LABORATOIRE D'ANNECY
DE PHYSIQUE THÉRIQUE

Precision Tests of Fundamental Physics With Cosmic Large-Scale Structure

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Supek Physics Colloquium, Ruđer Bošković Institute

Croatia, July 1st - 2026

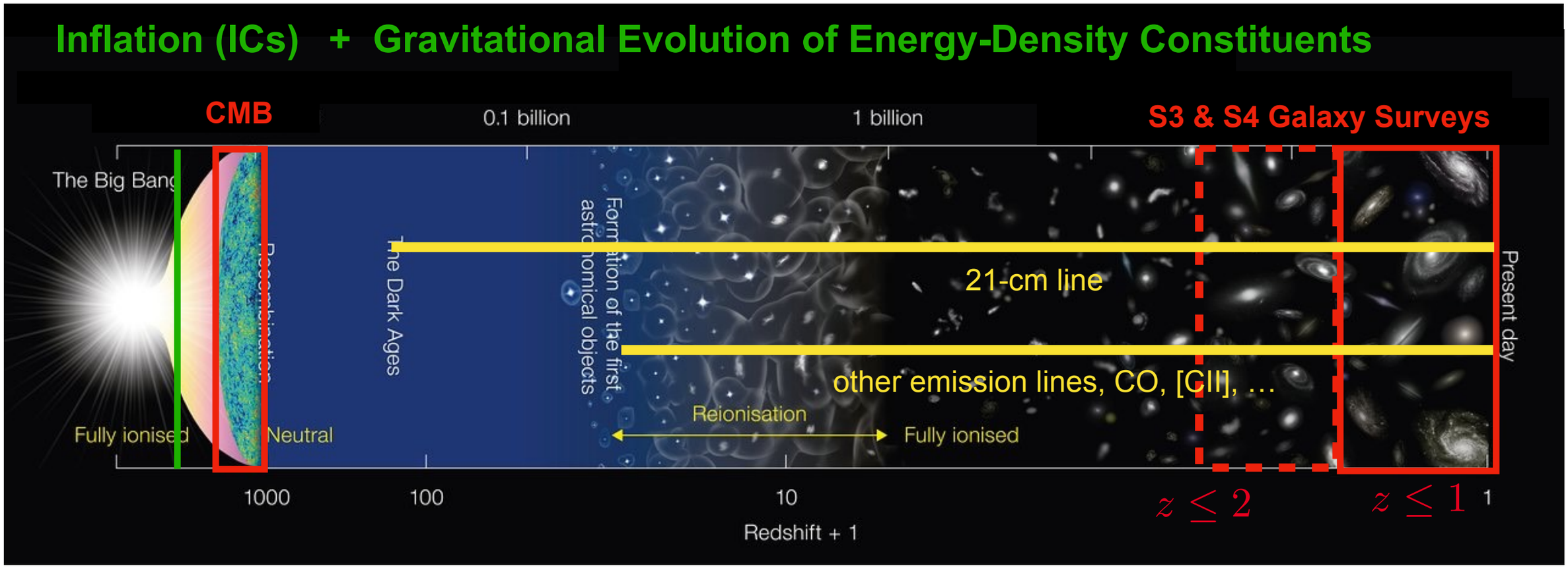
agence nationale de la recherche

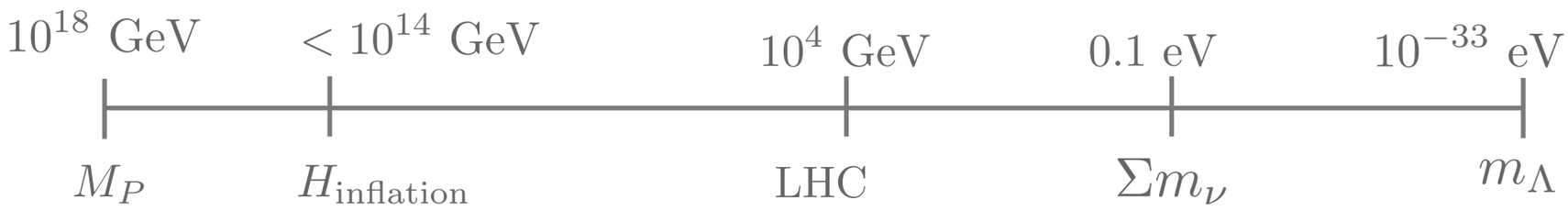
Roadmap

From Galaxy Distributions to Fundamental Physics

- The standard cosmological model — where new physics may enter
- Large-scale structure as a testing ground for fundamental physics
  - ❖ Physics of inflation and its imprints on the LSS
  - ❖ Beyond the power spectrum: extracting non-Gaussian information
  - ❖ Pushing into nonlinear scales: simulation-based inference
- Conclusions

