Cosmology from large-scale galaxy clustering

Zvonimir Vlah

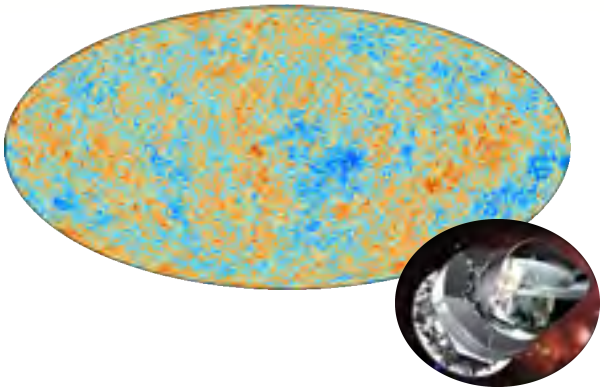
Introduction to KICC, Cambridge

Institut
Ruđer
Bošković

UNIVERSITY OF
CAMBRIDGE

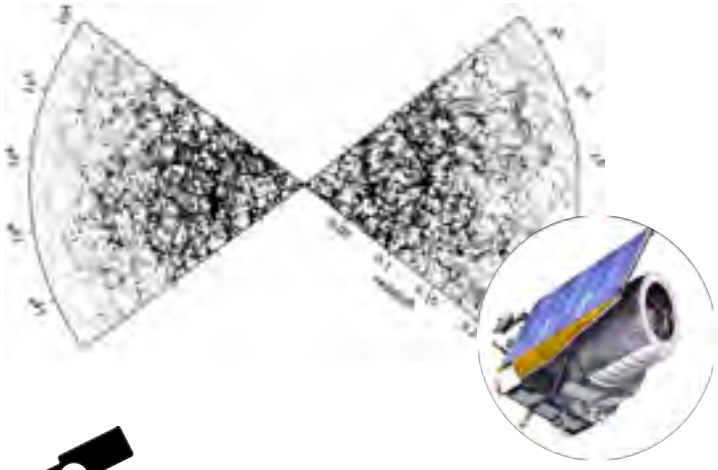
The scope and motivation

microwave background radiation



$\Longrightarrow$

structure formation



Physics motivation:

- Origin of structures & tests of gravity
- Expansion & composition of the universe
- Nature of dark energy and dark matter
- Neutrino mass and number of species

Observations:

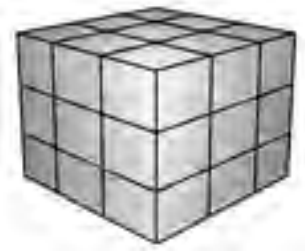
- DESI, Rubin, Euclid, DES, SKA, SPHEREx, CMB-S4, ...

Information:

CMB $\sim k^2$

$\Longrightarrow$

LSS $\sim k^3$

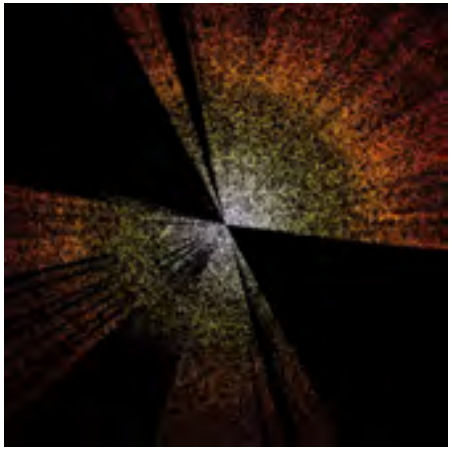


What are the challenges?

