New tests of dark matter and inflation with BOSS using perturbation theory

Mikhail (Misha) Ivanov
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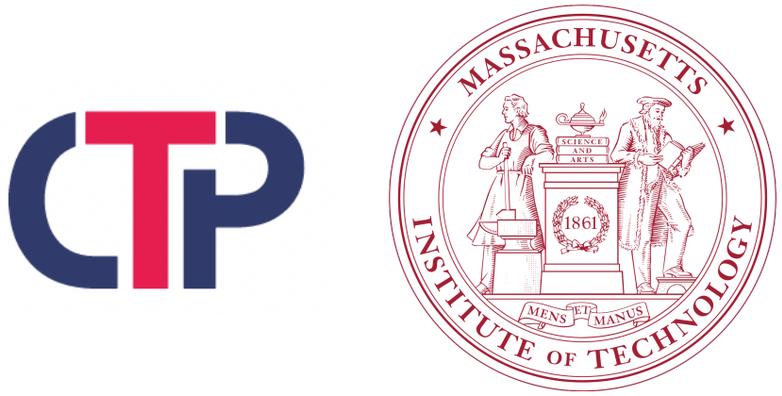
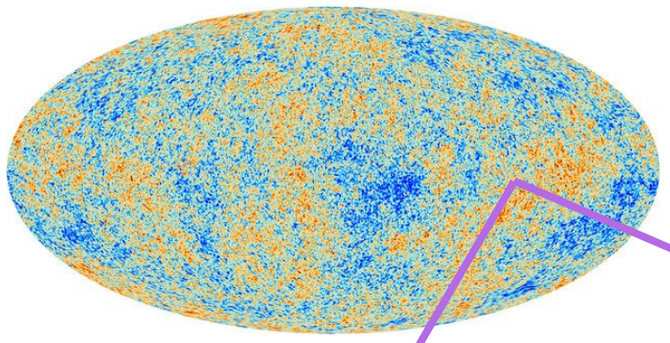


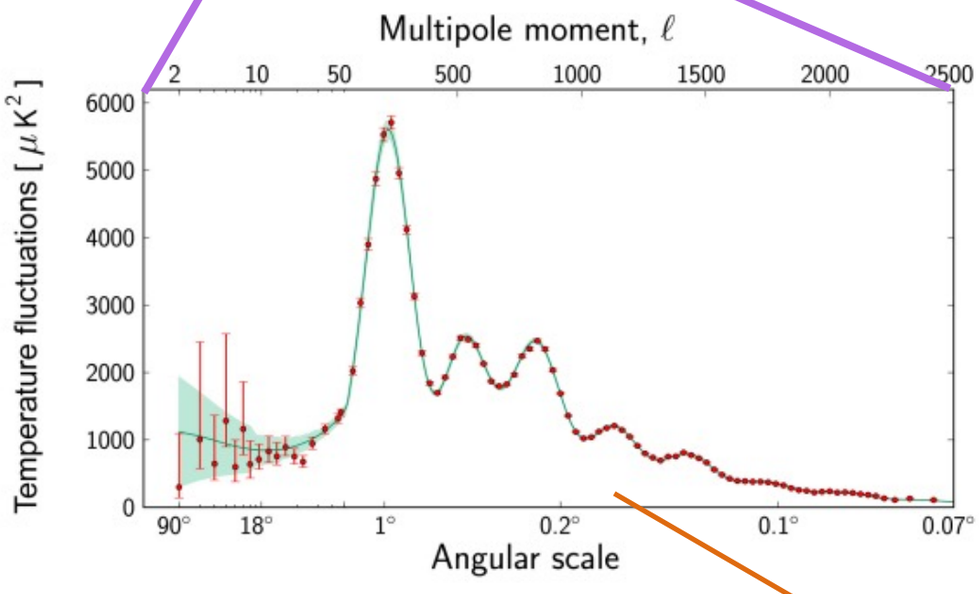
Theoretical Modeling of Large Scale Structure, 05/06/2024

EFT - based Full Shape Analysis

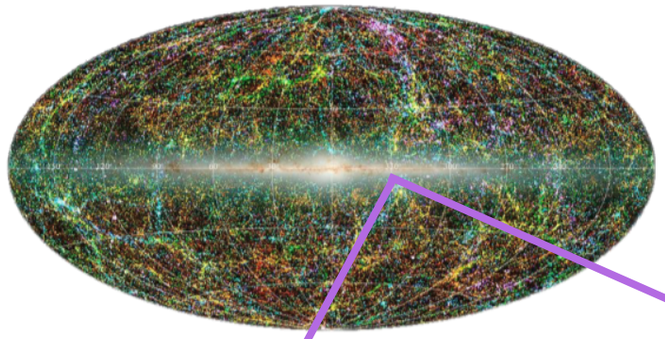
CMB:



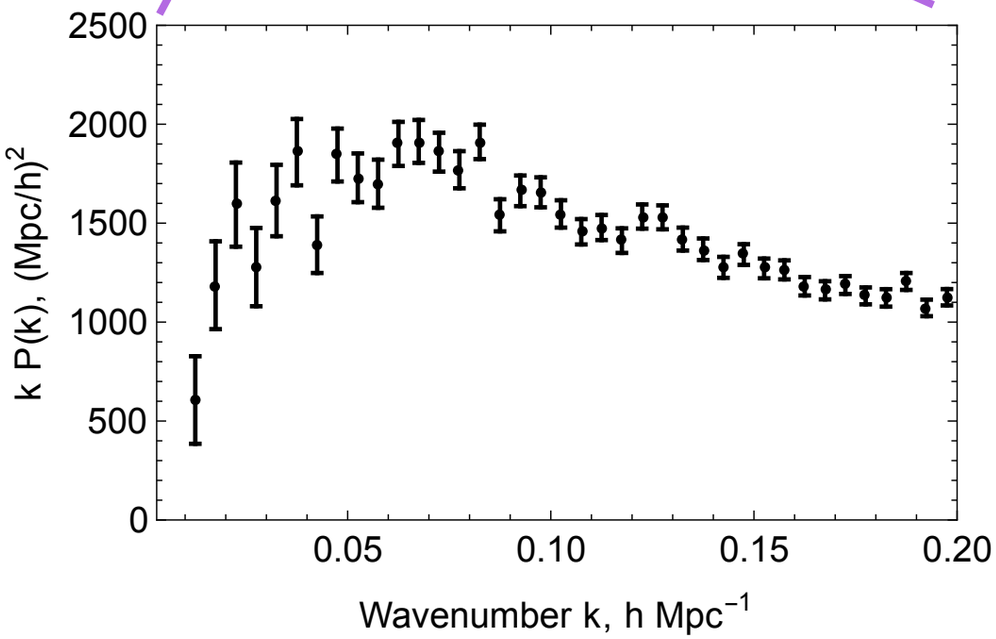
$$\frac{\delta T}{T}$$



LSS:



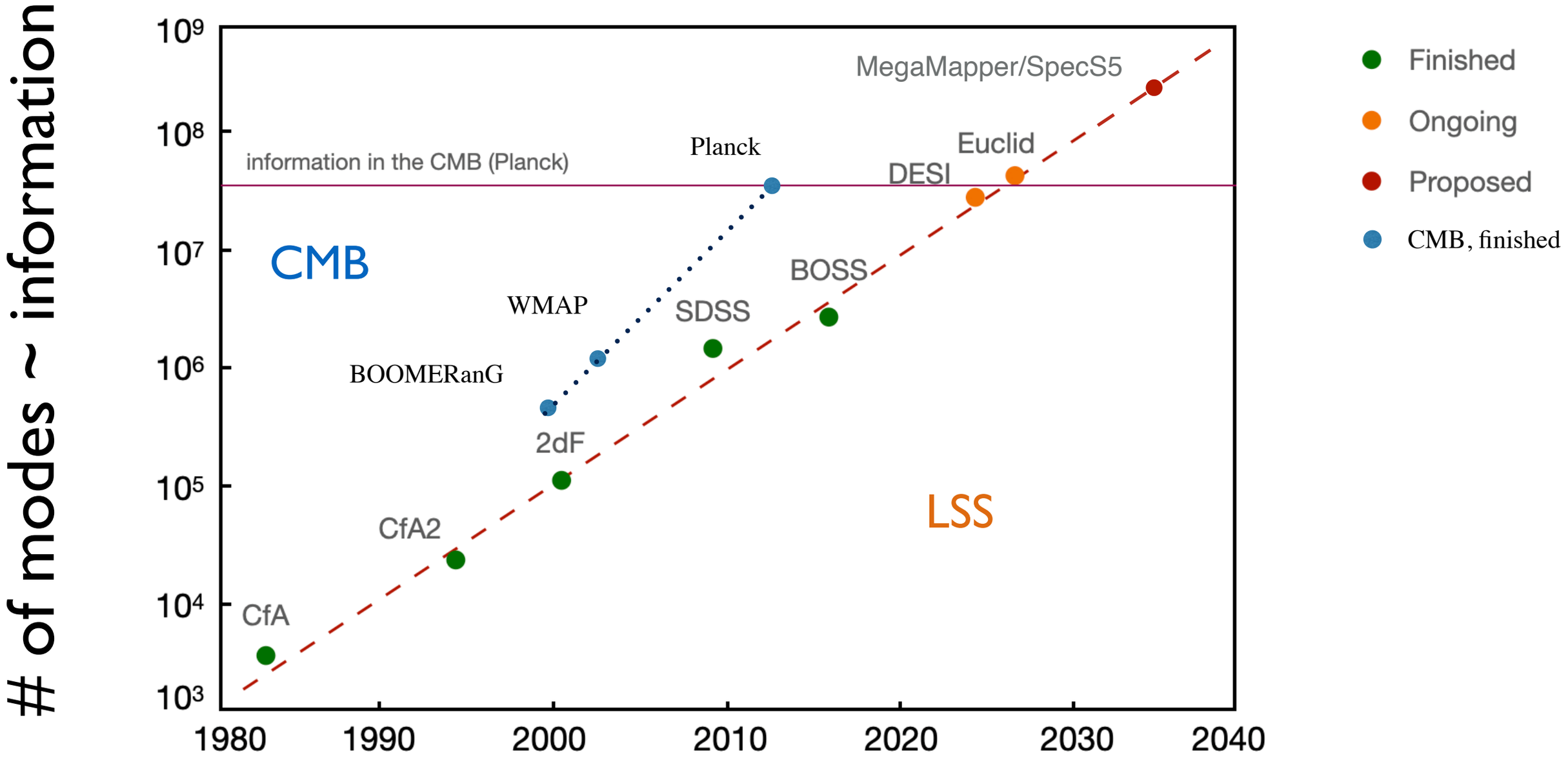
$$\frac{\delta \rho}{\rho}$$



Parameters: $\rho_{\rm dm}, \cdots$

- CMB and LSS probe different scales, different redshifts different physics !
- LSS is 3d —> contains orders of magnitude more information

