The Effective Field Theory of Large Scale Structure at 3Loops (1906.00997)

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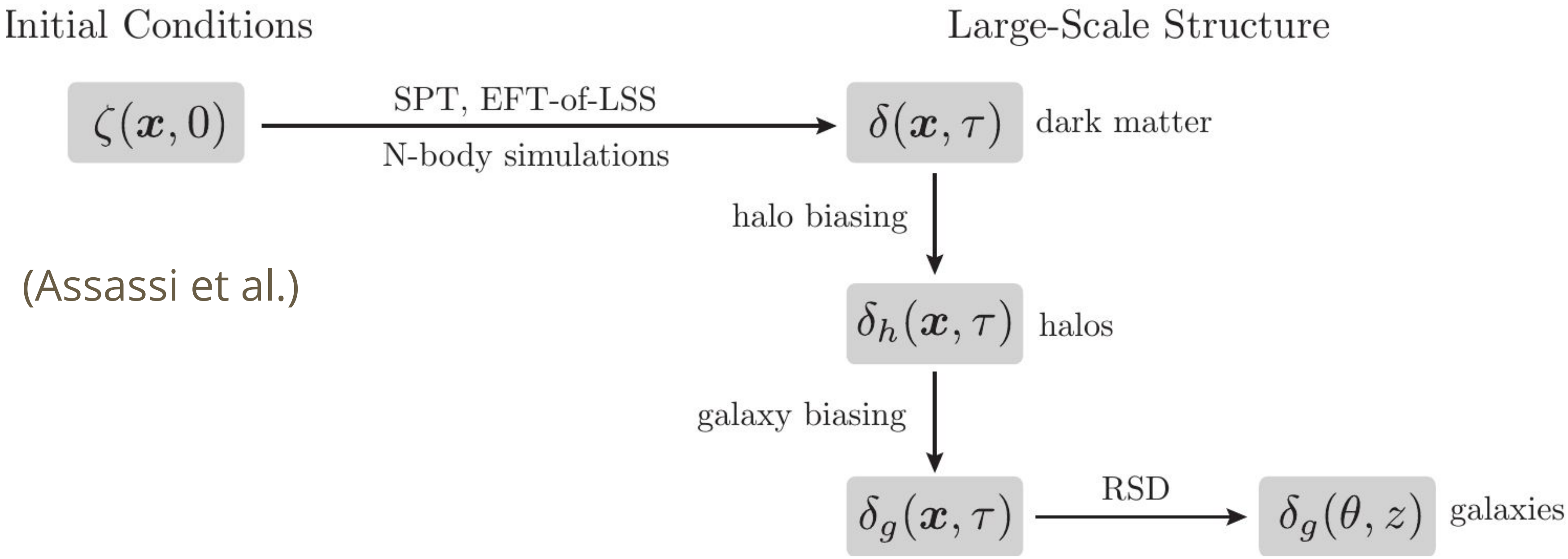
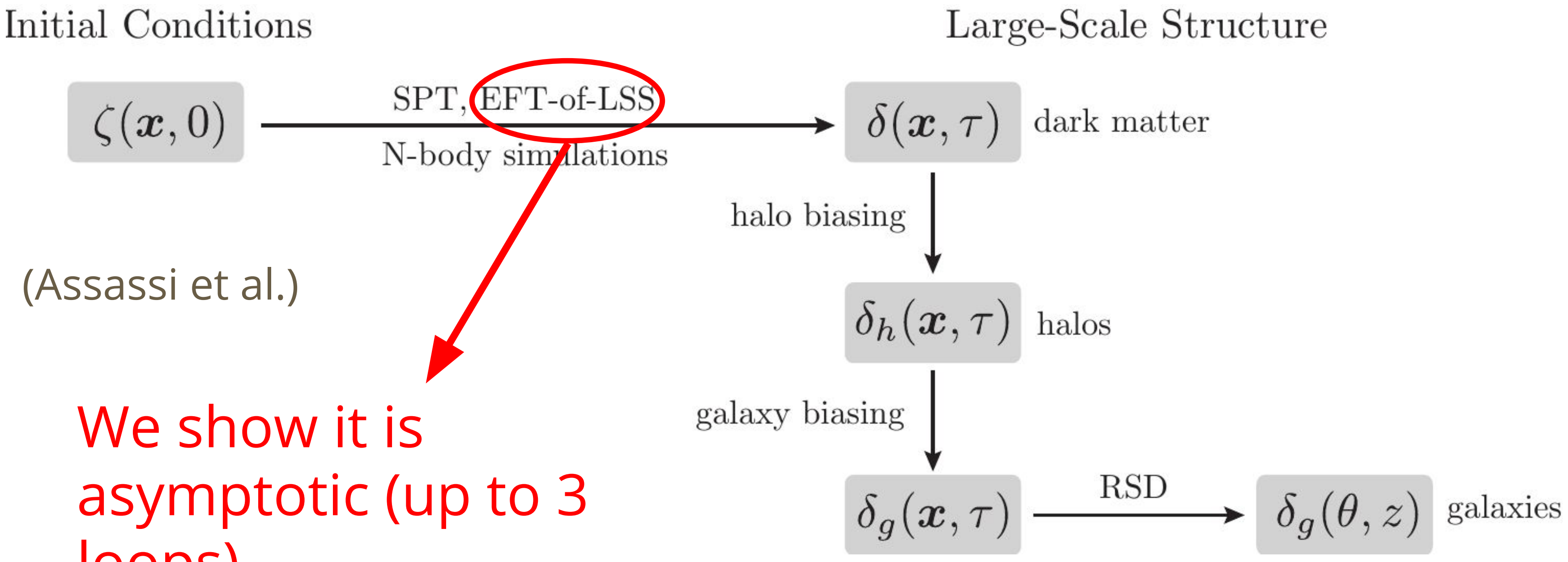
Motivation 1



