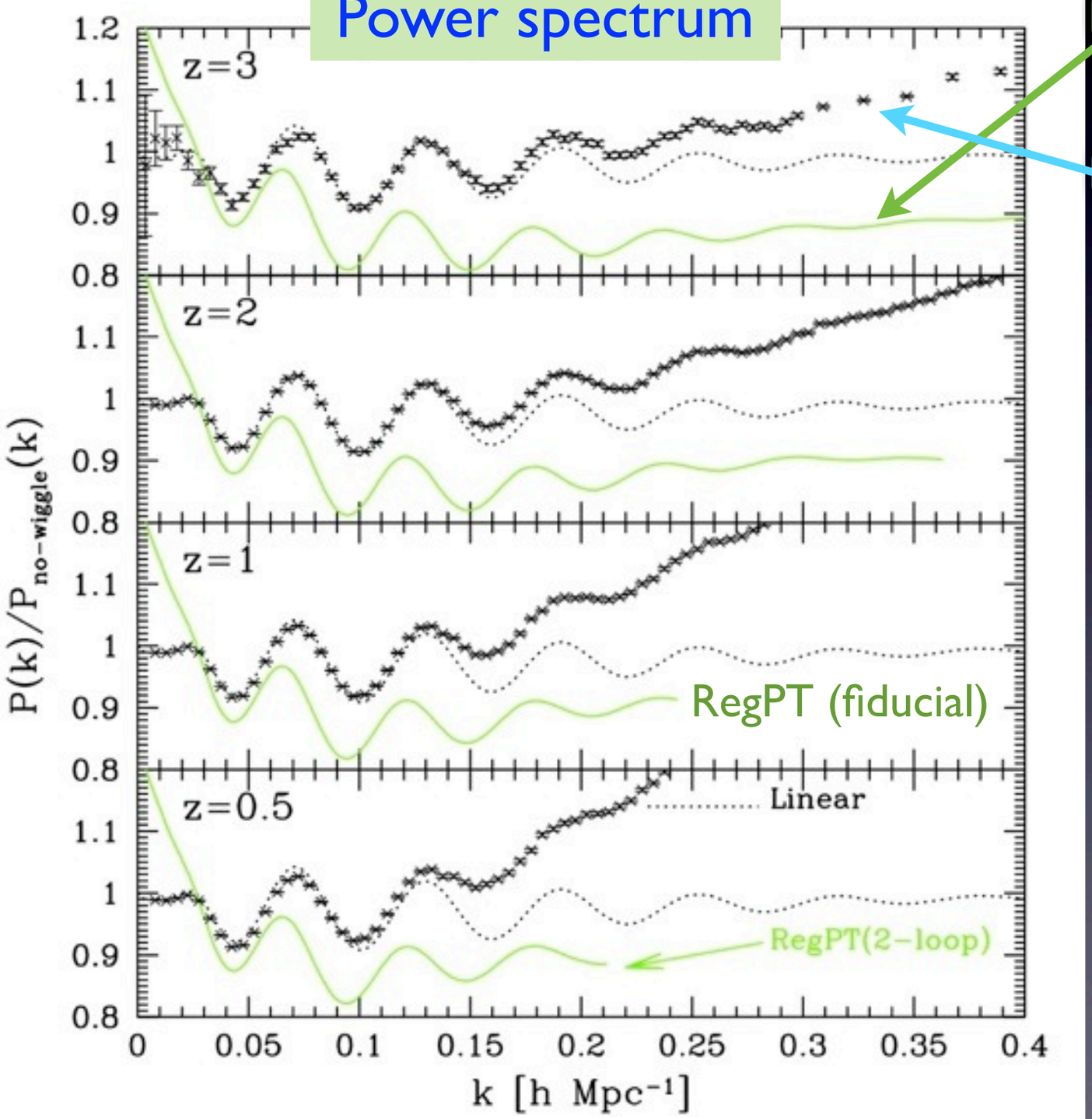
$$P(k) \longrightarrow \underbrace{P_{\text{un-perturb}}[k,\eta;P_{0,\mathrm{fid}}]}_{\text{pre-computed}} + P_{\mathrm{corr}}[k,\eta;\delta P_0]$$

Corrections needs to be newly evaluated, but with just 1D integration

Amazingly fast calculation (<1 min.) is possible !!