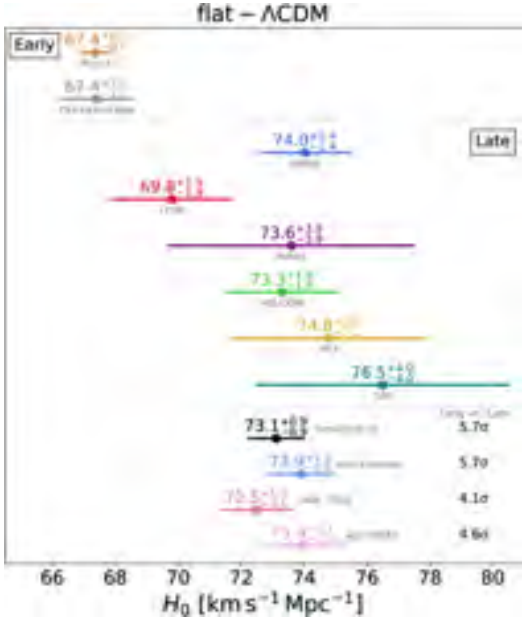
Nonlinear gravitational evolution, complex system (galaxies), multiscale dynamics, ...

Hubble parameter H_0, fluctuation variance σ_8.

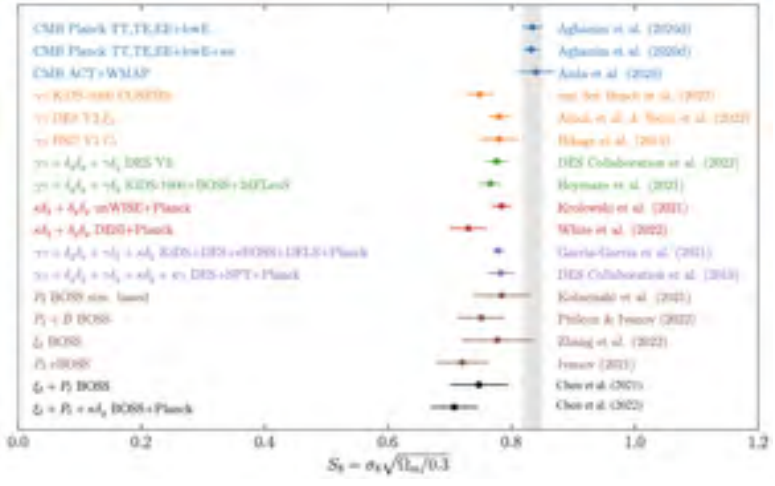
[DESI]



Are the 'n-σ' discrepancies a sign of new (beyond the ΛCDM) physics?

