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Measuring the Bispectrum in Galaxy Surveys

A comparison of DM codes

Johnathan Hung, with James Fergusson, Marc Manera, Tobias Baldauf and Paul Shellard

DAMTP, University of Cambridge

Outline

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  - Statistics
- LSS Bispectrum
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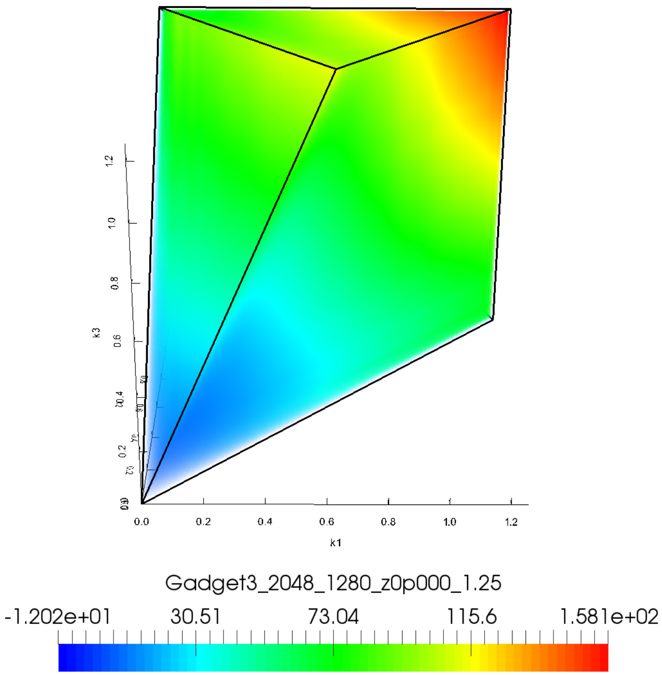

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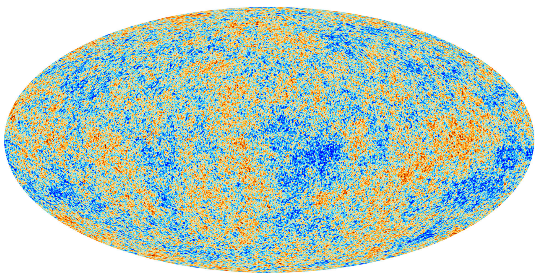
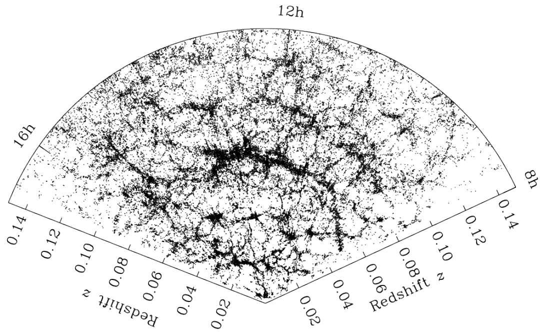
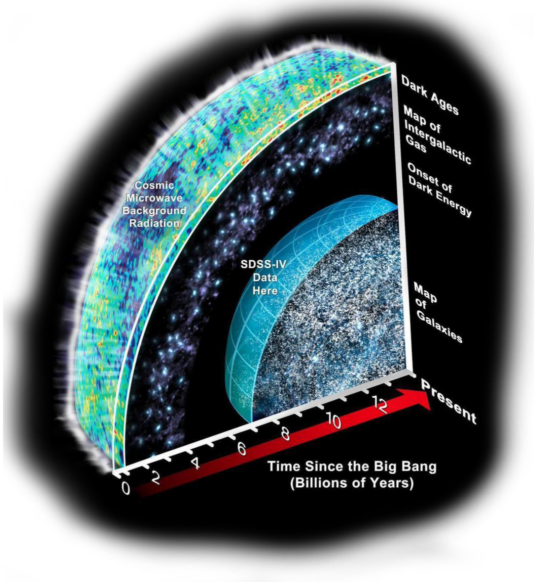
Introduction