(Assassi et al.)

Motivation 1 - Main message



(Assassi et al.)

We show it is asymptotic (up to 3 loops)

Main Methods

Trying to go beyond the linear scale:

- Standard Perturbation Theory (SPT);
- Effective Field Theories (EFTs);
- HaloFit and Halomodel;
- Vlasov solvers;
- Schrodinger Method;
- Resummation Methods;
- Simulations.

Standard Perturbation Theory (SPT)

Standard Perturbation Theory (SPT) (Bernadeau et al.)

Mass Conservation

$$\frac{\partial \delta(\mathbf{x},\tau)}{\partial \tau} + \nabla \cdot \{[1+\delta(\mathbf{x},\tau)]\,\mathbf{u}(\mathbf{x},\tau)\} = 0,$$

Euler

$$\frac{\partial \mathbf{u}(\mathbf{x},\tau)}{\partial \tau} + \mathcal{H}(\tau)\;\mathbf{u}(\mathbf{x},\tau) + \mathbf{u}(\mathbf{x},\tau)\cdot\nabla\mathbf{u}(\mathbf{x},\tau) = -\nabla\Phi(\mathbf{x},\tau) - \frac{1}{\rho}\nabla_j\left(\rho\,\sigma_{ij}\right),$$

Poisson

$$\nabla^2\Phi(\mathbf{x},\tau) = \frac{3}{2}\Omega_m(\tau)\;\mathcal{H}^2(\tau)\;\delta(\mathbf{x},\tau).$$

Standard Perturbation Theory (SPT) (Bernadeau et al.)

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Just Navier-Stokes

Poisson

$$\nabla^2\Phi(\mathbf{x},\tau) = \frac{3}{2}\Omega_m(\tau)\,\mathcal{H}^2(\tau)\,\delta(\mathbf{x},\tau).$$

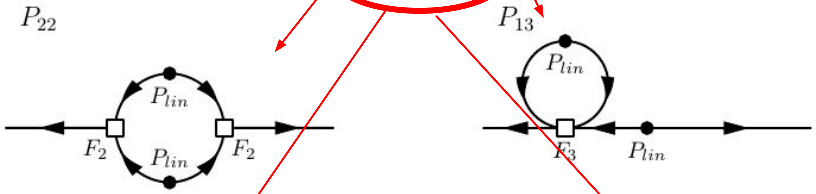
Standard Perturbation Theory (SPT) to Diagrams

(Bernadeau et al.)

$$\langle\delta\delta\rangle = \underbrace{\langle\delta_1\delta_1\rangle}_{\text{tree-level}} + \underbrace{2\langle\delta_1\delta_3\rangle + \langle\delta_2\delta_2\rangle}_{\text{1-loop}} + \underbrace{2\langle\delta_1\delta_5\rangle + 2\langle\delta_2\delta_4\rangle + \langle\delta_3\delta_3\rangle}_{\text{2-loop}} + \underbrace{\mathcal{O}(\delta_1^8)}_{\text{higher loop}}$$