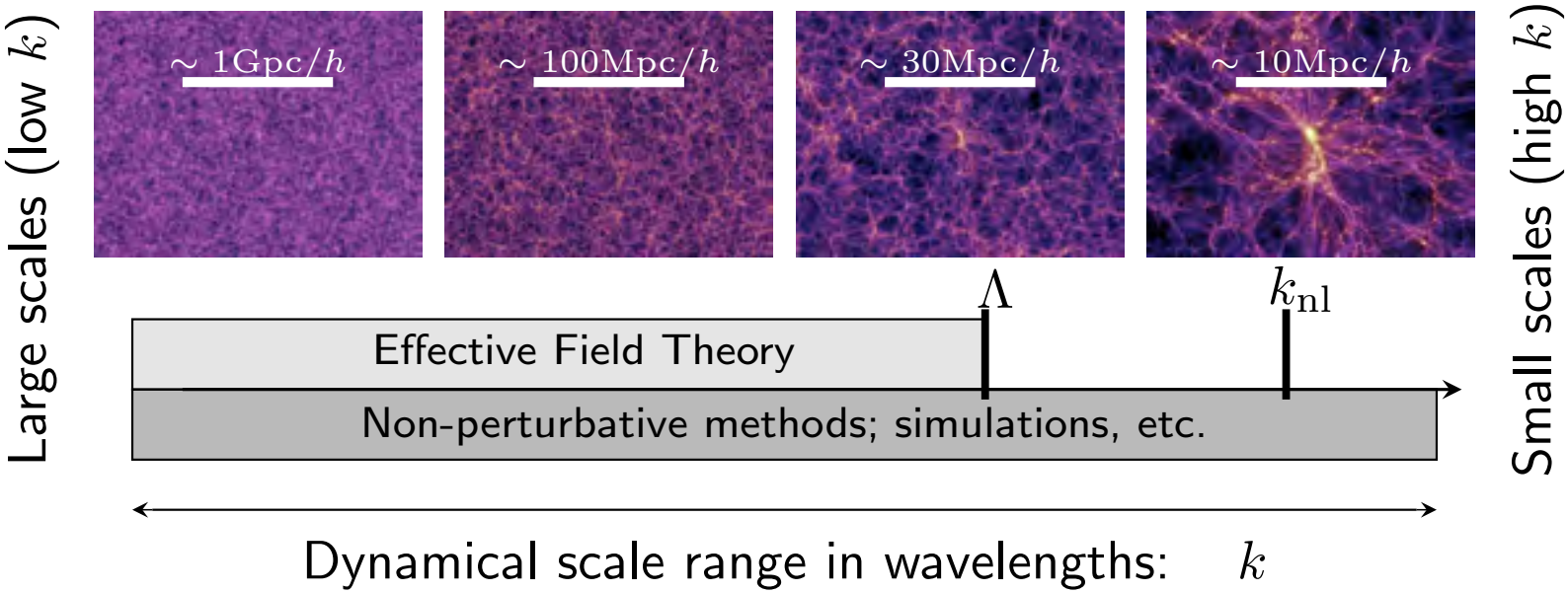


[HOLiCOW/Bonvin]



[Chen, 2022]

Overview of my research: contributions



Understanding gravitational clustering:

- Perturbation theory / Effective Field Theory
- N-body numerical simulations (+ HOD)
- Phenomenological and hybrid models (halo model)

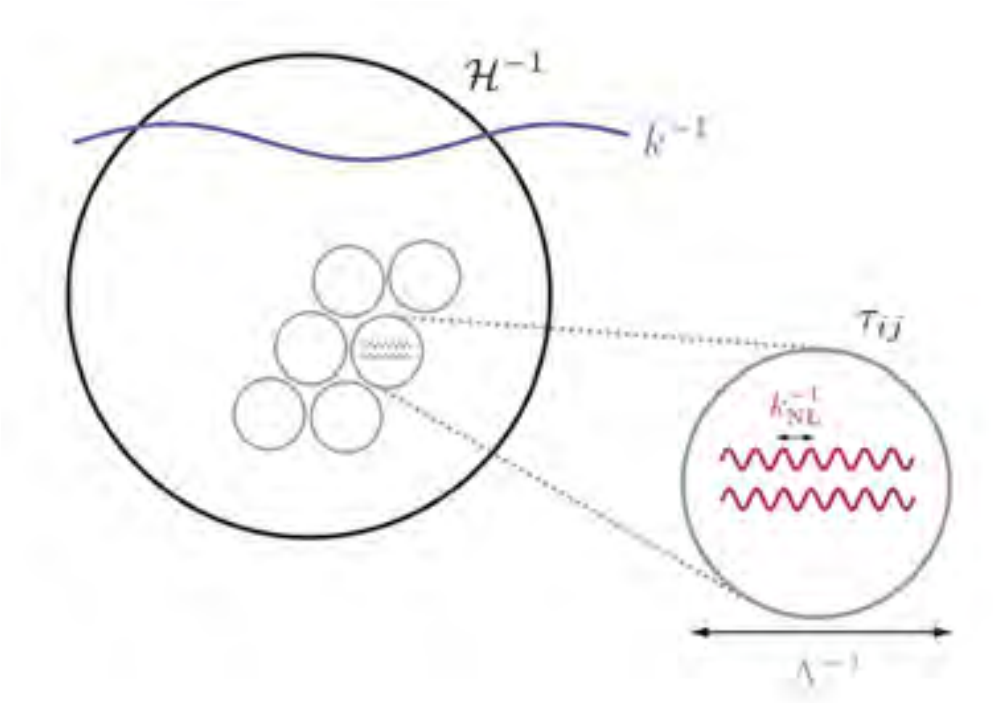
Effective Field Theory of dark matter clustering

Evolution of collisionless particles - Vlasov equation:

$$\frac{df}{d\tau} = \frac{\partial f}{\partial \tau} + \frac{1}{m}\boldsymbol{p}\cdot\boldsymbol{\nabla} f - am\boldsymbol{\nabla}\phi\cdot\boldsymbol{\nabla}_p f = 0, \quad \text{and} \quad \nabla^2\phi = \tfrac{3}{2}\mathcal{H}\Omega_m\delta$$

PT solution for long modes:

$$\delta(\boldsymbol{x}) = \delta_\Lambda^{(1)}(\boldsymbol{x}) + \delta_\Lambda^{(2)}(\boldsymbol{x}) + \delta_\Lambda^{(3)}(\boldsymbol{x}) - c_s^2(\Lambda)\nabla^2/k_{\rm NL}^2\delta_\Lambda^{(1)}(\boldsymbol{x})$$



Coarse graining/integrating out of the short modes.

