N-point Functions in the EFT of LSS:

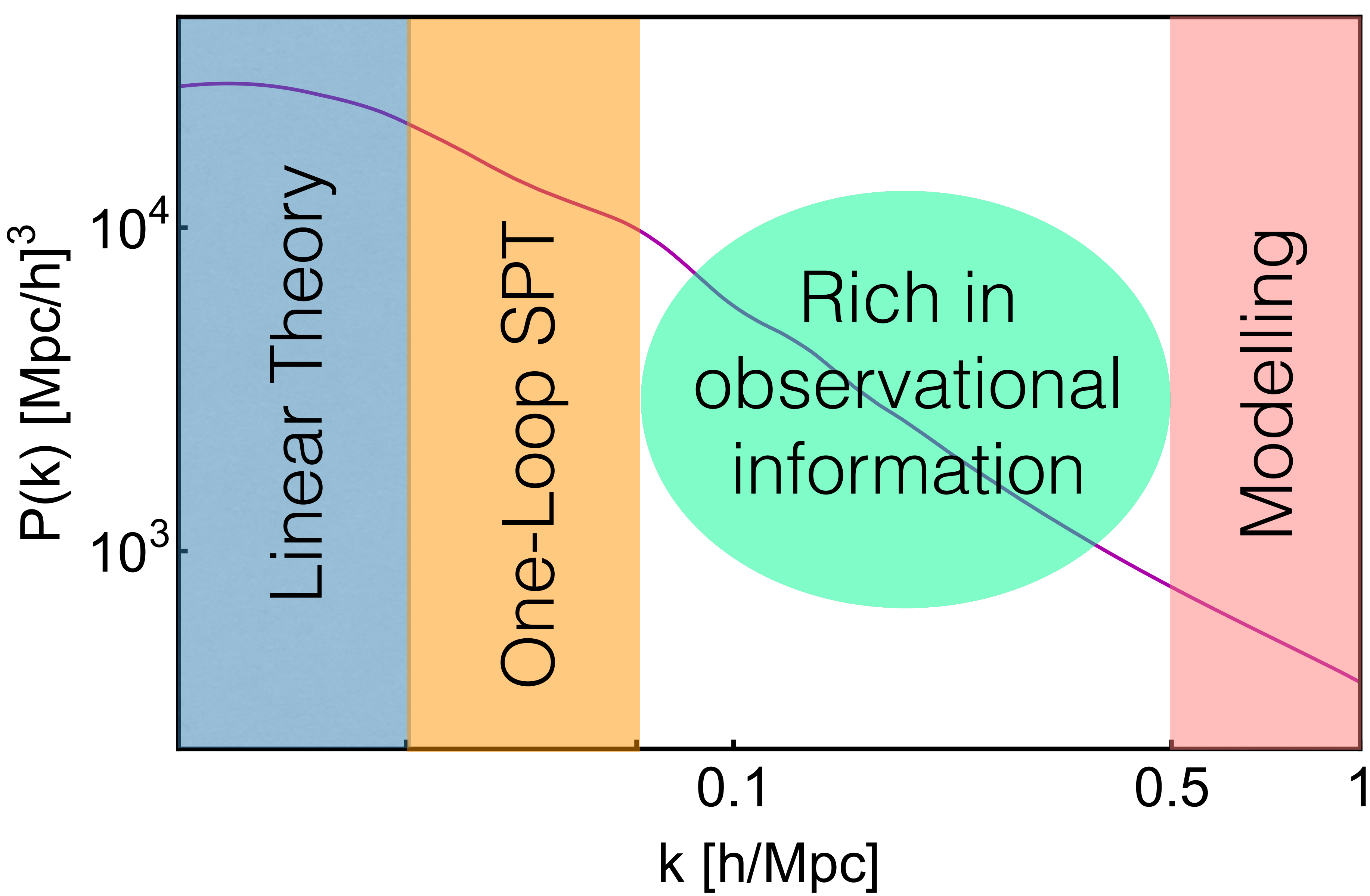
Practical Challenges and Future Prospects

Katelin Schutz
with Daniele Bertolini, Mikhail Solon, Jon Walsh, Kathryn Zurek
NL LSS: Theory Meets Expectations in Paris
May 26th 2016

Effective Stress Tensor

- Constructed to respect all relevant symmetries (statistical isotropy, conservation of mass and momentum, Galilean invariance)
- Captures all possible unknown microphysics
- Cancels (renormalizes) UV sensitivity of SPT integrals, makes SPT well-defined
- Rich additional physics at play (imperfect fluid interpretation, vorticity, memory effects)

The Era of Precision Cosmology?