Information in Galaxy Surveys

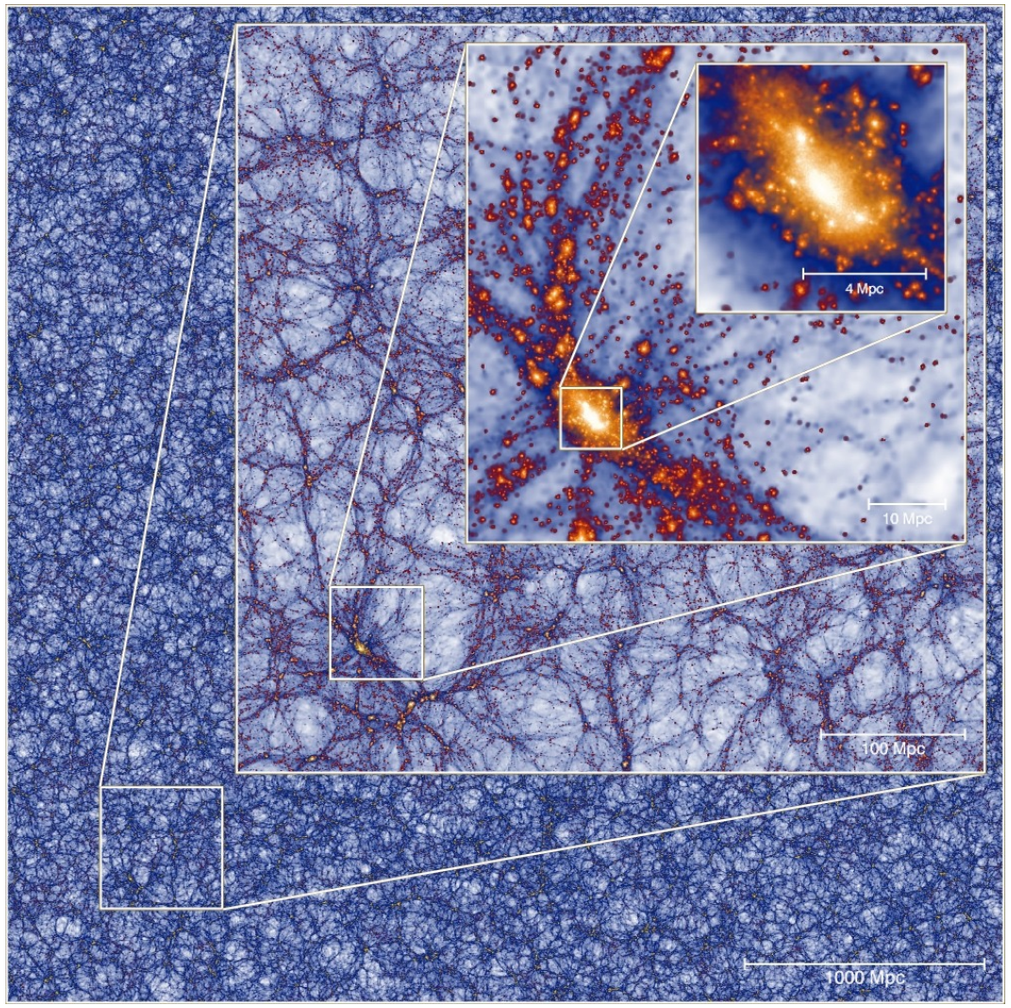


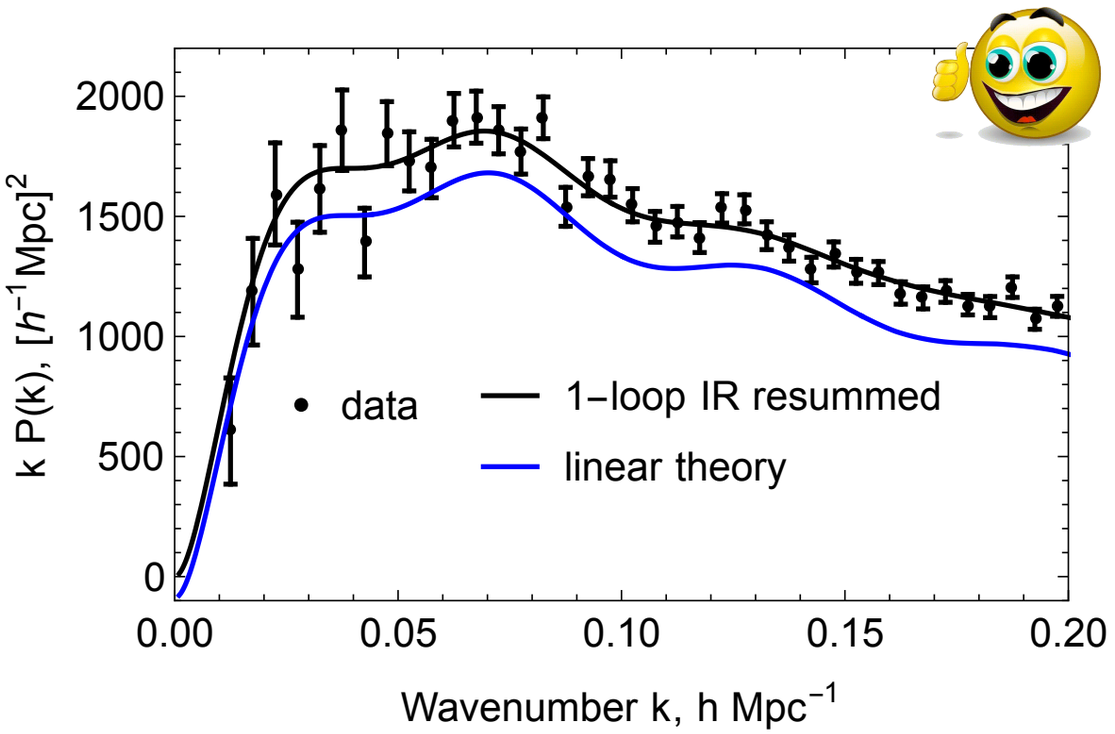
A new level of precision!

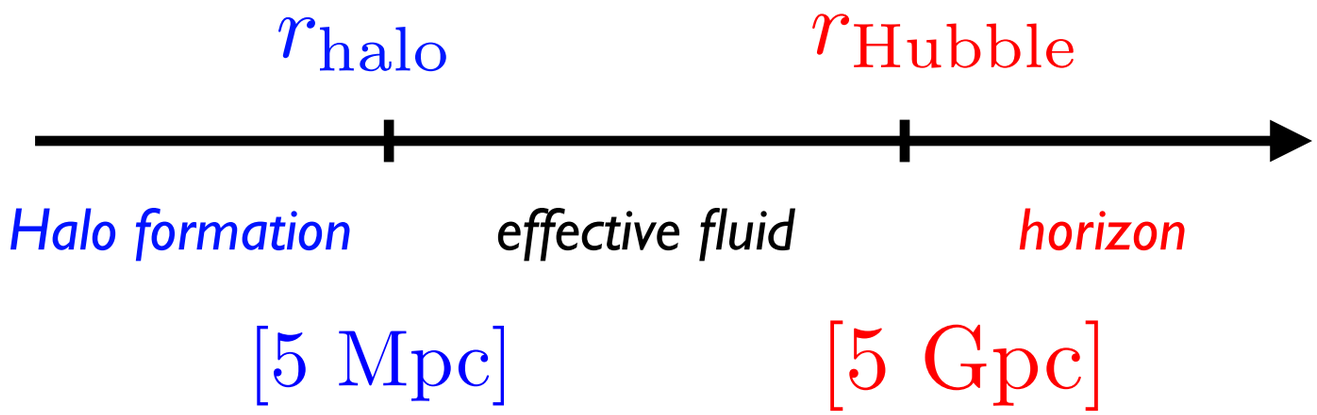
CMB: $H_0 = (67.36 \pm 0.5)\mathrm{km/s/Mpc}$ LSS: $H_0 = (67.36 \pm 0.05)\mathrm{km/s/Mpc}$

Chudaykin, MI (2019) Sailer, Castorina, Ferraro, White (2021)

PT (EFT) for LSS :







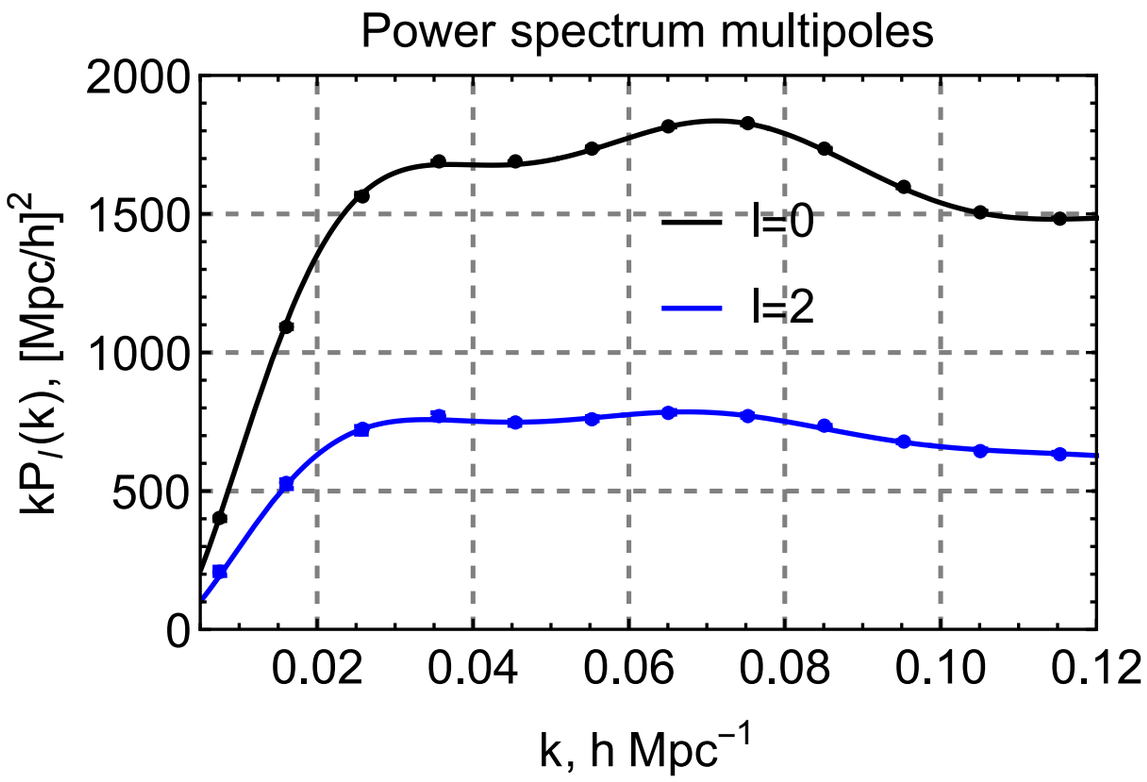
- EFT for Large Scale Structure:

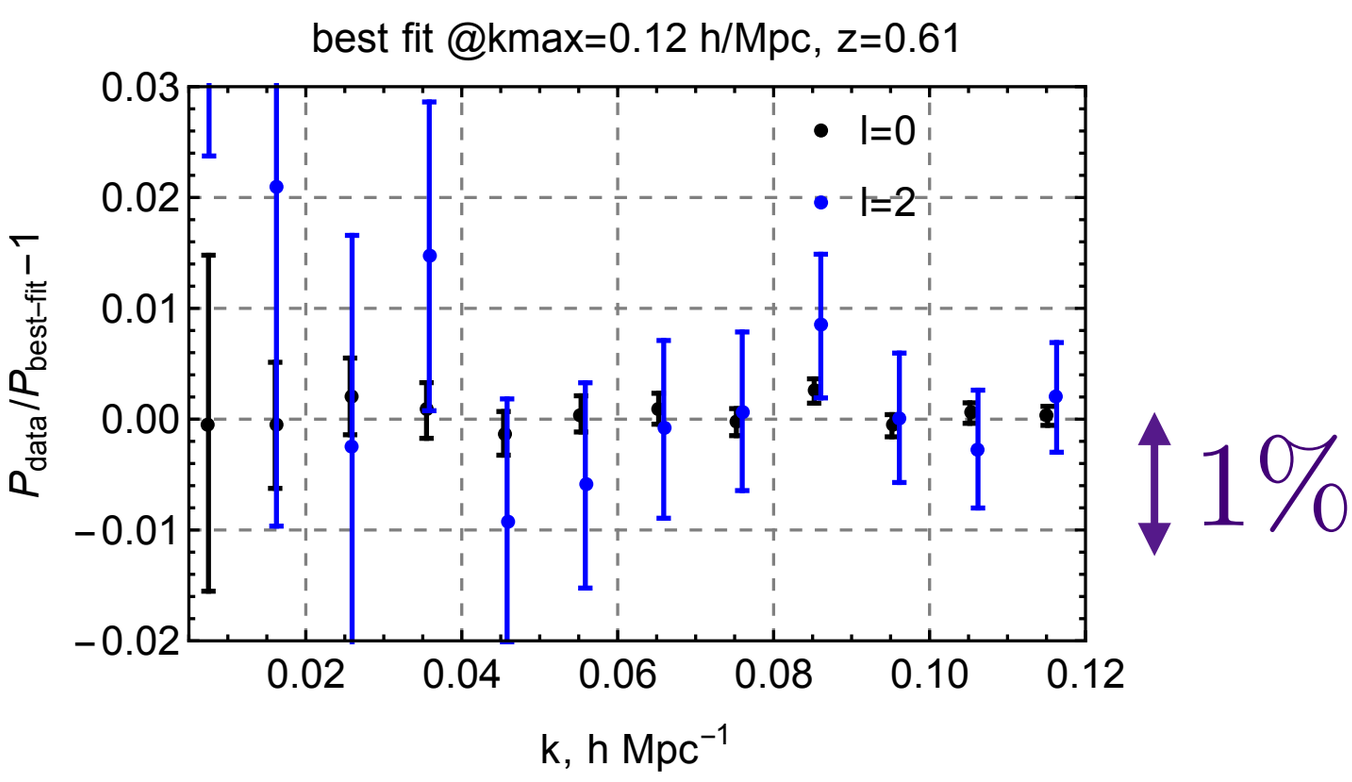
Baumann (2012), Nicolis, Carrasco, Senatore, Zaldarriaga, White, Chen, Vlah, Schmidt, Pajer, Baldauf, Hertzberg+++