1-LOOP

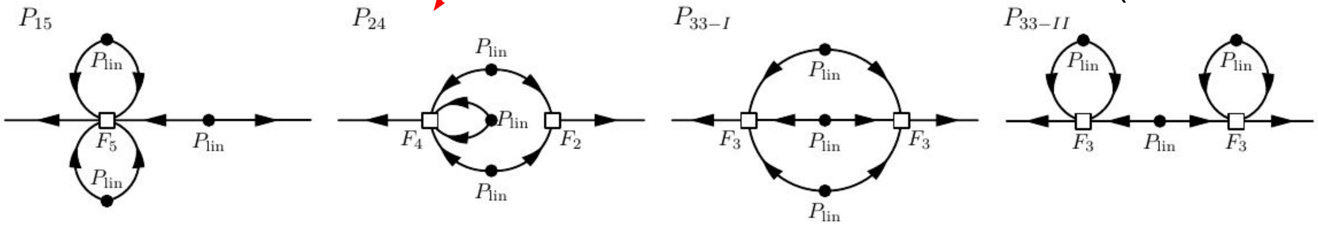
LEVEL:



(fromSimonović et al.)

2-LOOP

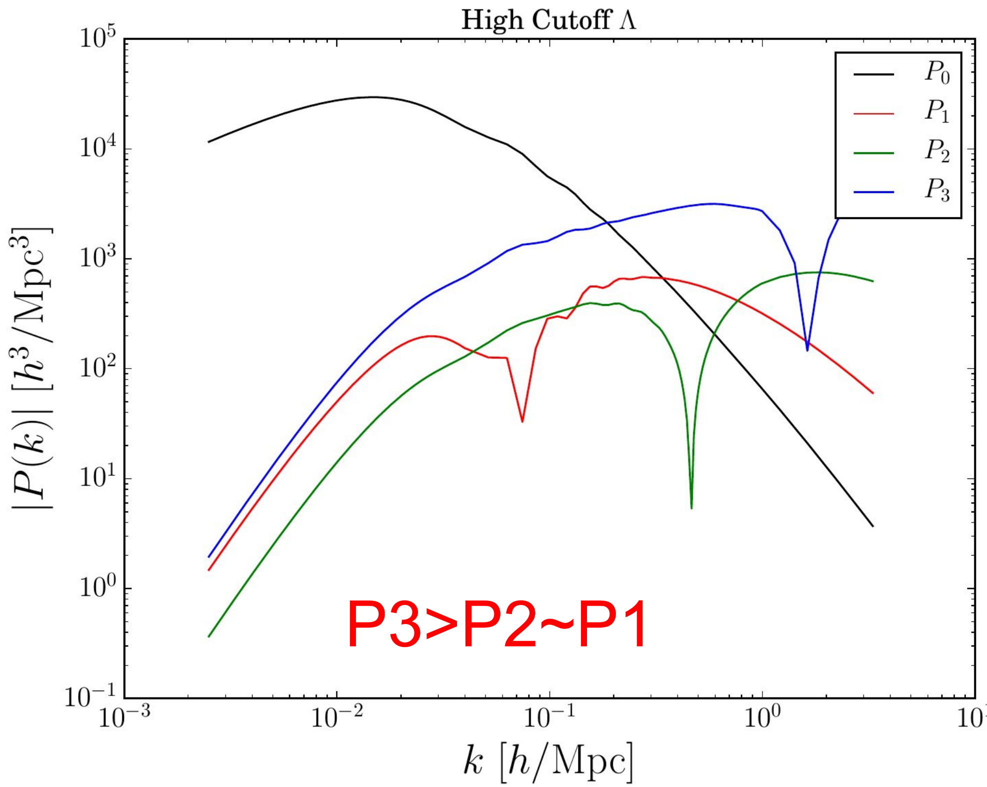
LEVEL:



Standard Perturbation Theory (SPT) Results

3-LOOP: Too scary to show

(Blas et al.)