CMB and LSS



CMB	LSS
2D dataset	3D dataset
Linear	Non-linear



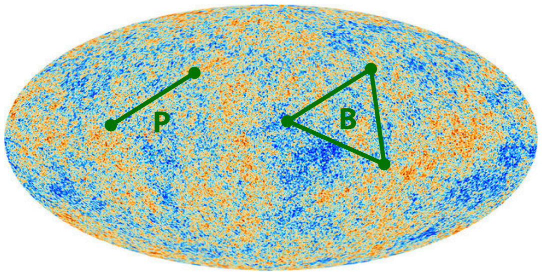


Both equally important:

Complementarity of scales

Cross-correlation

Statistics

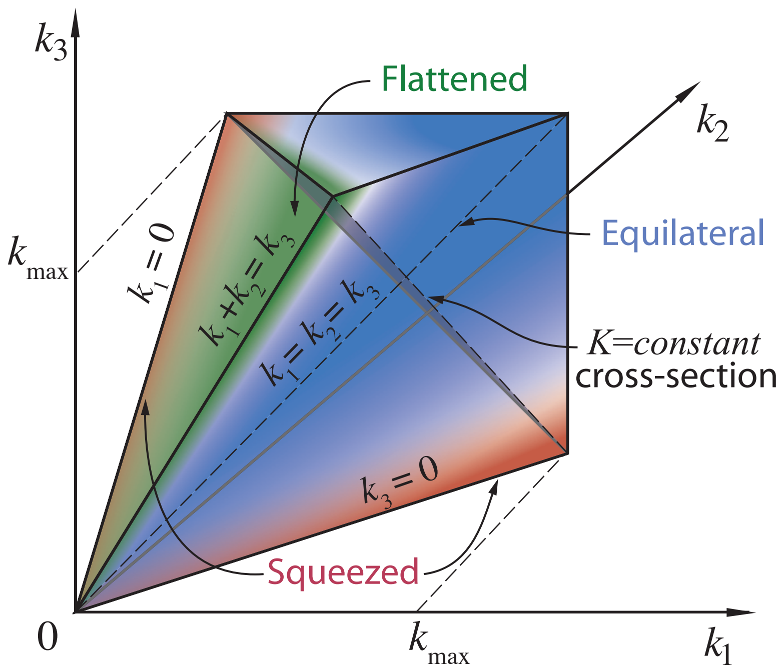


- Power spectrum, or two-point correlation function
- At small scales the bispectrum surpasses the power spectrum in signal-to-noise
  - Better at tracing non-linear evolution of structure
  - Break degeneracies in parameter space, e.g. bias
  - Investigate primordial non-Gaussianity
- We have developed a **fast** code (MODAL-LSS) for reconstructing the **full** bispectrum of cosmological simulations (Schmittfull et al. 2013)

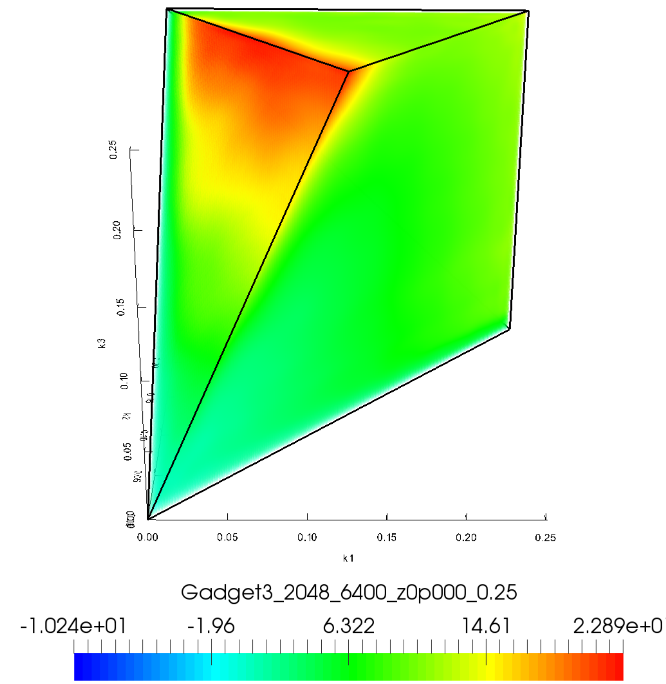
LSS Bispectrum

LSS Bispectrum

Bispectrum tetrapyd cut in half:



Simulation bispectrum:



Different shapes have strongest signals in different parts of the tetrapyd

The morphology gives us qualitative information about the bispectrum shape

MODAL-LSS

- General bispectra computationally intractable
- Expansion of signal-to-noise (SN) weighted bispectrum in separable basis:

$$\sqrt{\frac{k_1 k_2 k_3}{P(k_1)P(k_2)P(k_3)}} B^{th}(k_1, k_2, k_3)$$
$$\approx \sum_{n}^{n_{max}} \alpha_n^Q Q_n(k_1/k_{max}, k_2/k_{max}, k_3/k_{max})$$

- The basis functions are symmetrised products over polynomial functions:

$$Q_n(x, y, z) \equiv q_{\{r}(x) q_s(y) q_{t\}}(z)$$

  - Reduces bispectrum estimation from 3D problem to 1D problem
- Can use O(1000) modes for highly accurate reconstruction

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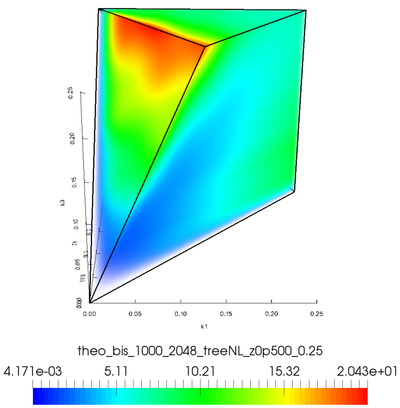
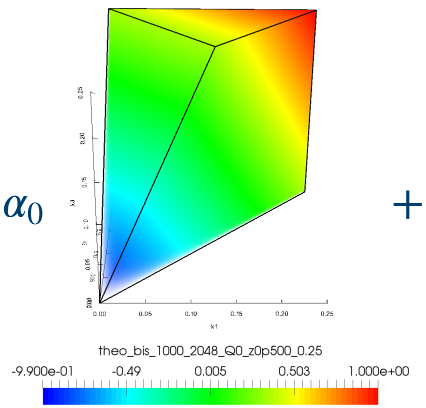
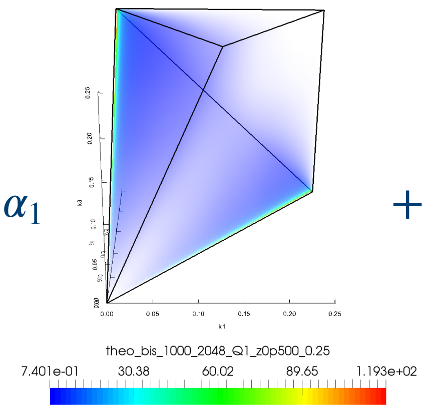
MODAL-LSS