Reconstruction of P(k) & ξ(r)

Power spectrum



Fiducial
cosmological model with wmap3

Target (N-body)
cosmological model with wmap5

Fiducial (wmap3)	Target (wmap5)
$\Omega_{\rm m} = 0.234$	$\Omega_{\rm m} = 0.279$
$\Omega_\Lambda = 0.766$	$\Omega_\Lambda = 0.721$
$\Omega_{\rm b}/\Omega_{\rm m} = 0.175$	$\Omega_{\rm b}/\Omega_{\rm m} = 0.165$
$h = 0.734$	$h = 0.701$
$\sigma_8 = 0.76$	$\sigma_8 = 0.817$

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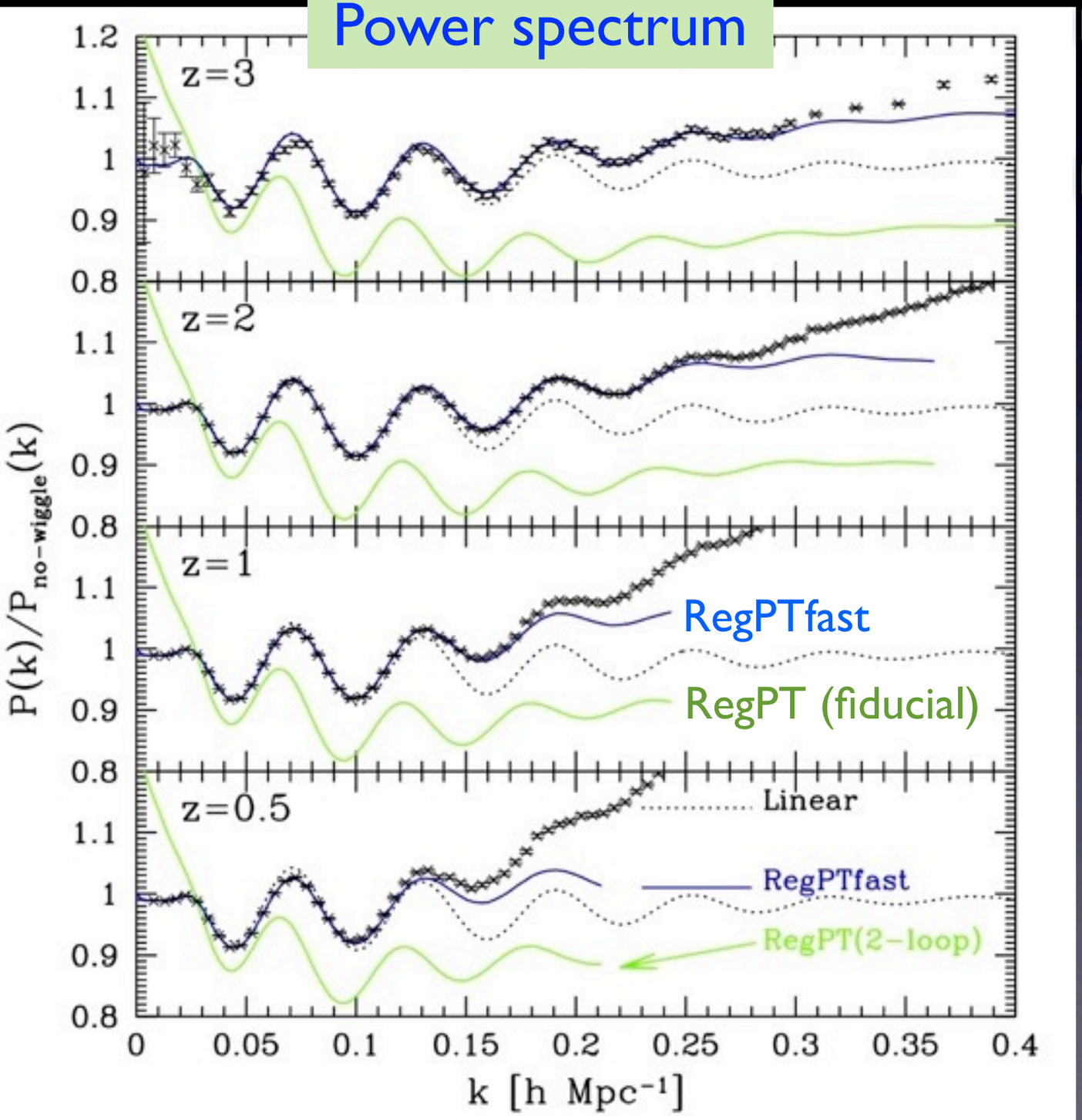
Power spectrum