Time-sliced perturbation theory (TSPT)

Blas, Garny, MI, Sibiryakov (2015)

Checks of EFT: data challenges





Nishimichi, Takada, MI, Simonovic, Zaldarriaga, D'Amico, Senatore, Zhang (2020)

White, Chen, Vlah, Castorina (2021)

Beyond - 2pt Challenge

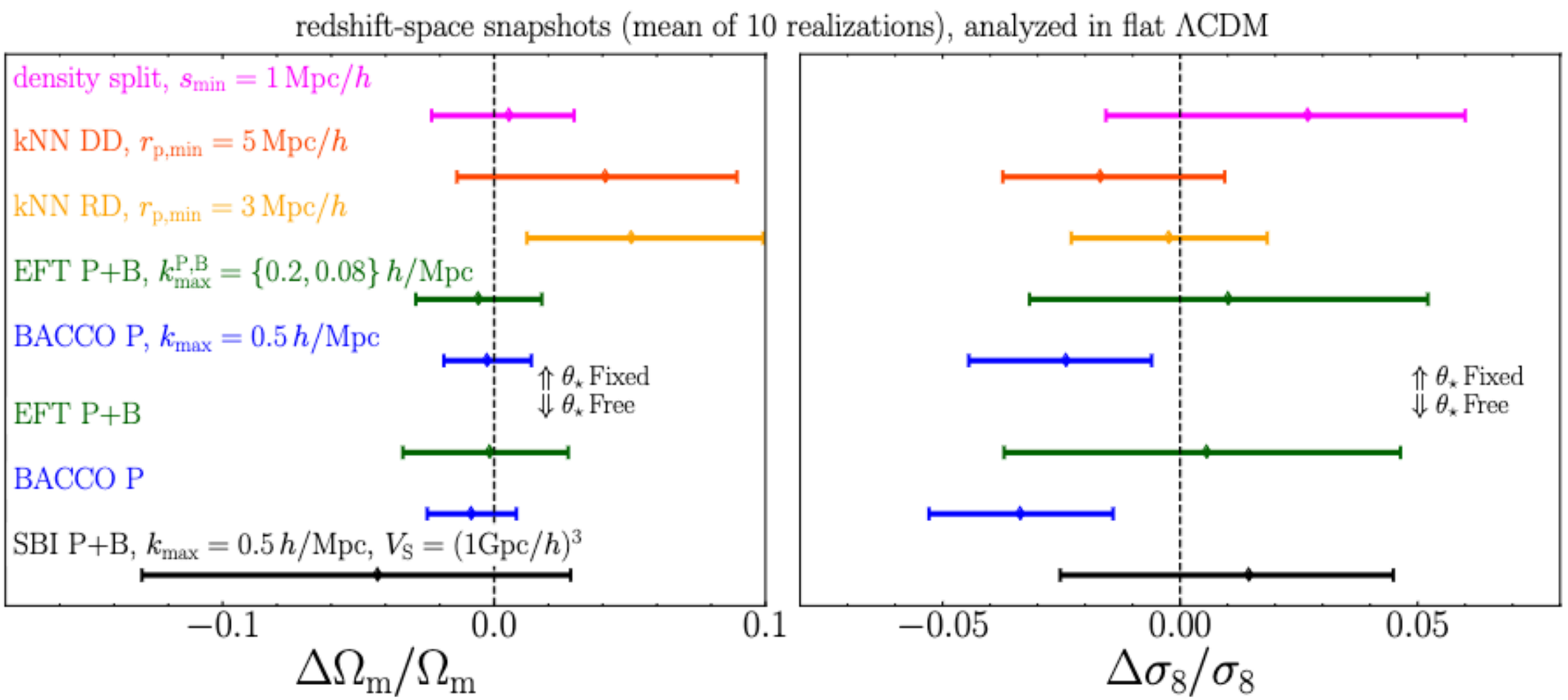


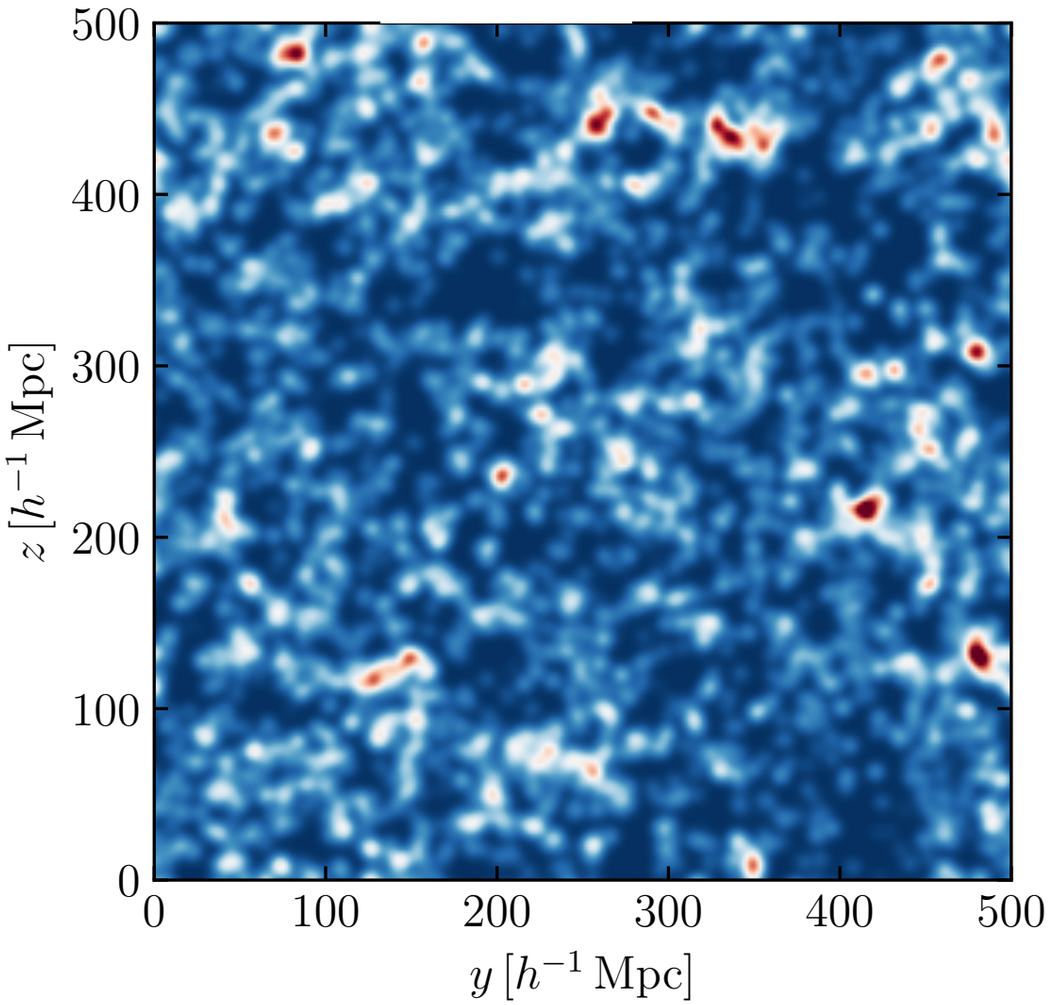
Figure 2. 1D marginalized constraints on $\Omega_{\rm m}$ and σ_8 for parameter-masked analyses of redshift-space mocks (mean of 10 realizations, errors of 1 box), marginalized over the remaining cosmological parameters of flat ΛCDM and nuisance parameters specific to each method.

E. Krause, MI, Philcox, Akitsu, Pallejero ++'24

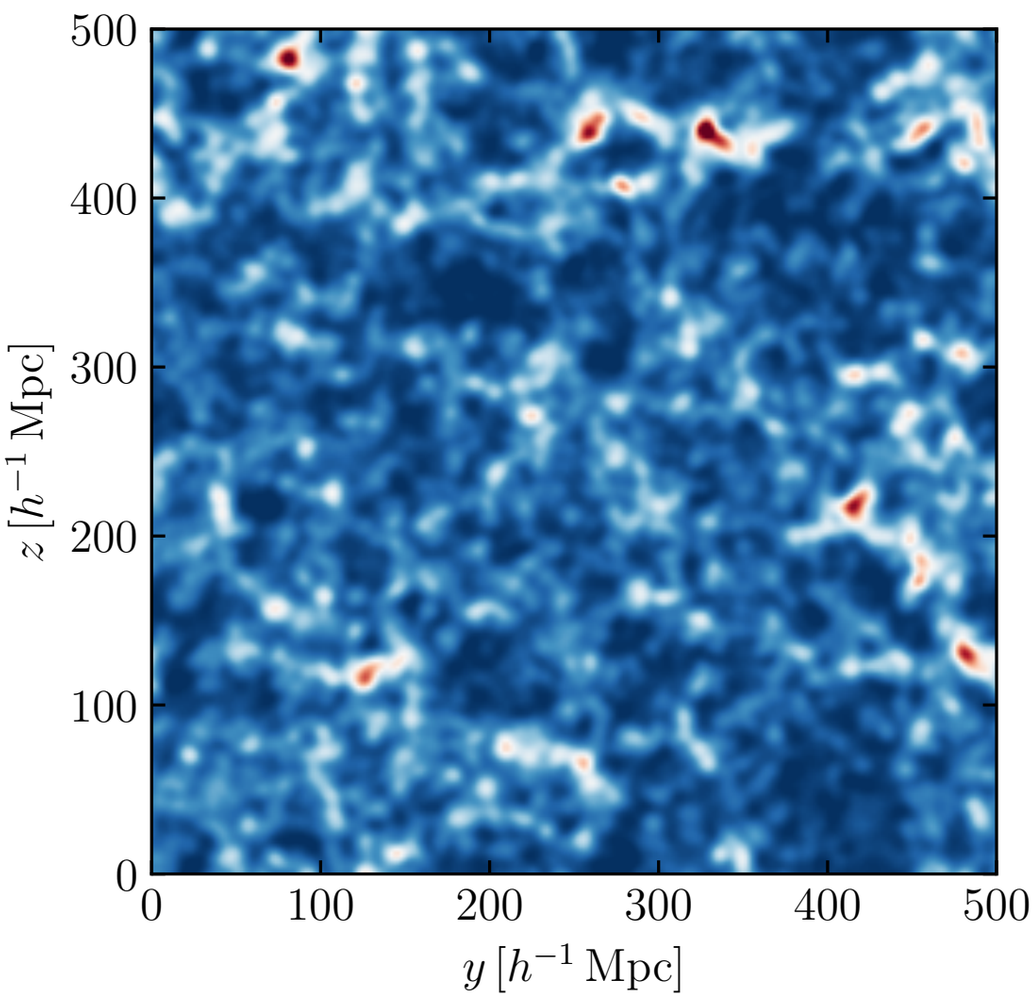
- Consider participating if you haven't yet!