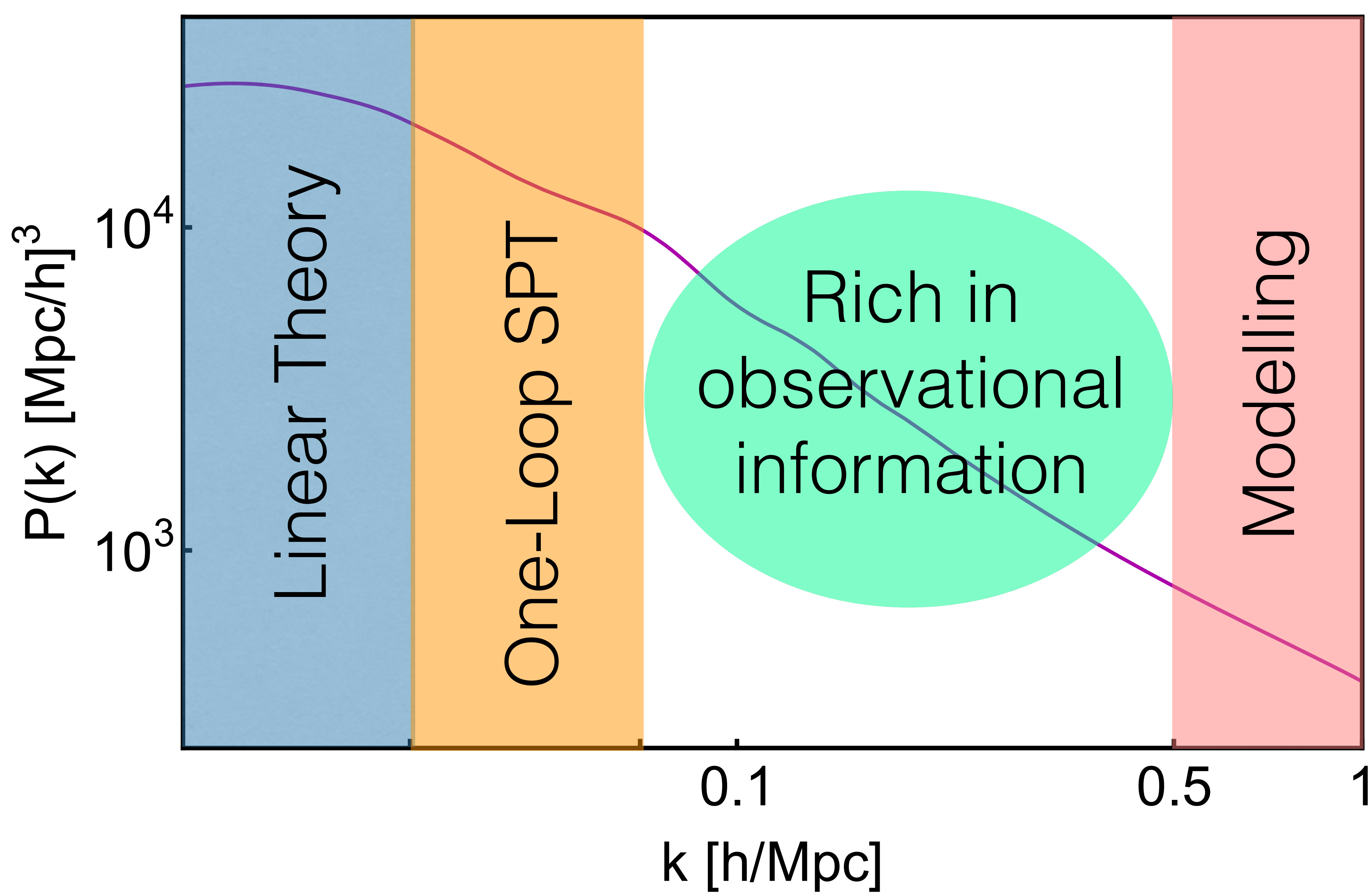


Number of Fourier modes at a given scale ~ k^3

Skew, kurtosis (3,4 point functions) stronger on these scales

Part I: The Covariance

The Era of Precision Cosmology?



Number of Fourier modes at a given scale ~ k^3

(expecting this to translate to extra independent info is actually naive!)

The covariance

$$\hat{P}(k_i) \equiv \frac{1}{V} \int_{V_{k_i}} \frac{d^3\mathbf{k}}{V_{k_i}} \delta(\mathbf{k})\delta(-\mathbf{k}) \,,$$

$$C(k_i, k_j) \equiv \langle \hat{P}(k_i)\hat{P}(k_j)\rangle - \langle \hat{P}(k_i)\rangle\langle \hat{P}(k_j)\rangle$$

$$C_{ij}^{\mathrm{NG}} = \frac{1}{V} \int_{V_{k_i}} \int_{V_{k_j}} \frac{d^3\mathbf{k}_1}{V_{k_i}} \frac{d^3\mathbf{k}_2}{V_{k_j}} \, T(\mathbf{k}_1, -\mathbf{k}_1, \mathbf{k}_2, -\mathbf{k}_2)$$

The covariance

$$C(k_i, k_j) \equiv \langle \hat{P}(k_i)\hat{P}(k_j)\rangle - \langle \hat{P}(k_i)\rangle\langle \hat{P}(k_j)\rangle$$

getting this quantity from N-body requires a large ensemble of simulations with slow statistical convergence— very expensive numerically!