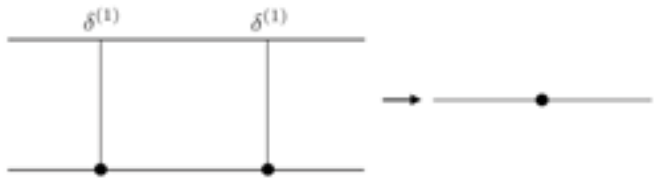
PT/EFT results for the power spectrum

One loop Power Spectrum results in the Eulerian PT:

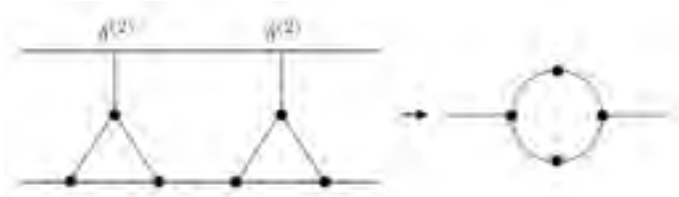
$$P(k) = \underbrace{P_0(k)}_{\text{LO}} + \underbrace{P_{22}(k,\Lambda) + 2P_{13}(k,\Lambda) - 2c_s^2(\Lambda)\frac{k^2}{k_{\rm NL}^2}P_0(k,\Lambda)}_{\text{NLO}}$$

Renormalization leads to the theory that is under control in the UV:

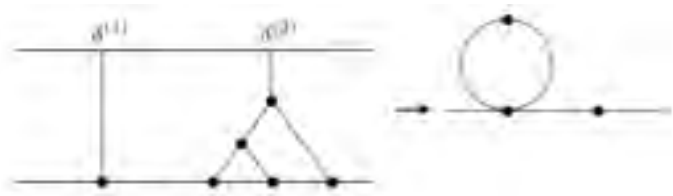
$$P_0(k) =$$



$$P_{22}(k) = \int_q F_{22}(q,k-q)^2 P_0(q) P_0(k-q) =$$



$$P_{13}(k) = 3P_0(k)\int_q F_{13}(k,q,-q) P_0(q) =$$

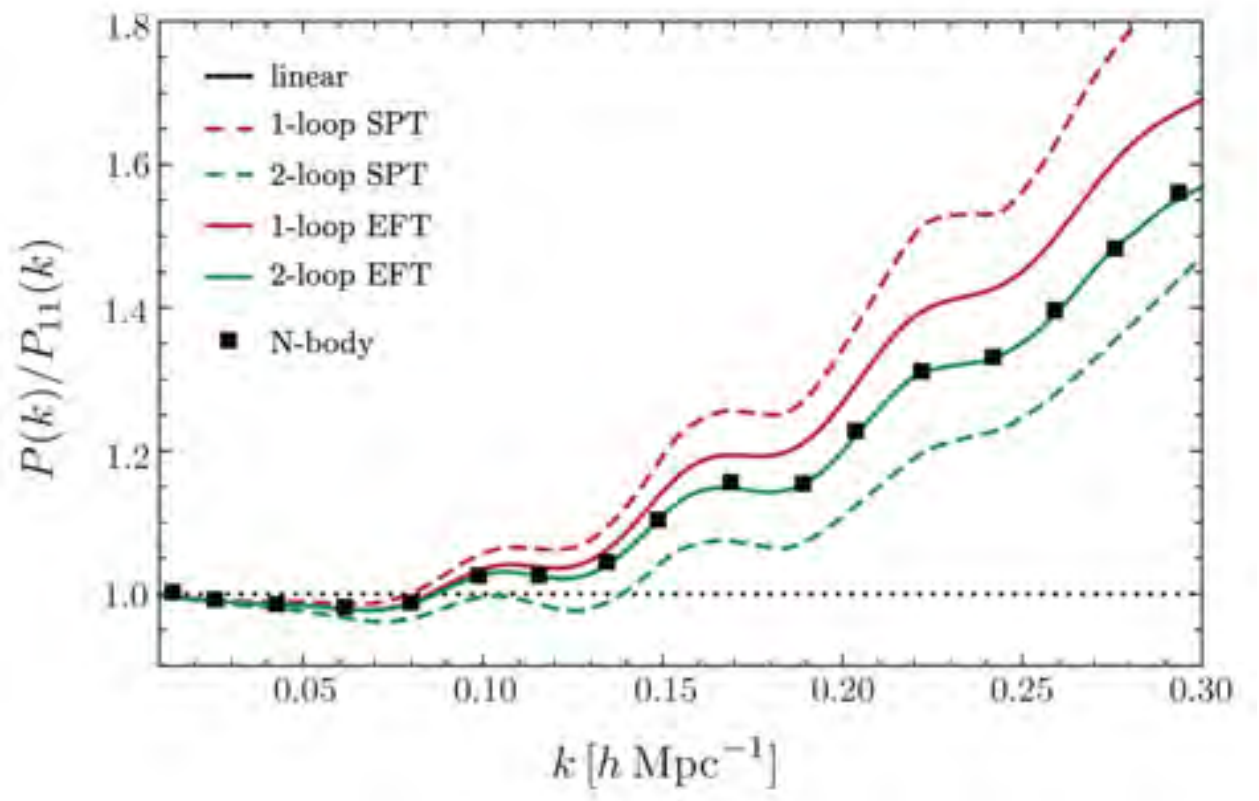


PT/EFT results for the power spectrum

One loop Power Spectrum results in the Eulerian PT:

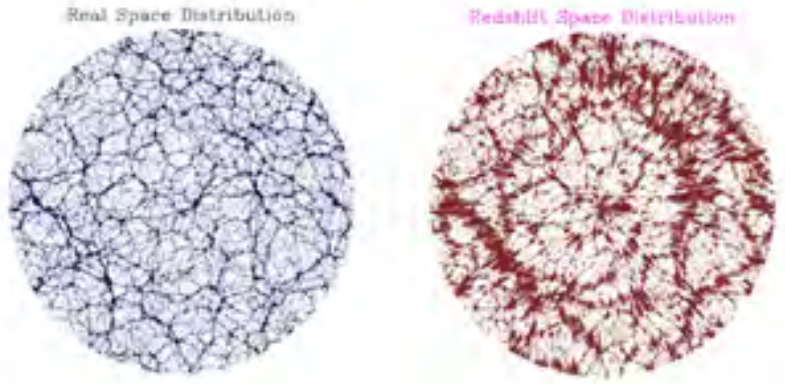
$$P(k) = \underbrace{P_0(k)}_{\text{LO}} + \underbrace{P_{22}(k,\Lambda) + 2P_{13}(k,\Lambda) - 2c_s^2(\Lambda)\frac{k^2}{k_{\rm NL}^2}P_0(k,\Lambda)}_{\text{NLO}}$$

Renormalization leads to the theory that is under control in the UV:



Redshift Space Distortions

[Feldman++;13]



Objects in redshift-space:

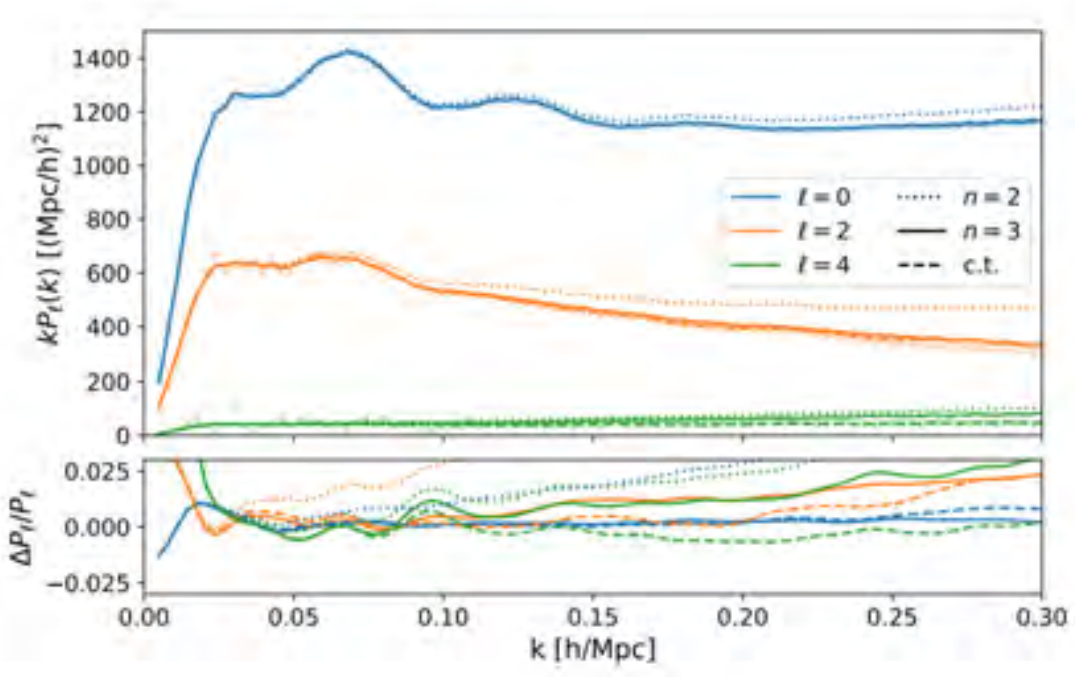
$$s = \boldsymbol{x} - f(\hat{n} \cdot v_x)\hat{n},$$

Density in redshift-space:

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

where the log growth rate is:

$$f = d\ln D/d\ln a.$$

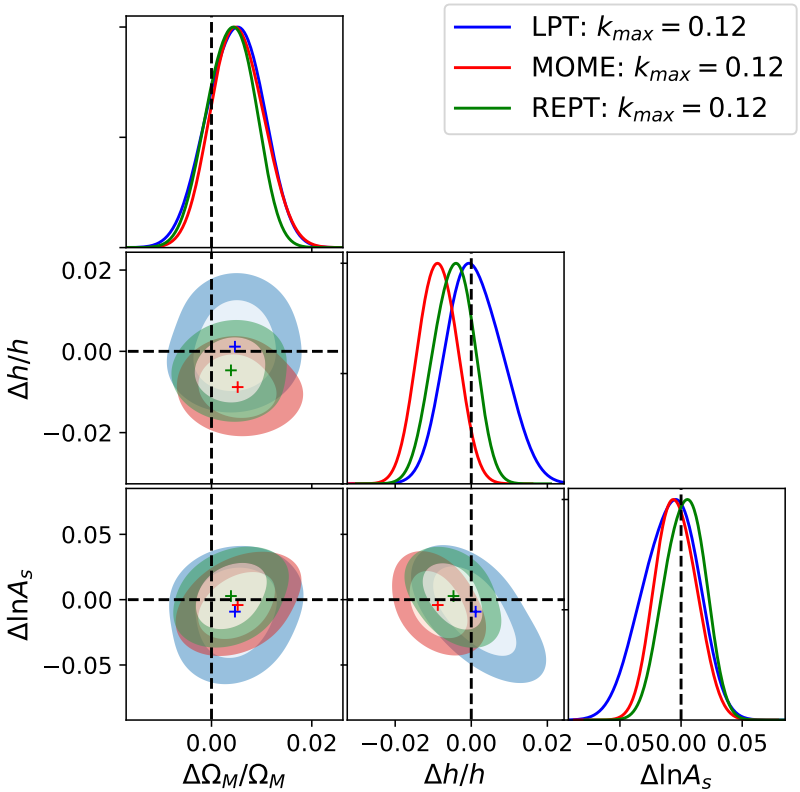


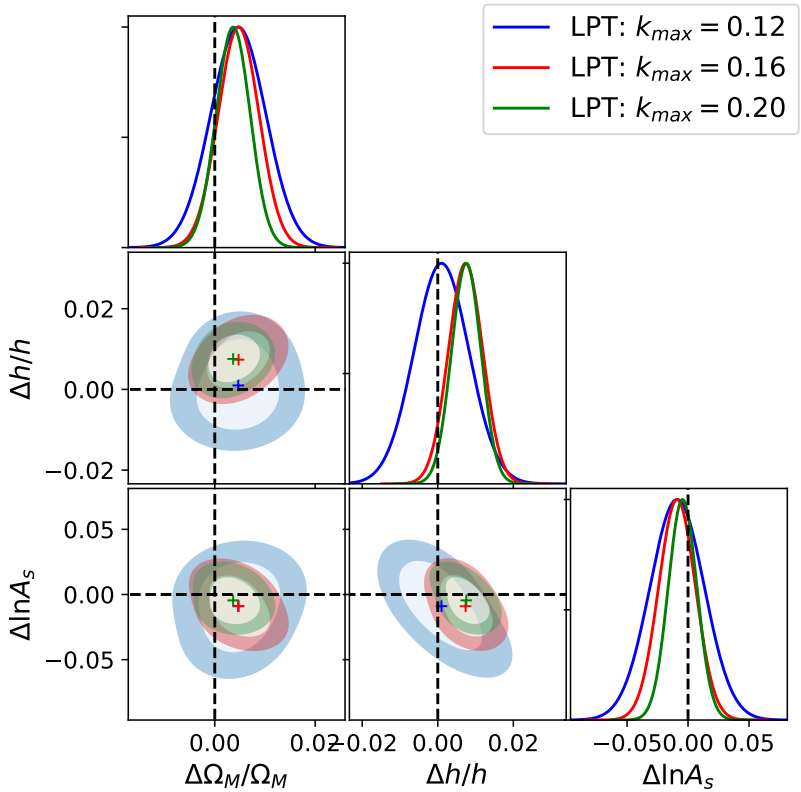
Generates sensitivity of correlators to velocity field.

How does this program work for the number statistics?

Application to Data: N-body & surveys.

Blind Challenge: [Chen, ZV & White:20, Chen, ZV++:20]





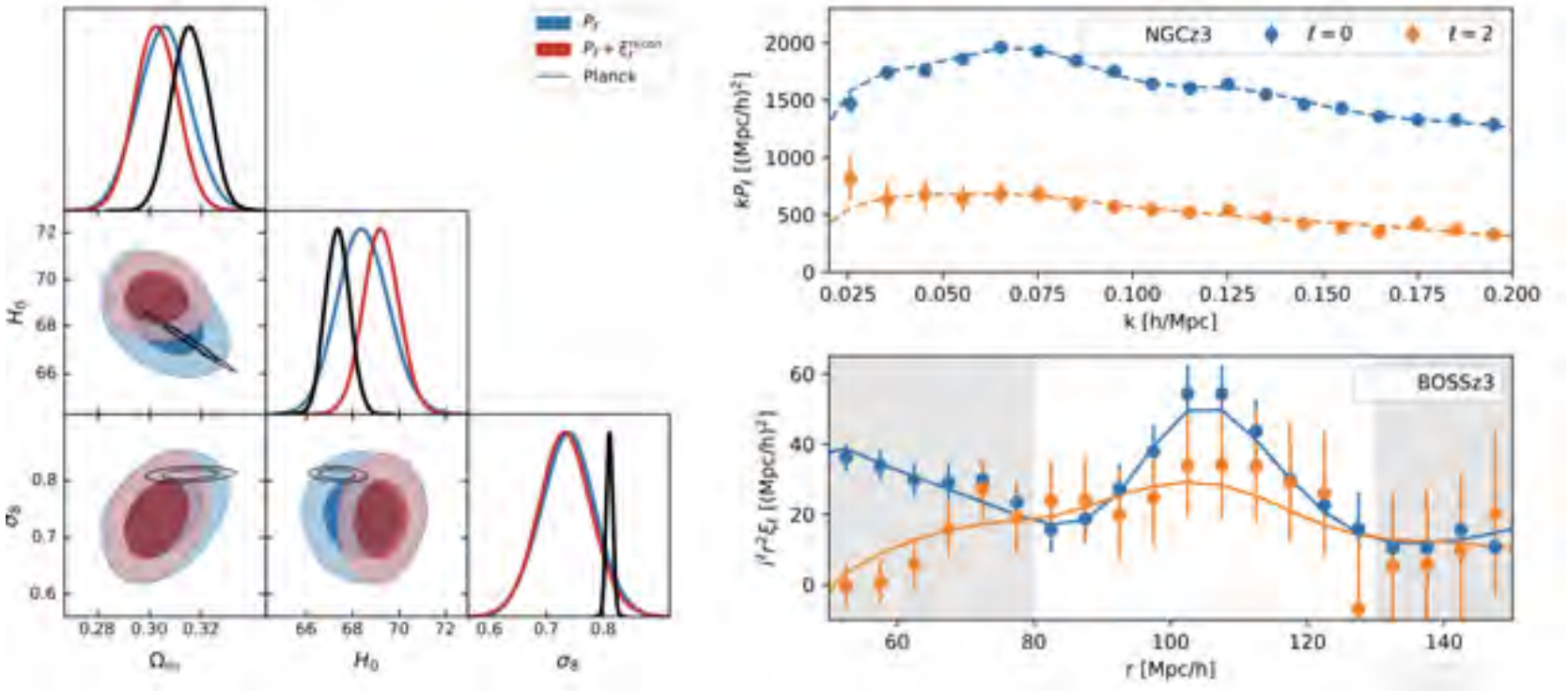
"PT Blind Challenge" Data - 3840Mpc/h, 3072^3 particles, with BOSS-like (DESI) signals [Nishimichi++;20]