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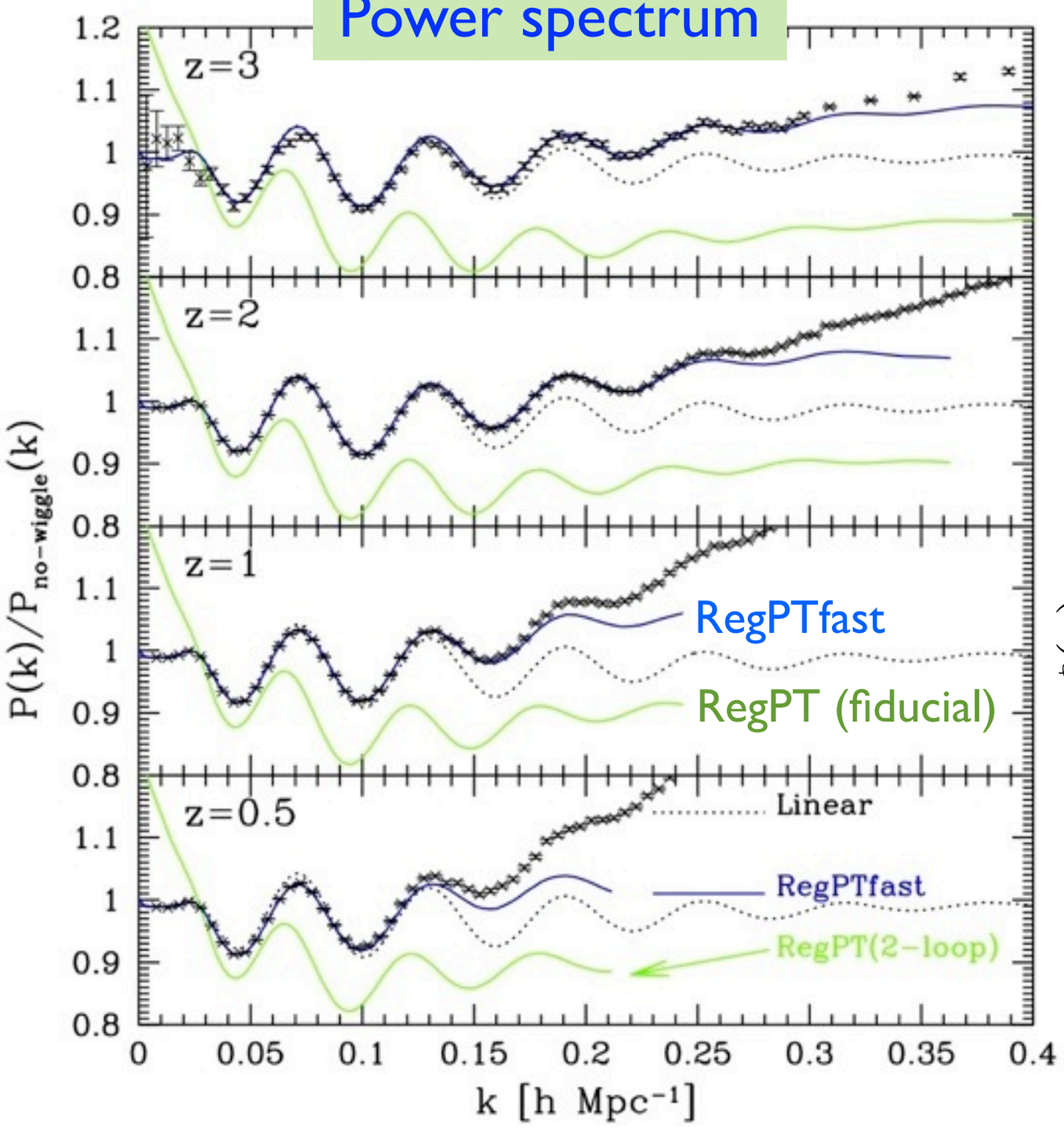