→ This observable is ripe for tackling analytically!

We were the first to make a complete 1-loop prediction for the covariance in SPT… Let's see if we can do better with EFT

Making an EFT prediction for the covariance, step by step

- Compute EFT operators at level of trispectrum (NNLO) and impose covariance configuration and angular averaging
- 4 old + 3 new coefficients, take 4 as being already measured from one-loop EFT power spectrum and bispectrum
- Are 3 EFT operators really necessary? Do both a naive theoretical expansion and PCA to see if they agree as a consistency check
- Measure new EFT coefficient from N-body data where appropriate

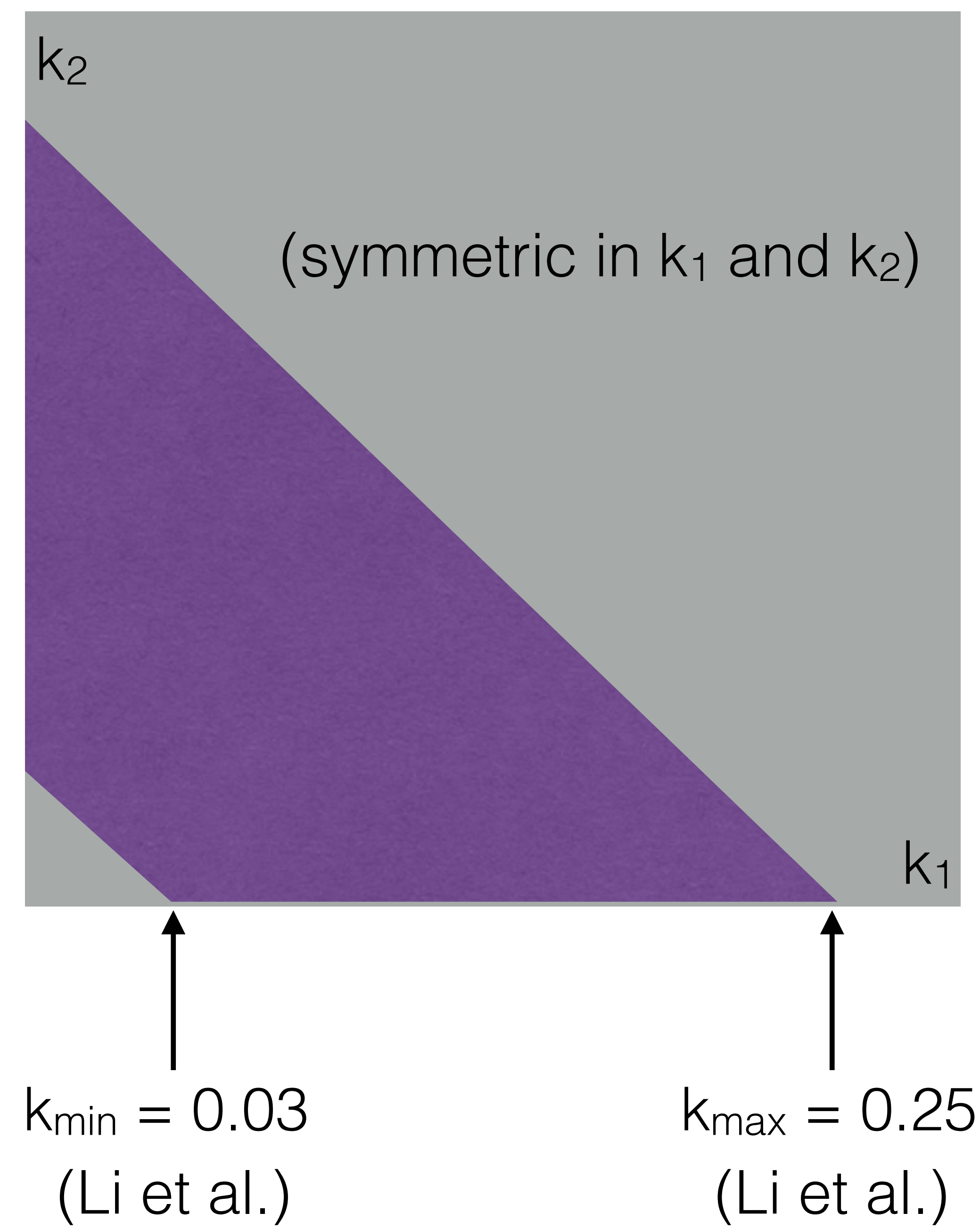
Simulations of the Covariance

- Li, Hu, Takada (2014)
- N = 3,584 x 500/h Mpc box simulations with 256^3 particles, as well as higher resolution simulations (512^3 particles) to test convergence and resolution dependence
- uses Gadget
- $h = 0.7$, $n_s = 0.96$, $\Omega_m = 0.286$, $\Omega_m = 0.047$, $\sigma_8 = 0.82$
- errors on covariance from bootstrap resampling

