KANSAS STATE UNIVERSITY

Higher orders and Smaller Scales

Lado Samushia @ New Strategies for Extracting Cosmology from Galaxy Surveys, 2nd edition, Sexten Center for Astrophysics

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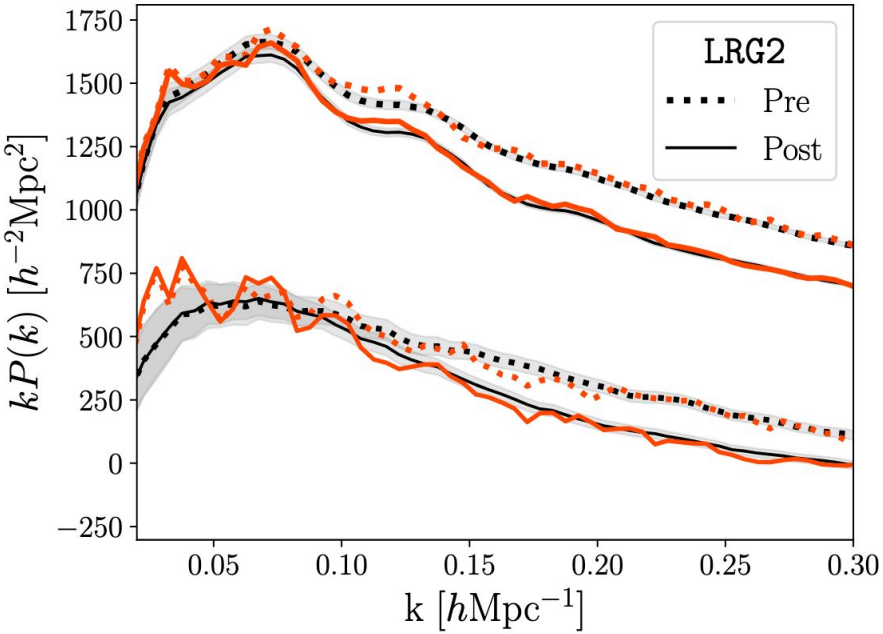
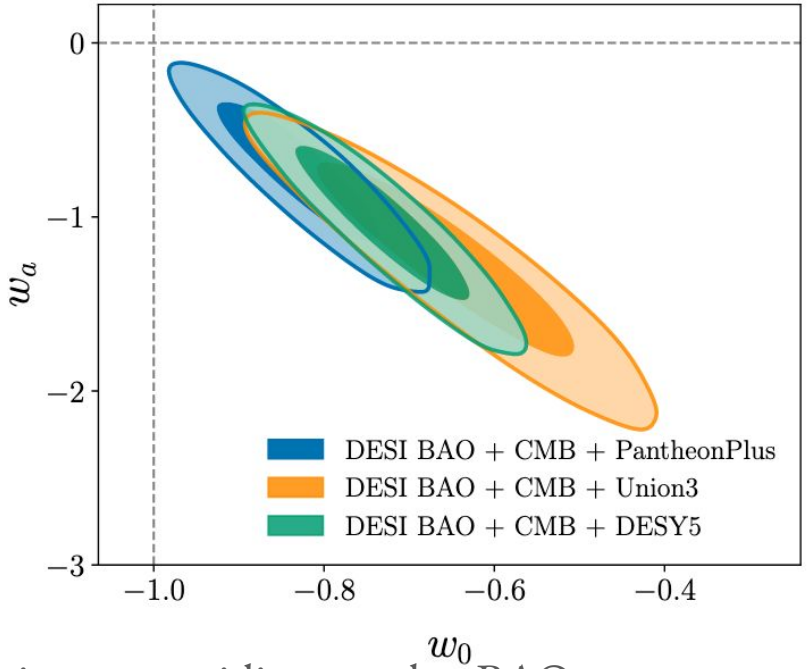
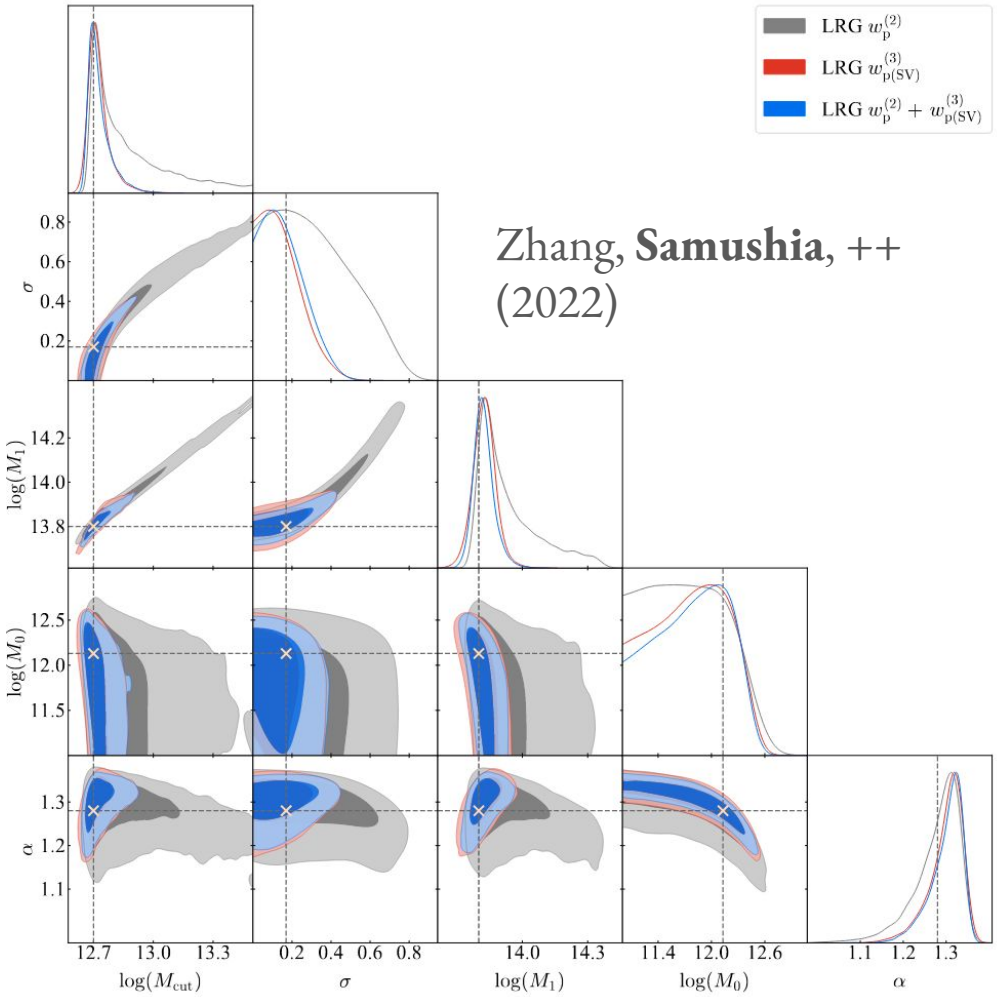