Field-level comparison

Simulation



EFT



- Success of the EFT is not due to fitting parameters

MI, Cuesta-Lazaro, Mishra-Sharma, Obuljen, Toomey'24

Schmittfull, Simonovic, MI, Philcox, Zaldarriaga'20

Schmittfull++'18, Nguen, Schmidt ++
Modi, White +++

CLASS-PT: a universal EFT calculator

Chudaykin, MI, Philcox Simonovic (2020)

Many codes in the market: *Velocileptors, Spinosaurus, CLASS-PT, PBJ, PiBird, CLASS-1loop, FAST-PM, etc.*

real space: Pmm, Pgm, Pgg

redshift space: P0,P2,P4,++

RSD Bispectrum: tree +1loop

PNG fNL loops

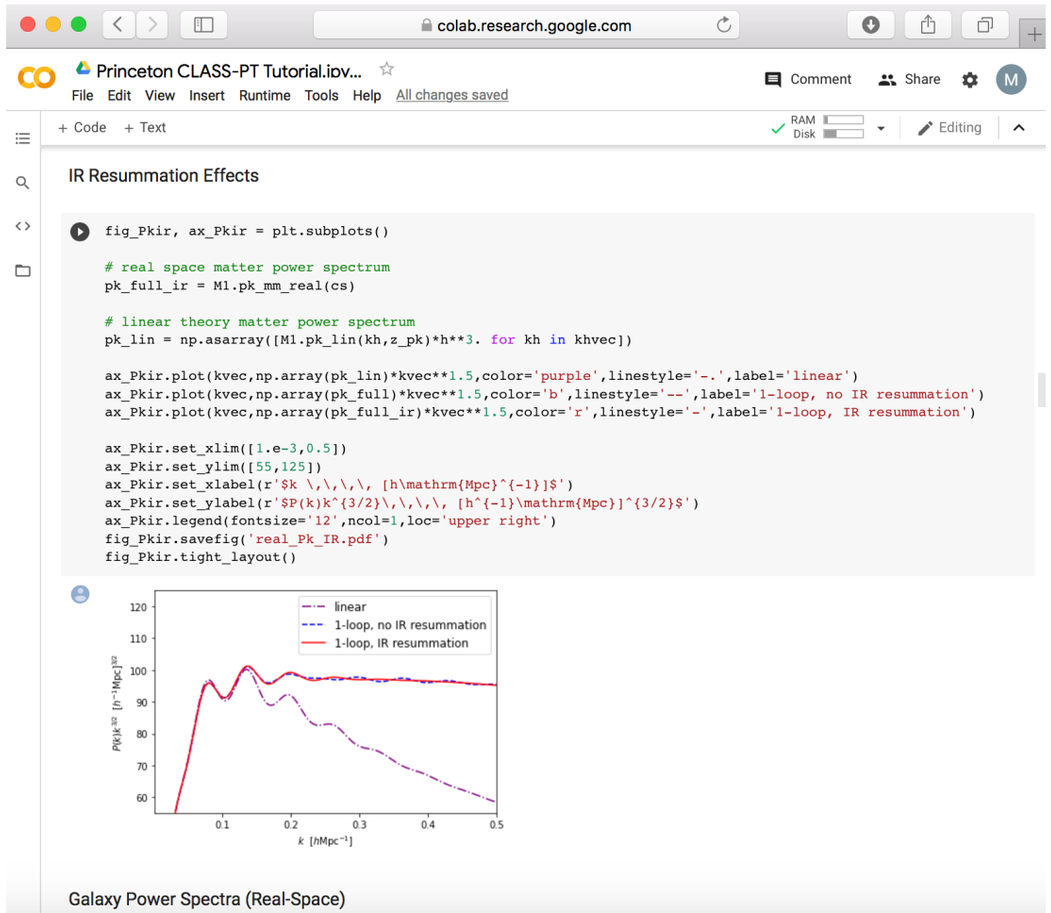
Coming up soon:

LOS-dependent operators

Field level transfer functions

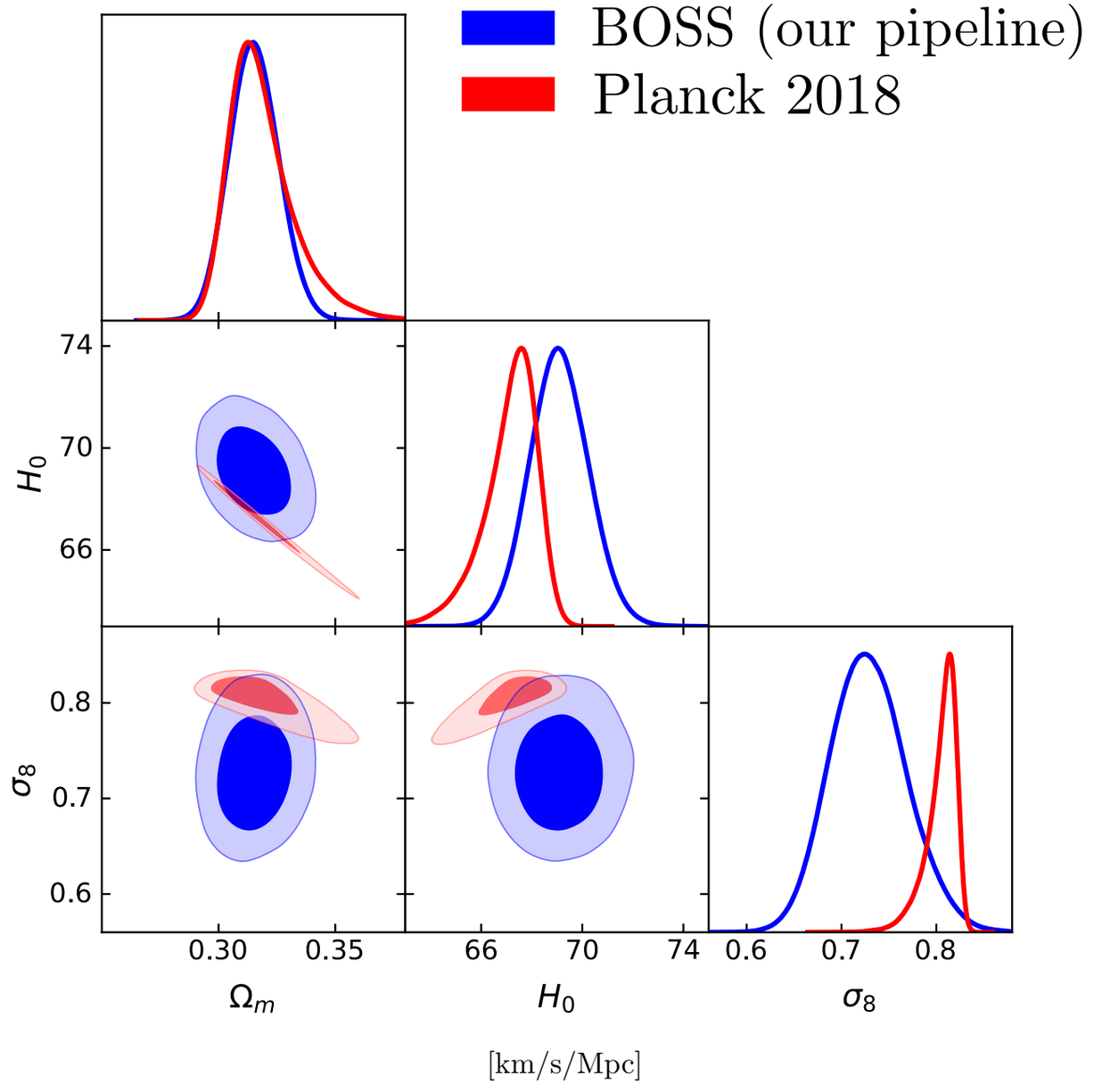
all in <1second!

https://github.com/Michalychforever/CLASS-PT



Happy coding!

Re-analysis of public BOSS 3x2pt + 3x3 pt data



MI, Simonovic, Zaldarriaga (2019), Philcox, MI (2021) ++
D'Amico, Kokron++(2019), Chen, White, Vlah (2021)

Re-analysis of public BOSS 7x2pt + 3x3 pt data

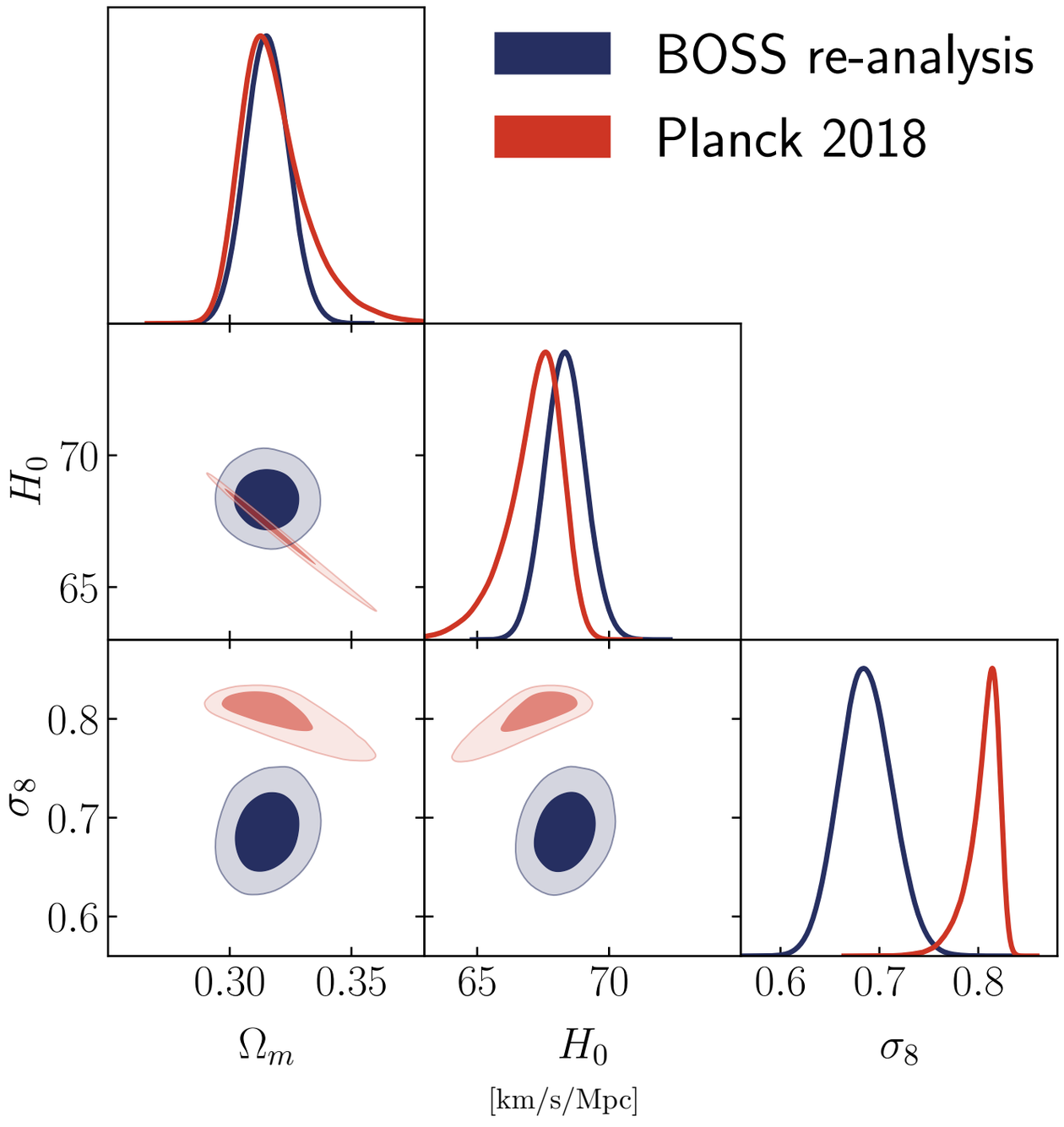
$$\{P_\ell, Q_0, B_\ell, \mathrm{BAO}, C_\ell^{\kappa g}\}$$

Parameter	68% limits
Ω_m	0.3154 ± 0.0087
H_0	68.34 ± 0.77
σ_8	0.687 ± 0.027
S_8	0.704 ± 0.031

strongest PT-based constraints!

Tension w Planck is growing!

$\approx 4\sigma$!



MI, Simonovic, Zaldarriaga (2019), Philcox, MI (2021) ++
MI, Philcox ++ (2023)
D'Amico, Kokron++(2019), Chen, White, Vlah (2021)

Chen, MI, Philcox, Wenzl, to appear!