- Blot, Corasaniti et al. (2014, 2015)
- N = 12,288 x 656/h Mpc box simulations with 256^3 particles and 96 x 656 Mpc box simulations with 1024^3 particles to test for resolution effects
- uses RAMSES
- $h = 0.72$, $n_s = 0.96$, $\Omega_m = 0.257$, $\Omega_m = 0.043$, $\sigma_8 = 0.8$
- errors on covariance from Wishart distribution (verified to ~10%)

Fitting Procedure

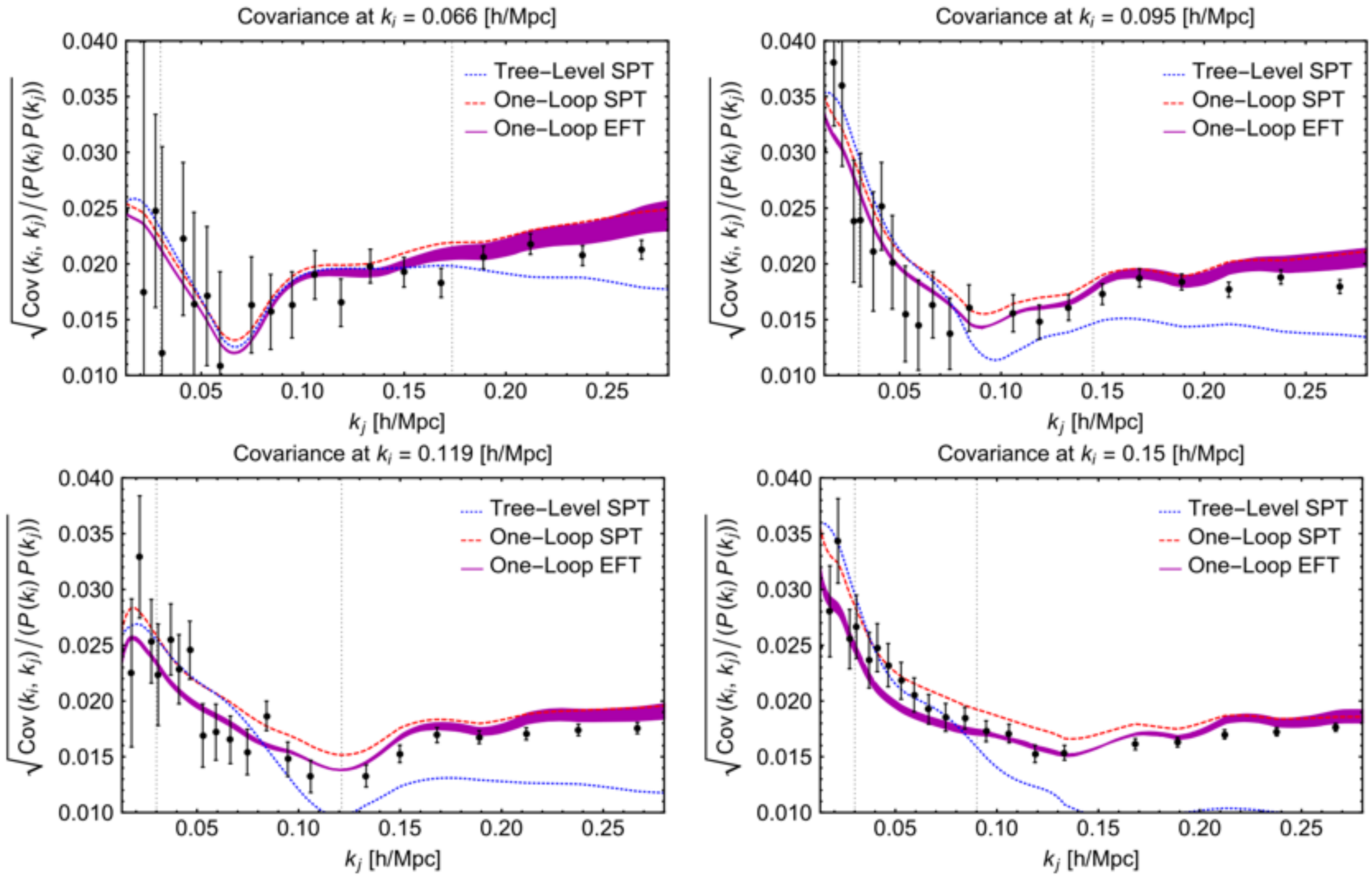
- Following Foreman, Perrier, Senatore (2015)
- Fit up to k_{max} where chi-squared per dof saturates to unity (corresponding to a high p-value)
- Also ensure that as the fitting window approaches k_{max} the measured EFT coefficients converge within reported measurement errors
- Exclude points at extremely low k where shot noise and systematics may be large and where cosmic variance is high anyway
- Do PCA to identify how many EFT shapes are actually necessary, ensure that the chi-squared is statistically indistinguishable from full fit



