Effective Field Theory of Structure Formation

Lecture 4: Redshift Space Distortions and Observations

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Outline:

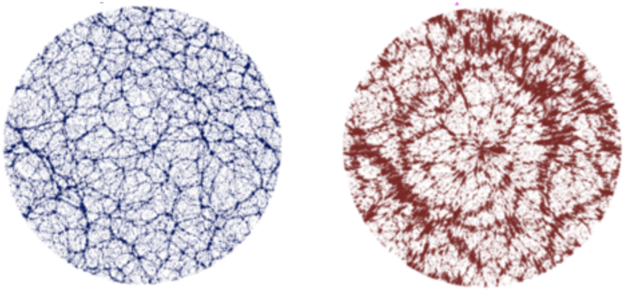
1. Redshift Space Distortions
2. Velocity-moment expansion of RSD
3. Cosmological Parameter Constraints: Simulations Challenge
4. Cosmological Parameter Constraints: Boss Galaxy Survey
5. Summary

Selected bibliography:

- Large-Scale Galaxy Bias, Desjacques et al., 2018, 1611.09787
- Lectures on EFTofLSS, Senatorel, (online notes)
- Modern Cosmology, Dodelson & Schmidt, 2021
- LSS of the Universe and PT, Bernardeau et al., 2002, astro-ph/0112551

Redshift Space Distortions

Galaxy field without RSD, and with RSD included.



[Feldman, 2002]

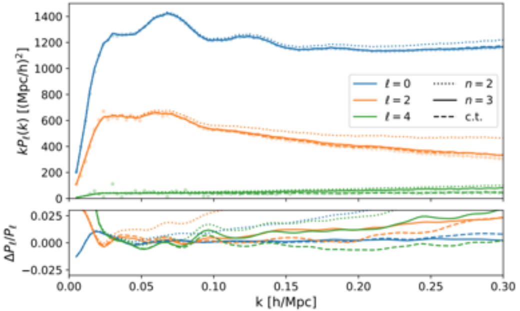
Redshift Space Distortions

Objects in redshift-space:

$$\boldsymbol{s} = \boldsymbol{x} - f(\hat{n} \cdot \boldsymbol{u})\hat{n},$$

Density in redshift-space:

$$\delta_s(k) = \left(b_1 + f\left(\hat{n} \cdot \hat{k}\right)^2\right)\delta(k).$$



Generates sensitivity of correlators to velocity field.

2. Velocity-moment expansion of RSD

Redshift Space Distortions: Velocity Expansions

$$1 + \delta_s(\boldsymbol{s}) = \int d^3x \, (1 + \delta_g(\boldsymbol{x}))\delta^{\rm D}(\boldsymbol{s} - \boldsymbol{x} - \boldsymbol{u}) \, ,$$

where $\boldsymbol{u} =$ really stands for $(\hat{n} \cdot \boldsymbol{u})\hat{n}$.

In Fourier space

$$(2\pi)^3\delta^{\rm D}(\boldsymbol{k}) + \delta_s(\boldsymbol{k}) = \int d^3x \, (1 + \delta_g(\boldsymbol{x}))e^{i\boldsymbol{k}\cdot(\boldsymbol{x}+\boldsymbol{u})} \, .$$

Power Spectrum

$$P_s(\boldsymbol{k}) = \int d^3r \; e^{i\boldsymbol{k}\cdot\boldsymbol{r}} \left\langle (1 + \delta_g(\boldsymbol{x}_1)) \, (1 + \delta_g(\boldsymbol{x}_2)) \, e^{i\boldsymbol{k}\cdot\Delta\boldsymbol{u}} \right\rangle_{\boldsymbol{r}=\boldsymbol{x}_1-\boldsymbol{x}_2}$$

Eulerian approach - expansion in powers/moments of $\Delta\boldsymbol{u}$.

Eulerian PT approach to RSD

- Eulerian approach (EPT):
  based on the velocity moment expansion:

$$P_s(k) = \sum_m \frac{i^m}{m!} k_{\hat{n}}^m \langle (1+\delta_1)(1+\delta_2)\Delta v_{\hat{n}}^m \rangle'$$

where IR-resummation can and is be done a posteriori via wiggle-no-wiggle split.