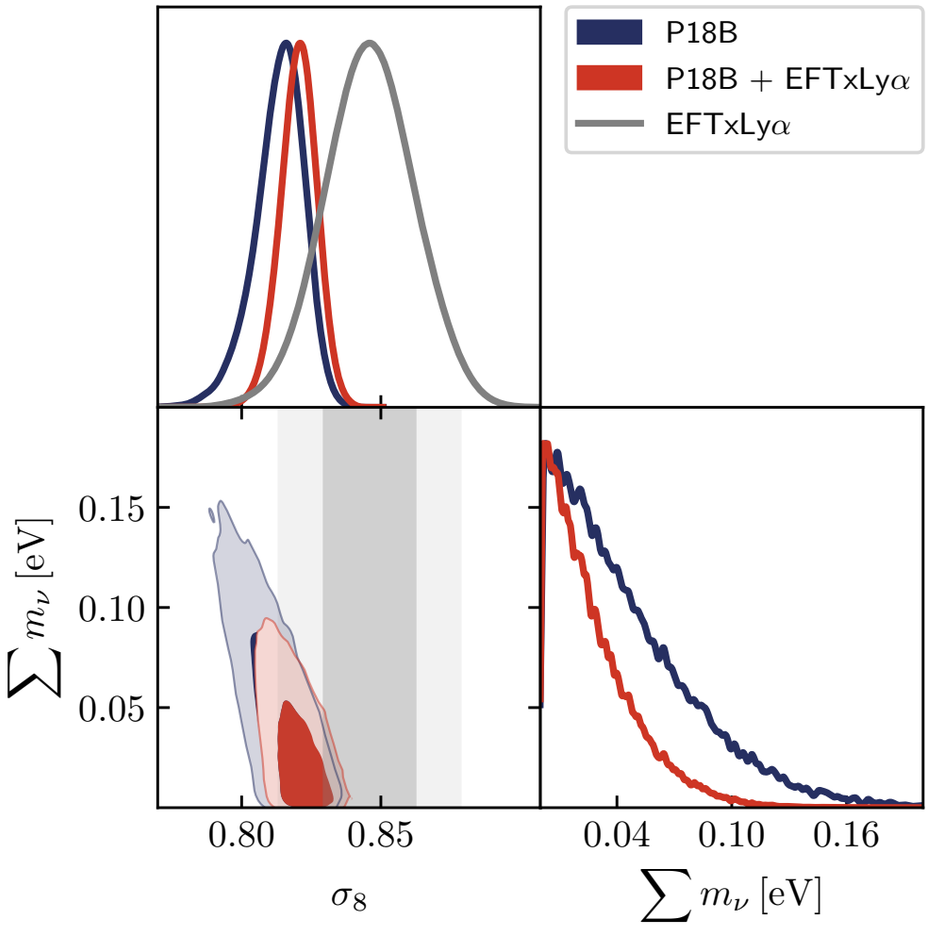
EFT for Lyman alpha

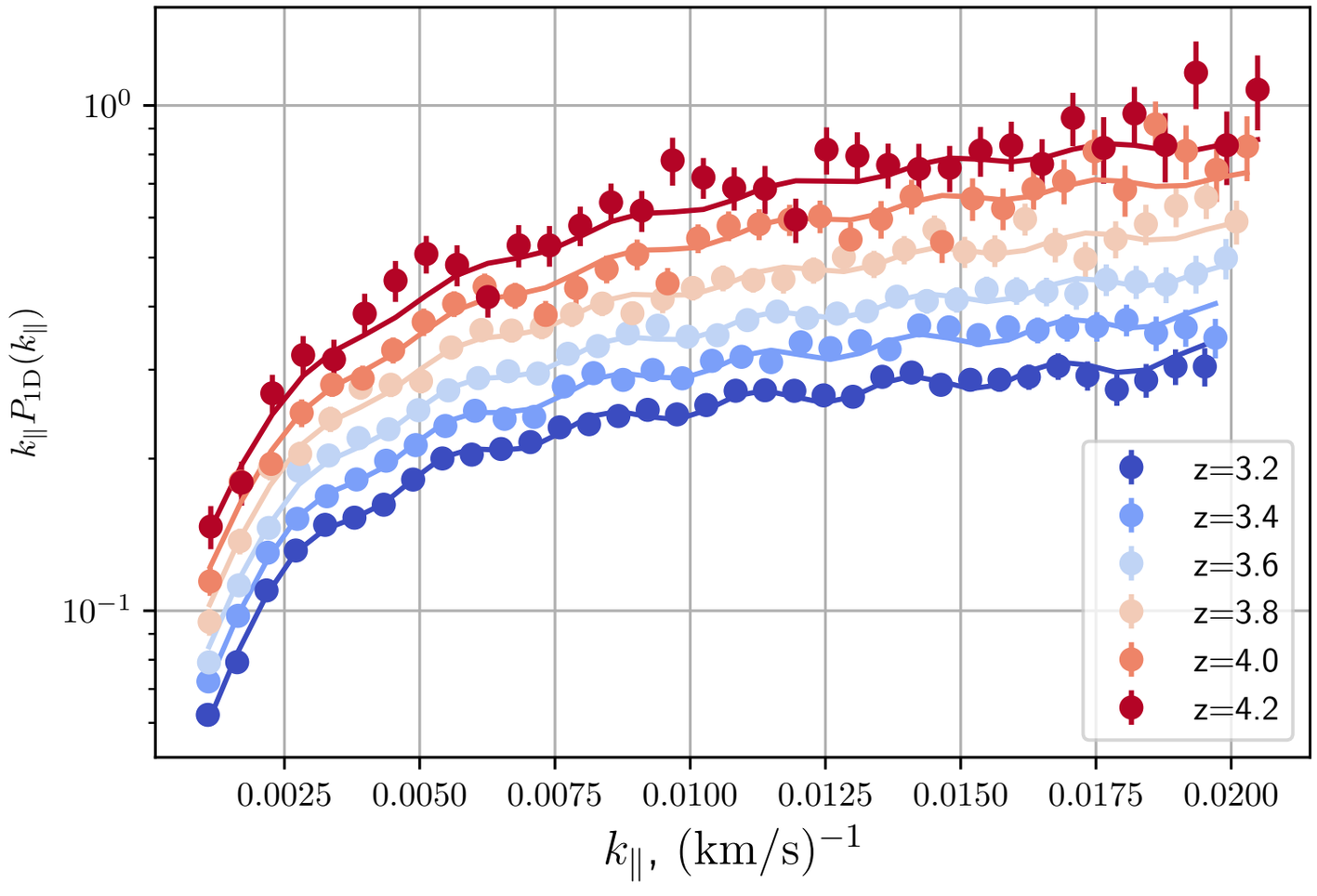
- Symmetries: LOS rotations (SO(2)), equivalence principle

$$\frac{F-\bar{F}}{\bar{F}} \equiv \delta_F = b_1\delta + b_\eta \hat{z}^i\hat{z}^j\partial_i\partial_j\Phi = b_1\delta + b_\eta\eta \quad + \ldots$$

Desjasques, Jeong, Schmidt (2018), Ivanov (2023)

- SDSS DR14 re-analysis:



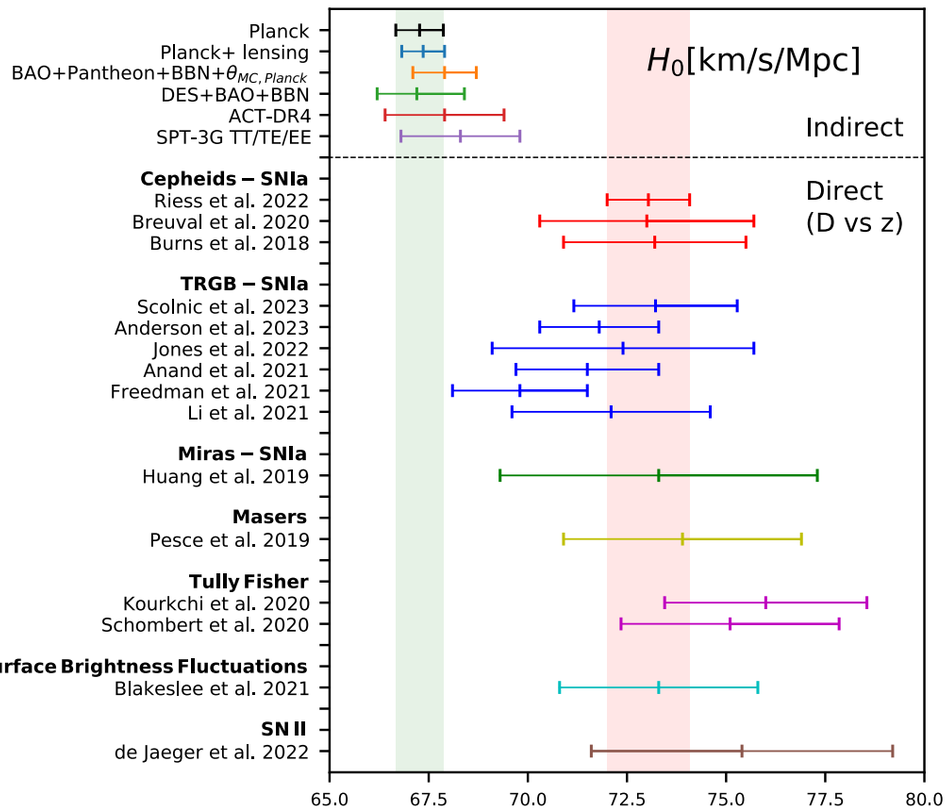


$$\sigma_8 = 0.841 \pm 0.017 \qquad \sum m_\nu < 0.08 \text{ eV}$$

MI, Toomey, Karacayli (2024)