Results for Li et al.:

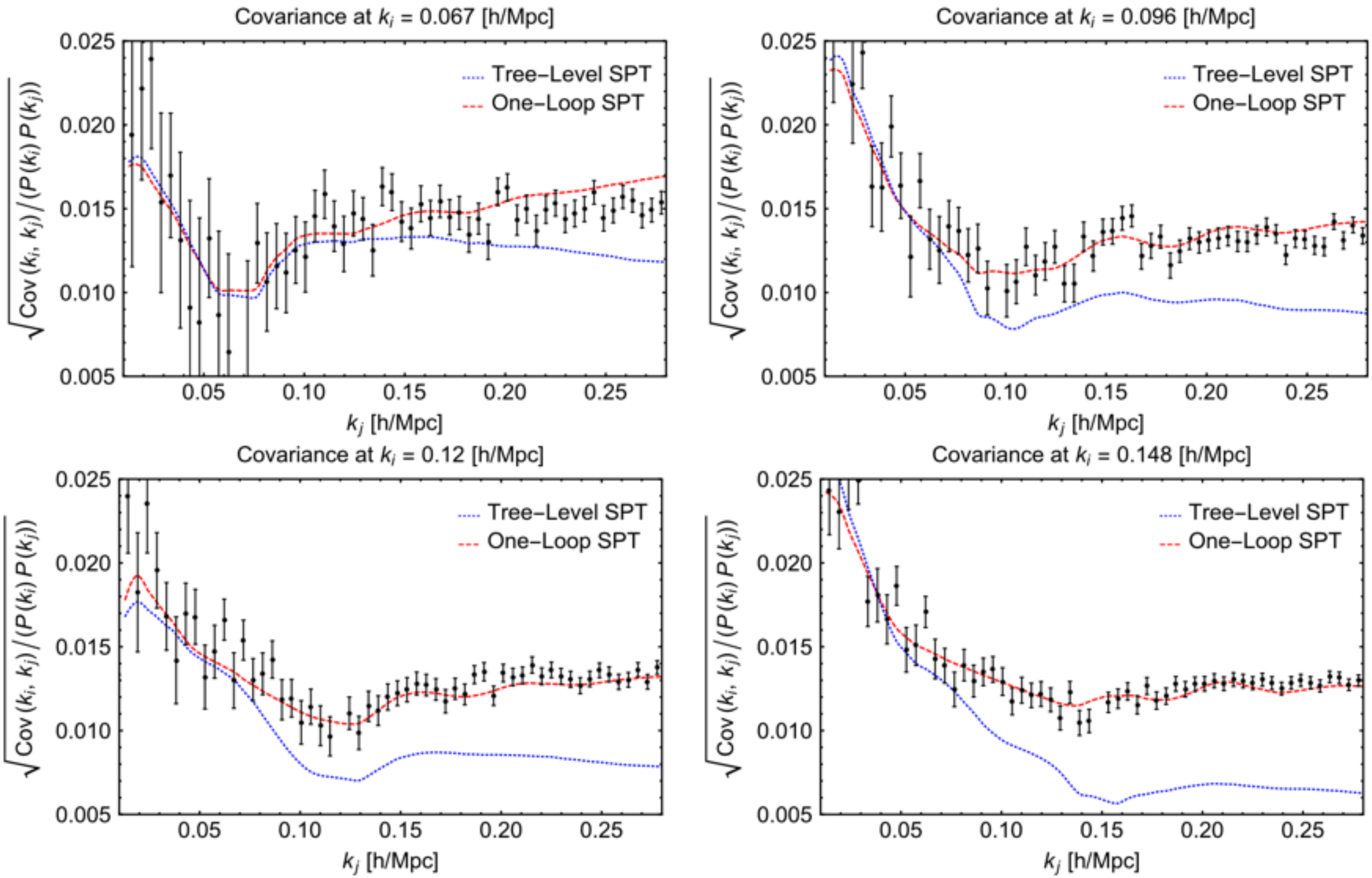
0-parameter SPT p-value ~ 10^{-4}

1-parameter EFT p-value ~1



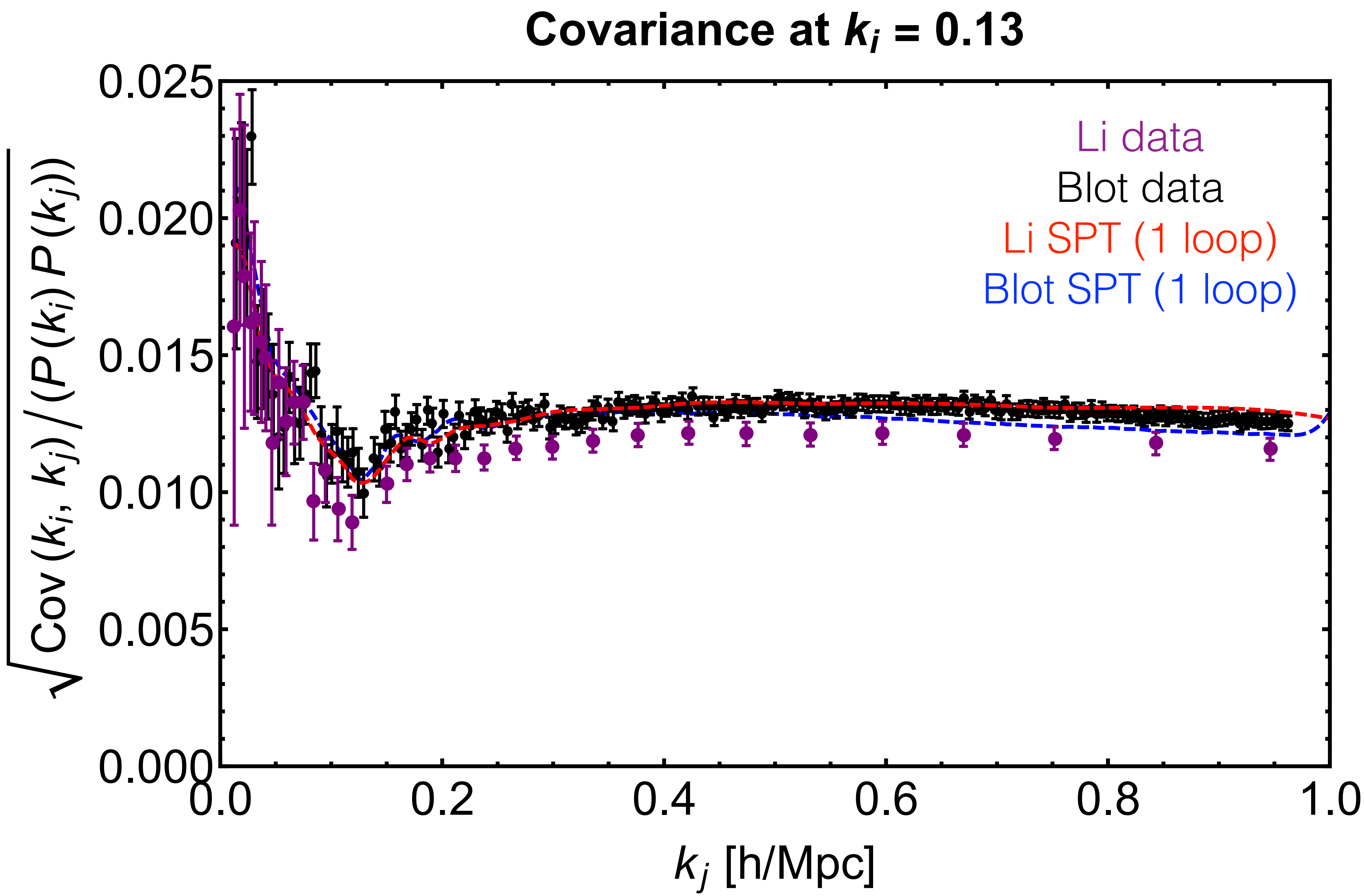
Bertolini, **KS**, Solon, Walsh, Zurek 1512.07630 v2

Results for Blot et al.: SPT 0-parameter p-value ~1 (to k=0.25!!)



Bertolini, **KS**, Solon, Walsh, Zurek 1512.07630 v2

What is going on here?



*note power spectrum normalization is the same for both

Source of differences:

- Differences in cosmology (probably not, based on what we learn from SPT similarities)
- Volume/boundary effects and separating out SSC from coupling to modes inside volume
- Mass resolution effects
- Gadget vs. RAMSES
- ???? ⟵ for I am but a humble theorist :)

Theoretical “pros and cons”

Li et al.