- How do FoG effects enter into the predictions
  small scale velocity dispersion can modulate the long-density fluctuations

$$\left\langle (1+\delta_1)(1+\delta_2)(\Delta v_{\hat{n}}^2) \right\rangle' \sim \left\langle v_{\hat{n}}^2 \right\rangle P_L(\boldsymbol{k}) \to \sigma_v^2 \mu^2 k^2 P_L(\boldsymbol{k})$$

- Lagrangian approach (LPT):
  RSD mapping contained in the displacement field:

$$\boldsymbol{\Psi}_s = \boldsymbol{\Psi} + f(\hat{n}\cdot\boldsymbol{u})\hat{n} = \boldsymbol{\Psi} + f(\hat{n}\cdot\dot{\boldsymbol{\Psi}})\hat{n}$$

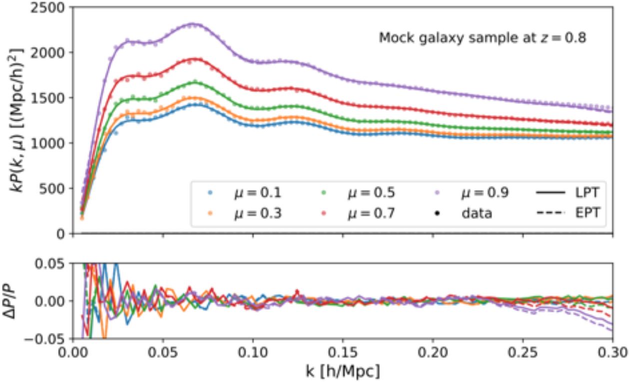
Application to Data: N-body & surveys

http://github.com/sfschen/velocileptors
[Chen, ++:20]

Features:

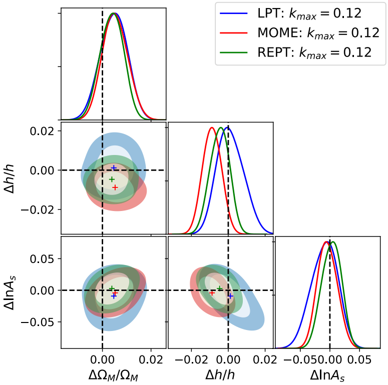
- Eulerian (EPT), Lagrangian (LPT),
- fast loop evaluations (FFT) – all codes take seconds,
- python, user-friendly, implementation. Requires numpy, scipy and pyFFTW.

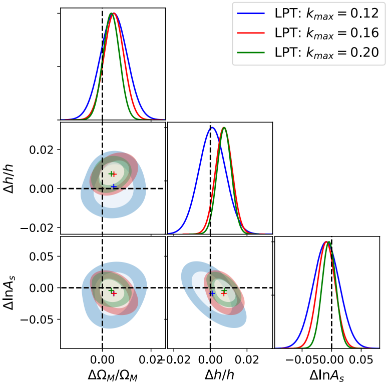
Application to N-Body Data: Mock galaxy sample



Application to Data: N-body & surveys

Blind Challenge: [Chen, ++:20]



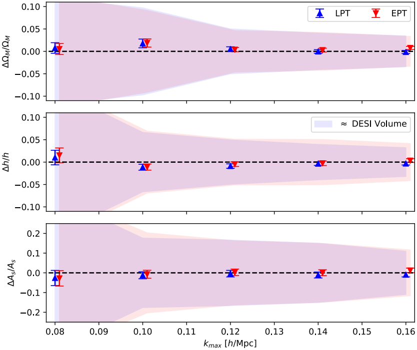


"PT Blind Challenge" Data - 3840Mpc$/h$, 3072^3 particles, with BOSS-like (DESI) signals [Nishimichi++;20]

https://www2.yukawa.kyoto-u.ac.jp/~takahiro.nishimichi/data/PTchallenge/

Application to Data: N-body & surveys

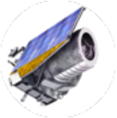
Blind Challenge: [Chen++:20]



All codes publicly available:

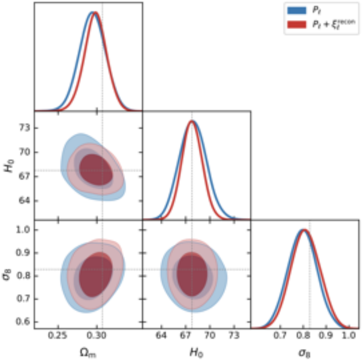
http://github.com/sfschen/velocileptors

Application to upcoming surveys DESI, LSST, EUCLID



Application to BOSS: full-shape + BAO recon.

