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Cosmology Near & Far:
Science with WFMOS
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Accurate Modeling for Matter Power Spectrum and Baryon Acoustic Oscillations

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Introduction

Precision measurement of baryon acoustic oscillations (BAOs)

→ BAO scale information to constrain expansion history

(require ~% level precision)

Need "accurate template" including various systematic effects

Focus of this talk

Accurate theoretical modeling for non-linear gravitational evolution of BAOs

Helpful to
- Check the parameterized template modeling
- Extract other cosmological information

Going beyond linear regime,

How can we check the accuracy of theory/methodology ?

Motivation

Although N-body simulation may be the ultimate methodology,
we need alternative treatment, at least for check of consistency

Analytic approach has been reloaded / improved !!

- Perturbation theory (PT) (e.g., Suto & Sasaki 1991)

  + "galaxy" biasing — Jeong & Komatsu (2008)

  + neutrinos — Saito, Takada & AT (2008)

- Improved perturbation theory

  Renormalized Perturbation Theory (**RPT**)
  Crocce & Scoccimarro (2006ab, 2008)

  Closure Approximation (CLA) — AT & Hiramatsu (2008)

See also, McDonald (2006); Matarrese & Pietroni (2007); Matsubara (2008)

Closure Approximation (CLA)

AT & Hiramatsu, ApJ 674, 617 (2008)

Based on fluid description of (CDM + baryon) components,

1. Diagramatic representation of (naïve) perturbation series

2. Renormalizaed expressions of perturbation series
   in terms of <u>three non-perturbative quantities</u>

   Power spectrum, Propagator, Vertex function

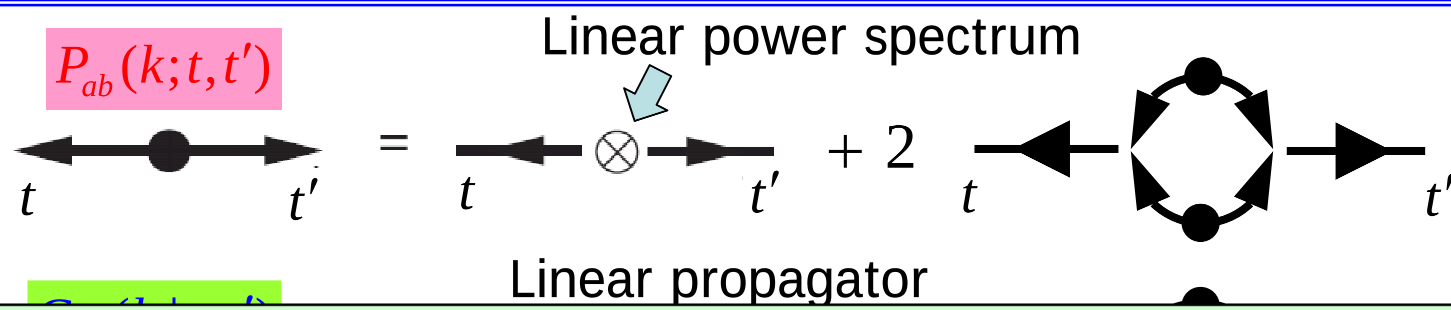
3. Truncation of renormalizaed expressions at ***1-loop order***
   \+ tree-level approx. of vertex function

⇨ **Closed system**
coupled with power spectrum and propagator

Closure Approximation (CLA)

Diagramatic representation

Power spectrum

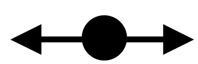
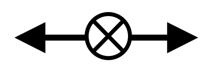


Need to solve P(k) and G(k) self-consistently ⇨ Full numerical treatment (discuss later)