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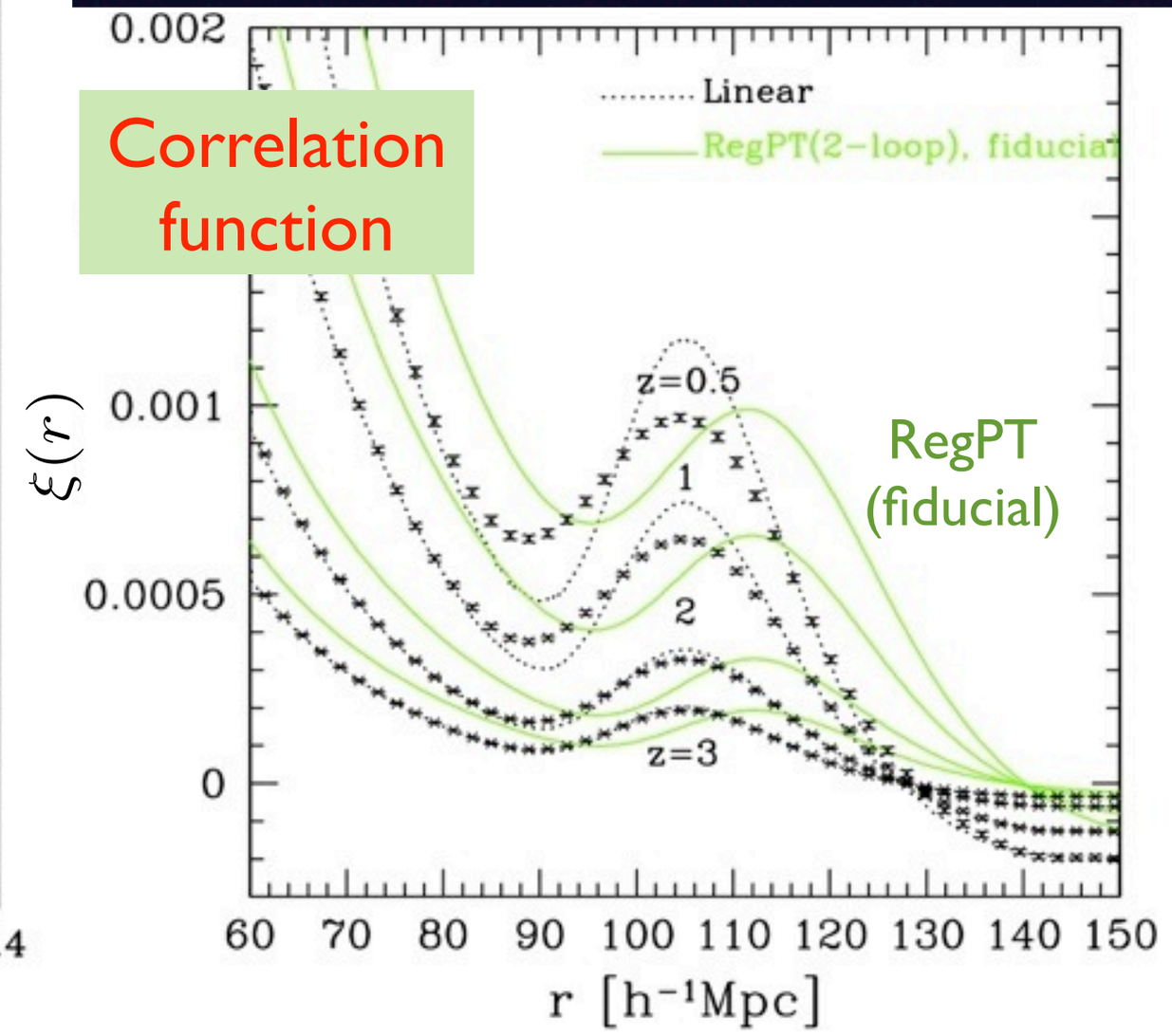
cosmological model with wmap3