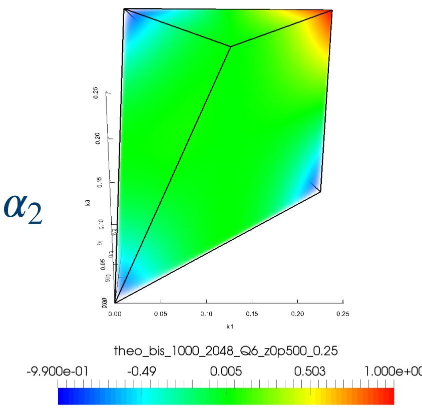
$= \alpha_0$



$+\alpha_1$



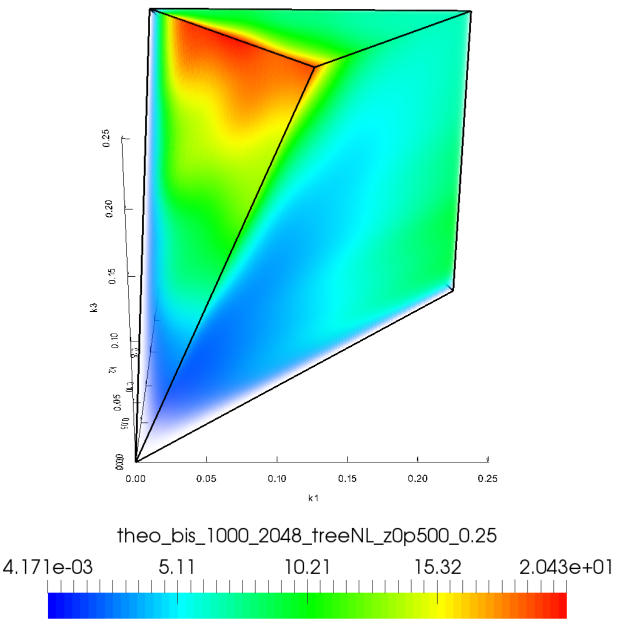
$+\alpha_2$



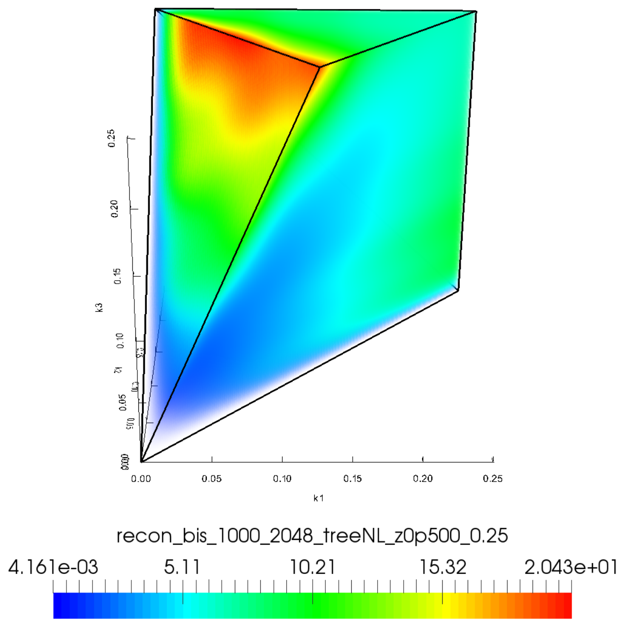
$+\cdots\cdots$

Bispectrum Theory Validation

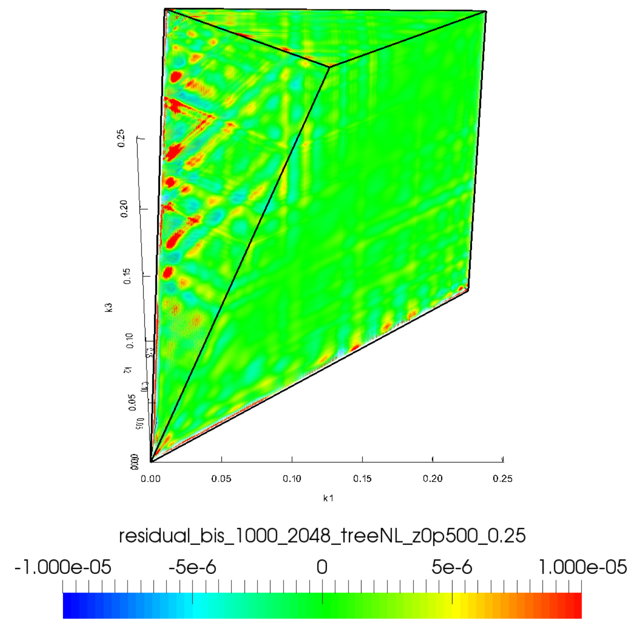
- Fractional deviation of 10^{-6} (with 1000 modes)