Standard Perturbation Theory (SPT) Problems

1) Small Scales are wrong described

2) Inserting a cutoff scale (non-physical)

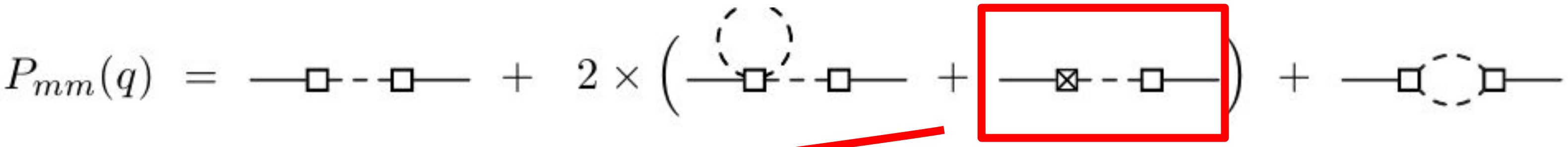
$$P_{22}(k,\tau) \equiv 2\int [F_2^{(s)}(\mathbf{k}-\mathbf{q},\mathbf{q})]^2 P_L(|\mathbf{k}-\mathbf{q}|,\tau) P_L(q,\tau)\, \mathrm{d}^3\mathbf{q},$$

$$P_{13}(k,\tau) \equiv 6\int F_3^{(s)}(\mathbf{k},\mathbf{q},-\mathbf{q}) P_L(k,\tau) P_L(q,\tau)\, \mathrm{d}^3\mathbf{q}.$$

Effective Field Theory

Effective Field Theory

Counterterm will 1) make the theory independent of Λ and 2) parametrize UV

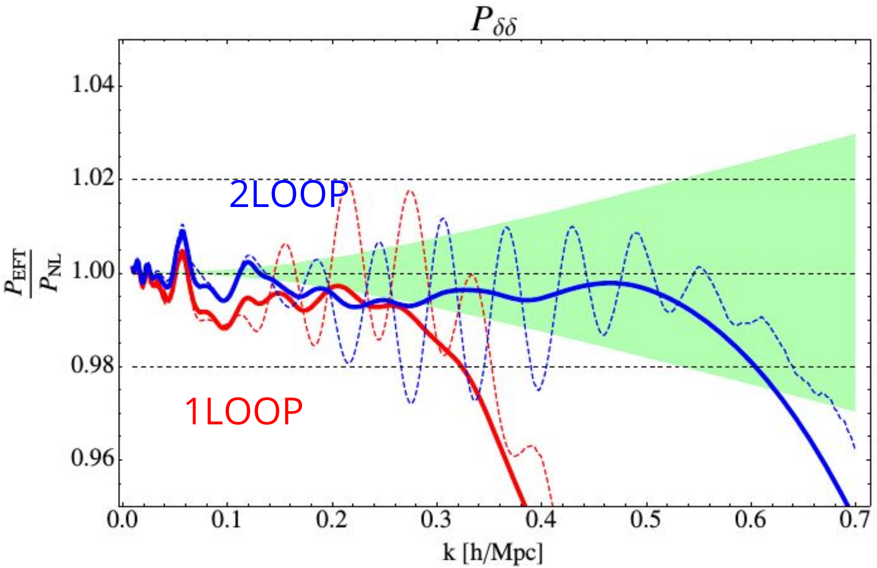


Counterterm: $2(2\pi)c^2_{s(2)}(z)\frac{k^2}{{k_{\mathrm{NL}}}^2}P_{11}(k)$ Sound Speed

State of the Art

2-loops / 3 free parameters

(Senatore and Zaldarriaga)



What about going to higher loops?

3Loops EFT

The allowed terms in the 3LoopEFT calculation are (with 9 free parameters):