- "Standard Cosmological Analysis": 2pt correlation on semi-linear scales: BAO -> Angular Distance and Hubble Parameter, Anisotropy -> Growth Rate
- Safe and Robust. Some variant of EFT. Few things to worry about (systematics? prior volume effects?)
- Surveys strategies and performance are still evaluated based on the forecast of SCA
- The amount of information is fundamentally limited

Cosmological analysis beyond semi-linear 2pt correlations

- Need to go to smaller scales or higher orders (or both) to get more information - were EFT is not expected to work well.
- Why I like 3-pt correlations:
  - Can be measured exactly within reasonable time
  - Easier to interpret theoretically
  - Likelihood can be understood
  - The origin of any potential signal/discovery/discrepancy with the standard model can be traced in the data
- Challenges of 3-pt correlations:
  - Very large data vector that will need to be somehow reduced
  - Not necessarily the most optimal (wavelets, KNN, Voids, etc. could be better)
  - Need to find a good alternative for the EFT
  - Expectations are unclear



Zhang, **Samushia**, ++ (2022)

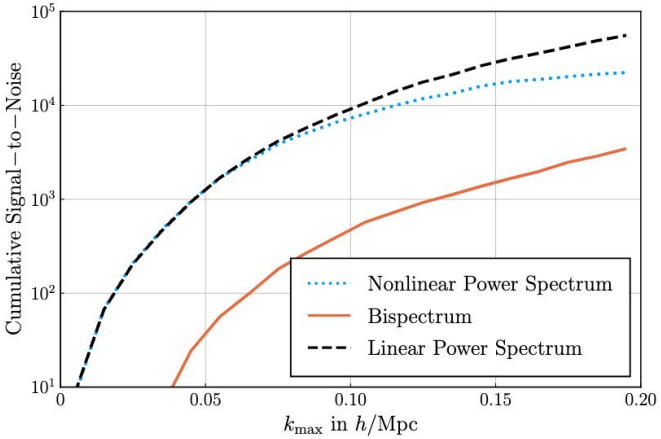
- Significant gain is expected from 3pt functions on small scales
- The analysis of the small scale clustering of DESI-LRG like samples based on AbacusSummit simulations
- Standard 5-parameter HOD model
- Significant (for some parameters more than a factor of 2) improvement on HOD parameters
- All parameter posteriors dominated by 3pt measurements (2pt measurement can be ignored)
- Posterior likelihood becomes more Gaussian
- Improvement is less drastic for parameters describing satellite galaxies

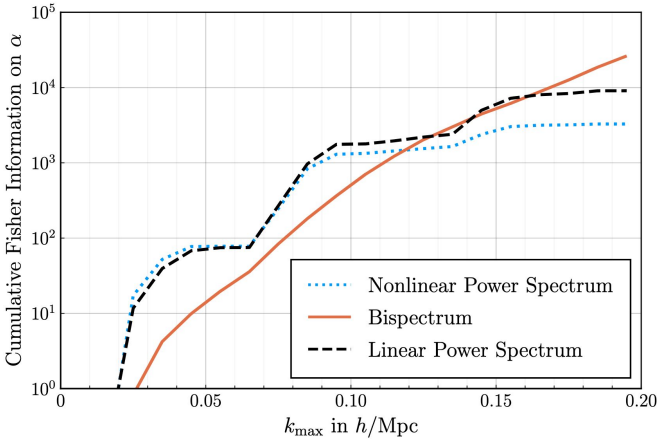
- Question: How much information is in mid-to-large-scale bispectrum?
- Answer: Forecasts are difficult to make. Or rather, there is no safe way of forecasting. If people do not like your forecasts, they will always be able to claim that you are wrong.

- Question: Why measure bispectrum when you can do reconstruction?
- Safe Answer: We should always make as many alternative/equivalent measurements as we can to make sure systematics are under control.
- Counter Question: Why are we measuring BAO in both power spectrum and the correlation function? The measurements are 99% correlated. We are doubling our work for no reason.

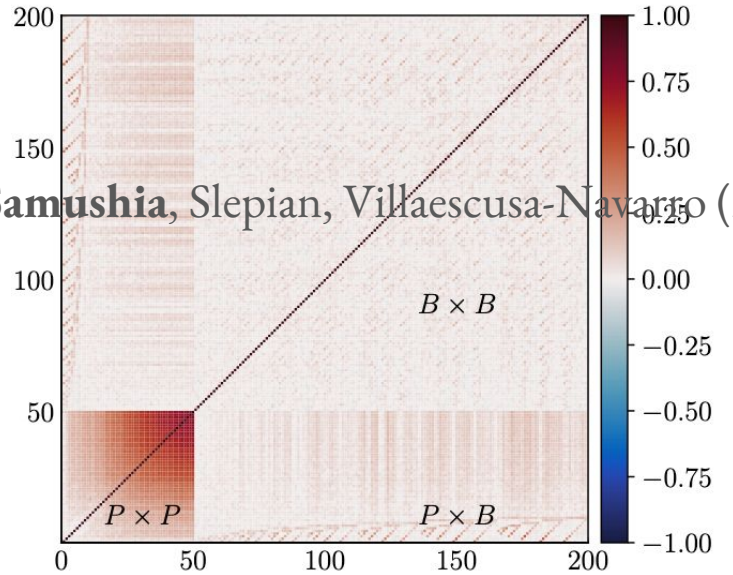
- Question to the Audience: If the BAO scale was exactly the same in all cosmological models, would we be able to use the BAO to derive cosmological constraints?

