Time Sliced Perturbation Theory (TSPT) for LSS

Diego Blas

w./ M. Garny, M. Ivanov, S. Sibiryakov 1512.05807, 1605.02149, 19xx.xxxx

check Ivanov+Sibiryakov (+ collaborators) 18/19 papers!

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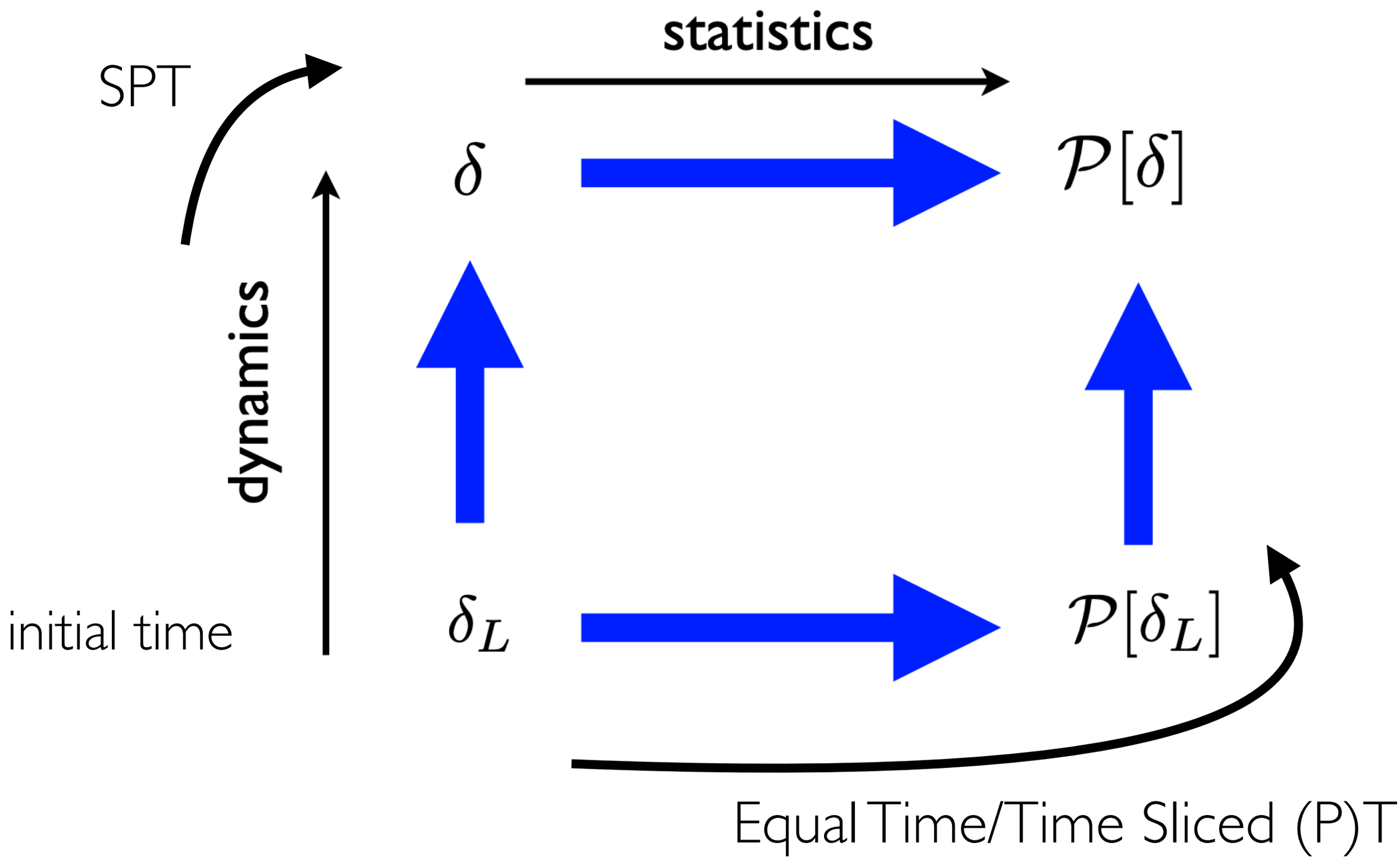
O(40) pages/paper

Dynamics of distribution function(al)



(also Valageas 01, 04)

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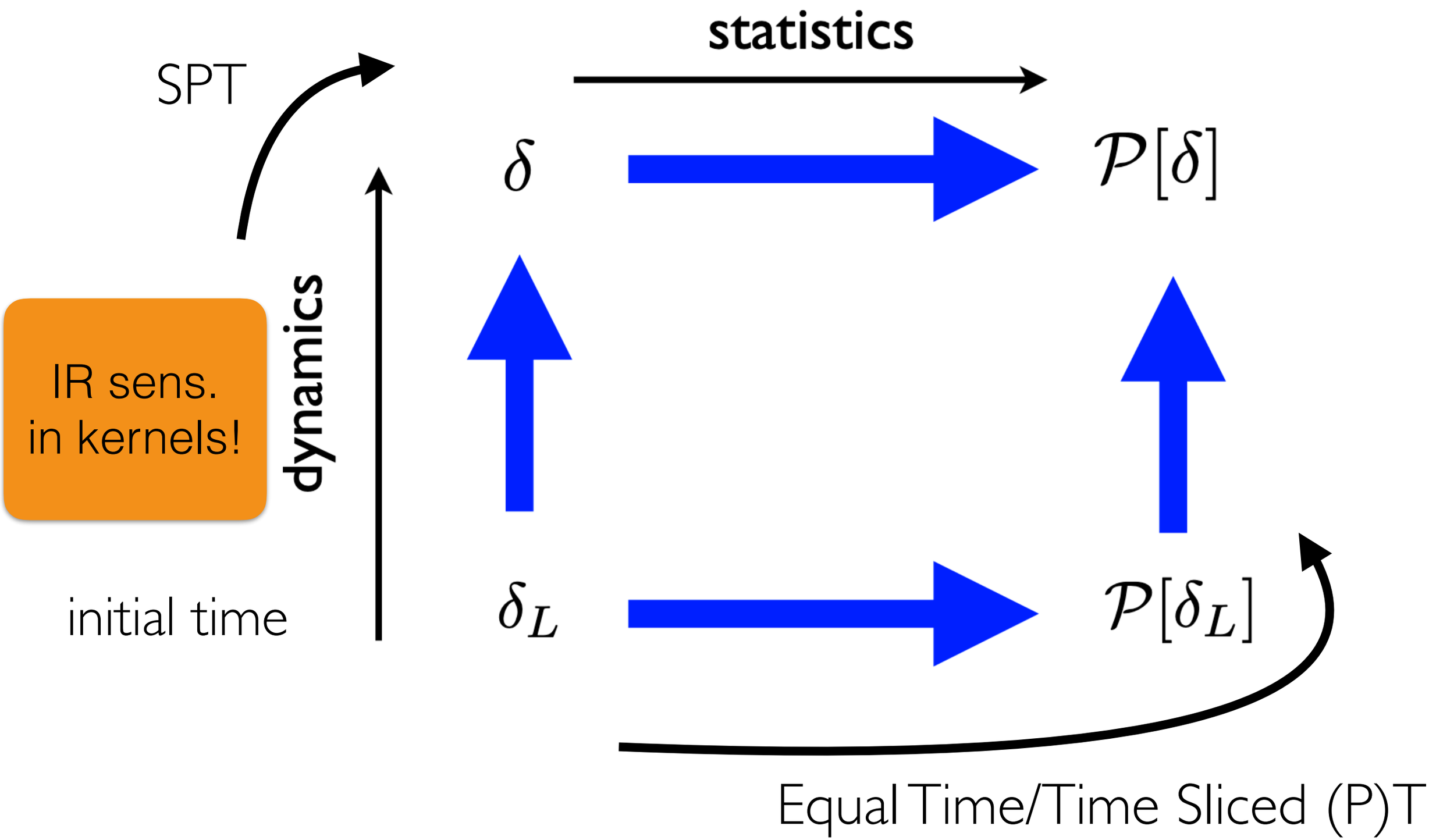