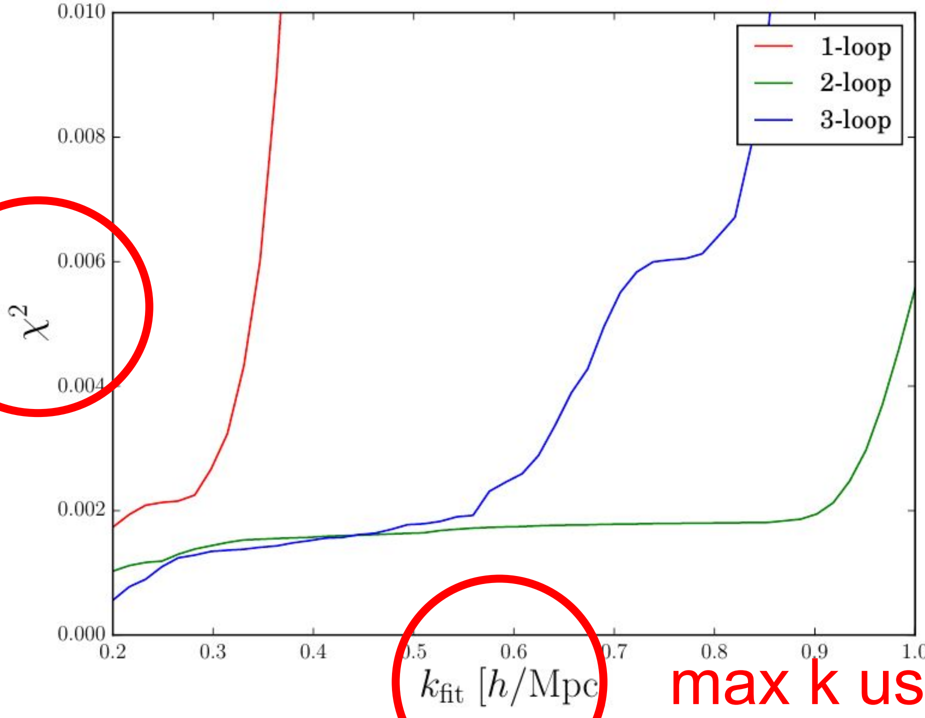
SPT

EFT

$$
\begin{aligned}
P^{\mathrm{EFT}}_{\text{3-loop}} = P_3 &- 2(2\pi)(c^2_{s(1)} + c^2_{s(2)} + c^2_{s(3)})k^2 P_0 - 2(2\pi)(c^2_{s(1)} + c^2_{s(2)})k^2 P_1 - 2(2\pi)c^2_{s(1)} k^2 P_2 \\
&+ (2\pi)^2\Big((c^2_{s(1)})^2 + 2c^2_{s(2)}c^2_{s(1)}\Big)k^4 P_0 + (2\pi)^2(c^2_{s(1)})^2 k^4 P_1 \\
&- 2(2\pi)(c_{2,\mathrm{quad}(1)} + c_{2,\mathrm{quad}(2)})k^2 P_{\mathrm{quad}} - 2(2\pi)c_{2,\mathrm{quad}(1)}k^2 P_{\mathrm{quad}_2} - 2(2\pi)^2(c_{4(1)} + c_{4(2)})k^4 P_0 \\
&- 2(2\pi)^2 c_4 k^4 P_1 + 2(2\pi)^3 c^2_{s(1)} c_4 k^6 P_0 + 2(2\pi)^2 c^2_{s(1)} c_{2,\mathrm{quad}(1)} k^4 P_{\mathrm{quad}} + (2\pi)^2 c_{\mathrm{stoch}} k^4 \\
&- 2(2\pi)^2 c_{4,\mathrm{quad}} k^4 P_{\mathrm{quad}} - 2(2\pi)^3 c_6 k^6 P_0 .
\end{aligned}
$$

3Loops EFT - Main Results

Comparing Pk with N-body simulation



max k used to the fit

3Loops EFT - Main Results

Why do we have the 3-loop being worse than the 2-loop for high k even with more free parameters?

3Loops EFT - Main Results

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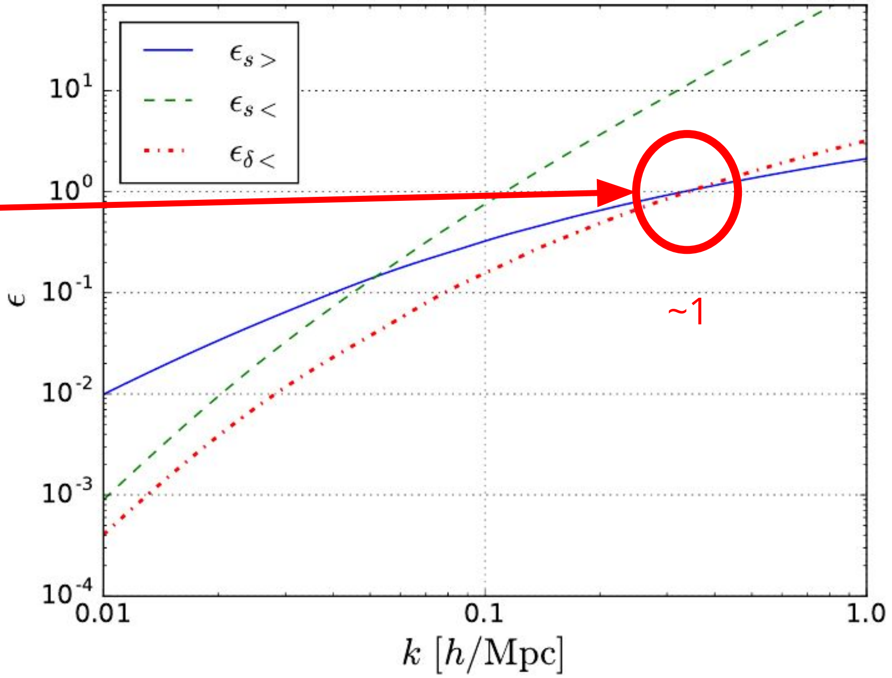
$$P_\ell(k) \xrightarrow{k \gg p} a_\ell \, P_0(k) \, (\epsilon_{\delta<}(k))^\ell + \dots ,$$