Samushia, Slepian, Villaescusa-Navarro (2021)



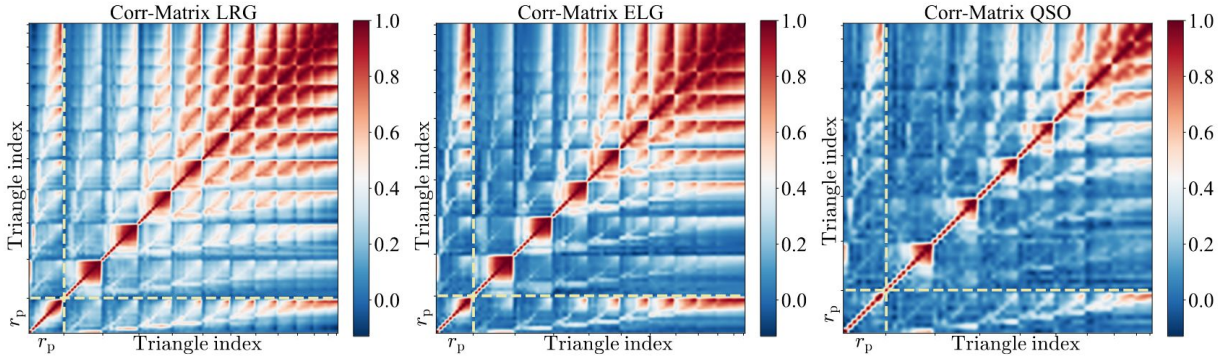


- Cumulative signal to noise is irrelevant for standard rulers. A power low power spectrum can not be used as a standard ruler even if is measured without error.
- The strength of the standard ruler depends on how it changes across scales (the derivative with respect to wavenumber - k).
- Weather the reconstructed field is a better standard ruler overall is unclear and there is no mathematical reason it should be.
- The top plot, based on QUIJOTE simulations, shows that if the biases were perfectly known bispectrum would be a better standard ruler than a linear power spectrum.



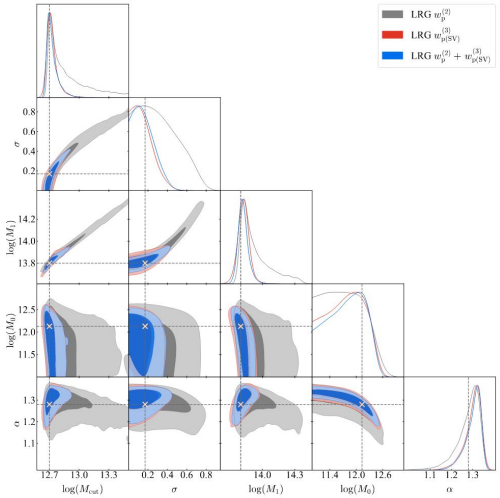
Samushia, Slepian, Villaescusa-Navarro (2021)

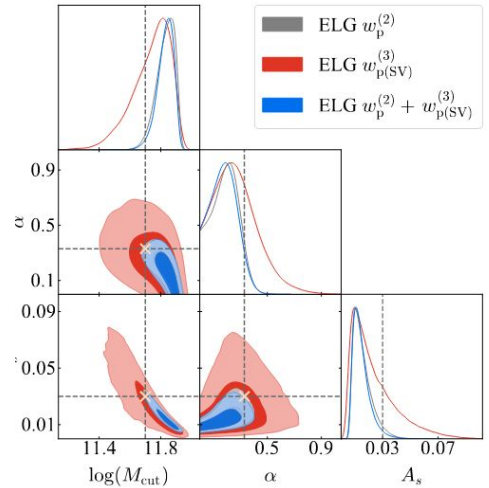
- Bispectrum and Power Spectrum are certainly correlated in theory but how correlated are they as measurements?
- Bispectrum covariances are hard to compute either analytically (need higher orders) or from the mocks (need many mocks).
- Empirical correlations, either from many mocks on large scales (QUIJOTE, left figure) or on smaller scales where data vectors are short (AbacusSummit, bottom figure)



do not look that overwhelming.