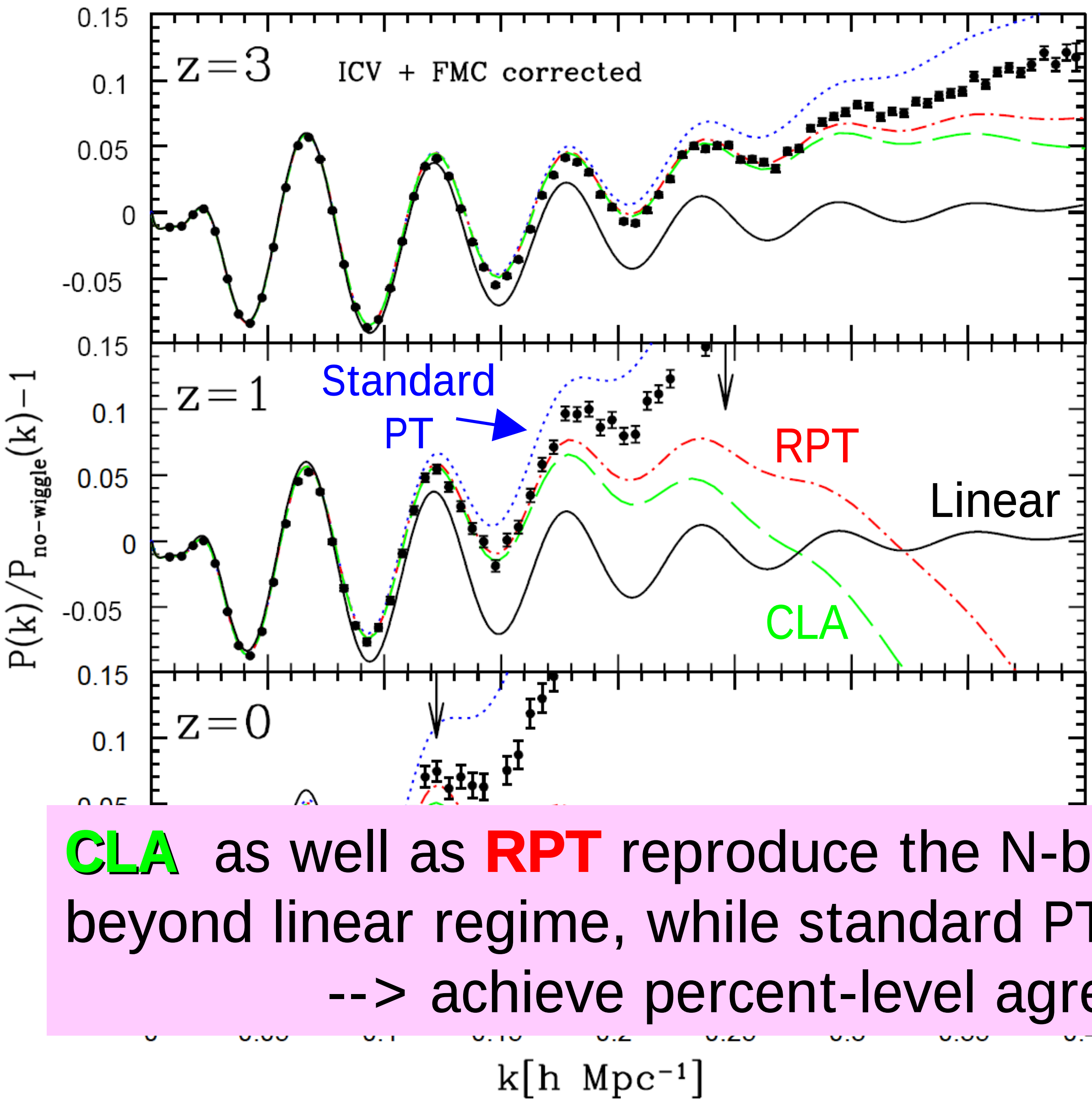
For analytic study,

Propagator: approximate solution by matching the asymptotic behaviors at low- and high-k

Power spectrum: iterative evaluation with Born approximation

(replacing  with  in renormalized diagram)

Power Spectrum



Leading-order calculation

RPT: 1-loop (Crocce & Scoccimarro)