(also Valageas 01, 04)

TSPT is not only PT…

$$\langle \delta_k(t)\delta_{k'}(t)\rangle = 2\pi^2\delta^{(3)}(k+k')P(k,t)$$

from generating function(al) at fixed time (Time Sliced)

$$\langle \delta_{k'}(t)\delta_k(t)\rangle = \frac{\delta^2 Z[J,t]}{\delta J_{-k}\delta J_{-k'}}\Big|_{J=0}$$

primordial Gaussian field* evolved in time (adiabatic i.c.)

$$Z[J,t] = \int [\mathcal{D}\delta_L(x)] \exp\left\{ -\int \frac{|\delta_L(k)|^2}{2P_L(k,t)} + \int J(x)\delta(x,t) \right\}$$

Perturbative techniques

NP techniques
("semiclassical")

*(PNG 1906.08697)

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Perturbative techniques

IR res.of BAO 1605.02149

IR res. primordial features 1906.08697

RG flow ("EFT extension") (in progress)

NP techniques ("semiclassical")

Counts-in-cells 1811.07913 (in progress)

*(PNG 1906.08697)

TSPT: PT story

$$Z[J,t] = \int [\mathcal{D}\delta_L(x)] \exp\left\{ -\int \frac{|\delta_L(k)|^2}{2P_L(k,t)} + \int J(x)\delta(x,t) \right\}$$

$$Z[J,t] = \int [\mathcal{D}\delta]\, \mathcal{P}[\delta,t] e^{\int [dk] J_k \delta_{-k}}$$

from conservation of probability

$$\frac{d}{dt}\left\{ [\mathcal{D}\delta]\, \mathcal{P}(\delta,t) \right\} = 0$$

solved in a perturbative recursive expansion around Gaussian

$$\mathcal{P}(\delta,t) = \frac{e^{-\sum_{n=2} \frac{1}{n!} \int [dk_i] \Gamma_n(t,k_n) \Pi \delta^n_{k_n}}}{\mathcal{N}}$$

$$\Gamma_n(\Gamma_m, \dot{\delta})$$
$$m < n$$

TSPT diagrams

PT* for $Z[J]$

$$Z[J,t] = \int [\mathcal{D}\delta]\, \mathcal{P}[\delta,t] e^{\int [dk] J_k \delta_{-k}}$$

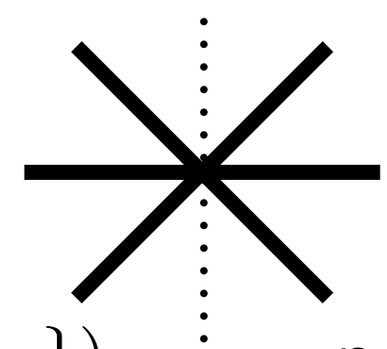
$$= \int [\mathcal{D}\delta] e^{-\frac{e^{-2t}}{2}\int [dk] \overline{\Gamma}_2^{tot}(k)\delta_k\delta_{-k}} \left(1 + \sum_{n=3} \frac{e^{-2t}}{n!} \int [dk_n]\, \overline{\Gamma}_n^{tot}(k_n)\, \Pi \delta_{k_n}^n + \ldots\right)$$