Zhang, **Samushia**, ++ (2022)





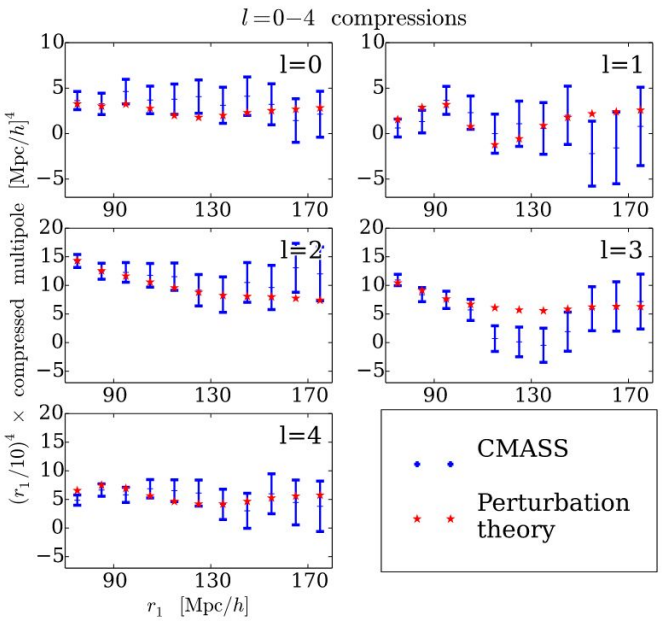
- BOSS analysis with 3 point correlations seems to result in modest improvements.
- The improvement offered by the 3 point correlations however depends on the sample, minimum scale, and the nature of modelling (EFT? Something better?).
- The scaling of constraints with survey volume is simple but the scaling with number density is complicated. Unclear what to expect from future high density samples (Roman?)
- Even in the same survey the difference between different tracers is huge. For DESI LRGs we see a huge improvement in HOD constraints, while for DESI ELGs the improvement is marginal.
- Beware of generalizing from BOSS CMASS results.

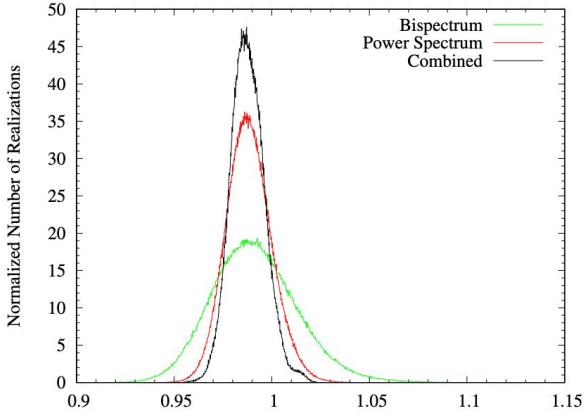
Zhang, **Samushia**, ++
(2022)

Slepian++ (2017)

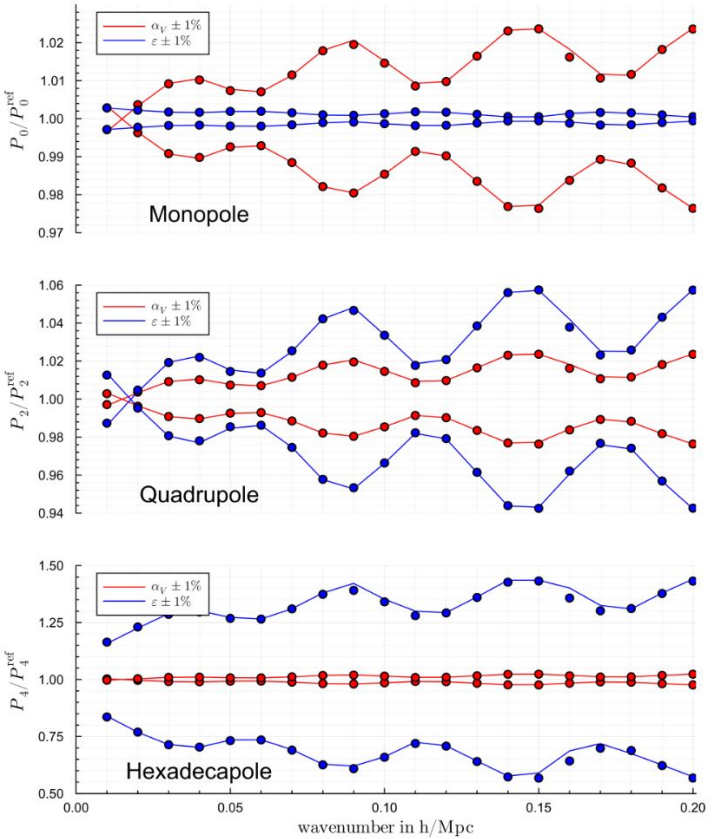
Let's measure BAO from the 3 point correlations