Signal



Reconstruction



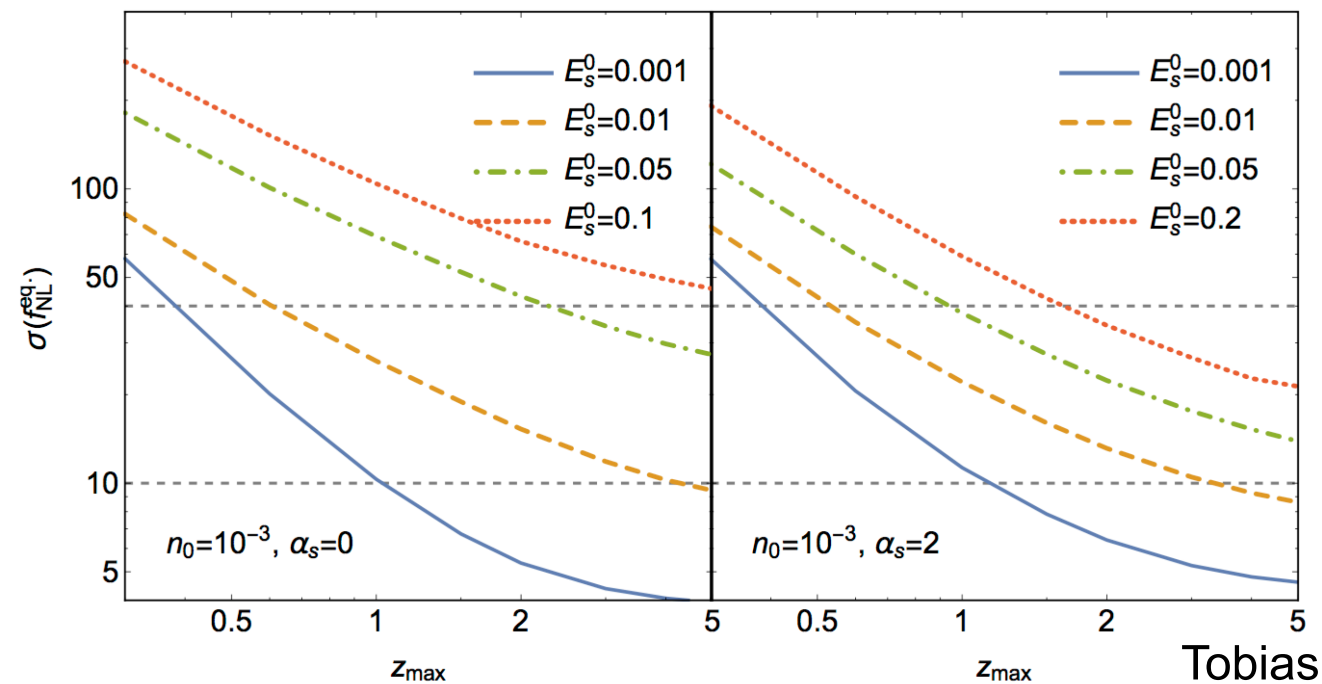
Residuals

Cosmological simulations

- N-body codes such as GADGET are expensive to run
- Need many runs to reduce statistical errors in estimation of covariance matrices, comparison to theory etc.
- Fast DM codes such as L-PICOLA: more than 100x reduction in CPU-hours (1000x for 2LPT)
- Can benchmark these codes with power spectrum and bispectrum
- Diagnostics:
  - Shape: $\mathcal{S}(B_i, B_j) \equiv \frac{[B_i, B_j]}{\sqrt{[B_i, B_i][B_j, B_j]}}$ Amplitude: $\mathcal{A}(B_i, B_j) \equiv \frac{[B_i, B_j]}{[B_i, B_i]}$

Cosmological simulations

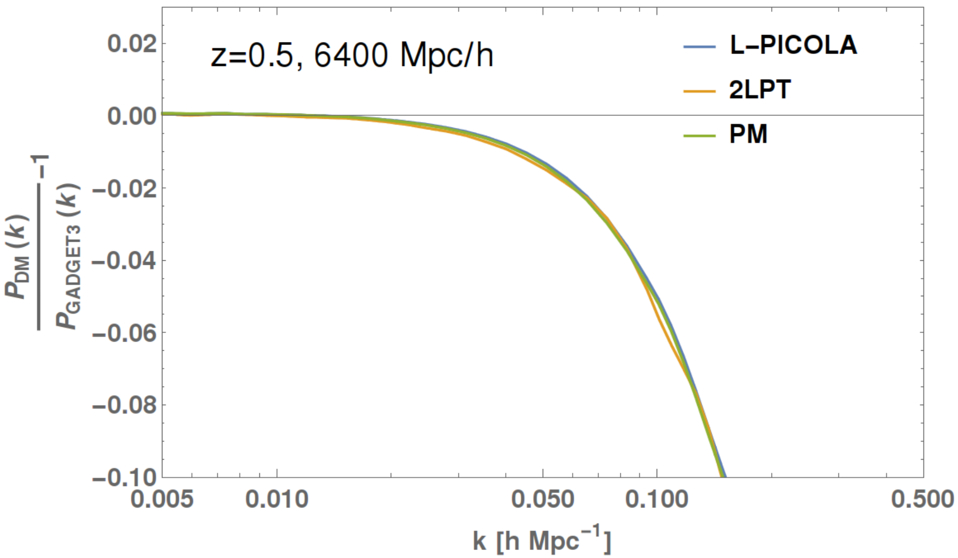
- Benchmarking important for detection of new physics, e.g. $f_{NL}^{eq.} \sim 1$
- MODAL-LSS helps setting down the yardstick