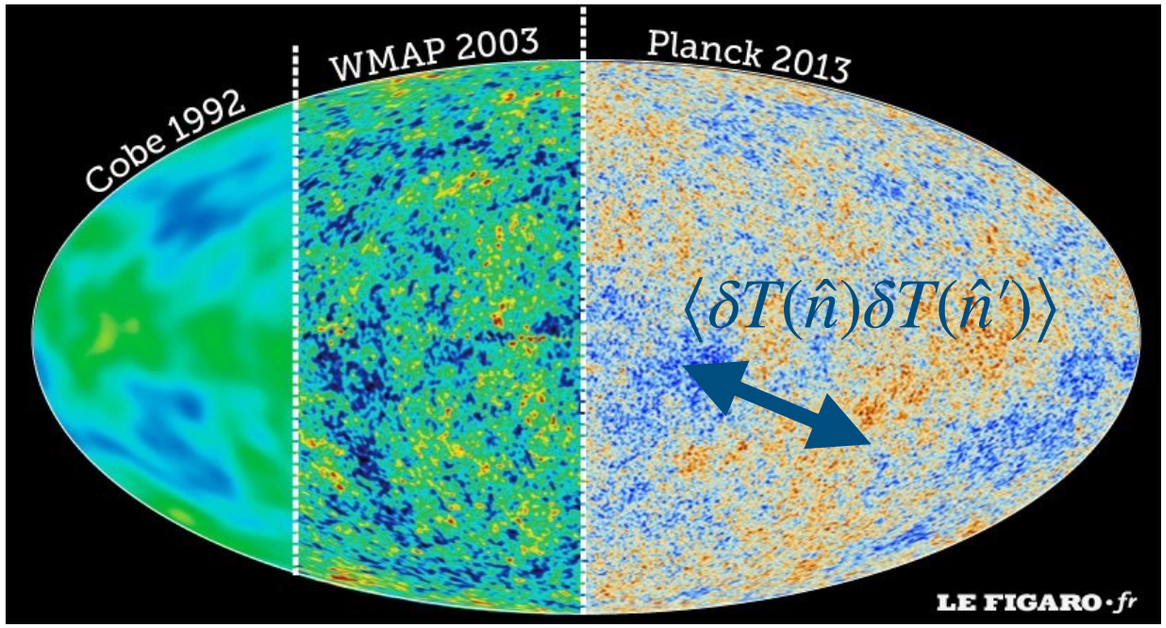
Timeline of the Universe

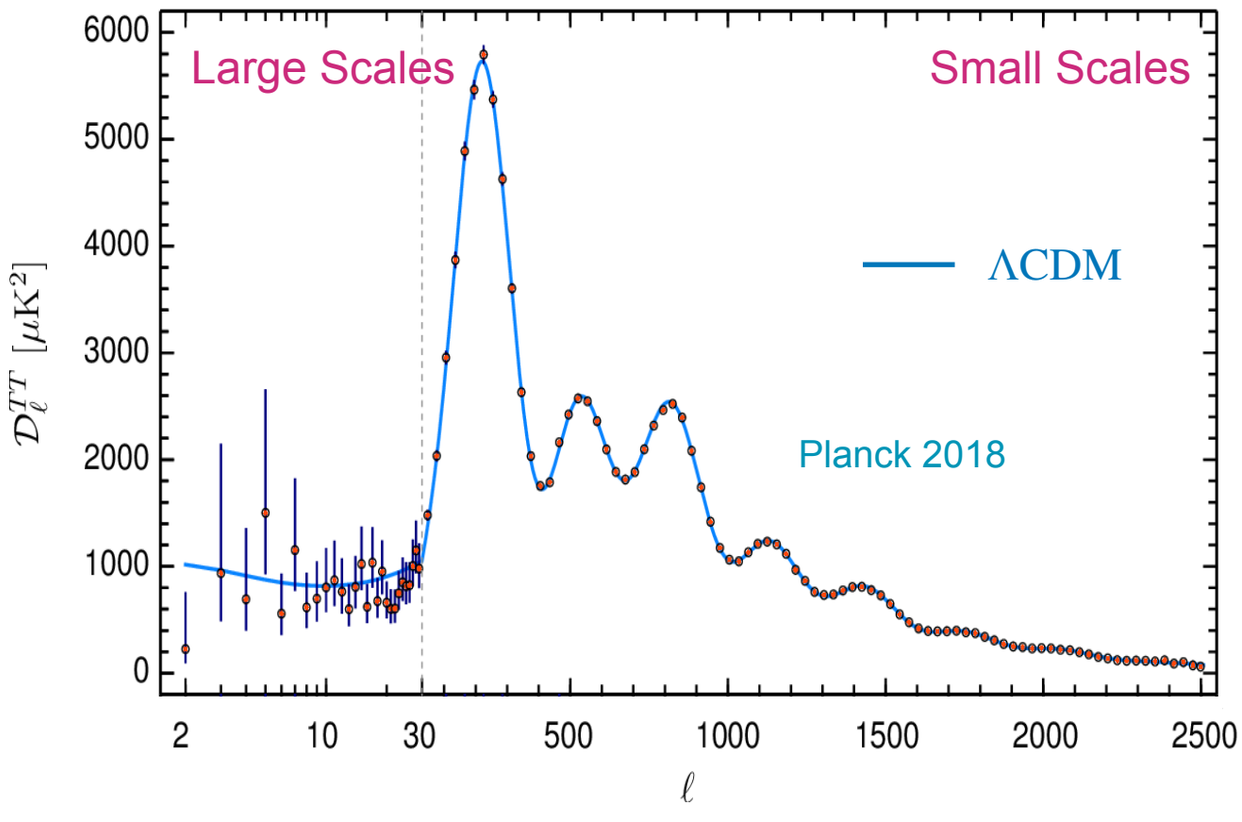




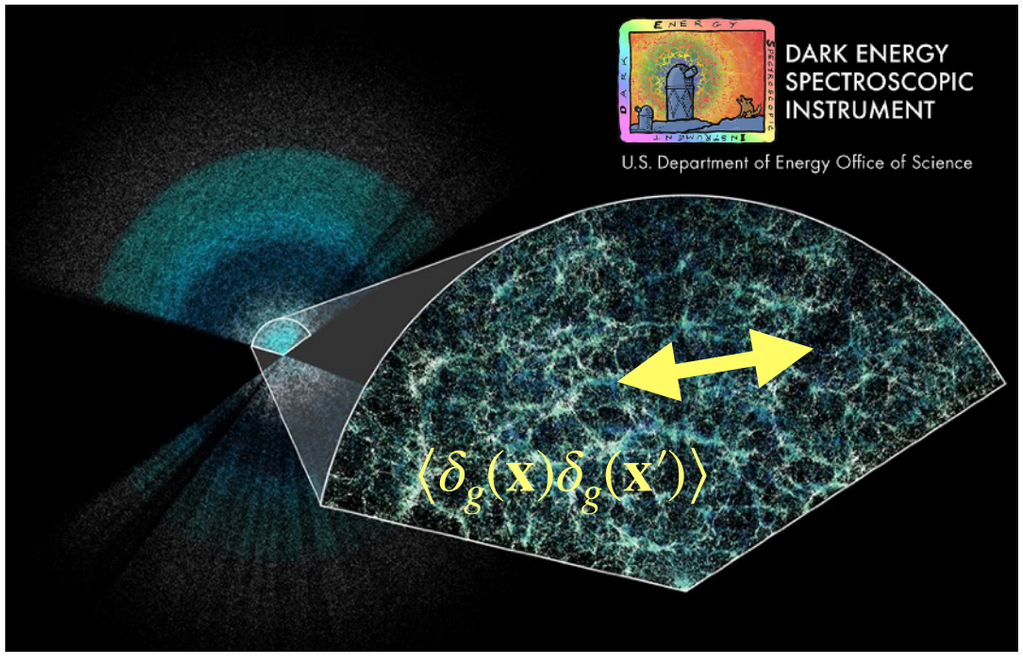
Era of Precision Cosmology

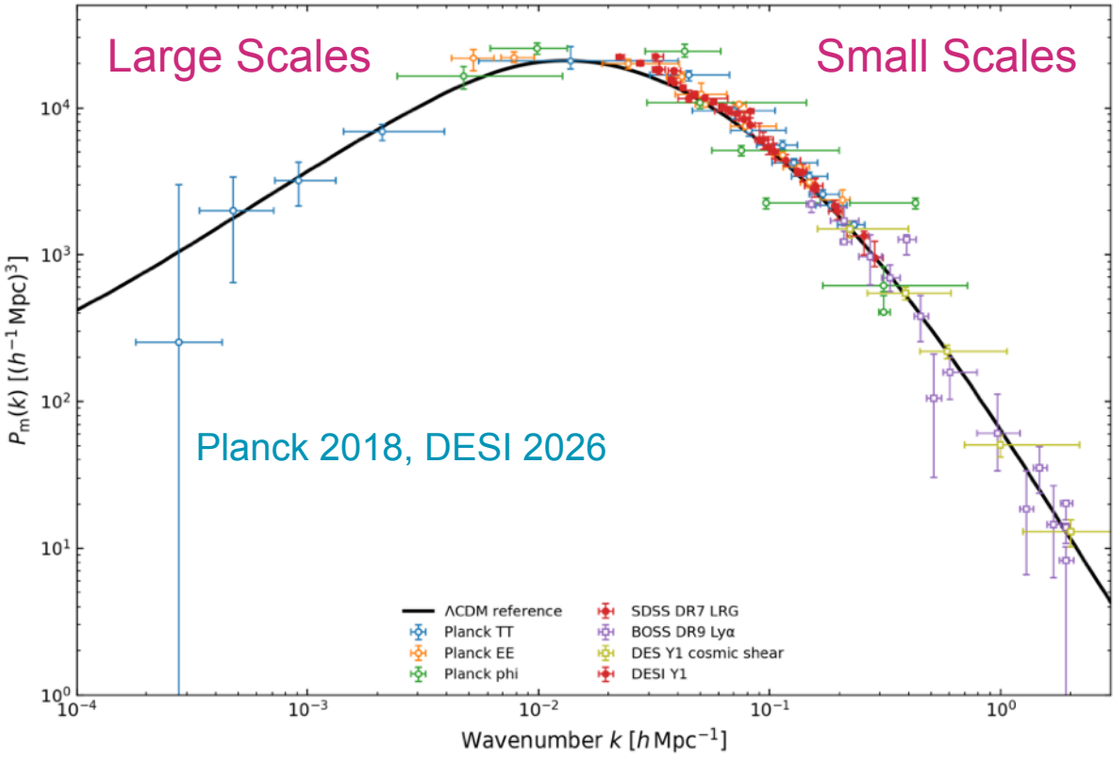
Cosmic Microwave Background





Galaxy/Quasar Distributions

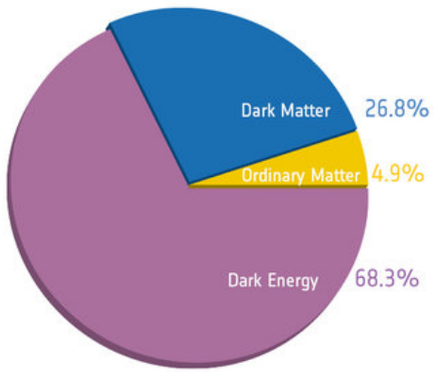




Concordance Model & Beyond

Where do we stand?