- SPT covariance breaks down where SPT power spectrum breaks down
- Fits with story of previous EFT of LSS literature
- Fit seems to work rather well beyond fitting window
- principle component from data agrees with one from theory

Blot et al.

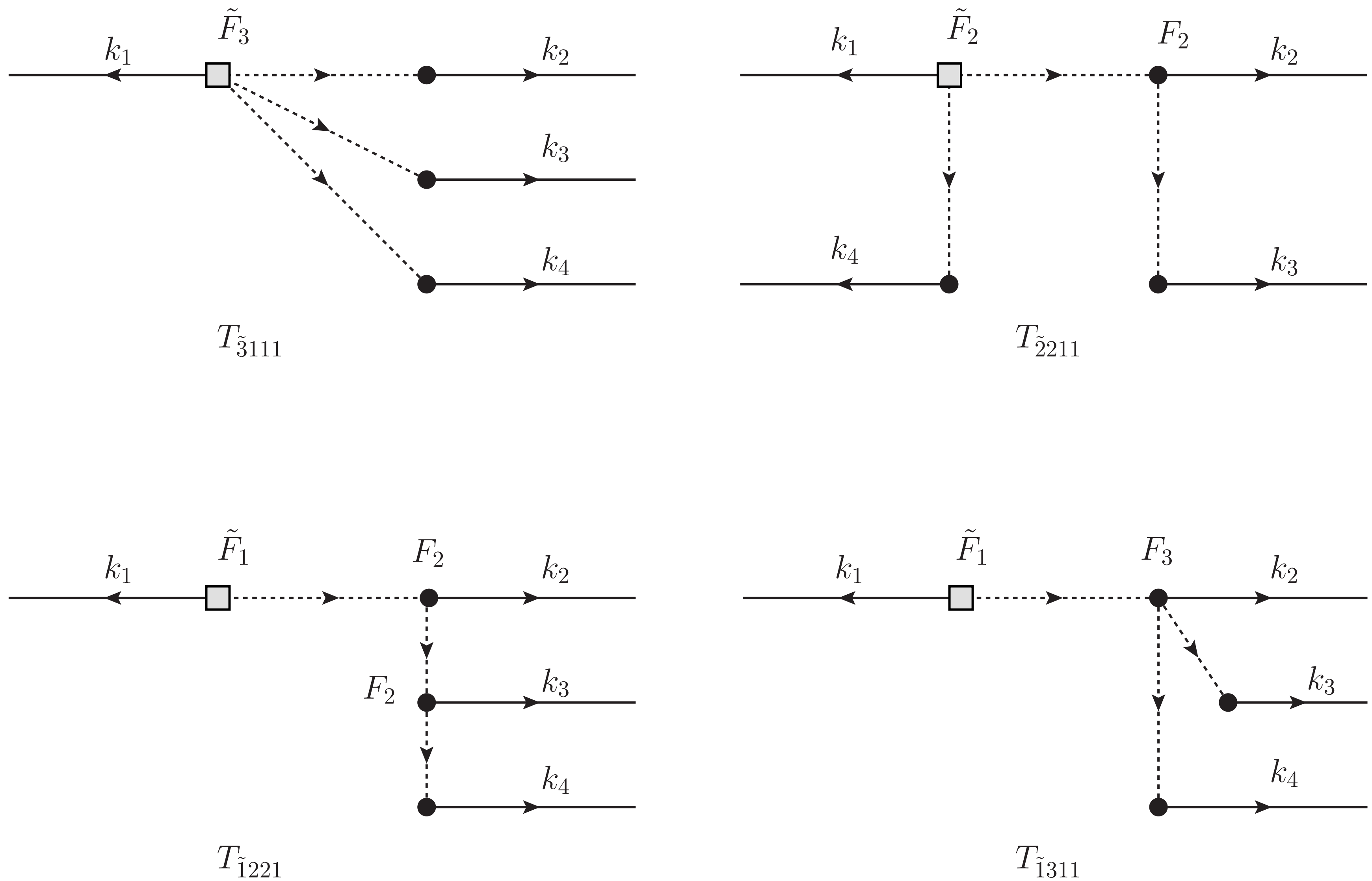
- Lots of ways to be wrong, only one way to be right— too much of a coincidence for SPT to work so well
- other evidence in literature suggests trispectrum is less sensitive to gravitational non-linearities than other observables
- SPT-only is incredibly convenient from a practical point of view

Upshot: need independent way to check analytics and simulations. A *classic* application of the EFT is not the way to go in this case!

Part II: Paths Forward

*Disclaimer: this part of the talk is slightly speculative

One idea: two-loop power spectrum as a check of other EFT observables



Checking measurements of bispectrum, covariance EFT coefficients is a check of the predictive abilities of the theory!