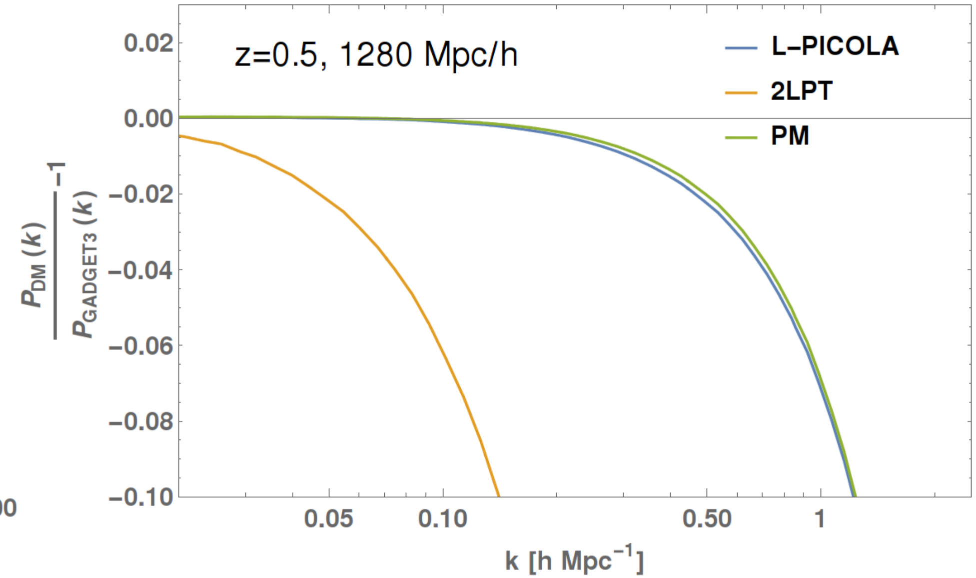


Tobias et al. 2016

Results

- We ran 6400 Mpc/h and 1280 Mpc/h GADGET3 simulations with 2048^3 particles and PMGRID of 2048 for maximum resolution
- We benchmarked L-PICOLA, 2LPT and PM against GADGET3
- We compare their power spectrum and bispectrum





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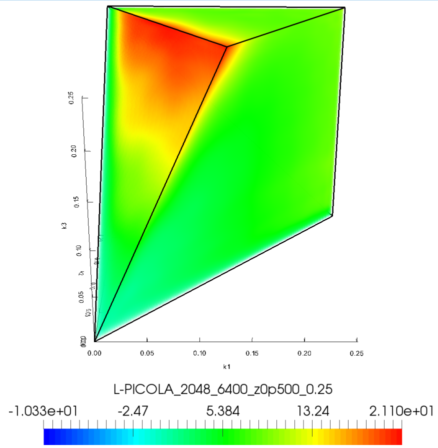
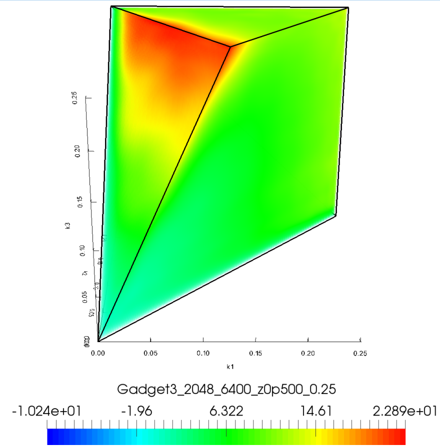
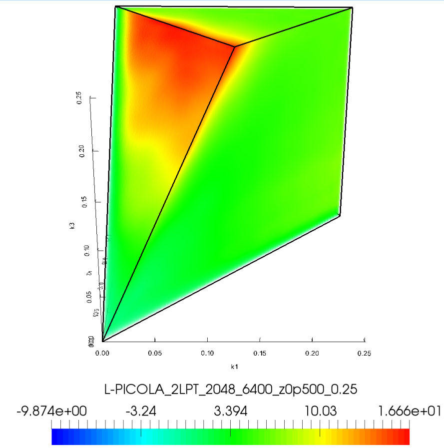
Bispectrum Results