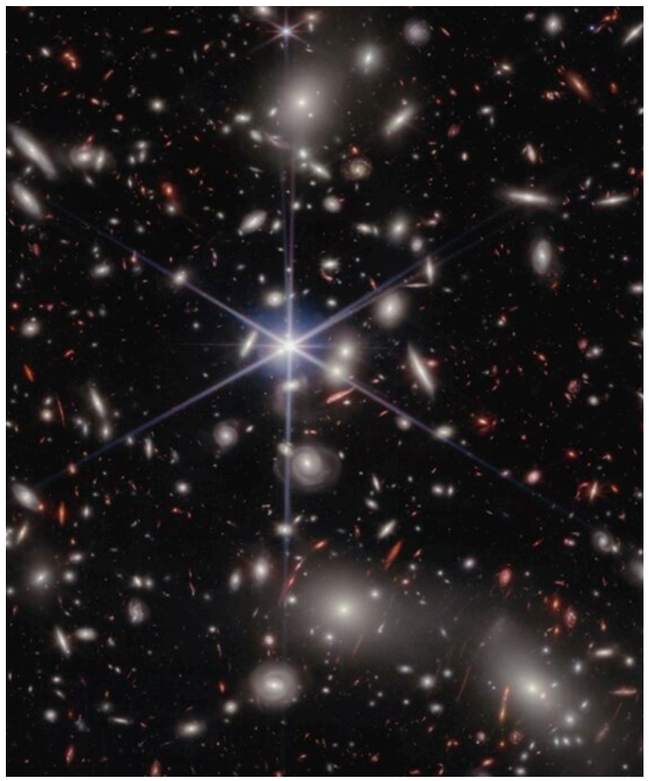
Beyond Standard Model Extensions

Exotic Energies



w/ Chudaykin, Dolgikh, Toomey, Hill, McDonough, An, He, Gluscevic

Dark Matter

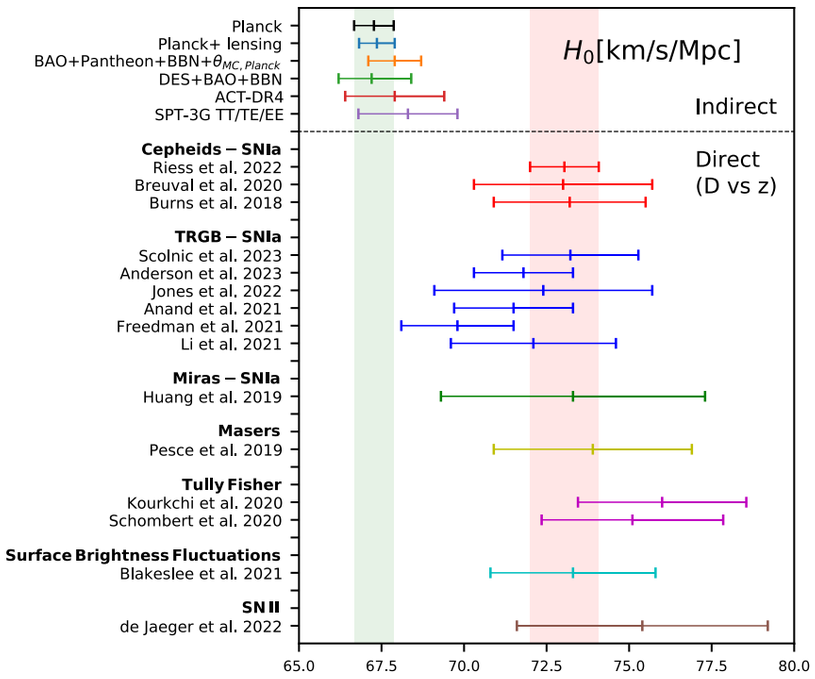


w/ Rogers, Lague, He, An, Gluscevic

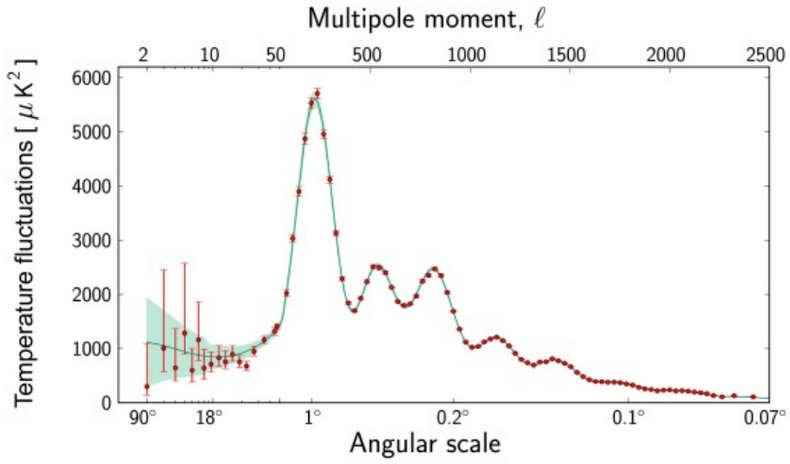
Inflation

w/ Philcox, Cabass Akitsu, Zaldariagga

Exotic Energy Before Recombination

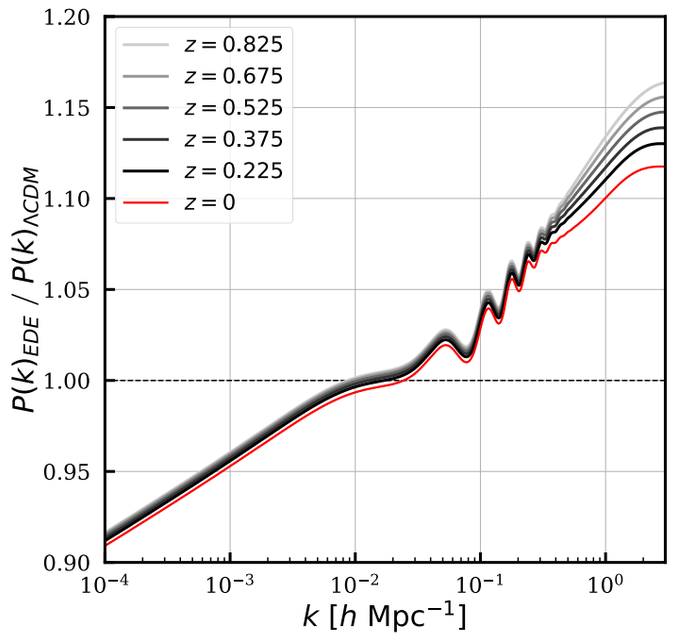


- Energy injections can address Hubble tension
- EFTxFS: new channel to break CMB degeneracies



Early DE

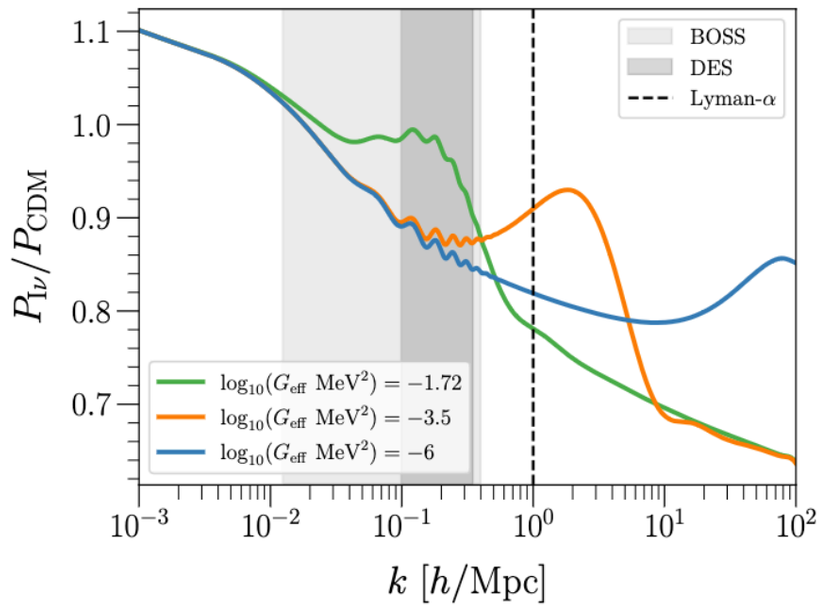
Karwal, Kamionkowski (2016) ++



MI, McDonough, Hill, Toomey, ++ (2020)

Self-interacting Neutrinos

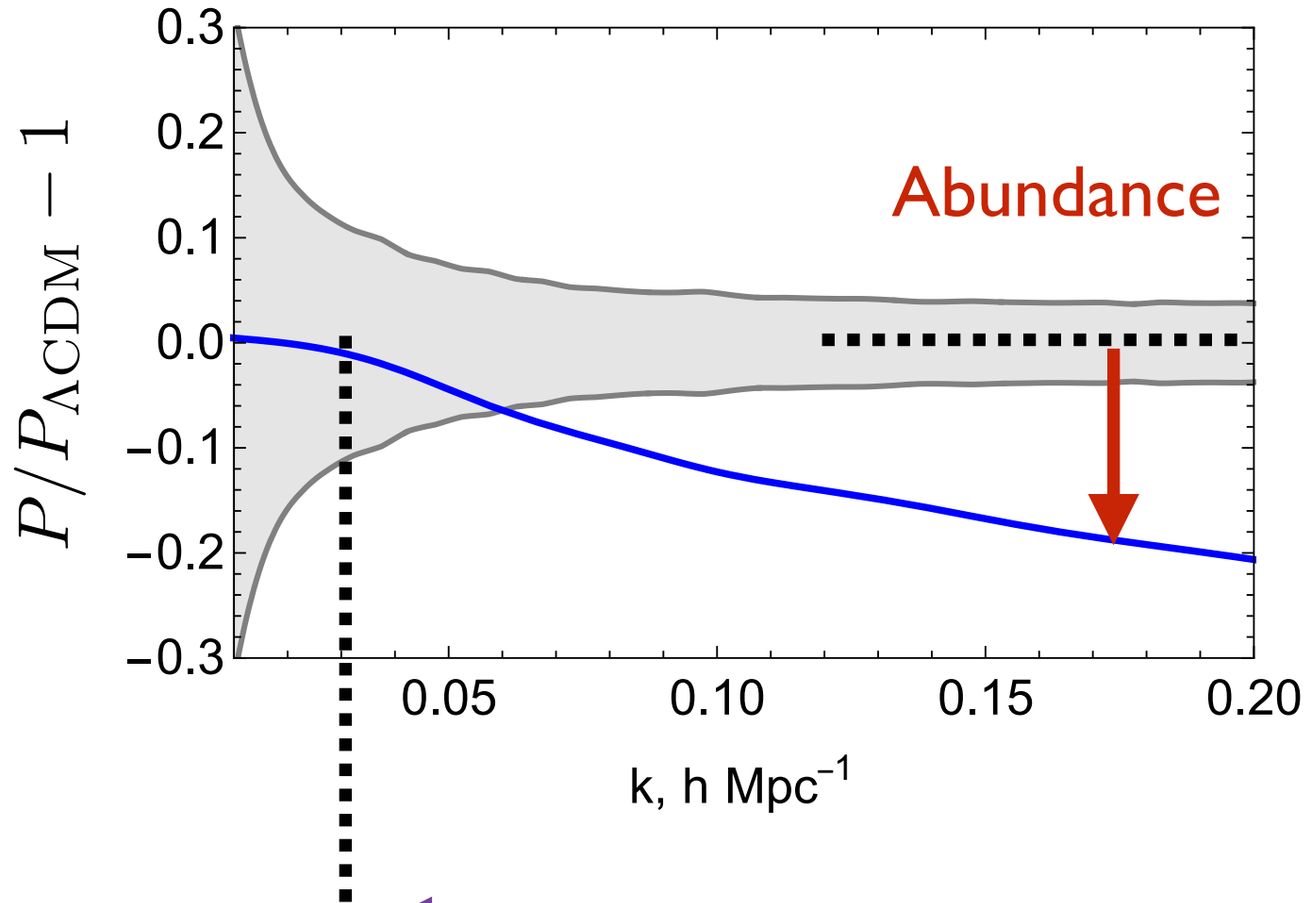
Cyr-Racine++ (2014) Kriesch++ (2020)



He, Rui, MI, Gluscevic (2023)

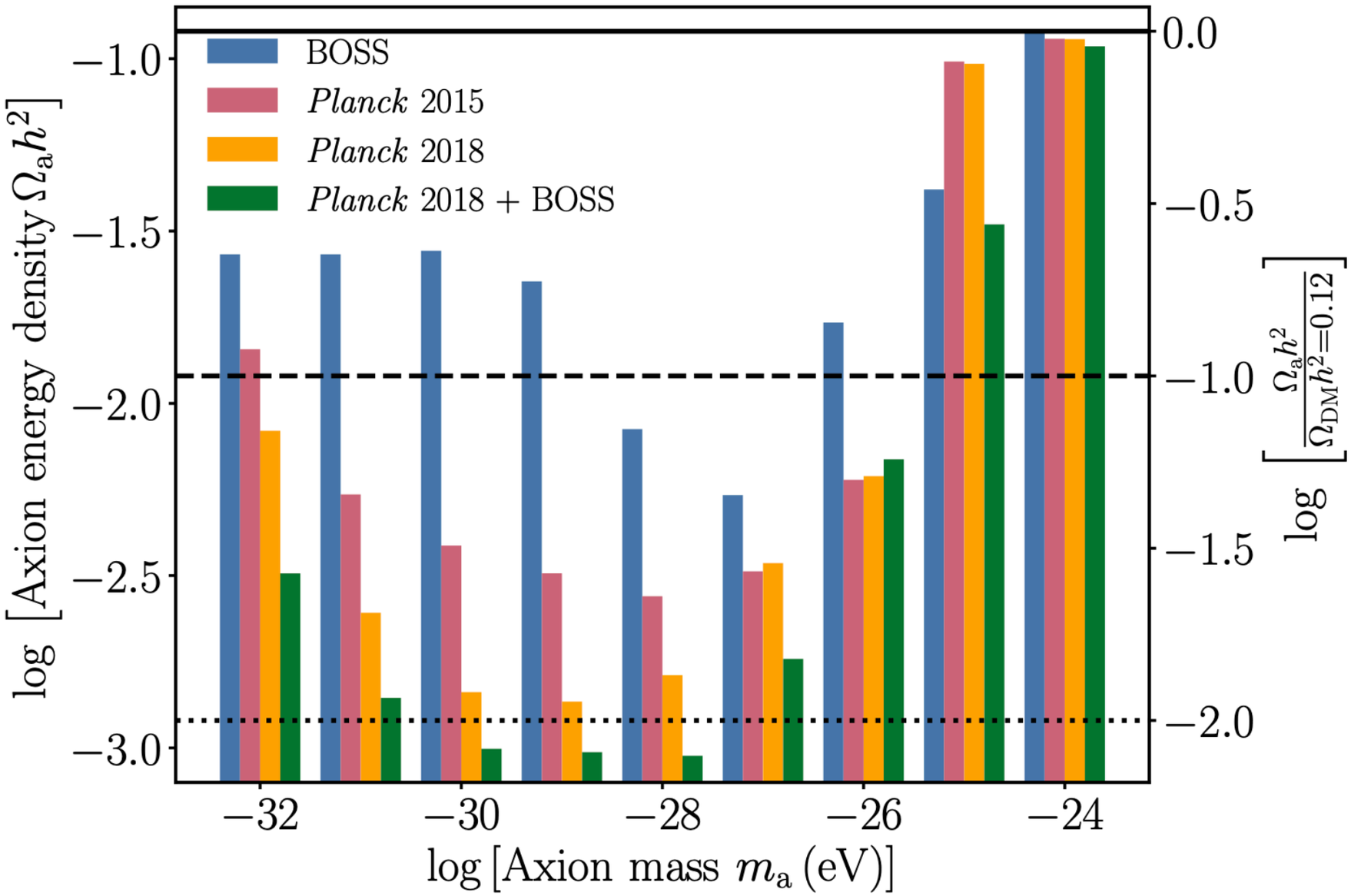
High Precision Dark Matter Probe

- Galaxy PS is a direct probe of dark matter fluctuations
- Imagine two DM components, one is <u>not</u> exactly cold
- ~ there's a Jeans scale beyond which it won't cluster!