gaussian integrals + Feynman diagrams

propagator

$1/\Gamma_2(t,k) = e^{2t} P(k,t_0)$

vertices

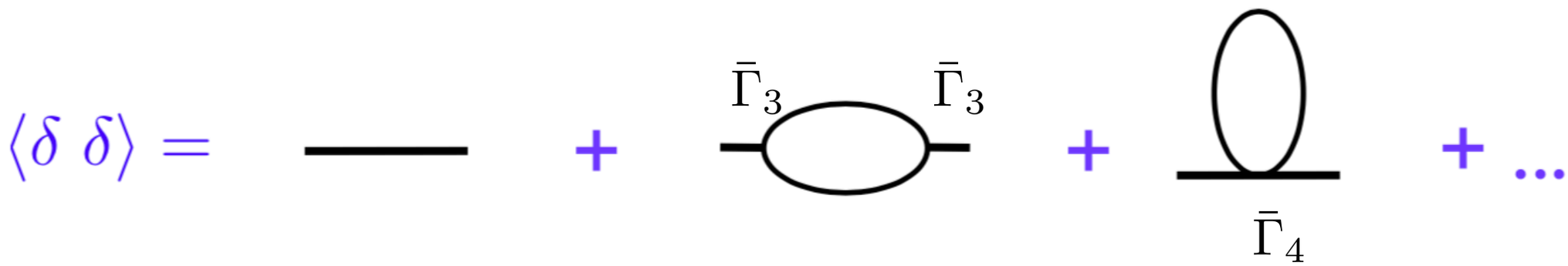


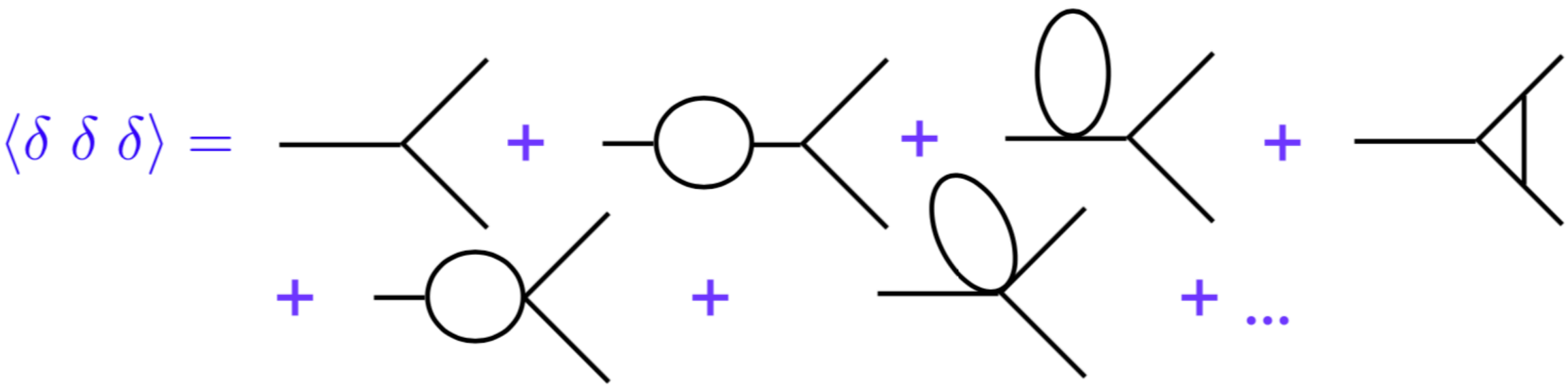
$e^{-2t}\Gamma_n(t,\{k_n\})$

n-lines

* beyond PT studies for CiC
Ivanov et al 1811.07913

n-point functions…



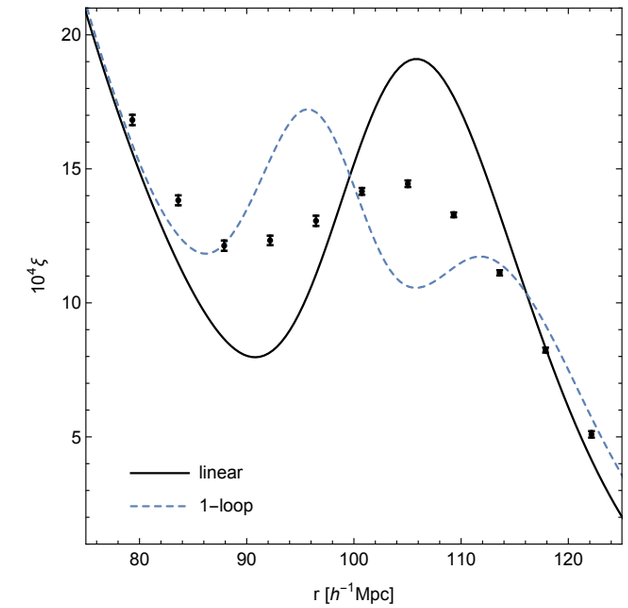


…with IR safe vertices

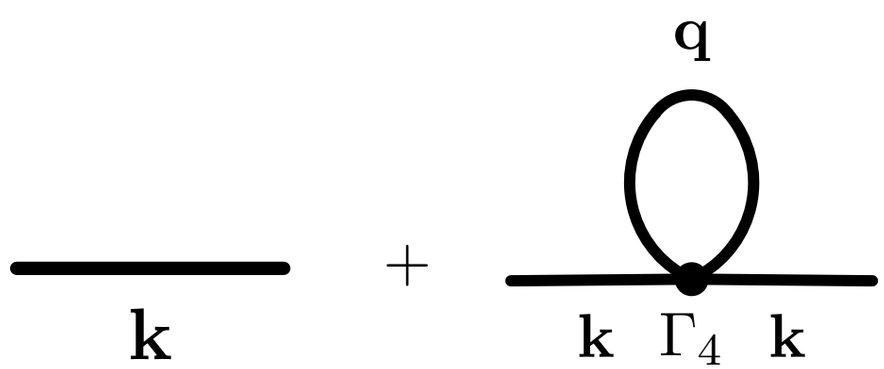
$$\lim_{\epsilon \to 0} \overline{\Gamma}_{n+m} \left(\epsilon q_1, \ldots, \epsilon q_m, k_1, \ldots, k_n \right) < \infty$$

TSPT at work: IR resummation of BAO

$$P_0 = P_{wiggles} + P_{smooth}$$

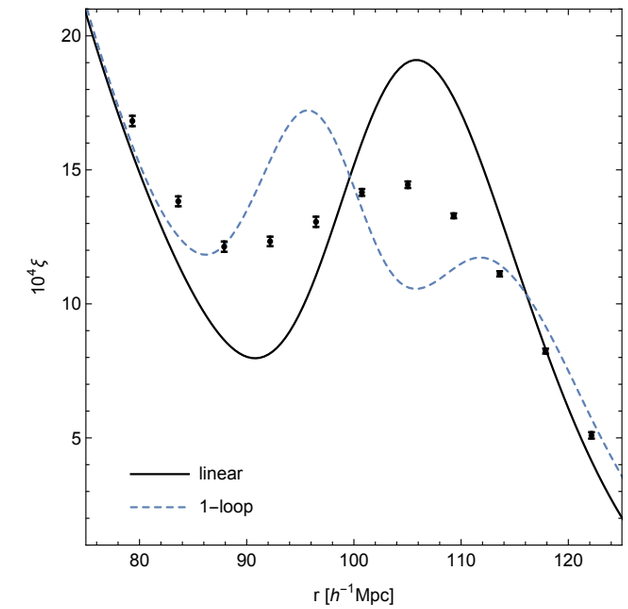


$P^{NL}_{wiggles} =$



$$P_w \qquad -\frac{1}{10}\frac{k^2}{k^2_{osc}}\int_{q\ll k}[dq]P_s(q)P_w(k) \sim P_w\left(\frac{k^2}{k^2_{osc}}\delta^2\right)$$

TSPT at work: IR resummation of BAO



$$P_0 = P_{wiggles} + P_{smooth}$$

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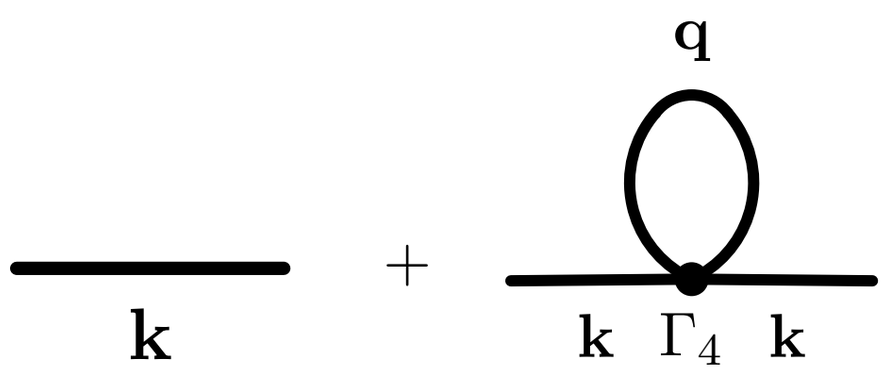

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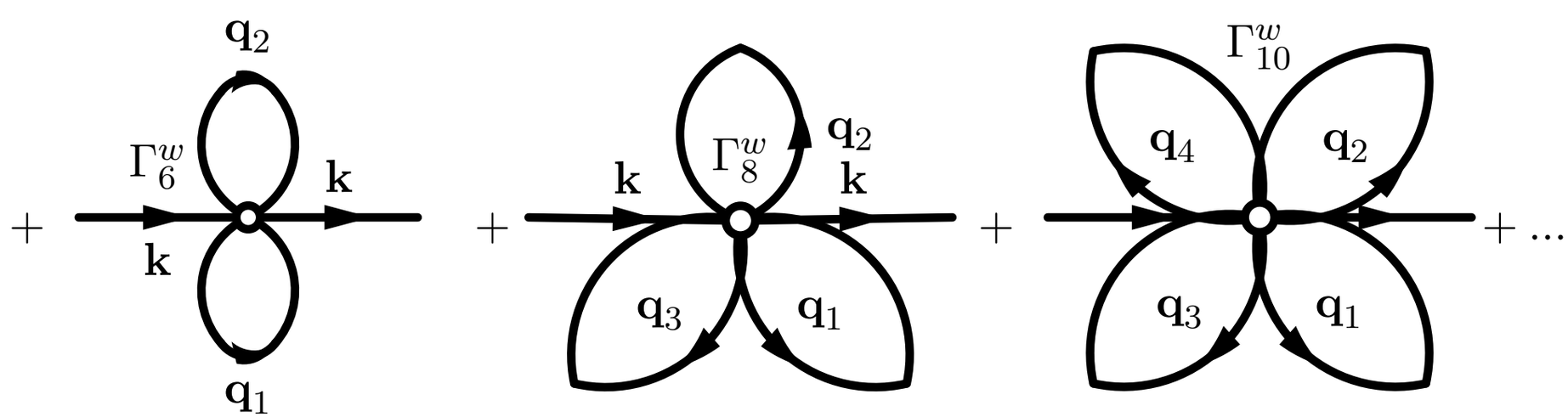

$$\sim P_w\left(\frac{k^2}{k^2_{osc}}\delta^2\right)^2 \qquad \sim P_w\left(\frac{k^2}{k^2_{osc}}\delta^2\right)^3$$