Mock constraints for z_3; $k \in (0.02, 0.20)h/\mathrm{Mpc}$

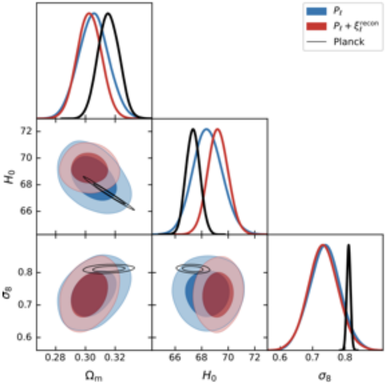


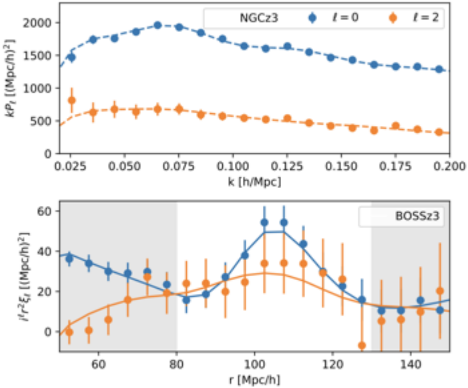
	P_ℓ	P_ℓ + BAO
$\ln(10^{10}A_s)$	3.09 ± 0.18	3.10 ± 0.17
Ω_m	0.294 ± 0.017	0.298 ± 0.014
H_0 [km/s/Mpc]	67.9 ± 1.7	67.8 ± 1.3
σ_8	0.797 ± 0.062	0.810 ± 0.063

True cosmology is $\Omega_m = 0.307115$, $H_0 = 67.77$, $\sigma_8 = 0.8288$.

Application to BOSS: full-shape + BAO recon.

BOSS galaxy PS+ξ

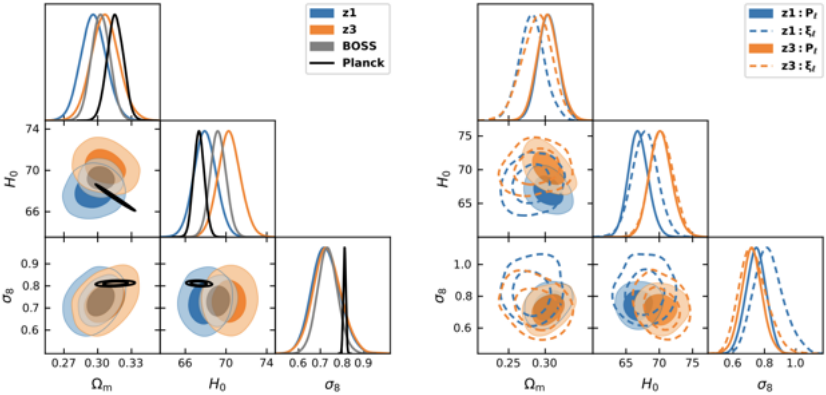




	P_ℓ	P_ℓ + BAO	Planck
$\ln(10^{10}A_s)$	2.84 ± 0.13	2.81 ± 0.12	3.044 ± 0.014
Ω_m	0.305 ± 0.01	0.303 ± 0.0082	0.3153 ± 0.0073
H_0 [km/s/Mpc]	68.5 ± 1.1	69.23 ± 0.77	67.36 ± 0.54
σ_8	0.738 ± 0.048	0.733 ± 0.047	0.8111 ± 0.0060

Application to BOSS: full-shape + BAO recon.

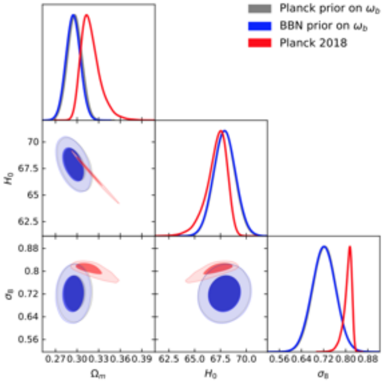
Two independent redshifts & pre- and post- recon.

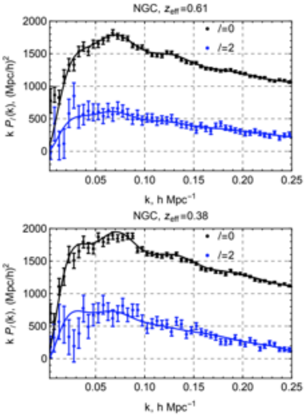


Recent applications to the current data surveys

Cosmological Parameters from the BOSS:

[Ivanov++:19, D'Amico++:19, . . .]





$$H_0 = (67.9 \pm 1.1)\ \text{km/s/Mpc}, \quad \Omega_m = 0.295 \pm 0.010, \quad \sigma_8 = 0.721 \pm 0.043$$

Current ν mass: & < 0.16eV (Planck+LSS) < 0.26eV (Planck)

Application to BOSS: full-shape + BAO recon.

A comparison of $\sigma_8 - \Omega_m$ constraints