Laguë++'21,
Rogers, Laguë, MI++'23

Axion Dark Matter constraints



Rogers, Laguë, MI, Akitsu, Cabass, Philcox ++ (2023)

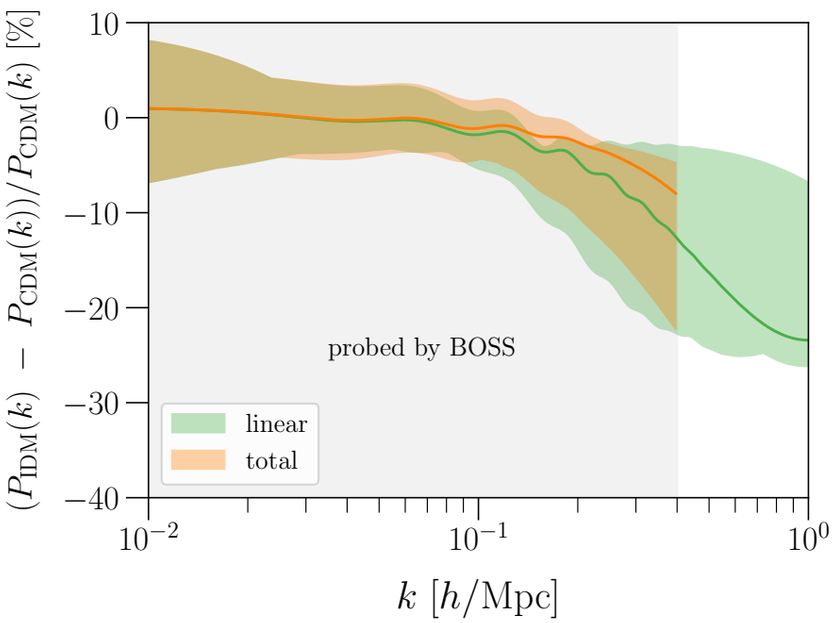
DM - baryon interactions

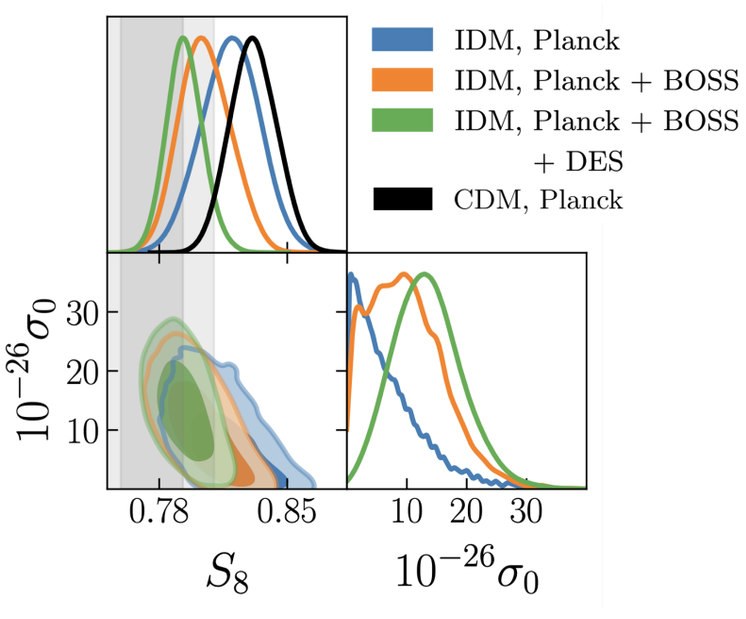
- motivated by direct detections

Dvorkin, Blum, Kamionkowski ++ (2014)
Gluscevic, Boddy (2018)
Slatyer, Wu (2018)

$\sim 10\%$ **of DM ~** $m_\chi \sim 1$ MeV **interacts w/ baryons**

$$\sigma_0 = 1.34^{+0.51}_{-0.67} \times 10^{-25}\ \mathrm{cm}^2$$





AAS NOVA Research highlights from the journals of the American Astronomical Society

HOME HIGHLIGHTS JOURNALS DIGEST

Could Interacting Dark Matter Solve a Problem with Our Models of the Universe?

Adam He, MI, Rui, Gluscevic (2023)

Constraints on Single-Field Inflation with LSS

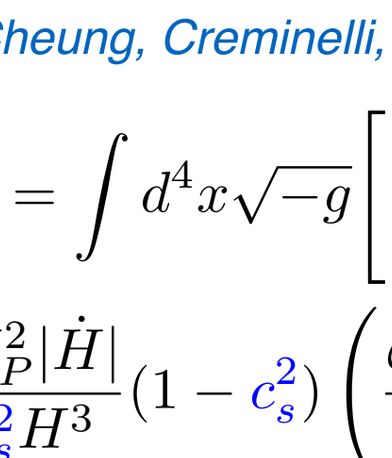
Effective Lagrangian

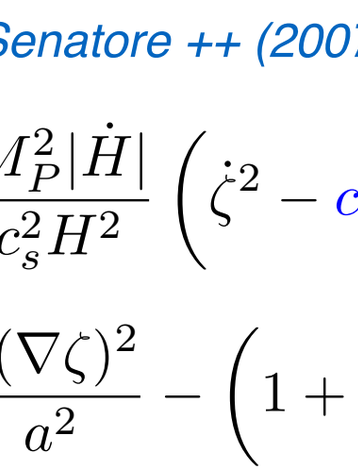
Cheung, Creminelli, Senatore ++ (2007)

$$S_{\rm EFT} = \int d^4x\sqrt{-g}\left[\frac{M_P^2|\dot H|}{c_s^2H^2}\left(\dot\zeta^2 - c_s^2\frac{(\nabla\zeta)^2}{a^2}\right)\right.$$
$$\left. + \frac{M_P^2|\dot H|}{c_s^2H^3}(1-c_s^2)\left(\frac{\dot\zeta(\nabla\zeta)^2}{a^2} - \left(1+\frac{2}{3}\frac{\tilde c_3}{c_s^2}\right)\dot\zeta^3\right)\right]$$

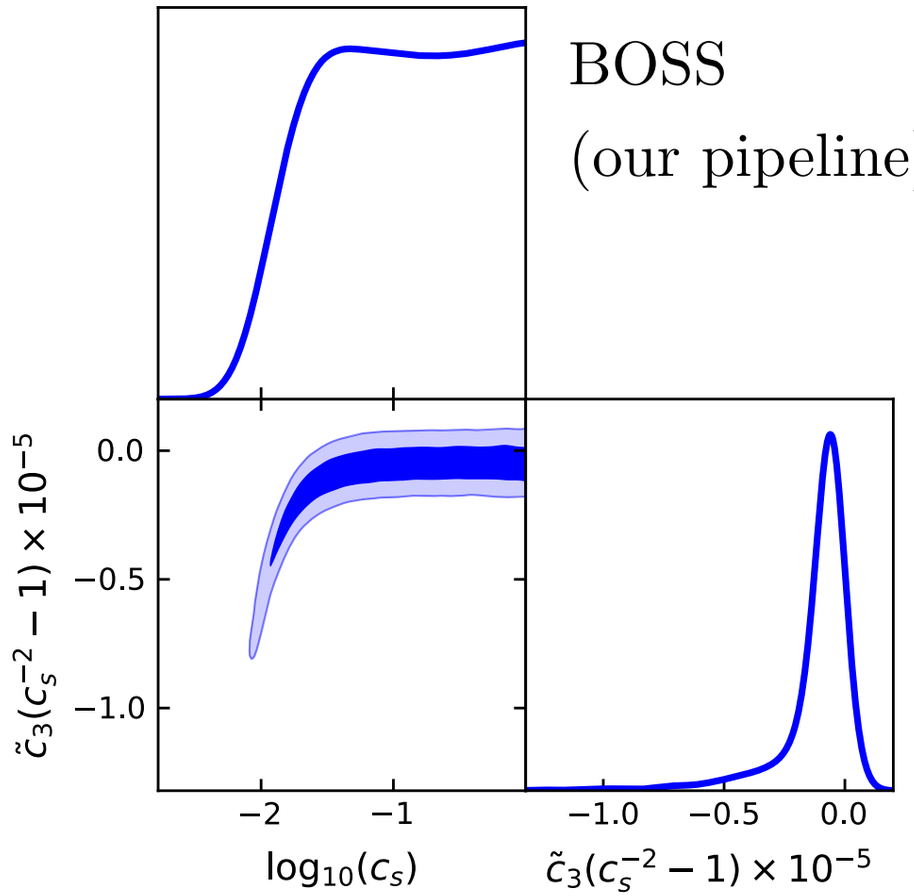
Interactions, speed of propagation, + #of fields

- $c_s \geq 0.013$ at 95% CL





Cabass, MI, Philcox ++(2022a, 2022b)



BOSS limits:

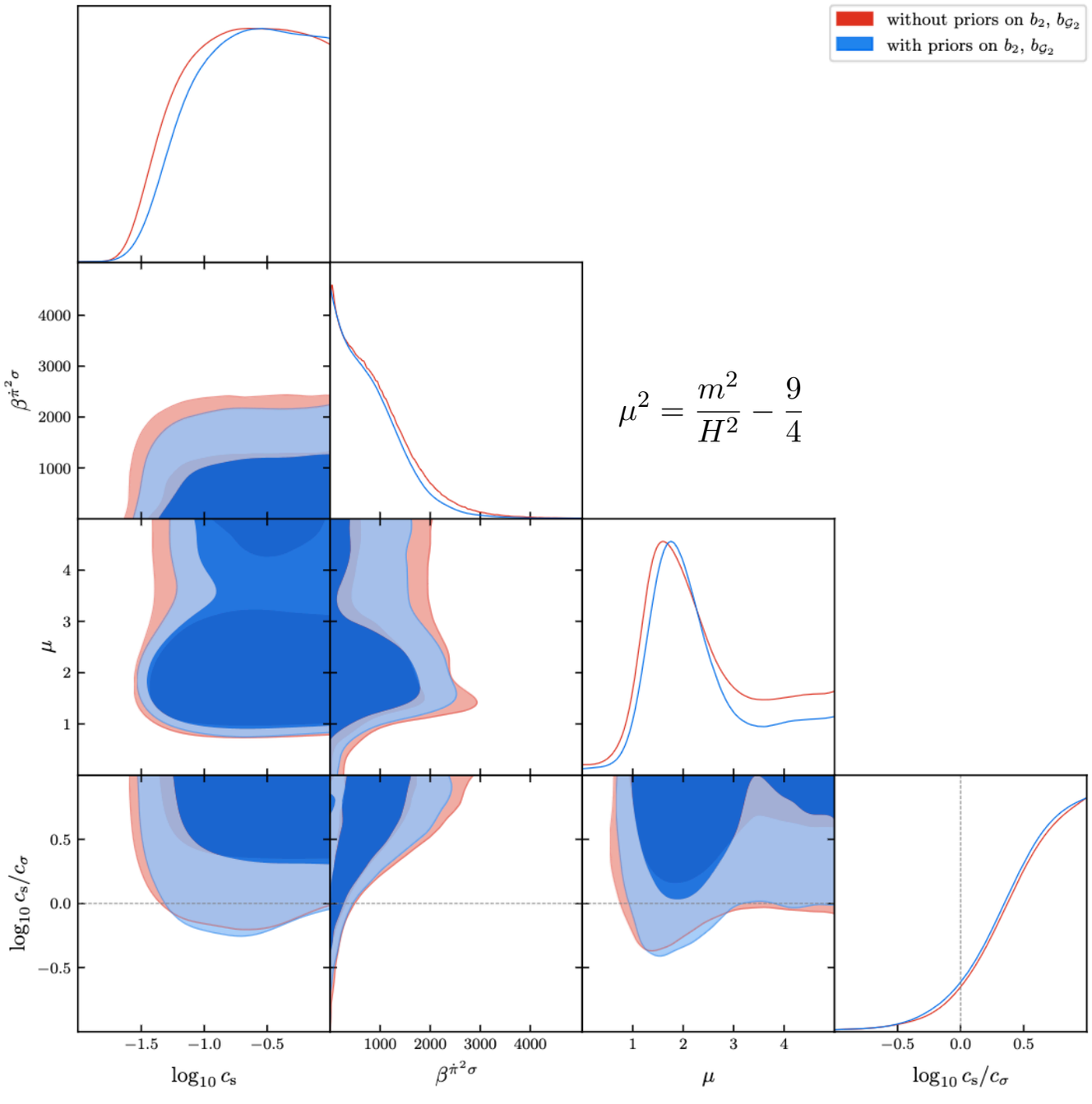
$$f_{\rm NL}^{\rm equil} = 260 \pm 300$$
$$f_{\rm NL}^{\rm ortho} = -23 \pm 120$$
$$f_{\rm NL}^{\rm local} = -33 \pm 28$$