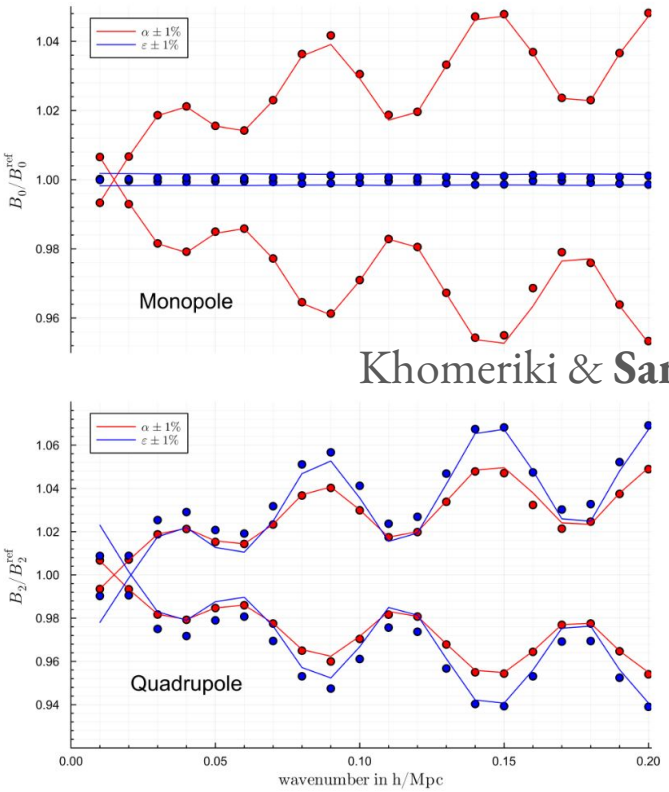
- Has been done before in BOSS.
- A relatively systematics safe measurement in 2 point correlation. No obvious reason why this would change in the 3 point correlation.
- Transparent analysis
- May be able to get away with something simpler than the full fledged EFT
- Intuition based on the 2 point correlation: Even though the BAO signal extends to high wavenumbers in the Fourier space, the frequency is generated by a large scale signal and is easier to model than the "shape".





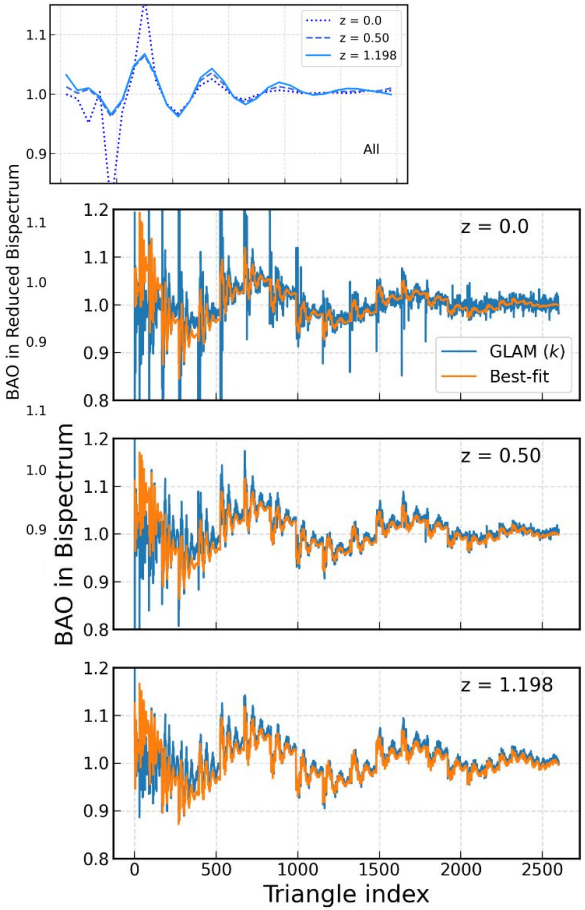
Pearson & **Samushia** (2018)