Target (N-body)

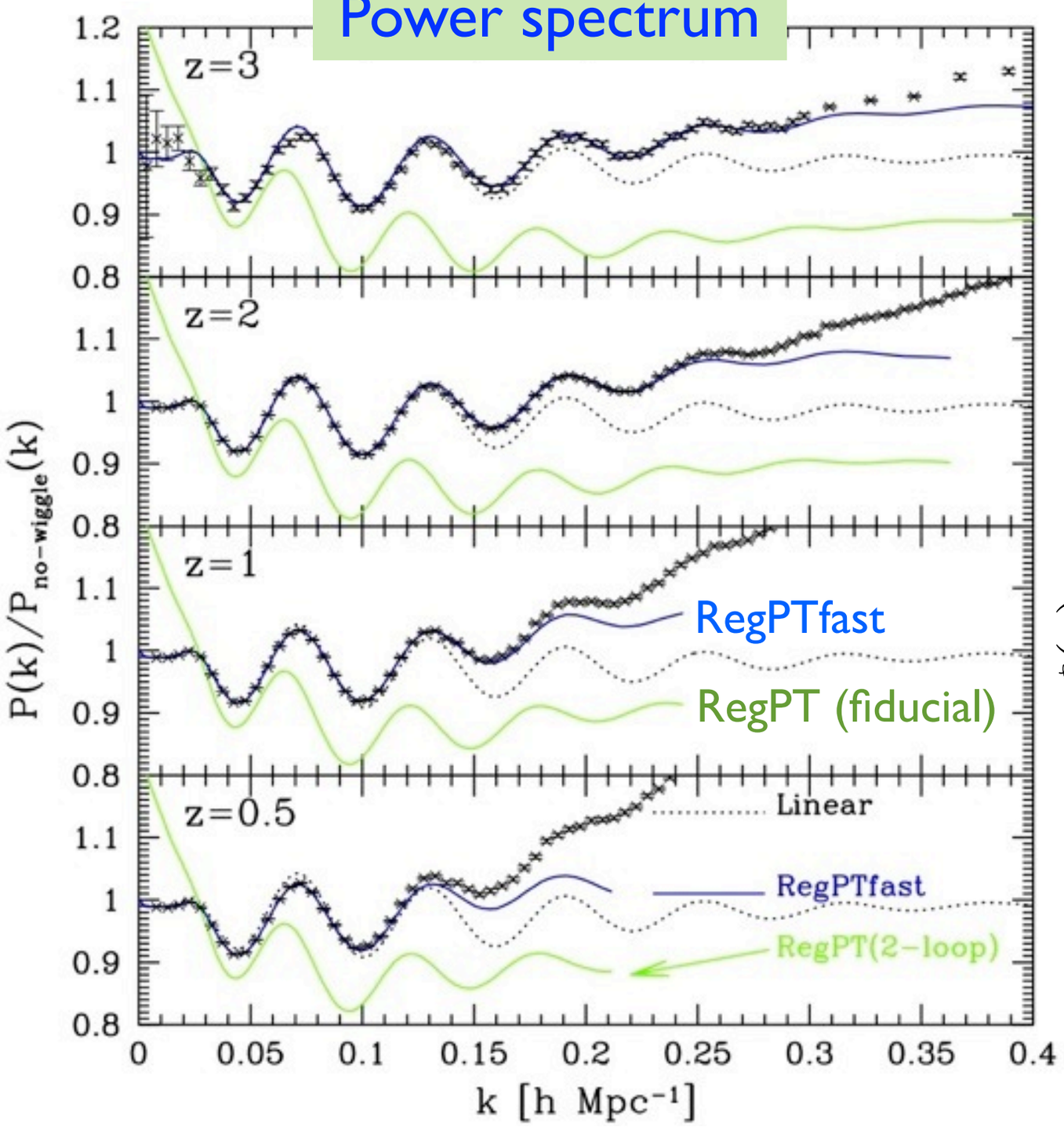
cosmological model with wmap5

Correlation function



Reconstruction of P(k) & ξ(r)