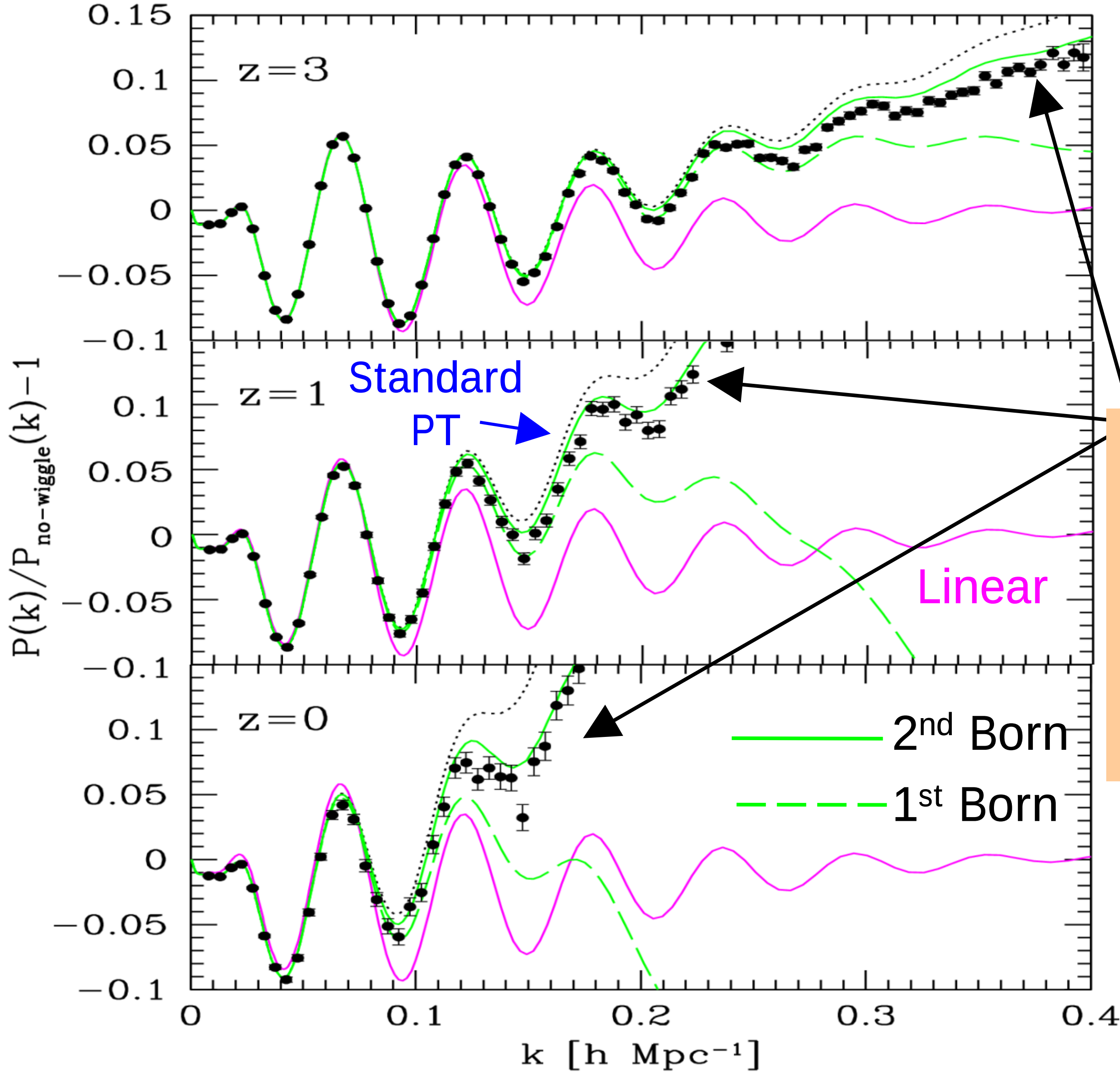
CLA: 1st Born (This work)

CLA as well as **RPT** reproduce the N-body results quite well beyond linear regime, while standard PT failed.

--> achieve percent-level agreement at some ranges

in prep.

Including Higher-order (CLA)