TSPT at work: IR resummation of BAO

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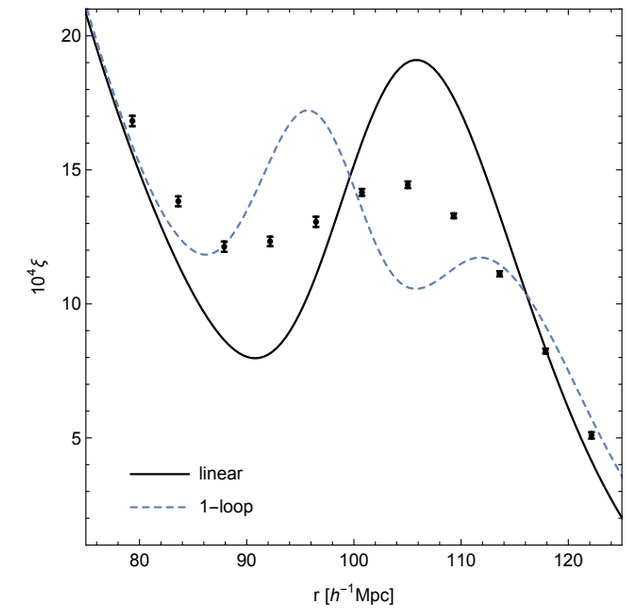

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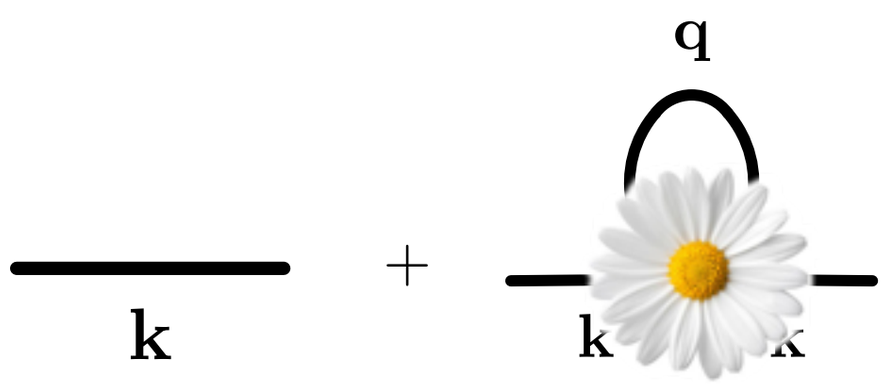

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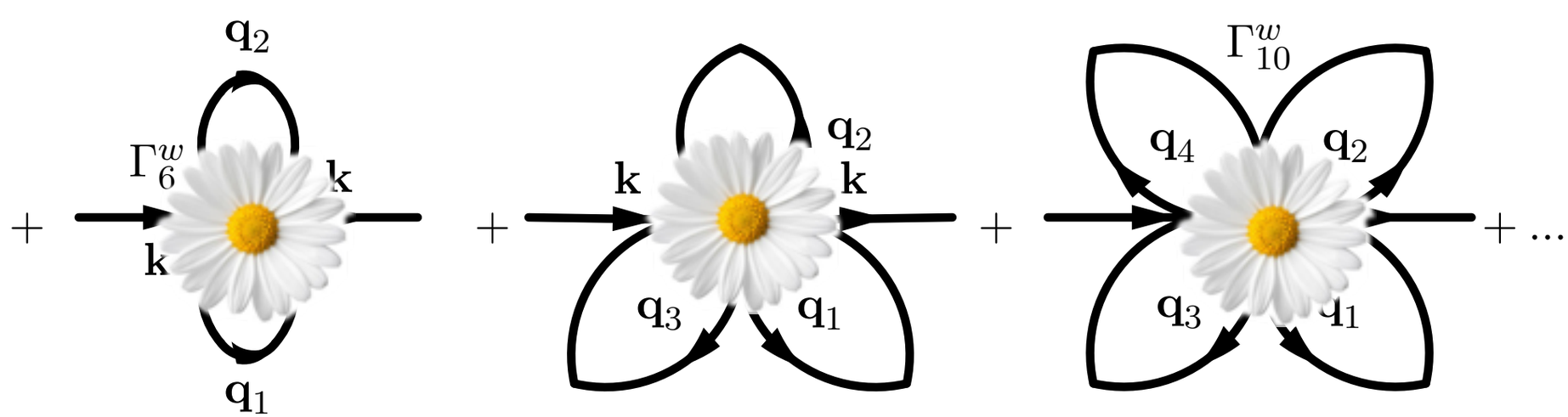

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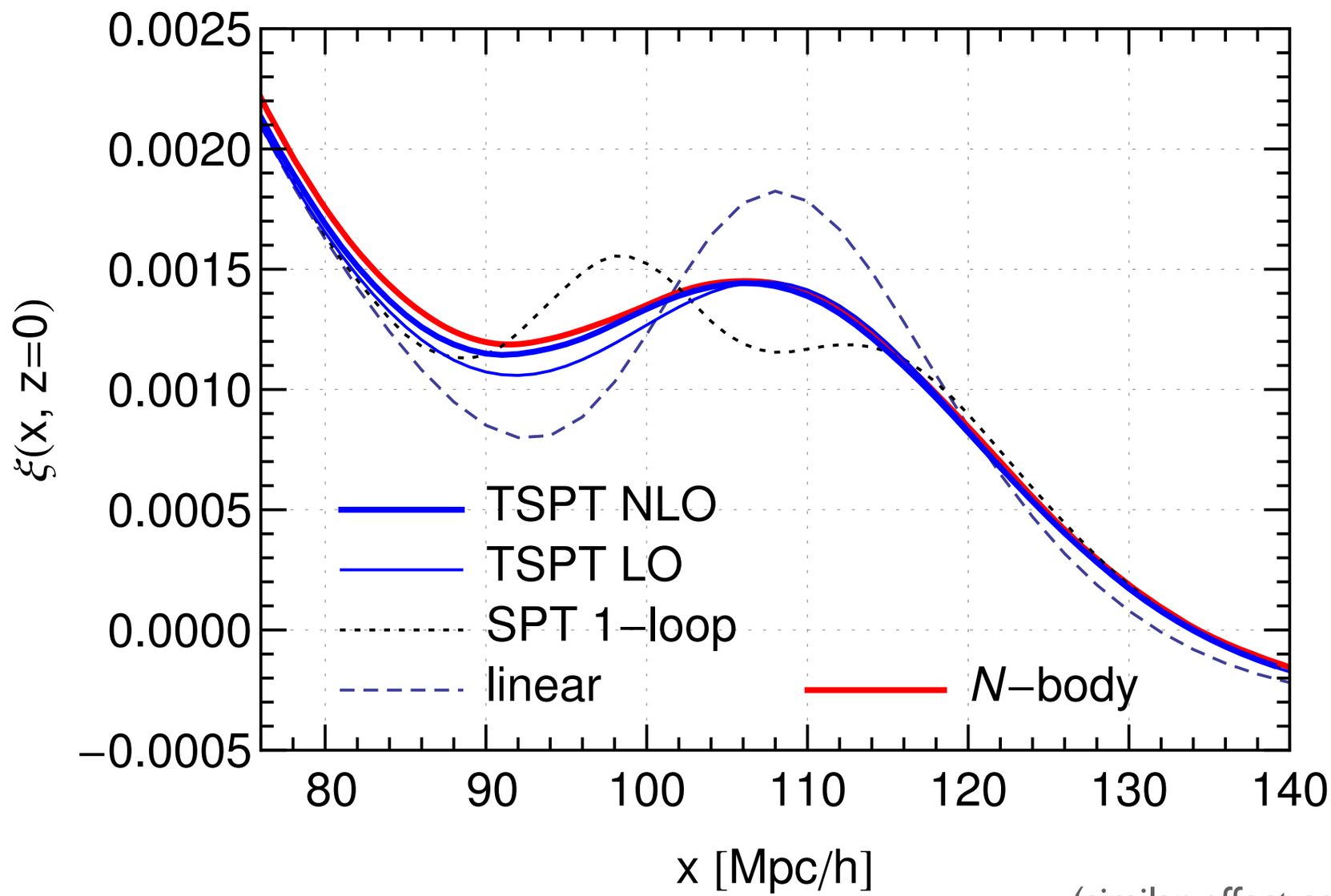
TSPT resummation of BAO