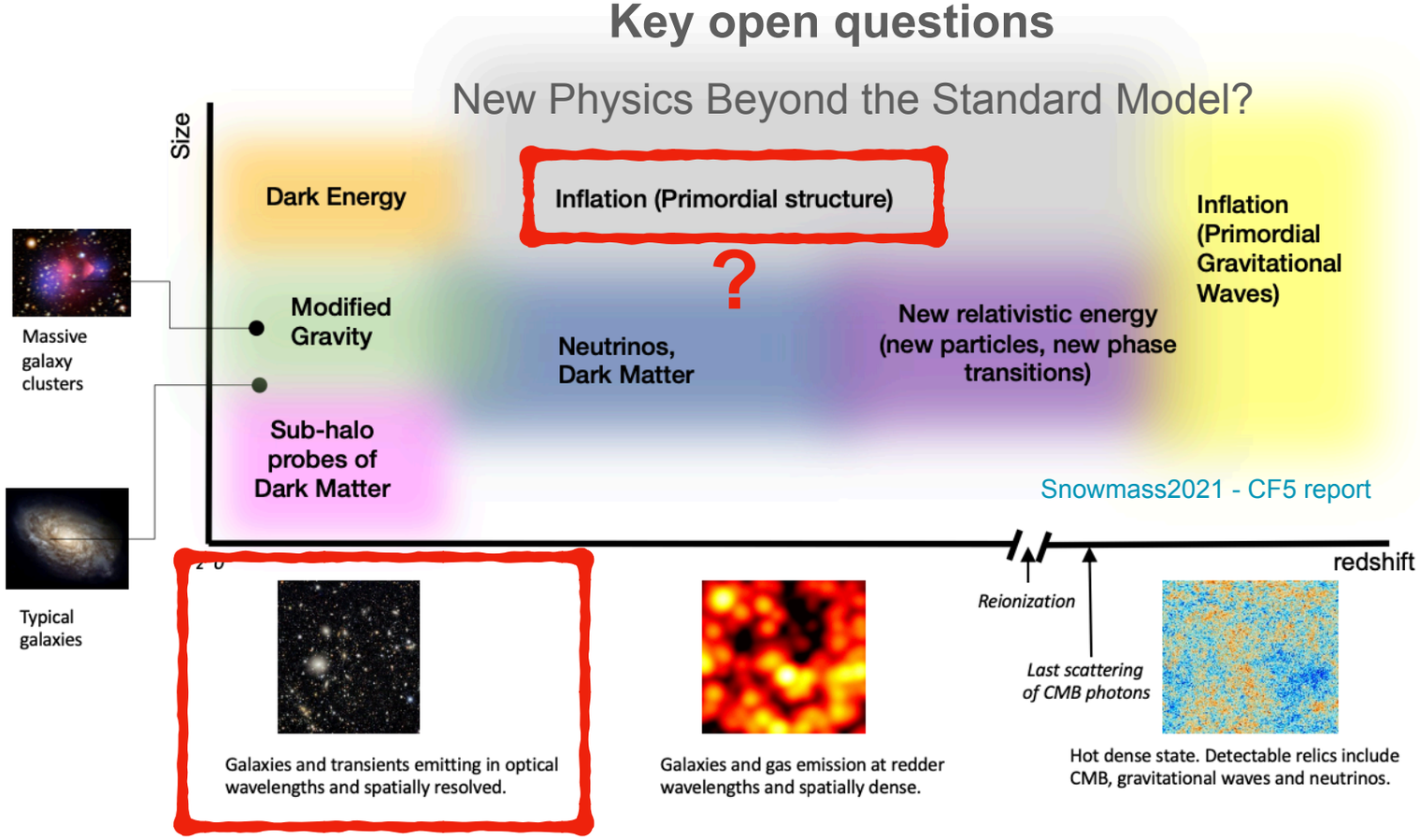
- Consistently (?) describe the origin, composition, and evolution with a simple phenomenological model



ΛCDM

+ single-field inflation
+ massive neutrinos

Key open questions



Snowmass2021 - CF5 report

Path forward

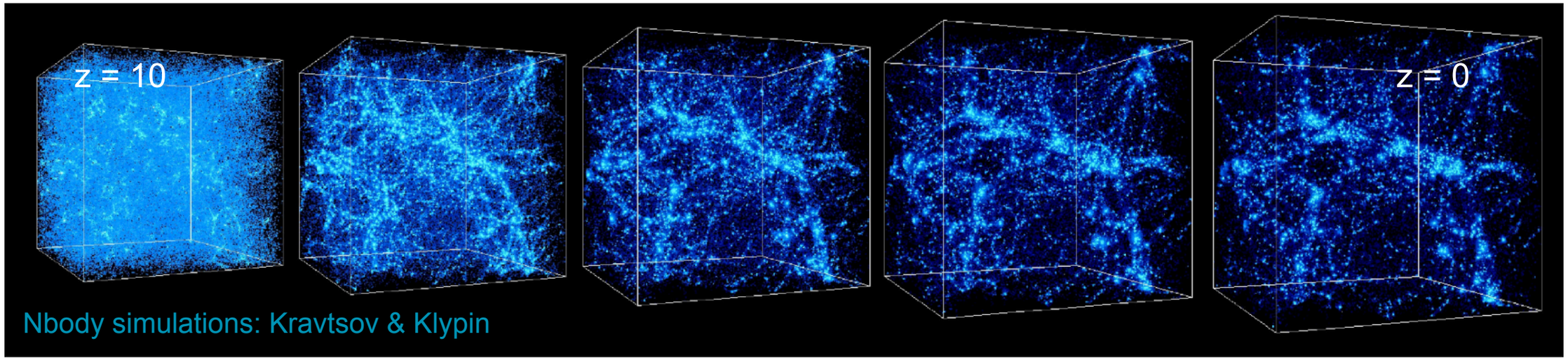
- Test the model with higher precision data
- Test the consistency of different datasets
- Test the model where it has not been tested (high redshift & horizon scales)

→

- Tensions in ΛCDM: new physics vs systematics
- Increased ability to do model-dependent searches of subtle beyond ΛCDM imprints

Cosmic Large-Scale Structure (LSS)

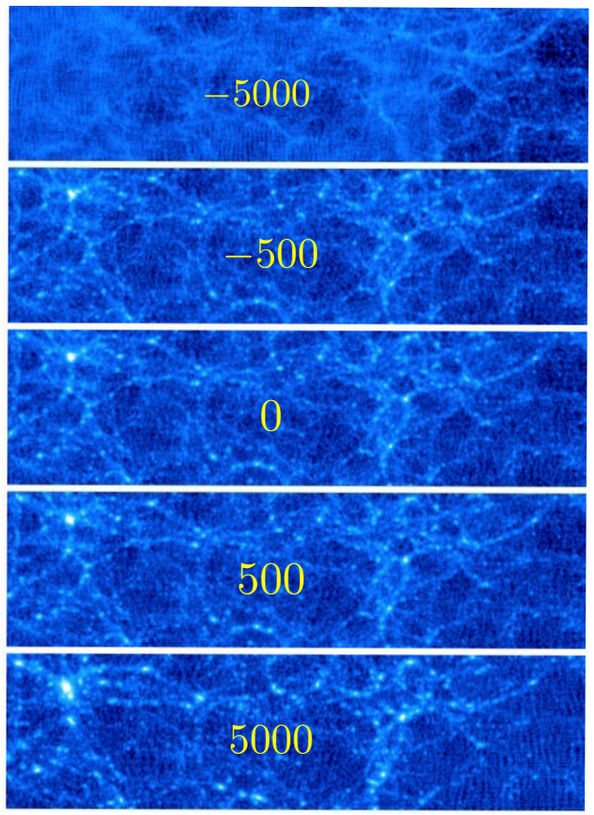
formed under the influence of gravity from inflationary-era primordial fluctuations



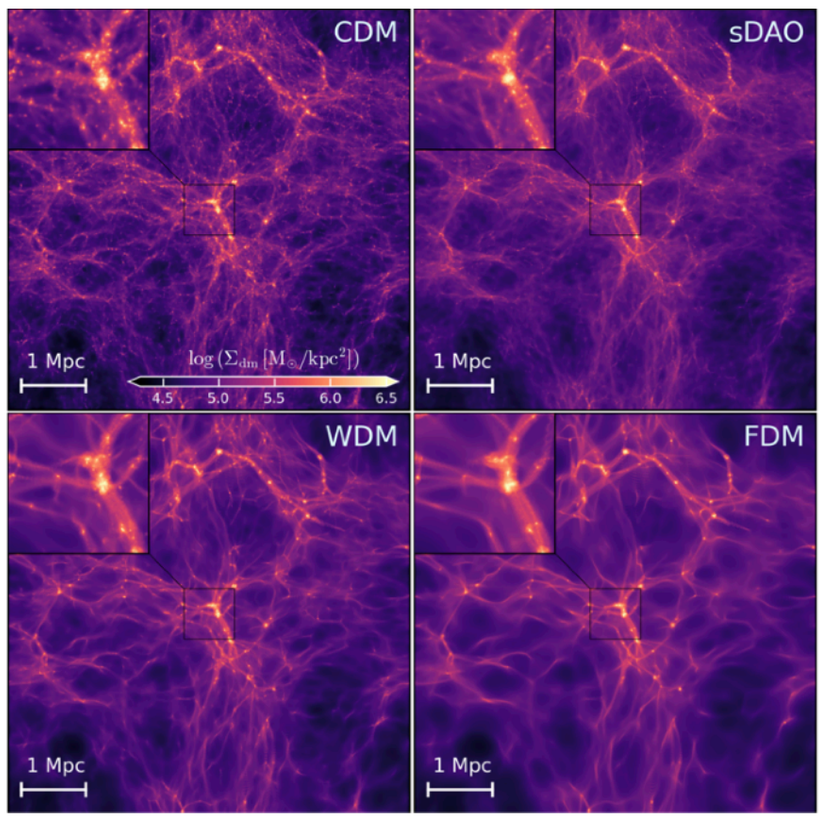
Promise

- Sensitive to ICs, constituents, and evolution of the Universe
- Lower cosmic variance (3D vs 2D)
- The rich structure carries distinct imprints of new physics