L-PICOLA



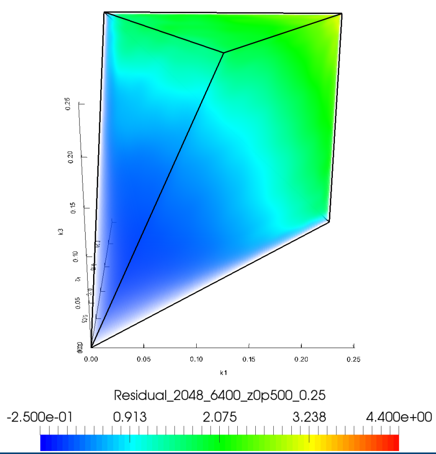
GADGET3

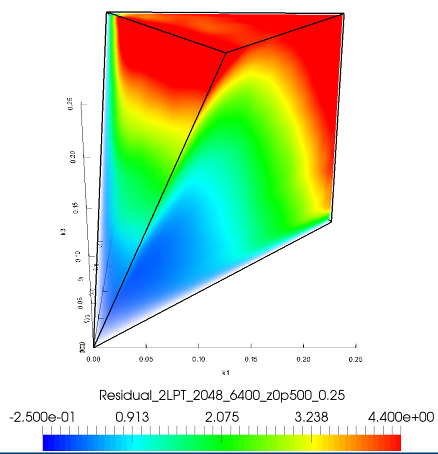


2LPT

- 6400 Mpc/h

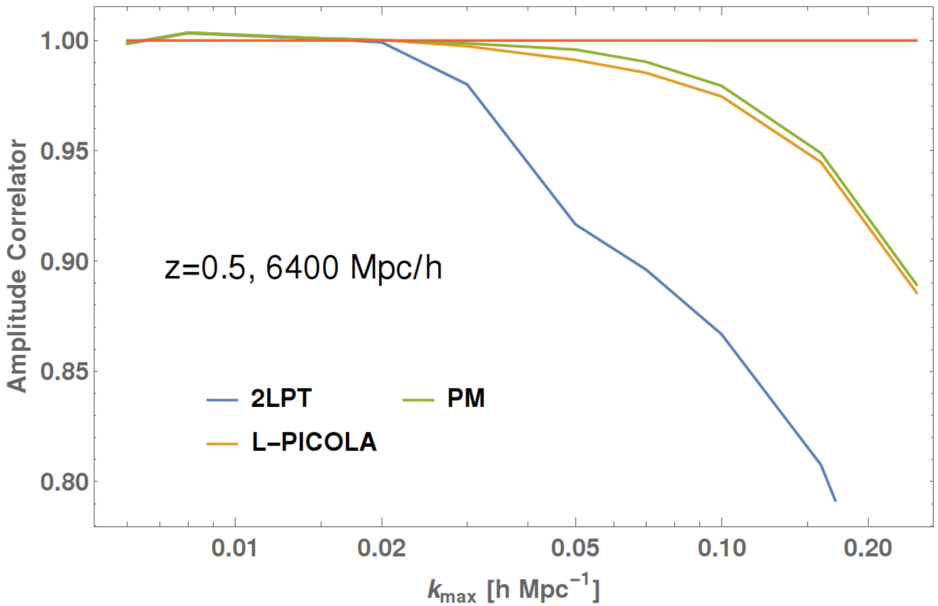
L-PICOLA residuals

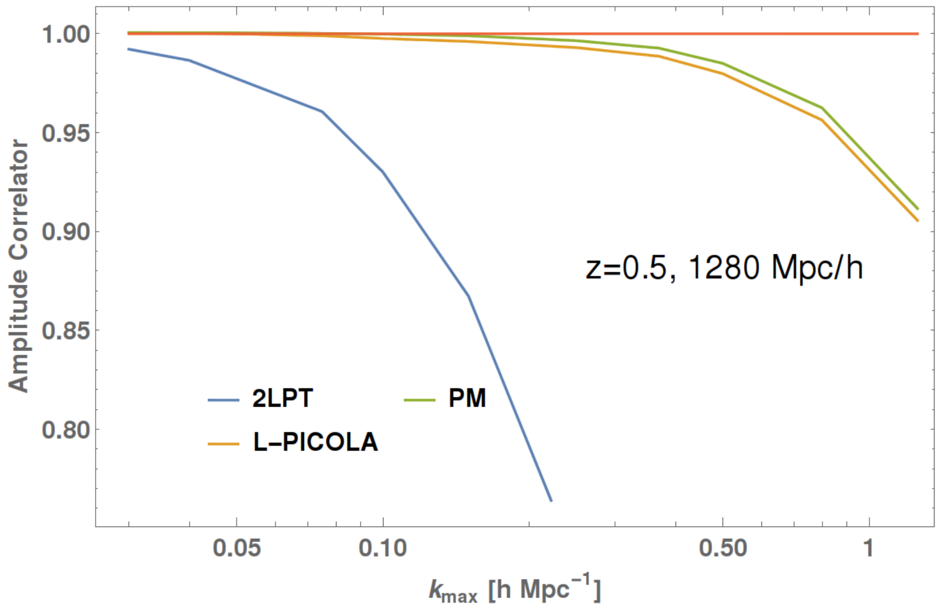




2LPT residuals, 2x magnitude of L-PICOLA ones

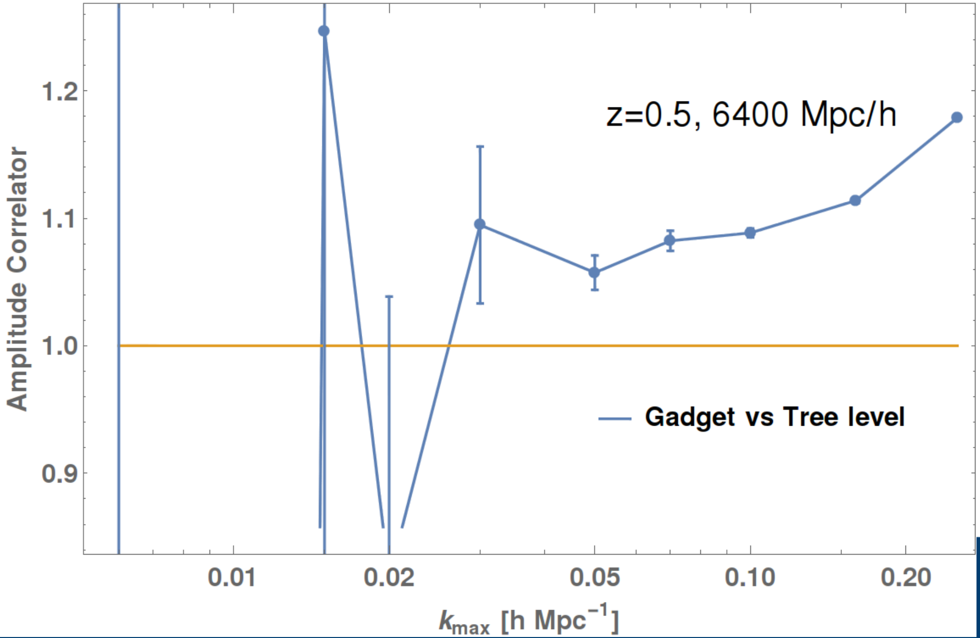
Bispectrum Results





Bispectrum Results

- Theoretical modelling of DM bispectrum is challenging, e.g. "3-shape" model by Lazanu et al.
- MODAL-LSS can allows easy and quick validation and differentiation between these models
- At large scales DM bispectra is predominantly tree level



Conclusions

Conclusions and Future work

- LSS will become very important cosmological observable
  - Bispectrum computationally difficult but will provide a wealth of information for breaking parameter degeneracies, constrain early universe scenarios, and investigating primordial NG or alternatives to GR
  - Computation made efficient by MODAL-LSS code
- Need many N-body simulations for parameter estimation etc.
  - Fast codes can be benchmarked through bispectrum, and power spectrum can't
- Will move towards halo codes with galaxy survey data in mind