Power spectrum



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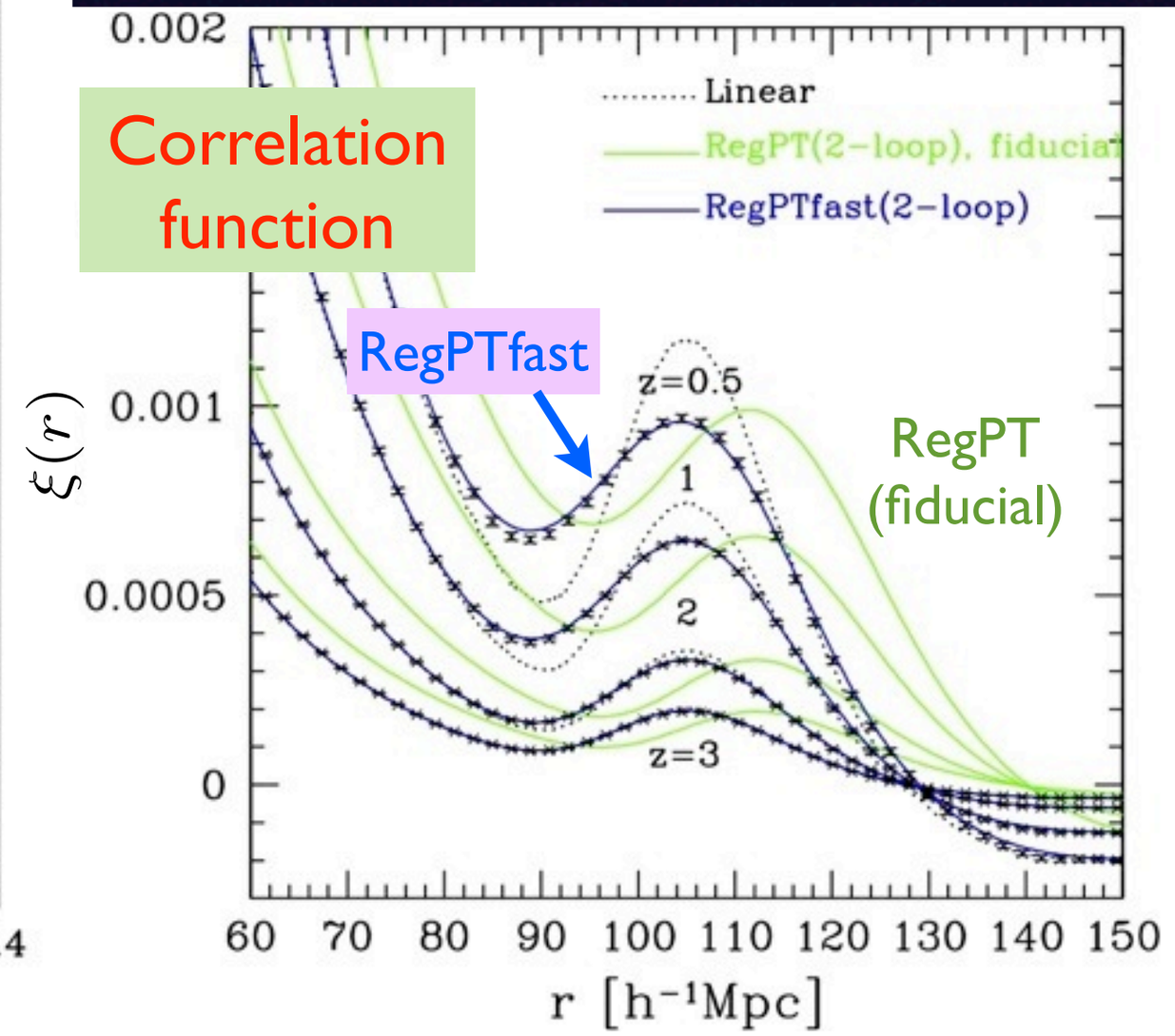

Summary

A new improved PT treatment of power spectrum calculations based on the non-perturbative formulation with multi-point propagators

Regularized PT (RegPT)

- Application to precision modeling of BAOs

- Accelerated calculations for P(k) & ξ(r) by perturbative reconstruction scheme

RegPTfast

The effect of redshift distortions can be easily taken into account combining a model of redshift distortions

Codes for RegPT will be (hopefully) publicly available soon