Primordial non-Gaussianity



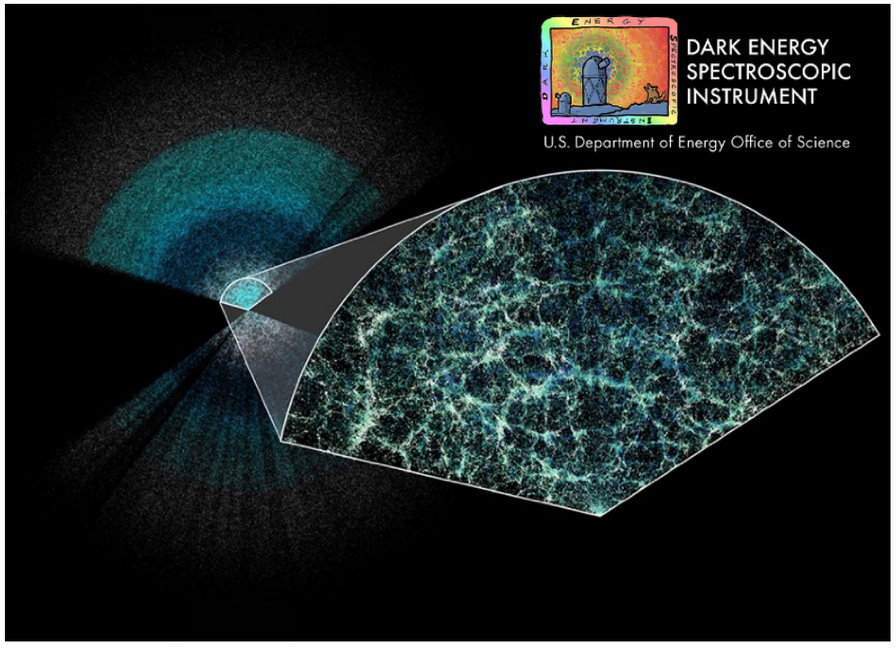
Nature of dark matter



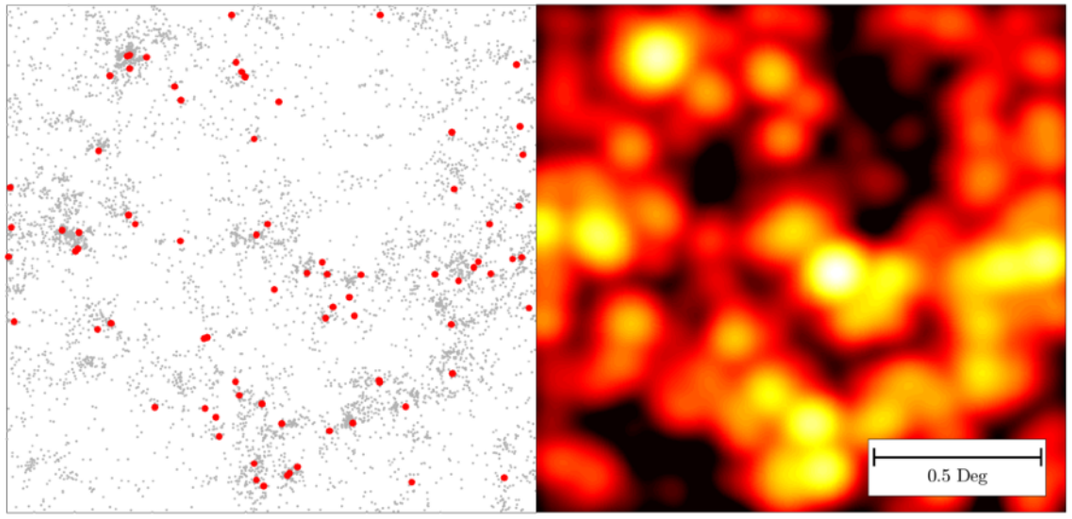
Probes of the LSS

Visible Matter as a Tracer of Dark Matter

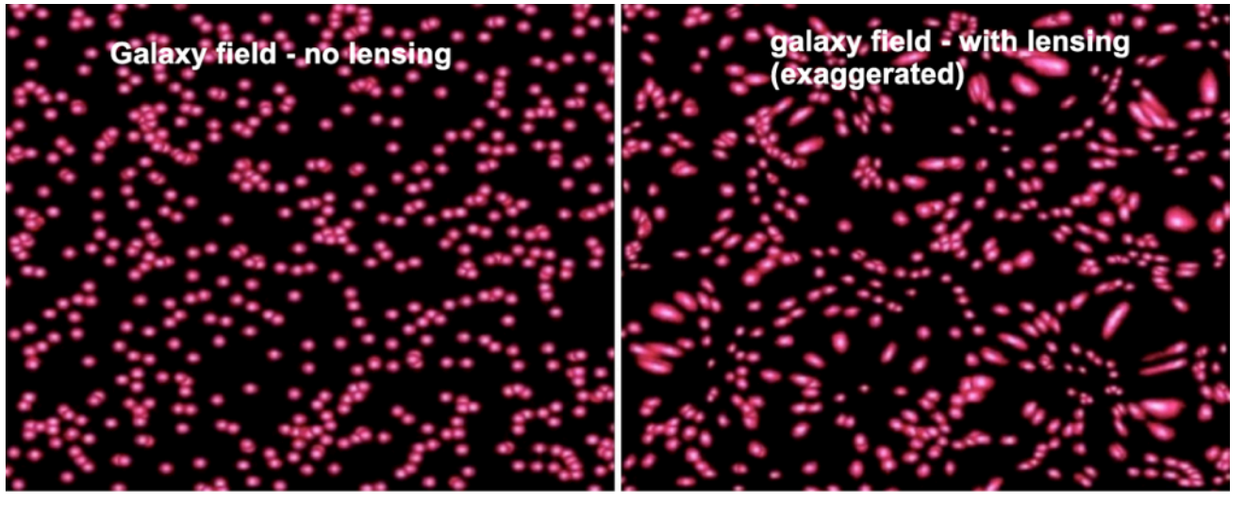
Galaxy/Quasar Distributions



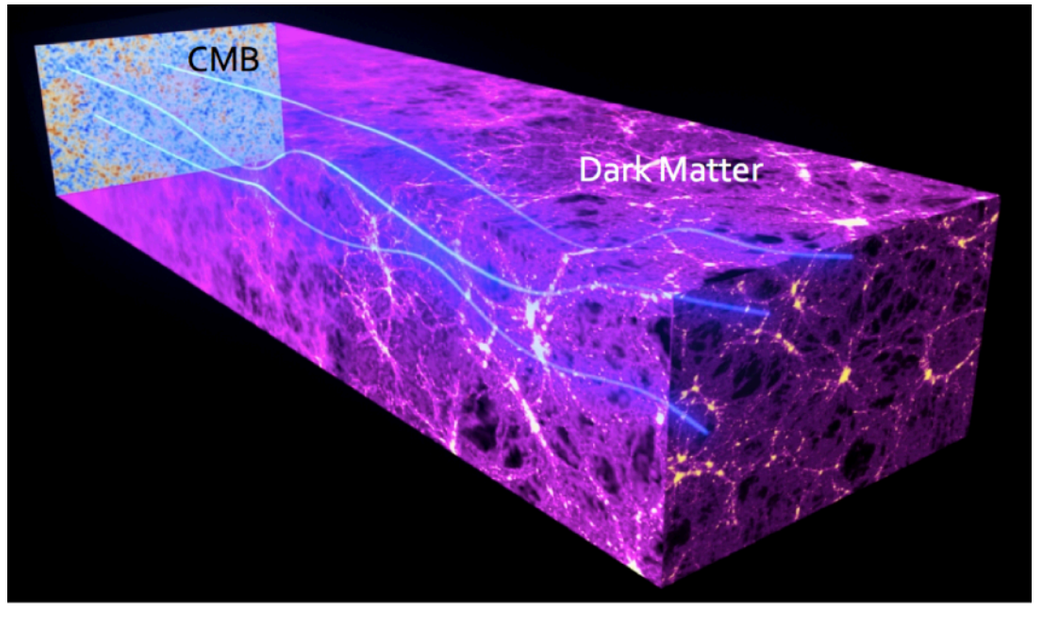
Line Intensity Mapping (21cm, CO, [CII], …)



Galaxy Weak Lensing (magnification & shear)

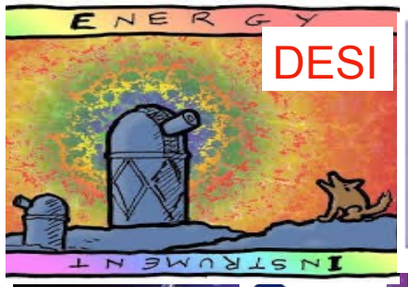


CMB Weak Lensing



LSS Observational Landscape: Why Now?