loop order

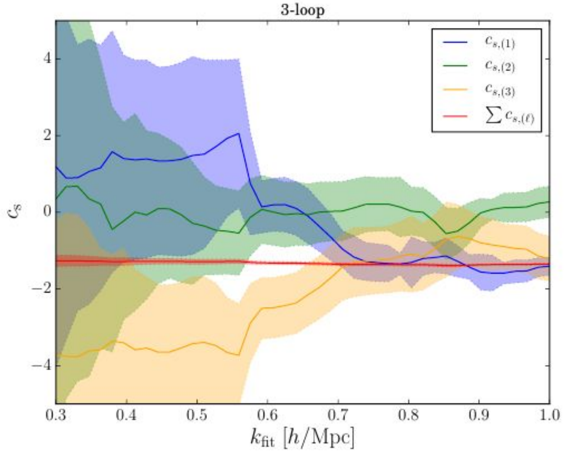
$$\epsilon_{\delta<}(k) = \int_0^k \frac{d^3p}{(2\pi)^3} P_0(p) \, ,$$

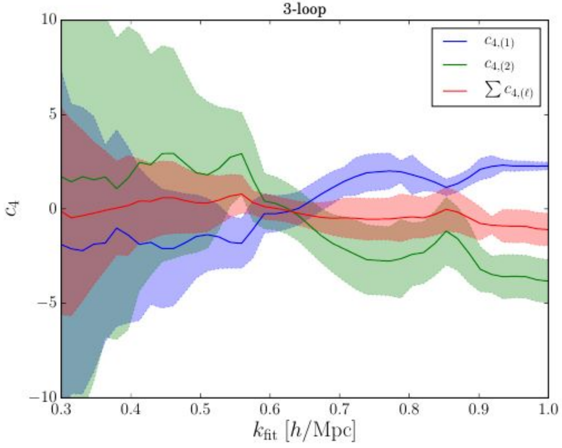


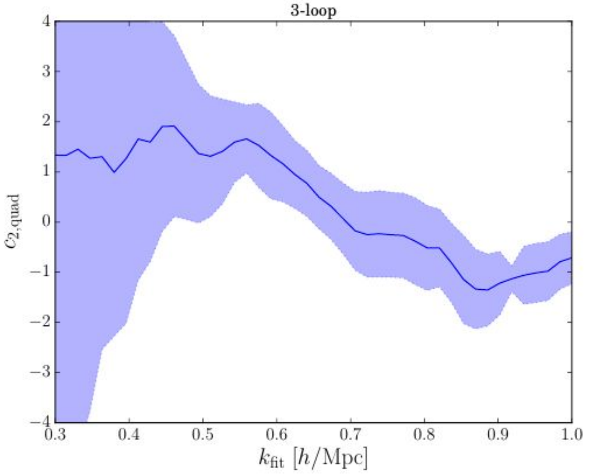
3Loops EFT - Conclusions

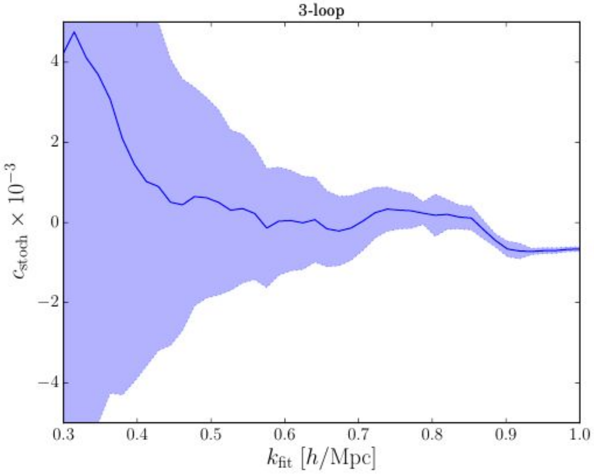
- SPT asymptotic behaviour jeopardizes EFT approach for higher loops;
- 3-loop calculation still the best description at $k<0.45$ 1/hMpc;