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

Contributions to the EFT approach to LSS

Application to BOSS: shape + BAO recon. [Chen, ZV+:20, Chen, ZV++:21]

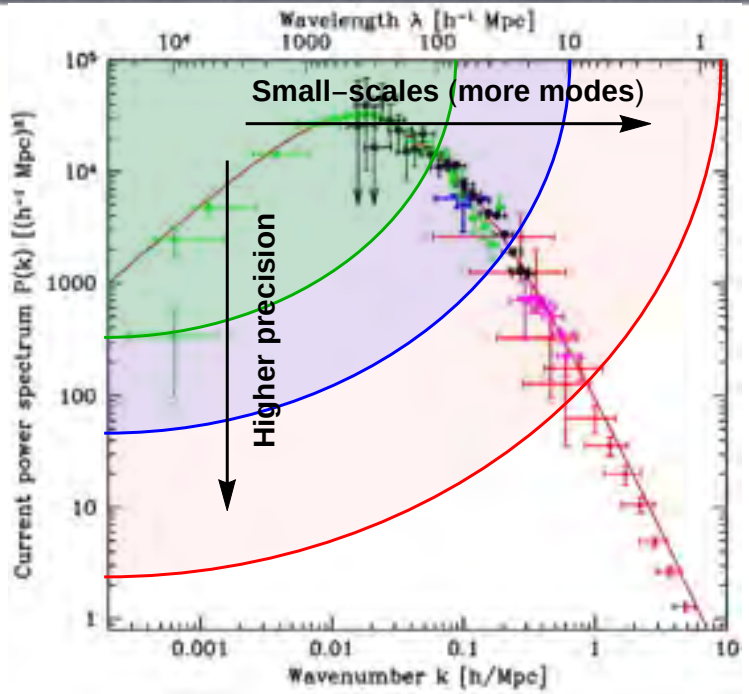
BOSS galaxy PS+ξ



	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

Conclusions

Galaxy clustering:



- provides us with a high accuracy tests of the ΛCDM paradigm and to probe new physics beyond it.
- cosmic expansion across time and dark energy equation of state
- measurement of the overall amplitude of fluctuations, correlator shapes and BAO feature
- nature of dark matter and high confidence detection of the total mass of neutrinos, while the new physics beyond searches include
- tests of the validity of GR, equivalence principle, and probe dark sector long-range interactions
- probing effective number of light relics and exotic dark matter scenarios