Stage4 Galaxy Surveys



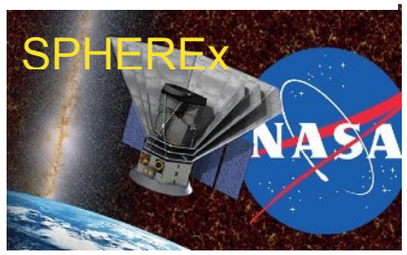


Prime Focus Spectrograph

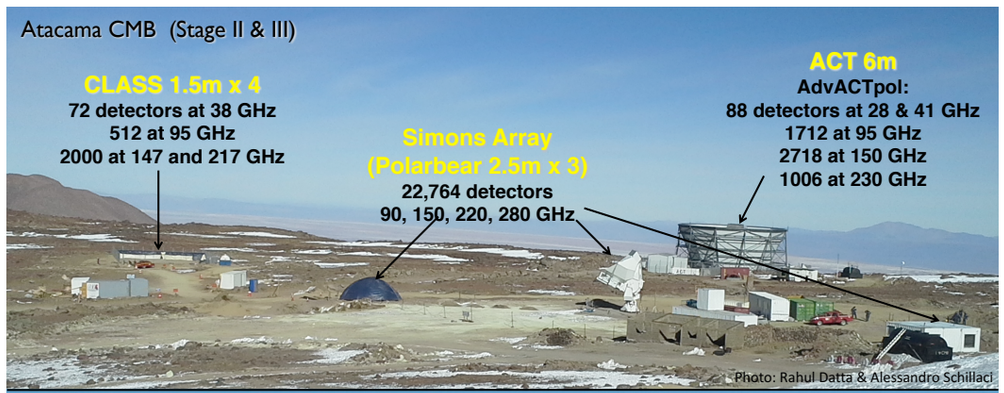


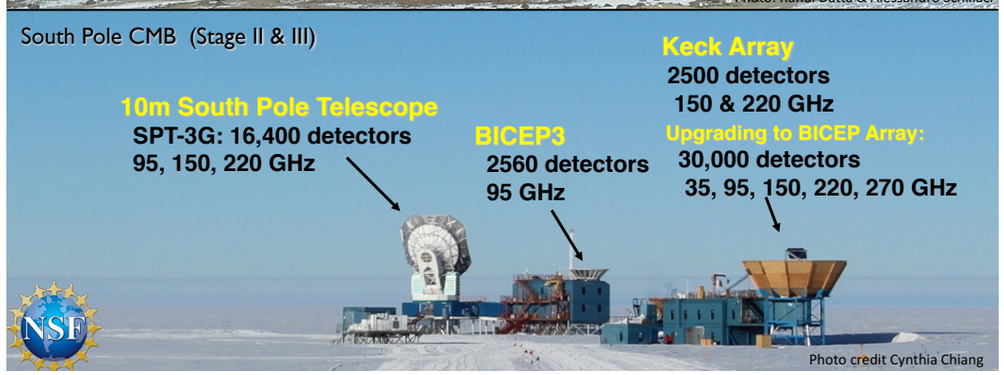






CMB Experiments





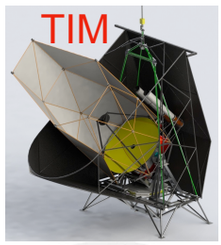
Intensity Mapping Surveys



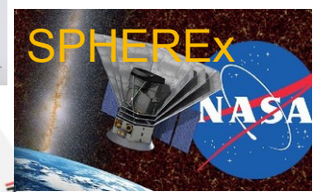




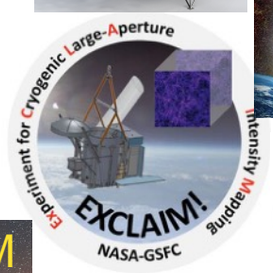










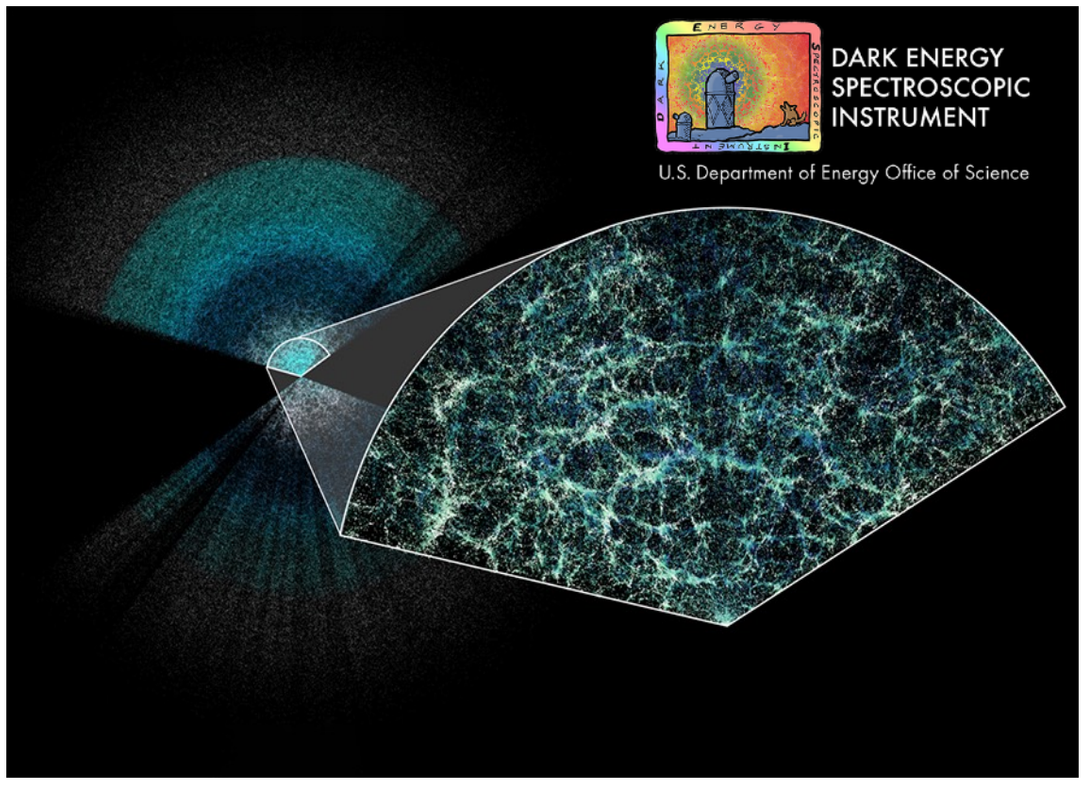






Focus of This Talk

Galaxy/Quasar Distributions



$$\delta_g(\mathbf{x}, z) = \frac{N_g(\mathbf{x}, z)}{\bar{N}(z)} - 1$$

$$\langle \delta_g(\mathbf{x_1}) \delta_g(\mathbf{x_2}) \rangle \quad \langle \delta_g(\mathbf{x_1}) \delta_g(\mathbf{x_2}) \delta_g(\mathbf{x_3}) \rangle \quad \cdots$$