Another idea: see if we can measure the trispectrum from a single simulation

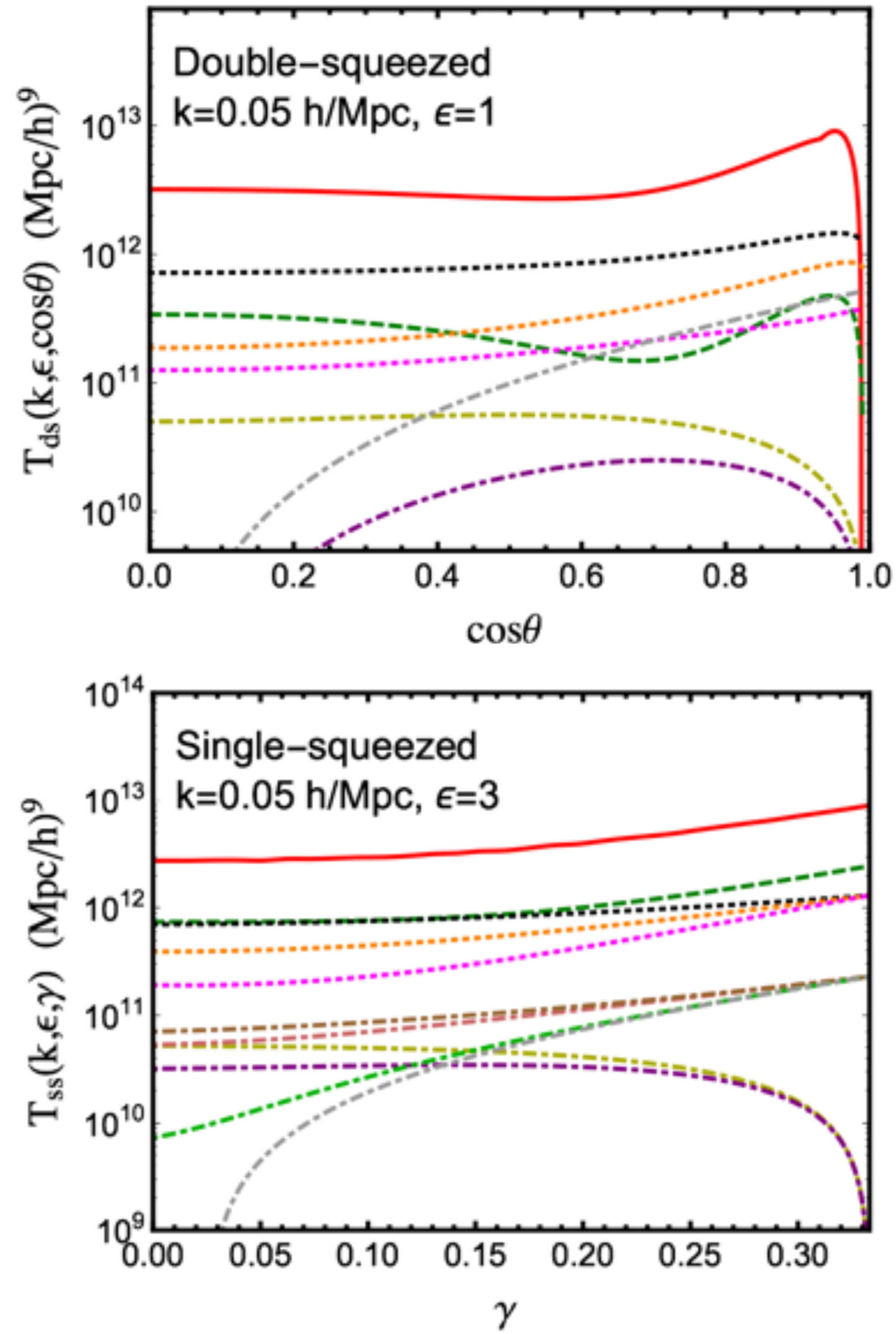
- Free from complicated systematics incurred by having a large ensemble of simulations

- the trispectrum is a worthwhile and interesting observable in its own right (carries information about primordial non-Gaussianity from inflation)

- Challenge: the trispectrum has never been measured from a simulation!

Measuring the matter trispectrum

- make a theory prediction (for both 1-loop SPT and EFT)
- Project theory prediction onto *separable* basis of shapes
- project N-body data onto same shapes
- see if principle components expected from EFT are also principle components of the data



shapes from Regan, Shellard, Fergusson (2010)

Bertolini, **KS**, Solon, Zurek 1604.01770

Conclusions

- We have made first SPT and EFT one-loop prediction for both covariance and trispectrum
- EFT relies on simulations which can have systematics
- On the other hand, we want theory for checking results of simulations on mildly nonlinear scales (it would be amazing if SPT accurately reproduced the covariance up to k~0.3!)
- Need to think creatively about independent ways to access same information