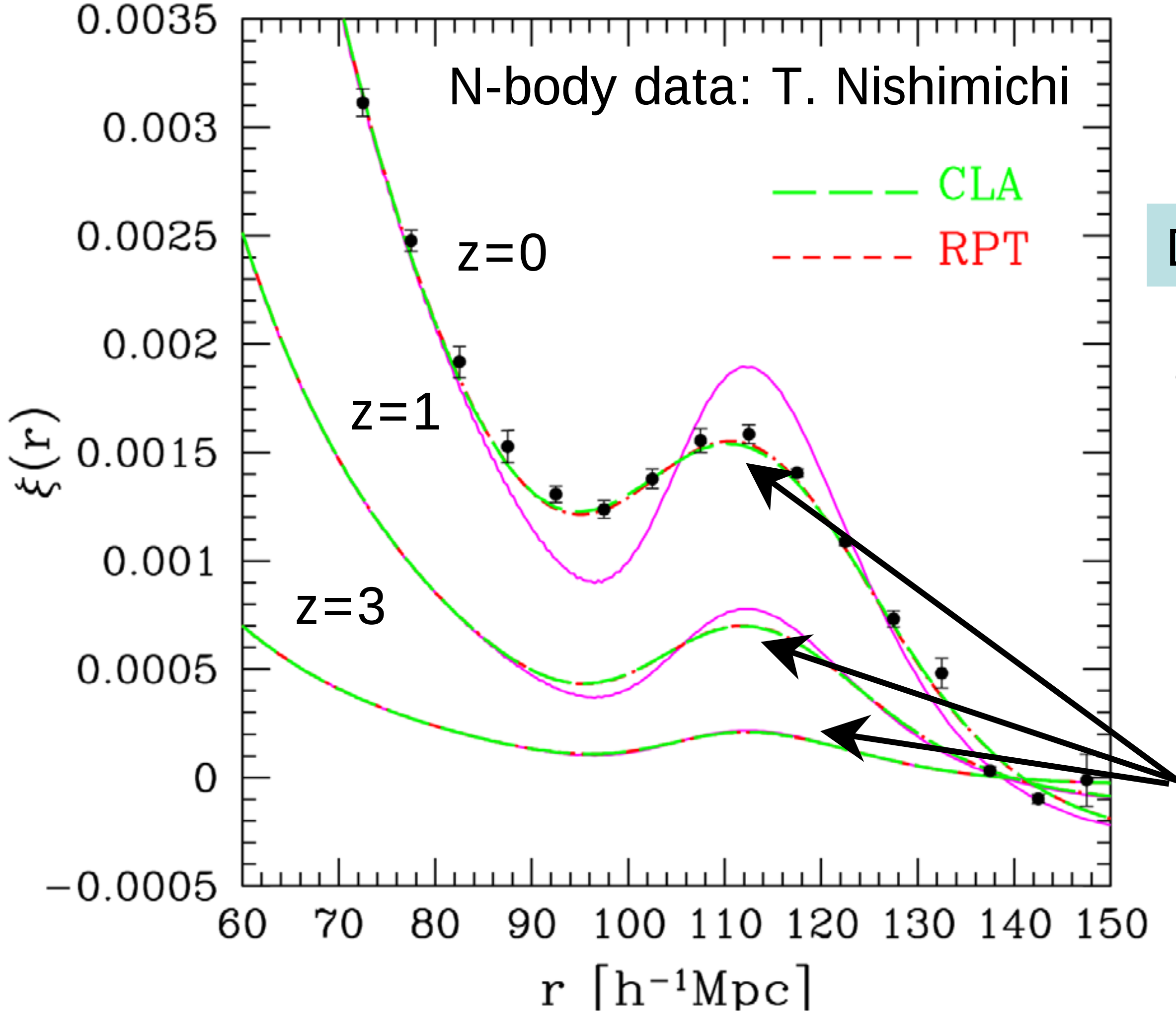


Inclusion of higher-order correction improves the prediction, reproducing the N-body results quite well.

AT & Hiramatsu (2008) in prep.

Two-point Correlation Function

Leading-order calculation is sufficient to describe the non-linear behavior of acoustic peak



Def.

$$\xi(r) = \int \frac{dk\,k^2}{2\pi^2} P(k) \frac{\sin(k\,r)}{k\,r}$$

Both approximations almost converge and agree with simulations

Summary and Discussions

Analytic approach based on perturbation theory (**PT**) has been reloaded and can be used as accurate modeling for BAOs

Several non-perturbative methods have been proposed, aiming at modeling non-linear evolution of BAOs beyond standard PT.

Closure approximation (**CLA**), Renormalized perturbation theory (**RPT**)

Accuracy of theory/methodology has been tested comparing N-body simulation with analytic approach

Agreement with sub-% level at low-k, few % level at high-k

Discussions

CLA has a capability to compute power spectrum even faster than RPT in more general situations (-->next slide)

CLA in Numerical Treatment

Evolution equations corresponding to the truncated diagrams:

$$\widehat{\Lambda}_{ab}(\eta)\, P_{bc}(k;\eta,\eta') = \int \frac{d^3\boldsymbol{q}}{(2\pi)^3}\, \gamma_{apq}(\boldsymbol{q},\boldsymbol{k}-\boldsymbol{q})\, \underline{K_{cpq}(-\boldsymbol{k},\boldsymbol{q},\boldsymbol{k}-\boldsymbol{q};\,\eta,\eta')},$$

Bispectrum

$$\widehat{\Lambda}_{ab}(\eta)\, G_{bc}(\boldsymbol{k}|\eta,\eta') = 4\int_{\eta'}^{\eta} d\eta'' \int \frac{d^3\boldsymbol{q}}{(2\pi)^3}\, \gamma_{apq}(\boldsymbol{q},\boldsymbol{k}-\boldsymbol{q})\, \gamma_{lrs}(-\boldsymbol{q},\boldsymbol{k})$$
$$\times G_{ql}(|\boldsymbol{k}-\boldsymbol{q}||\eta,\eta'')\, P_{pr}(q;\eta,\eta'')\, G_{sc}(\boldsymbol{k}|\eta'',\eta').$$

Operator: $\widehat{\Lambda}_{ab}(\eta) \equiv \delta_{ab}\frac{\partial}{\partial\eta} + \begin{bmatrix} 0 & -1 \\ -3/2 & 1/2 \end{bmatrix}$ Time variable: $\eta \equiv \ln D_+(z)$

- By numerically solving these equations, CLA provides a fully non-perturbative answer including higher-order corrections

(See poster by **T. Hiramatsu**)

- Modification to the cases of modified gravity models is easy

(Hiramatsu, Koyama & Taruya, in prep.)