Physics of Inflation

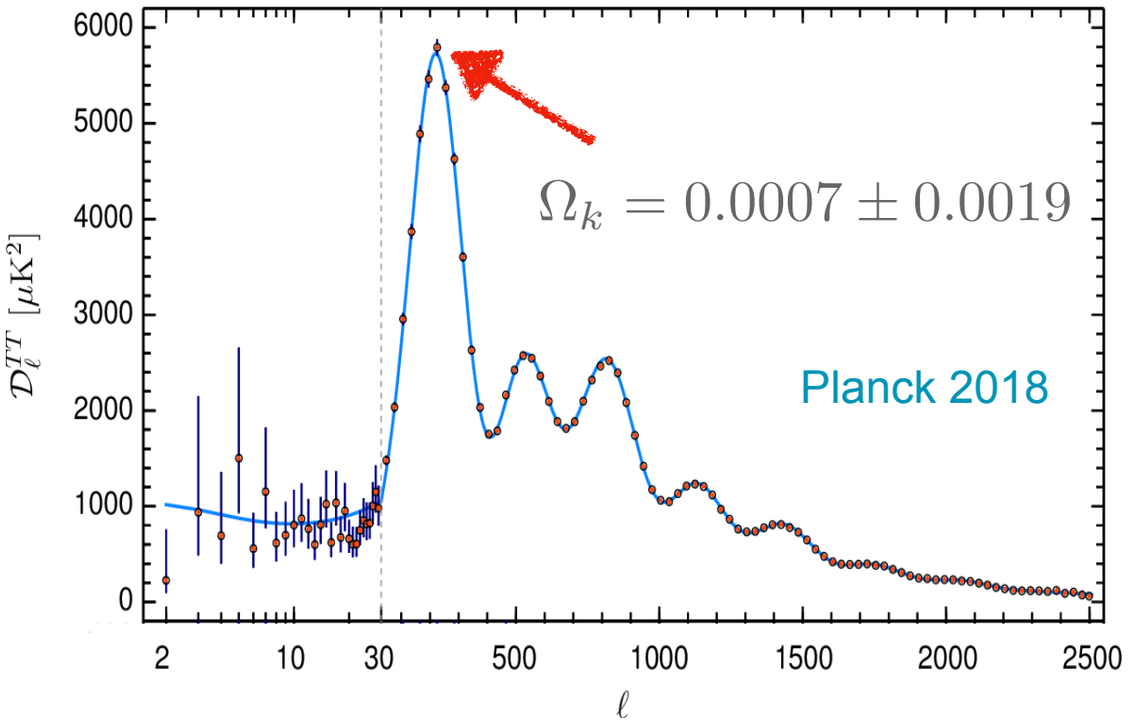
(number of degrees of freedom,
Interactions among them, Symmetries)

Challenges: non-linear nature of structure formation

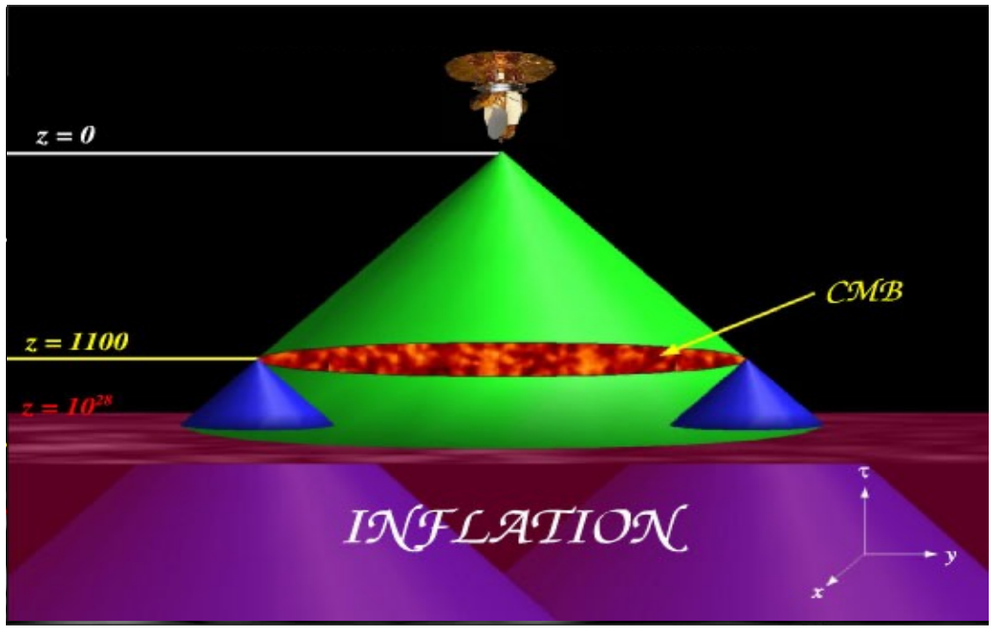
- Accurate forward modeling beyond linear theory
- Choosing sufficient statistics: beyond 2-point correlation functions
- Extracting information from scales in non-perturbative regime

Cosmic Inflation: Background

Why is the universe so flat?



Why is the universe so smooth?



Courtesy of W. Kinney

Phase of accelerated expansion: Elegant

Has to End, Dynamic

~~Λ~~ $\rightarrow$ $V(\phi)$

Cosmic Inflation: Perturbations

Did it actually happen?