- There seems no space for higher loop calculations. We pushed the theory to its limits;
- Higher N-Point functions could in principle disentangle counter-terms degeneracies and confirm asymptotic behaviour of EFT .

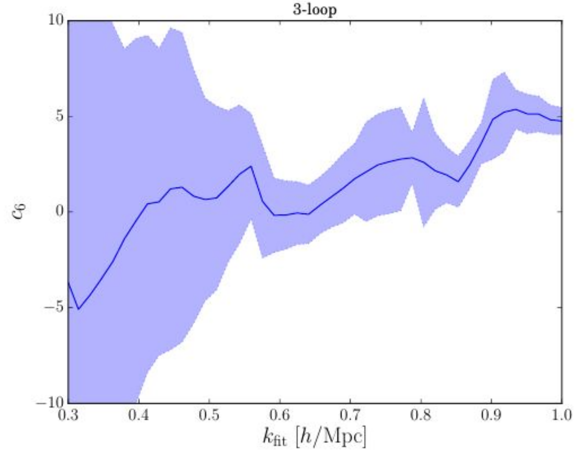
Extra 1 - RG flow



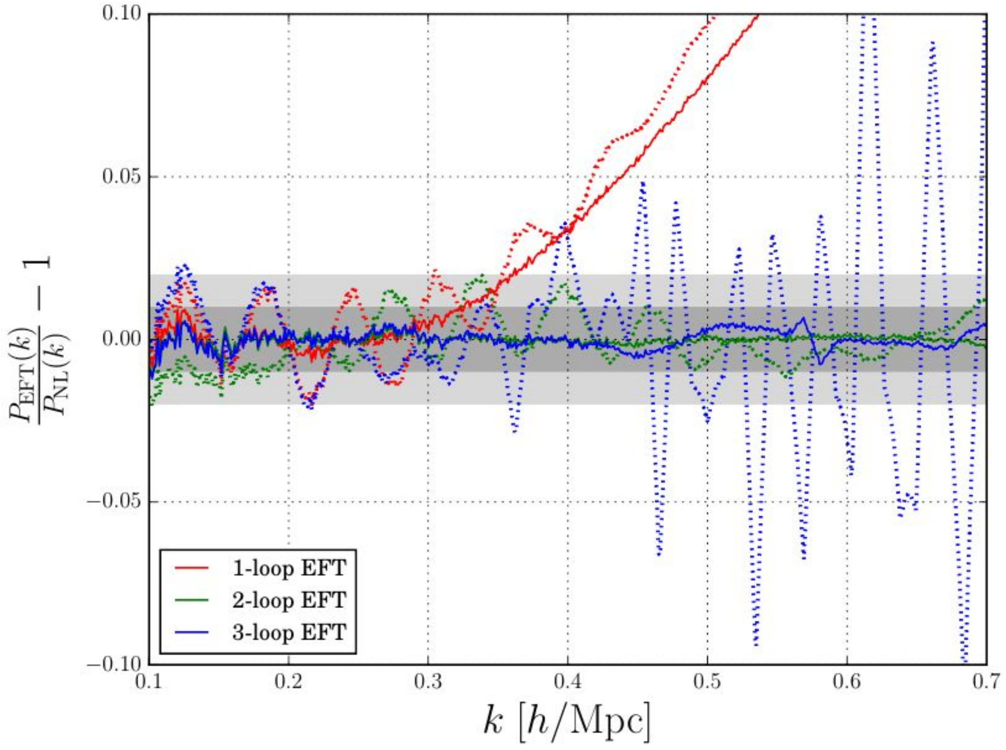








Extra 2 - IR resummation



Extra 3- compare w/ sim