DB, Garny, Ivanov, Sibiryakov 1605.02149

$$P(k) = P_s(k) + e^{-k^2\Sigma^2} P_w(k)$$

$$\Sigma^2(k_{BAO}) = \frac{4\pi}{3}\int_0^{k_L} dq P_s(q)\left(1 - j_0\left(q r_{BAO}\right) + 2 j_2\left(q r_{BAO}\right)\right)$$

same damping as Baldauf et al. 15



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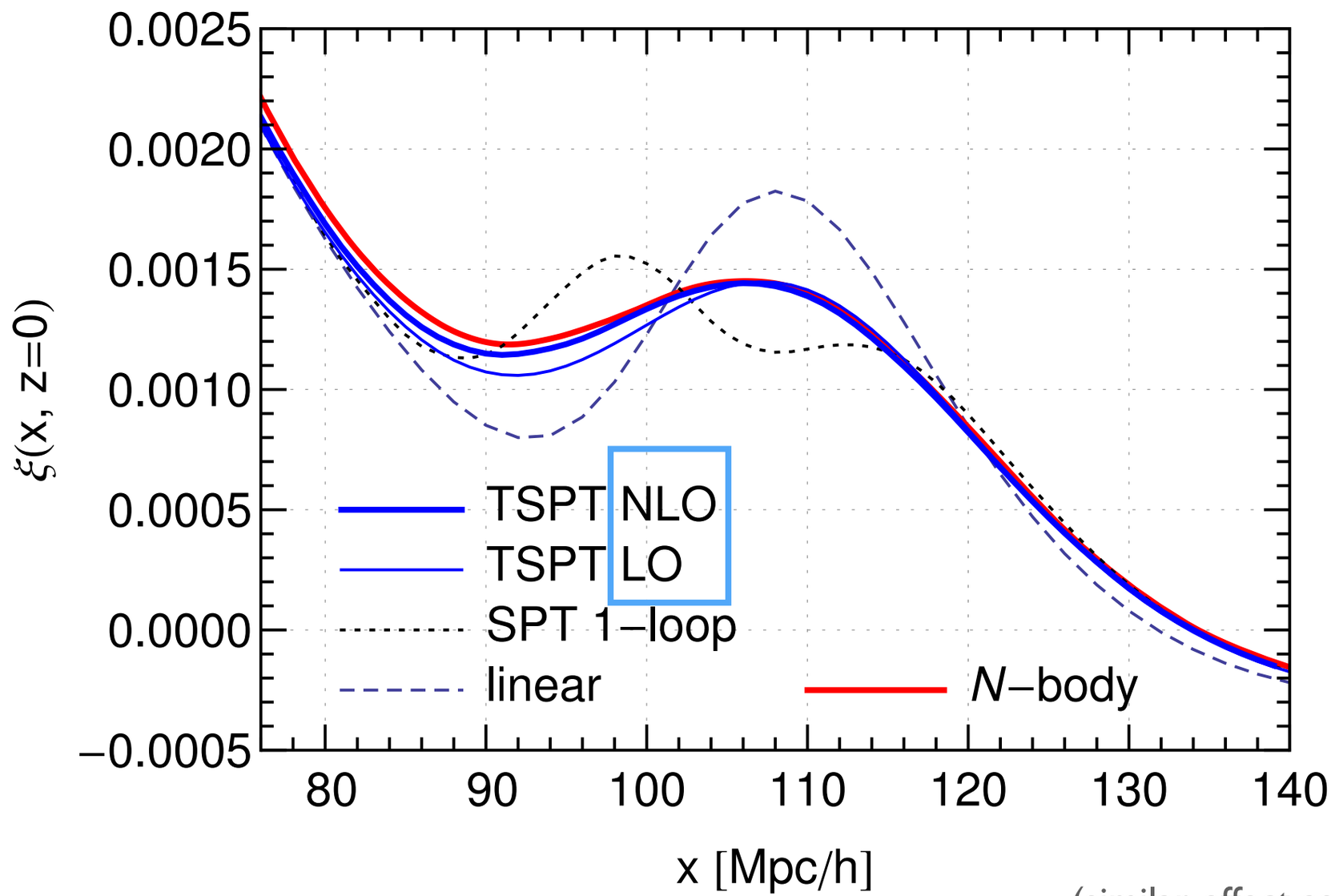


(similar effect as other IR resummations)

TSPT resummation of BAO

- diagrammatic technique 'easily' extended beyond L
- diagrammatic technique *easily* extended to n-point

needed? why not! (to get best precision!)

TSPT resummation in 2019

- including RSD + bias Ivanov, Sibiryakov 1804.05080

small deviation wrt standard formalism

- resummation of oscillating features in PS

Vasudevan et al1906.08697

$$P_L(k) = P_{L,\Lambda CDM} + A_{\rm lin}\cos(\omega k) + A_{\rm log}\cos\left(\gamma \log k/k_*\right) \qquad \gamma \gg 1$$

damping of feature with $\Sigma^2(k/\gamma)$

TSPT for PNG

Vasudevan et al1906.08697

$$\mathcal{P}\left[\delta; t_0\right] = \mathcal{N}^{-1} \exp\left\{ -\int [dk] \frac{\delta_{\mathbf{k}} \delta_{-\mathbf{k}}}{2P_L(k)} - \int \frac{[dk]^3}{3!} \Gamma_3^{(3)}\left(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3\right) \delta_{\mathbf{k}_1} \delta_{\mathbf{k}_2} \delta_{\mathbf{k}_3} \right\}$$