Primordial Fluctuations

- Tensor Modes
- Scalar Modes $\zeta(\mathbf{k}) \propto \delta\phi$

Probe statistical properties to shed light on physics of the very early Universe



particle production: virtual to real

inflation + QM = fluctuations



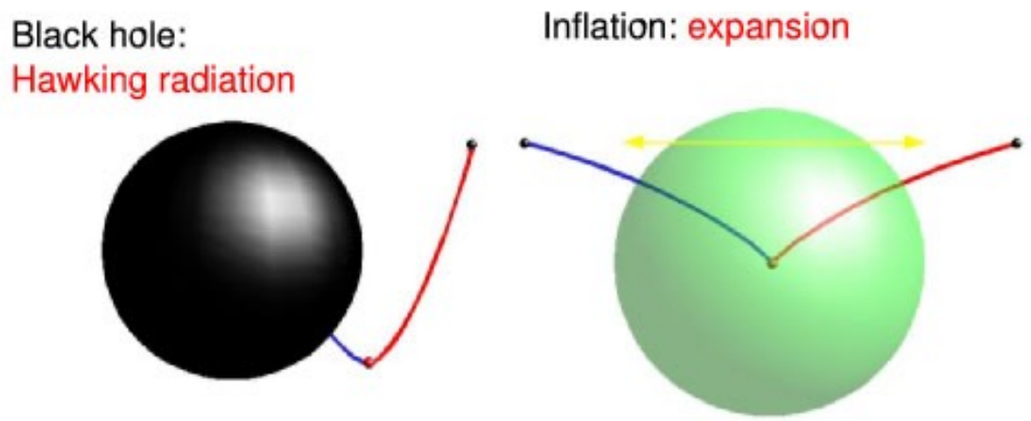


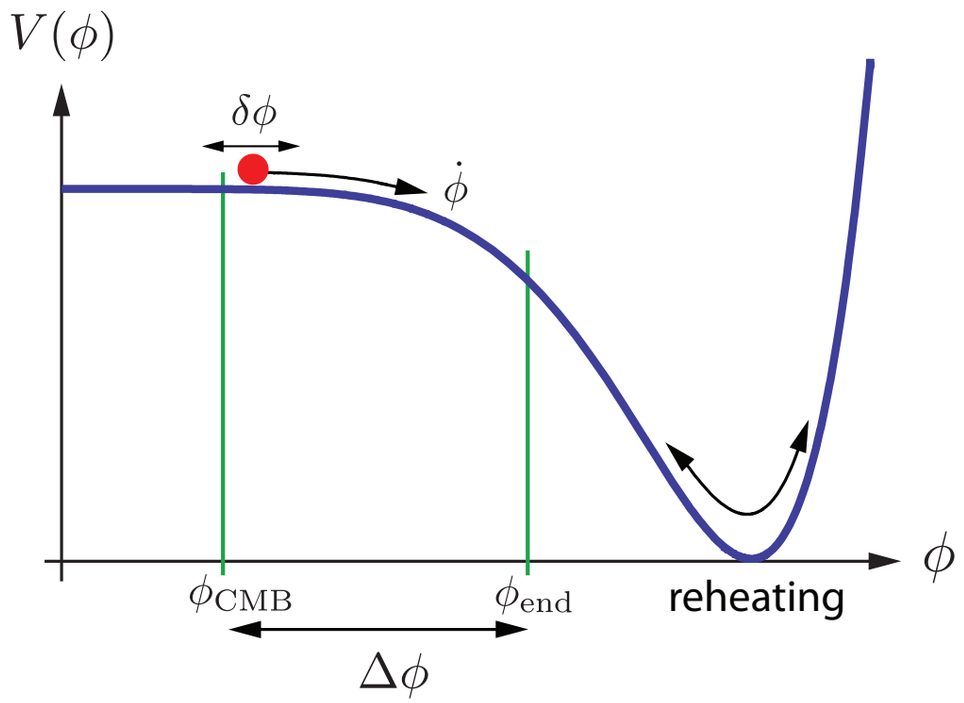
Fig: Courtesy of W. Kinney

Cosmic Inflation: Fluctuations

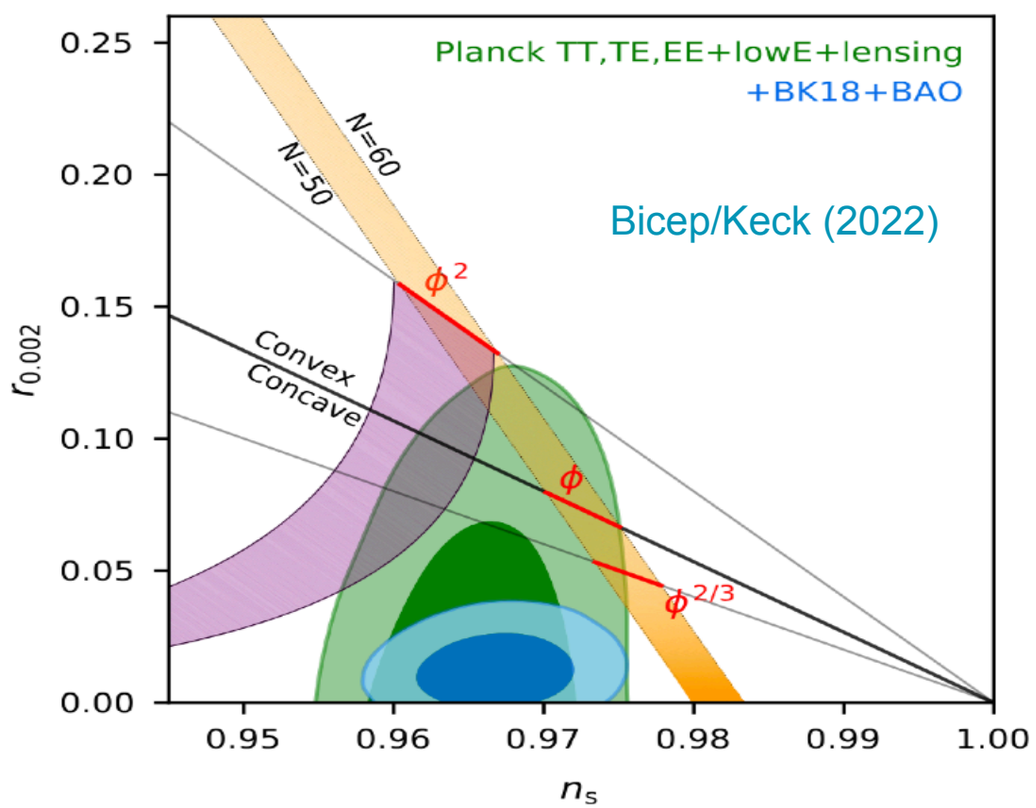
☑ Scale-invariant $\quad n_s = 0.9665 \pm 0.0038 \qquad k^3 P_\zeta(k) = (2\pi^2) A_s (k/k_*)^{n_s - 1}$

☐ Gaussian **Field Content and dynamics during inflation: LSS**

☐ Gravitational waves **Energy-scale of inflation: CMB**



Courtesy of D. Baumann



Field Content and Interactions during Inflation

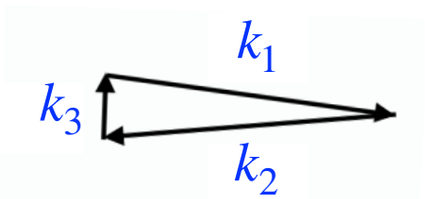
$$\langle \zeta(\mathbf{k}_1)\zeta(\mathbf{k}_2)\zeta(\mathbf{k}_3)\rangle = (2\pi)^3\delta_D(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_3)B_\zeta(k_1,k_2,k_3)$$

$$B_\zeta(k_1,k_2,k_3) = f_{\rm NL}k_1^{-2}k_2^{-2}k_3^{-2}S(k_1,k_2,k_3)$$

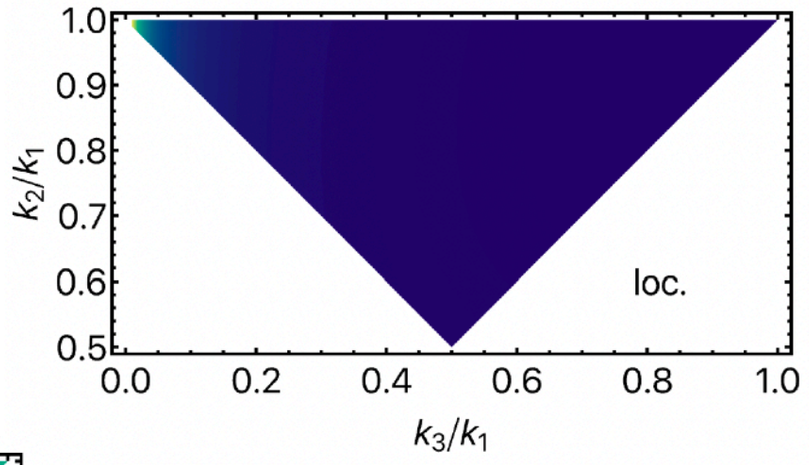
Many more inflationary scenarios:

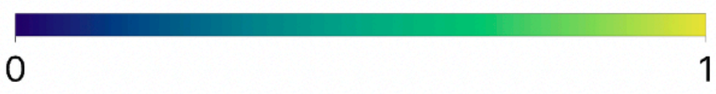
- non Bunch-Davies vacuum state
- cosmological collider (massive particle with spin)
- …

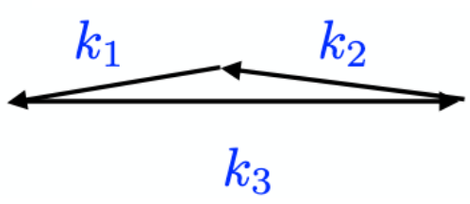
Distinct shapes characterizing specific inflation models



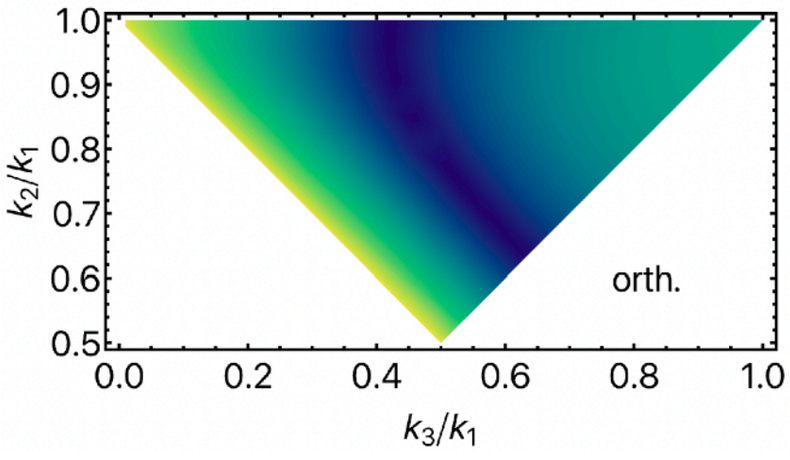
Local: Multifield

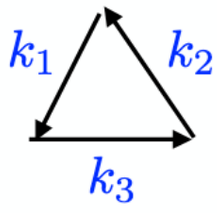




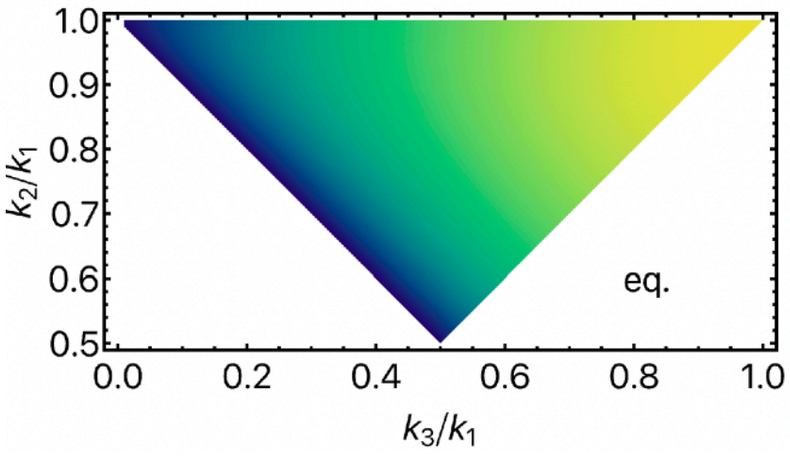


Orthogonal: single-field





Equilateral: single-field



Fundamental Symmetries in Early Universe

- Is the Universe invariant under a **point reflection**? $f(\mathbf{x}, \mathbf{y}, t) \stackrel{?}{=} f(-\mathbf{x}, -\mathbf{y}, t)$
- **General relativity** and **hydrodynamics** preserve parity
- Can there be physical mechanisms in **early** or **late** Universe that violate parity?
- In which sector? **Scalar** vs **tensor** imprints