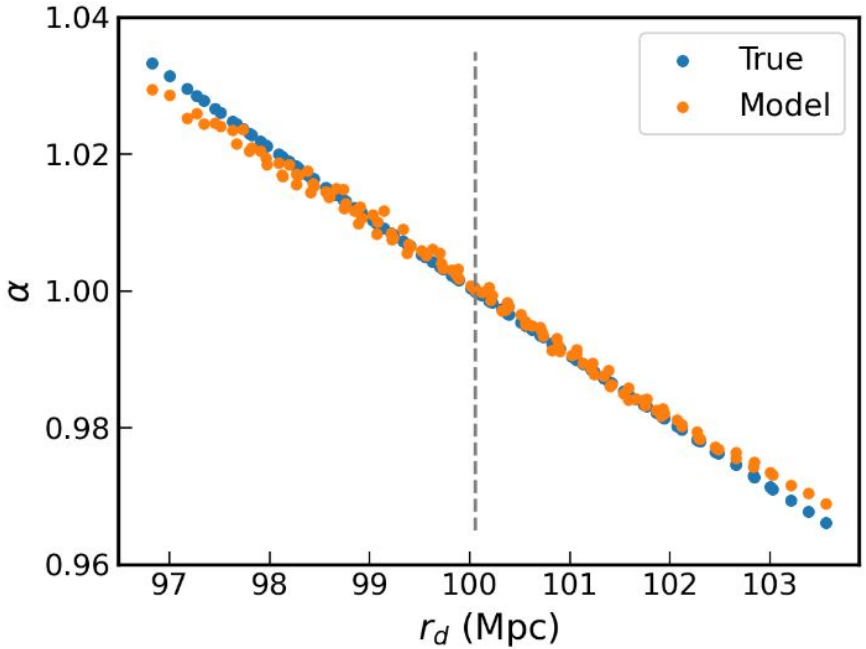
Khomeriki & **Samushia** (2024)

The expected BAO signal in the bispectrum is pretty much similar to that in the bispectrum.



Behera & **Samushia** (2024)

- Thanks to Francesco Prada's group, we had 1000 cubic Gigaparsecs of N-body simulations that were identical except for the initial conditions (with and without BAO) with enough resolution for LRGs.
- With these simulations we can unambiguously extract the "pure BAO" signal.
- We know that when it comes to the bispectrum EFT struggles to go much beyond k ~ 0.1 Mpc/h.
- Is the "pure BAO" easier to model at smaller scales?
- How simple of a model you can get away with without inducing significant bias?
- We didn't have a good estimate of covariance so we can make statements about the bias but not about the errors.
- The BAO signature is clearly visible in the bispectrum at all redhsifts and to wavenumbers up to k ~ 0.3 Mpc/h
- A very simple tree level based theory seems to be performing OK.



Behera & **Samushia** (2024)

- Systematic offsets in BAO parameter seem to be small even with this simple analysis, especially if the template is close to the true cosmology.
- The systematics increase for offset cosmologies.
- This is very promising given that the modeling was extremely simple.
- Many things would need to be done before something like this can be done on DESI data:
  - covariances
  - observational systematics (especially fiber assignment)
  - window effects
  - BAO signal extraction
  - HOD systematics

Summary

- Analysis of 3 point correlations has its advantages over fully nonlinear measures of clustering.
- I would go even further and say that it has some advantages over field level inference. You know exactly where your signal/discrepancy comes from.
- Depending on sample density and bias, the gains from the bispectrum analysis may be better than what you would naively expect.
- Measuring specific signals, such as a BAO peak frequency, may have advantages over straightforward EFT fits with many bias parameters.