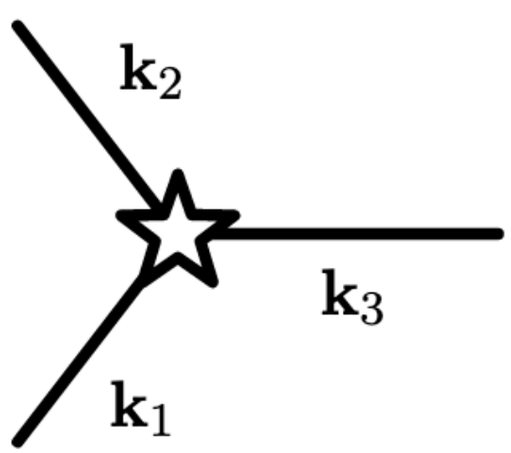
for small PNG

$$(2\pi)^3 \delta_D^{(3)}\left(\mathbf{k}_{123}\right) B_L\left(k_1, k_2, k_3\right) = -\Gamma_3^{(3)}\left(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3\right) P_L\left(k_1\right) P_L\left(k_2\right) P_L\left(k_3\right)$$

on can find the new PDF $\qquad g(t) = e^t$

$$\Gamma_n\left(\eta; \mathbf{k}_1, \ldots, \mathbf{k}_n\right) = \frac{1}{g^2(\eta)} \overline{\Gamma}_n\left(\mathbf{k}_1, \ldots, \mathbf{k}_n\right) + \frac{1}{g^3(\eta)} \overline{\Gamma}_n^{NG}\left(\mathbf{k}_1, \ldots, \mathbf{k}_n\right)$$

extra vertices



$$= -\frac{1}{g^3(\eta)} \frac{1}{3!} \bar{\Gamma}_3^{NG}(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3)$$

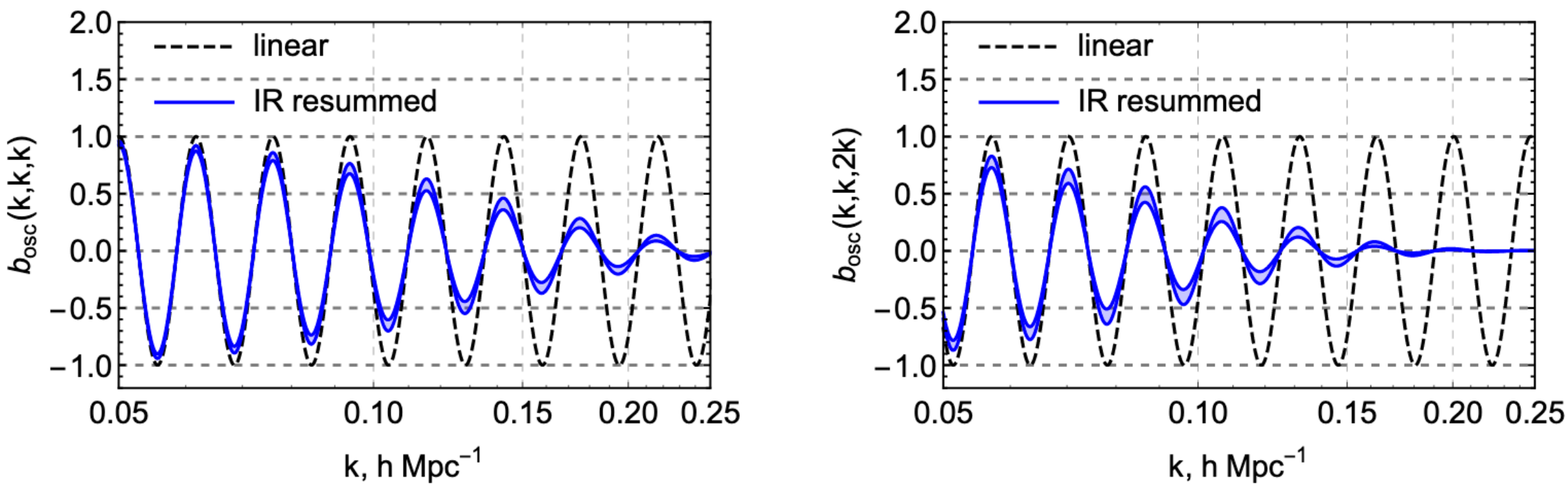
TSPT for PNG: axion monodromy

Vasudevan et al1906.08697

$$B_\zeta\left(k_1,k_2,k_3\right)=f_{NL}^{\rm res}\frac{4\mathcal{A}_\zeta^4}{k_1^2k_2^2k_3^2}\left[\sin\left(\gamma\ln\frac{k_t}{k_*}\right)+\frac{1}{\gamma}\sum_{i\neq j}\frac{k_i}{k_j}\cos\left(\gamma\ln\frac{k_t}{k_*}\right)+O\left(\frac{1}{\gamma^2}\right)\right]$$

Flauger, Pajer 1002.0833

$$B_{\delta\delta\delta}^{NG,\rm LO}\left(\eta;k_1,k_2,k_3\right)=g^3(\eta)e^{-g^2(\eta)\Sigma_B(k_1,k_2,k_3)}B_L\left(k_1,k_2,k_3\right)$$



+ new (small) term for the squeezed limit after IR resummation!

also Beutler et al1906.08758

What about the UV?

(always in progress)

$$\delta_{k,\Lambda} = \delta_k \Theta(\Lambda - k)$$

$$Z_\Lambda[J,t] = \int [\mathcal{D}\delta_\Lambda]\, \mathcal{P}_\Lambda[\delta_\Lambda, t] \exp\left\{ \int^\Lambda [dk] J_k \delta_{-k} \right\}$$

$$\int_0^{\Lambda_1} [\mathcal{D}\delta] \int_{\Lambda_1}^{\Lambda} [\mathcal{D}\delta]\, \mathcal{P}_\Lambda \equiv \int_0^{\Lambda_1} [\mathcal{D}\delta]\, \mathcal{P}_{\Lambda_1}$$