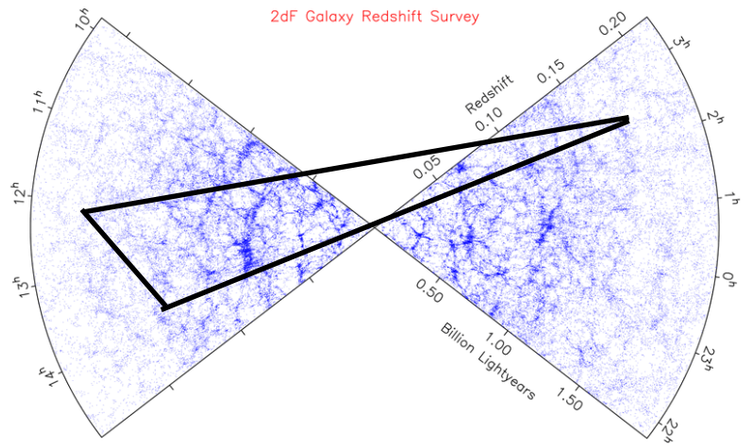
see also Castorina, D'Amico, +++

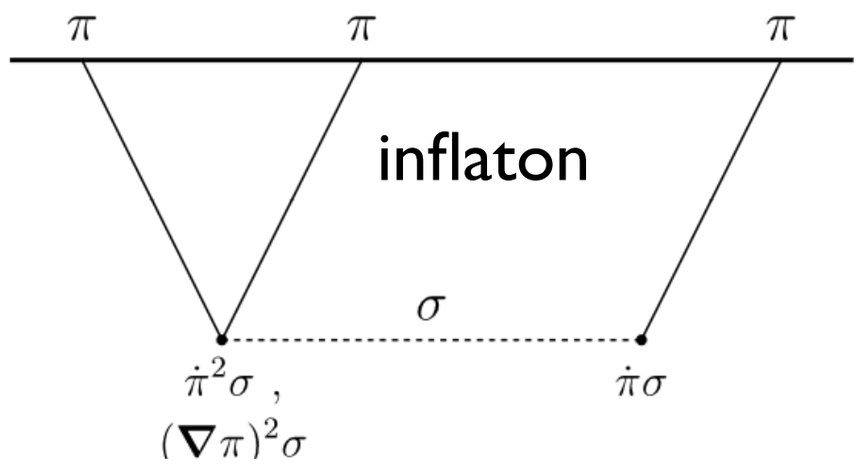
More detail in Oliver's talk next!

Cosmological Collider in Action

- Decay of massive particles during inflation
- First constraints (using BOSS)







massive scalar

Chan, Wang (2009)

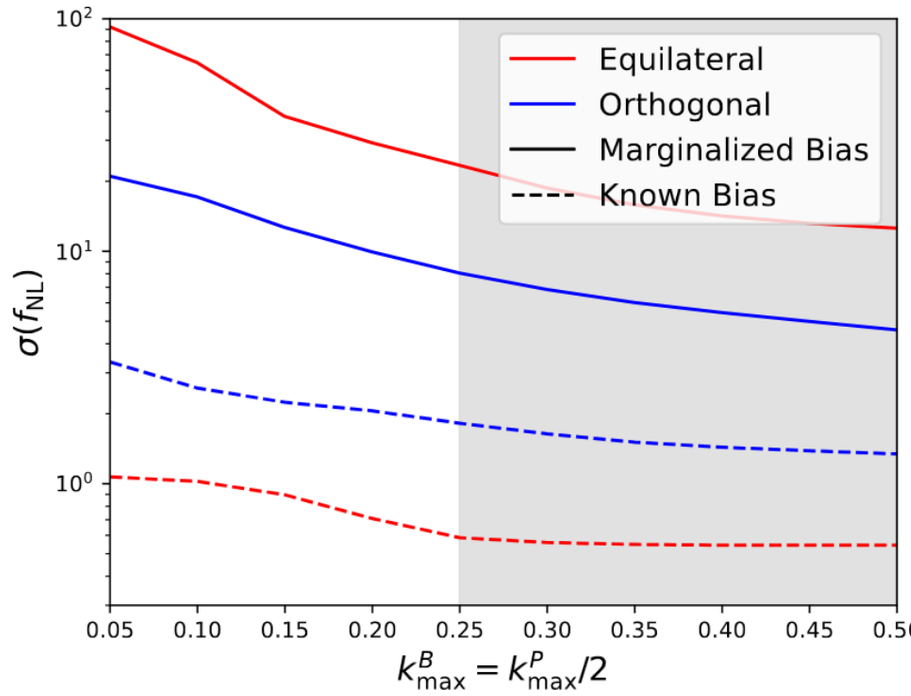
Arkani-Hamed, Maldacena (2015)

Cabass, Philcox, MI, Akitsu+(2024)

More detail in Oliver's talk next!

Improving EFT with Simulation - based priors

- Marginalization over nuisance parameters is the main show stopper

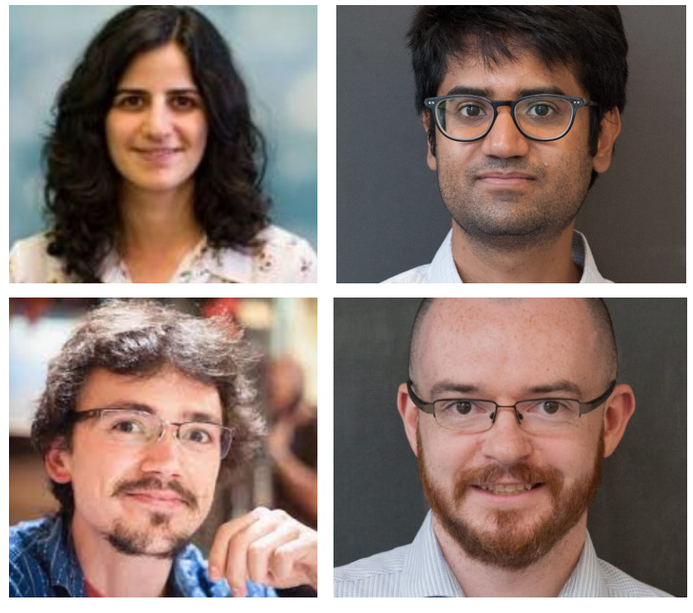


Philcox, MI, Cabass, Simonovic, Zaldarriaga (2022)

- One can get better priors from simulations (HOD, hydro, abundance matching, etc.)

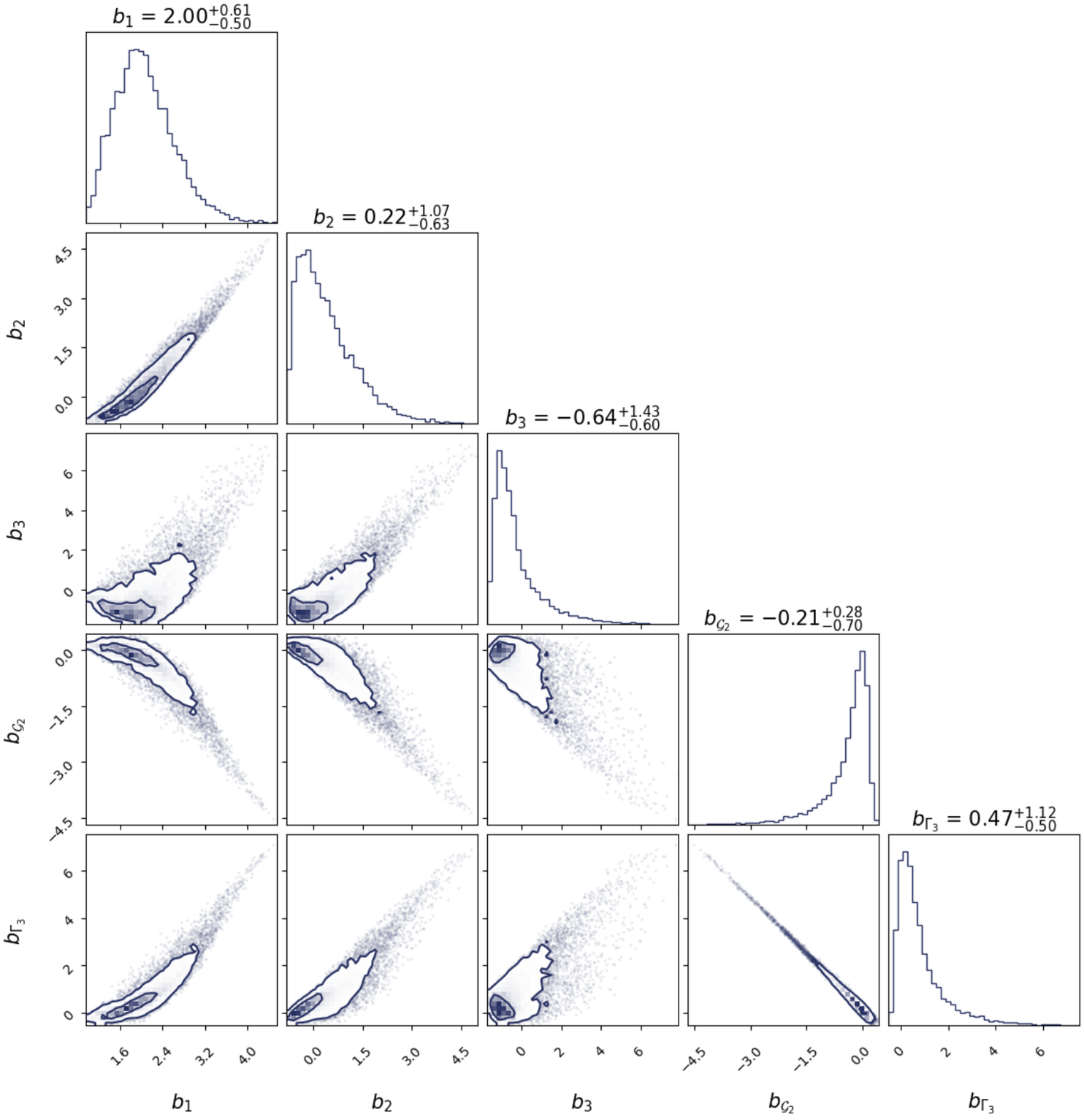
MI, Cuesta-Lazaro, Mishra-Sharma, Obuljen, Toomey'24

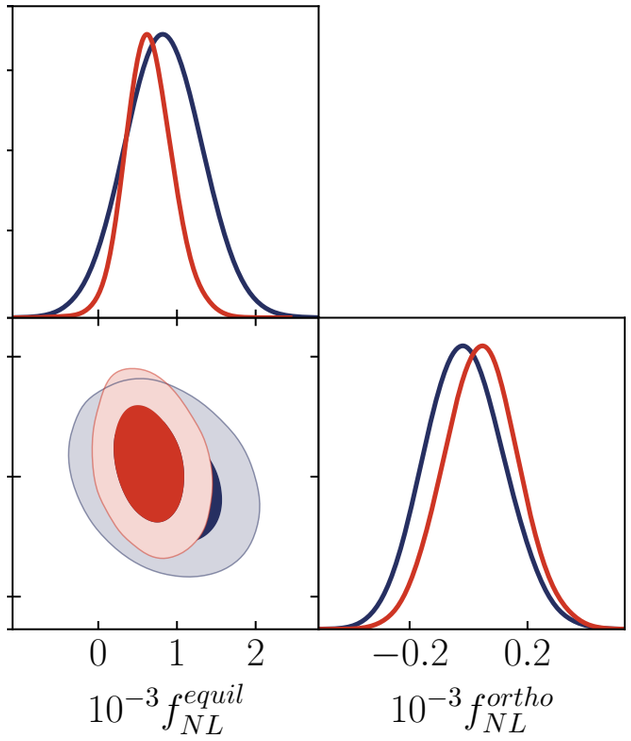
see also Sullivan, Seljak, Singh' 21



HOD-based priors

>10,000 mocks ⟶ Normalizing flows ⟶ Priors for EFTxFS





$\approx 40\%$ Improvement!

MI, Cuesta-Lazaro, Mishra-Sharma, Obuljen, Toomey'24

Baryons fall in halos and form galaxies

This physics constrains b2, but this info is missing in EFT

Summary

- EFT/PT - robust *analytic* tool for LSS
- Cosmo. parameters similar to CMB - better in future
- Novel ways to test new physics
- Many O(1) question on inflation, DM and exotic energies can be answered with future LSS surveys

Thank you!