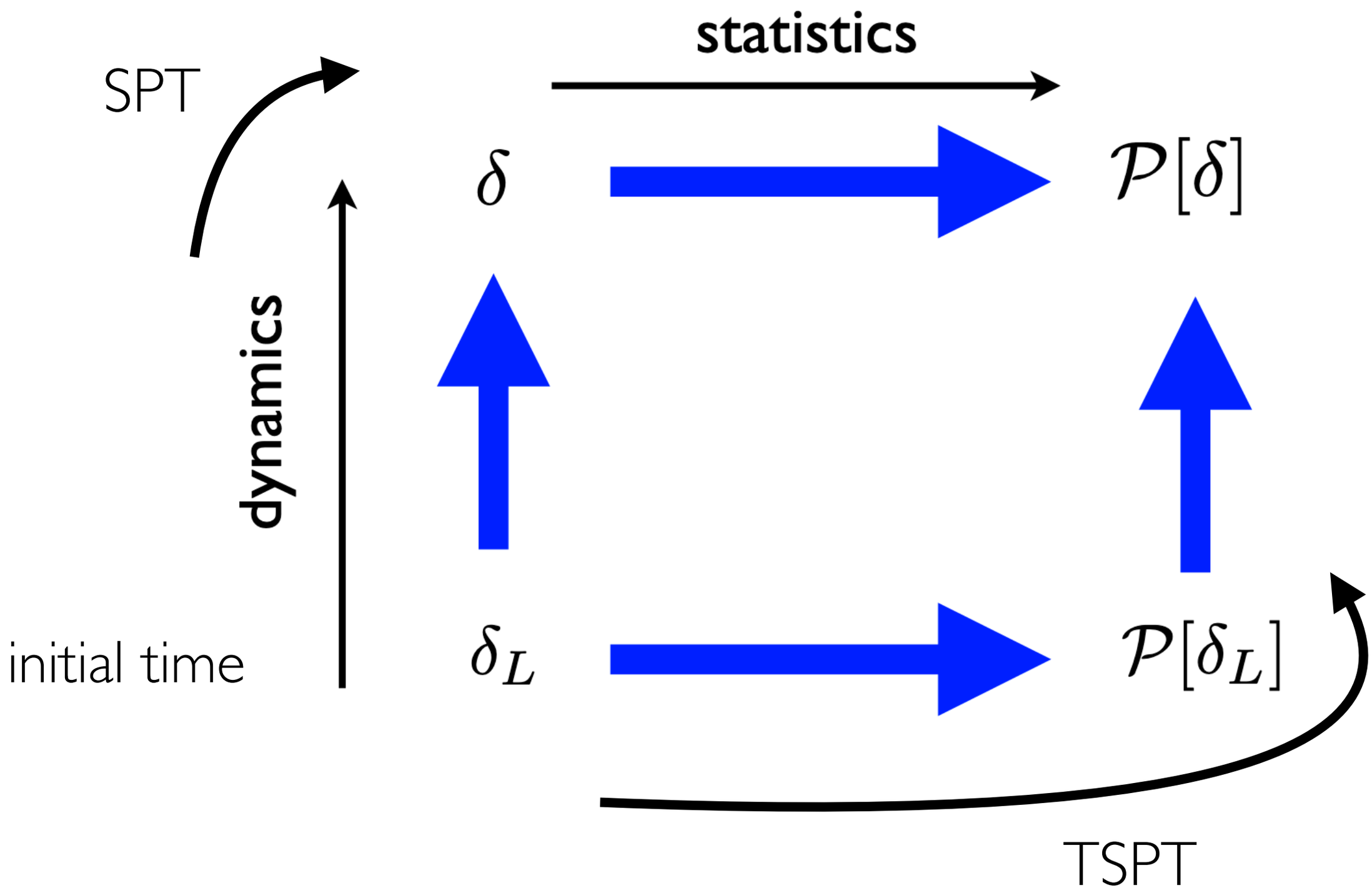
The distribution acquires **counterterms** to compensate cut-off dependent integrals

$$\mathcal{P}_\Lambda \equiv e^{-\Gamma_\Lambda} = e^{-\Gamma^{TSPT} - \sum \alpha_n(\Lambda,t) C_n(k)}$$

Wilsonian/Polchinski RG: $\dfrac{d}{d\Lambda}\Gamma_\Lambda = \mathcal{F}(\Gamma_\Lambda)$

New insights on counterterms of EFTofLSS?

Conclusions



Conclusions

- TSPT alternative to SPT/LPT for equal time observables

- So far useful for:

  - IR resummation of primordial features (BAO/Primordial)

  - New insights on counts-in-cells statistics

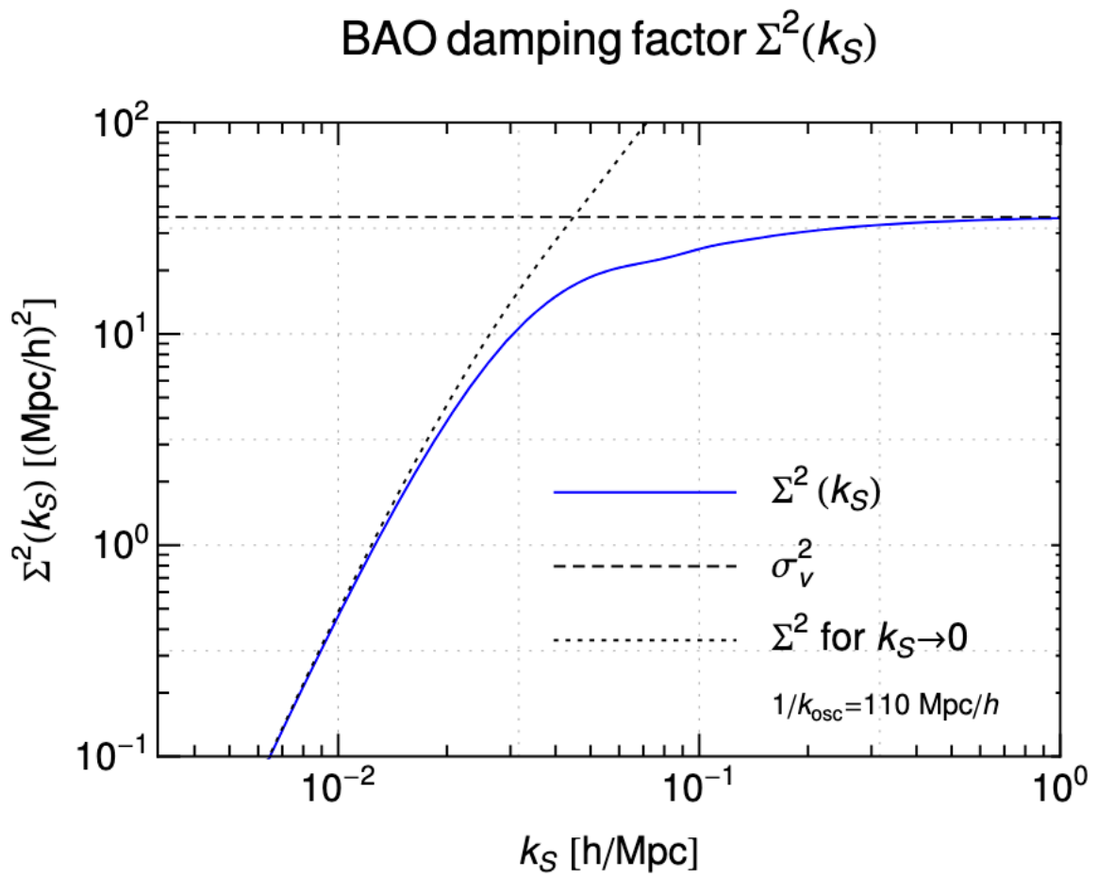
The near (?) future

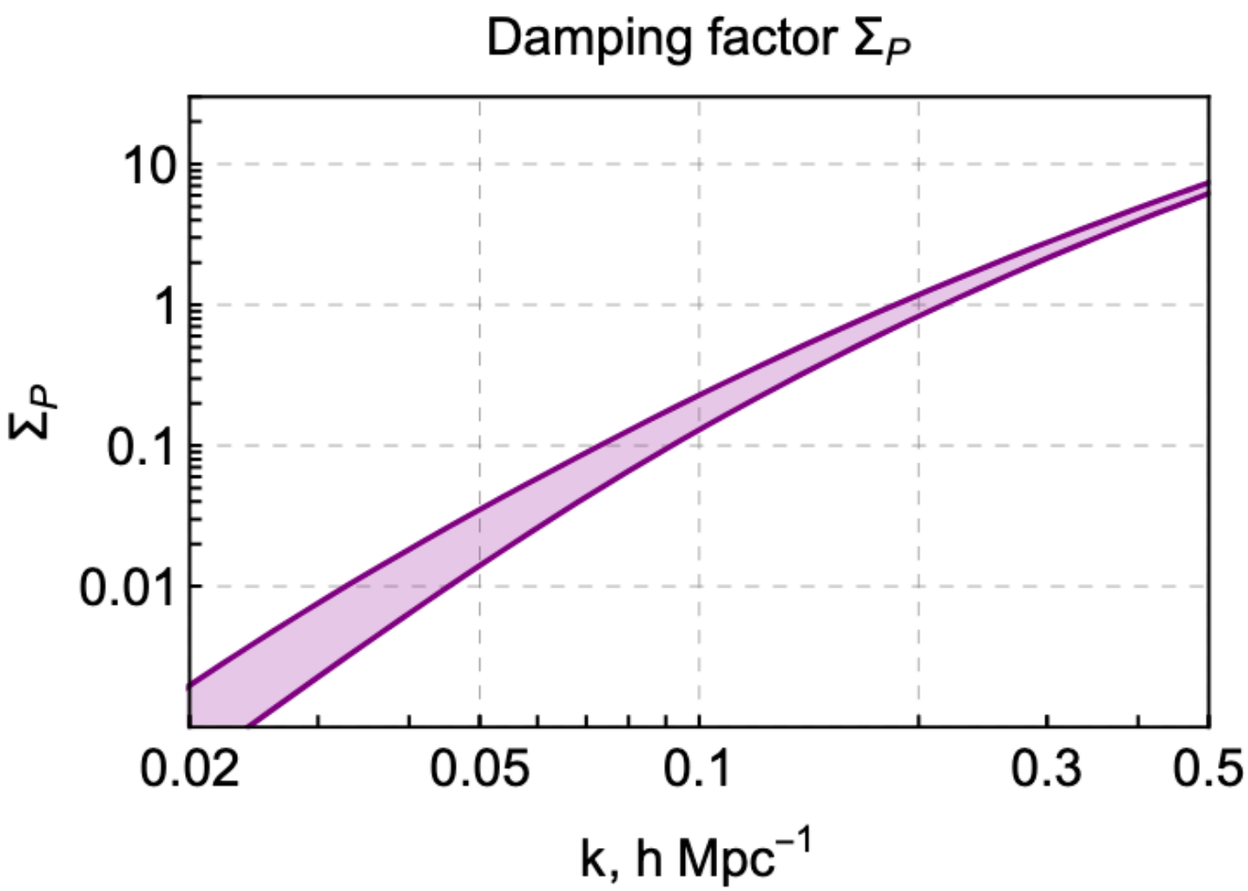
- *PT-like:* More on PNG: squeezed limit + other PNG

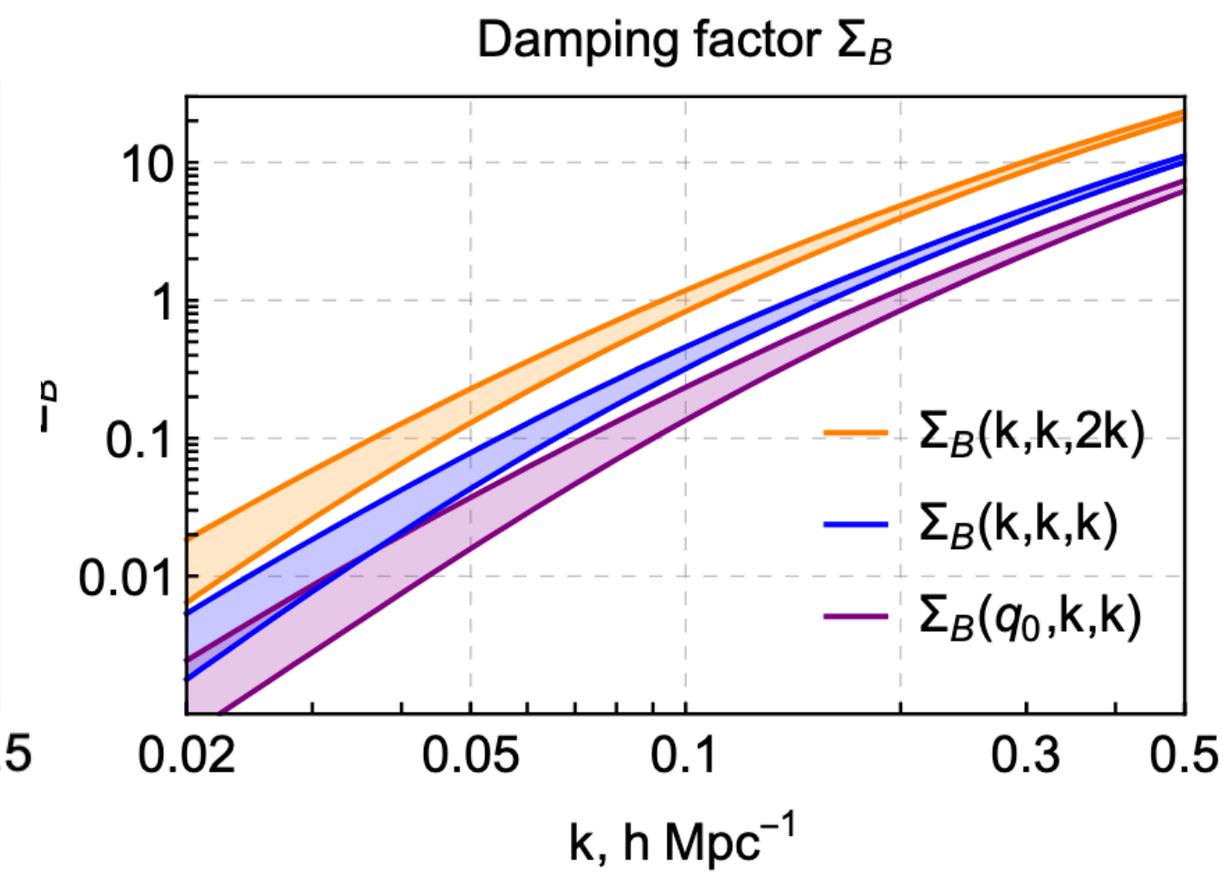
- *EFT-like:* Wilsonian RG flow

- *Non-perturbative:* Continue exploration of counts-in-cells.
  Other non-perturbative ideas?

- *Connection to:* Gonzalo Palma's and Giovanni Cabass's talks


BAO damping factor $\Sigma^2(k_S)$
$\Sigma^2(k_S)$ [(Mpc/h)^2]
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-1}
10^0
k_S [h/Mpc]
$\Sigma^2(k_S)$
σ_v^2
Σ^2 for $k_S \to 0$
$1/k_{osc}$=110 Mpc/h


Damping factor Σ_P
Σ_P
10
1
0.1
0.01
0.02
0.05
0.1
0.3
0.5
k, h Mpc^{-1}


Damping factor Σ_B
10
1
0.1
0.01
0.02
0.05
0.1
0.3
0.5
k, h Mpc^{-1}
Σ_B(k,k,2k)
Σ_B(k,k,k)
$\Sigma_B(q_0$,k,k)

Counts in Cells statistics

Ivanov et al 1811.07913

$$\mathcal{P}\left(\delta_*\right) = \mathcal{N}^{-1} \int \mathcal{D}\delta_L \exp\left\{ - \int_{\mathbf{k}} \frac{\left|\delta_L(\mathbf{k})\right|^2}{2g^2 P(k)} \right\} \delta_{\mathrm{D}}^{(1)} \left(\delta_* - \overline{\delta}_W\left[\delta_L\right]\right)$$