Ghost Inflation

Cosmological Collider

Helical Primordial Magnetic Fields

U(1) Gauge field coupled to inflation

Chiral Gravity (eg. Chern-Simons)

Chiral Gauge Dynamics during Inflation

Parity-violation along photon trajectory

Galaxy Clustering

Galaxy Shapes

CMB Polarization

Galaxy Spin

Parity-odd signature in Scalar Observables

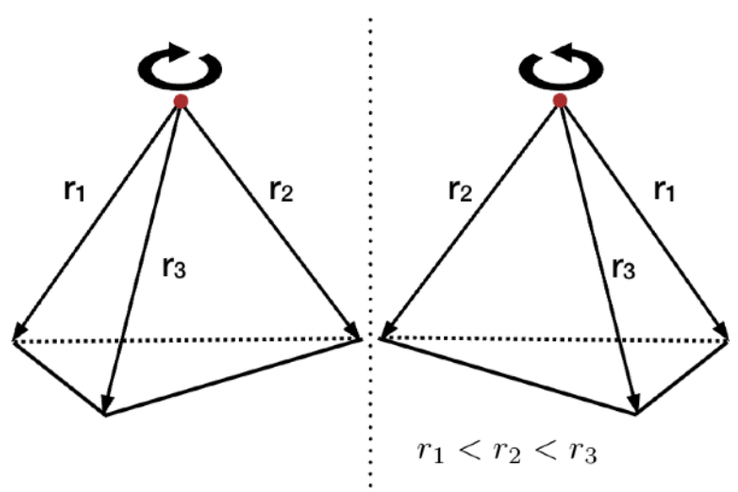
- Scalar sector parity violation appears at the lowest-order in 4-point correlation function
- Lowest-order scalar observables are CMB and galaxy clustering 4pt-CFs

- Non-Bunch-Davies initial condition
- Cosmological collider
- U(1) Gauge field coupled to inflation
- Helical primordial magnetic fields

Tensor-sector parity violation can also induce scalar signatures

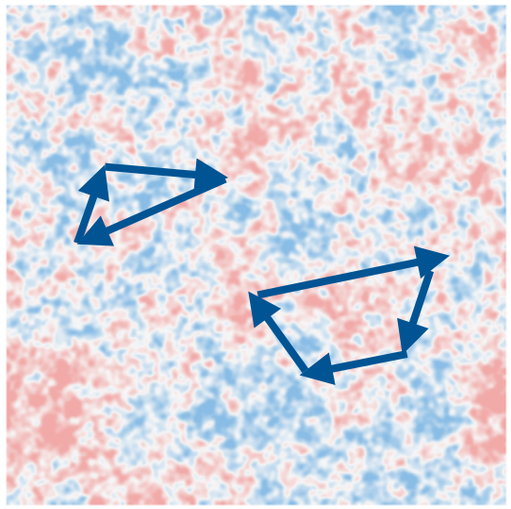


Figure by J. Hou



Early- and Late-Time Probes of PNG and Parity

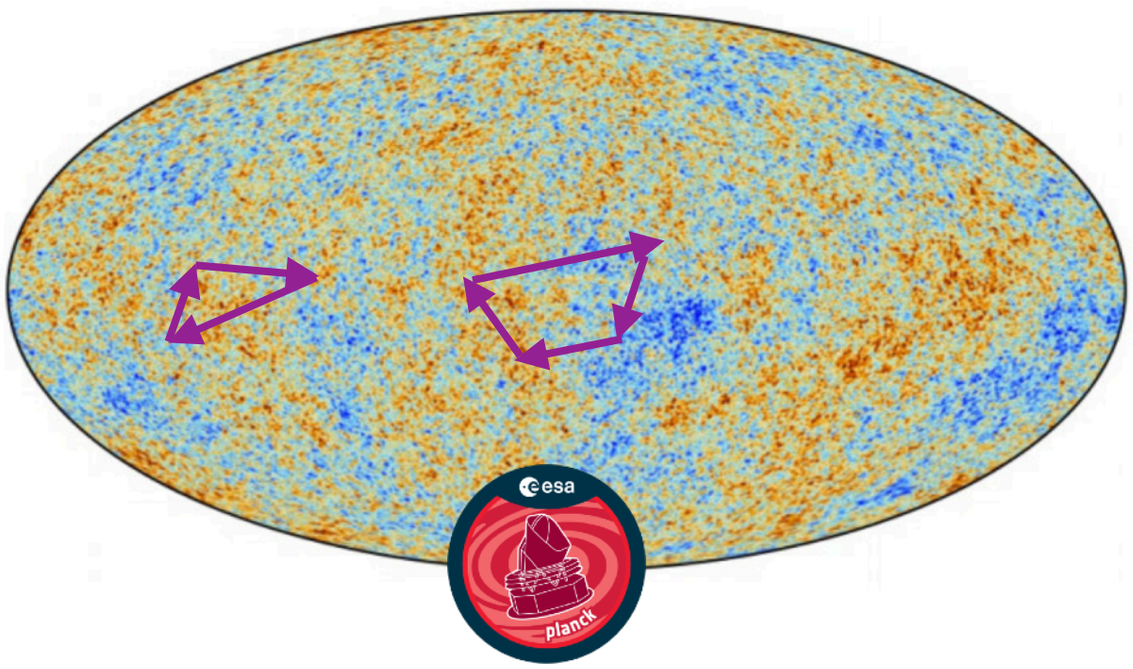
$\langle \zeta^3 \rangle, \langle \zeta^4 \rangle$



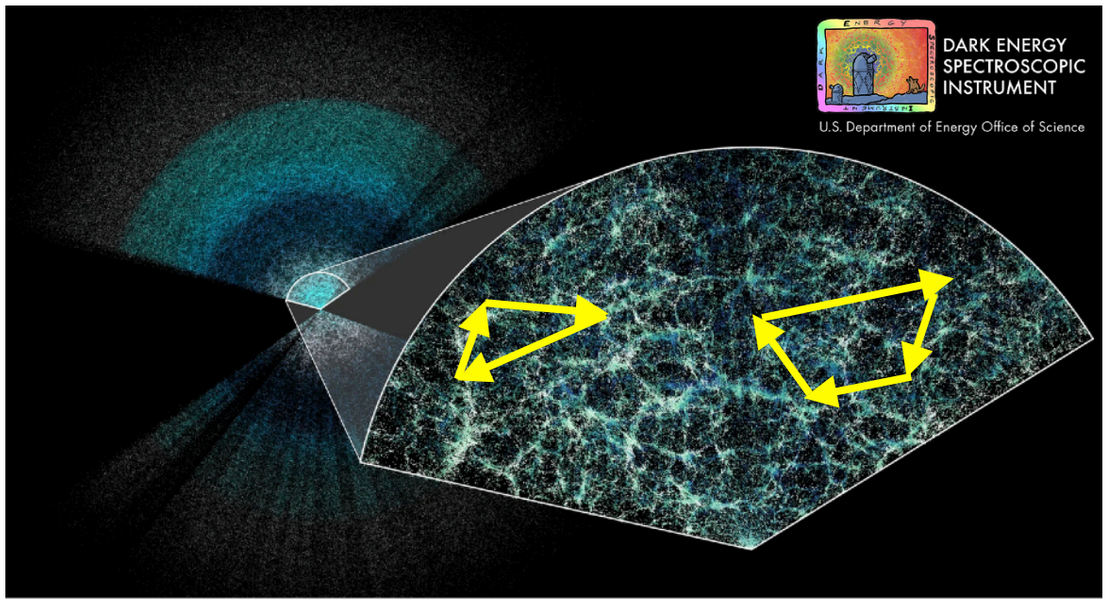
Non-linear Physics
- DM evolution
- DM-galaxy relation
- Peculiar Velocities

Linear Physics

$\langle \delta T^3 \rangle, \langle \delta T^4 \rangle$

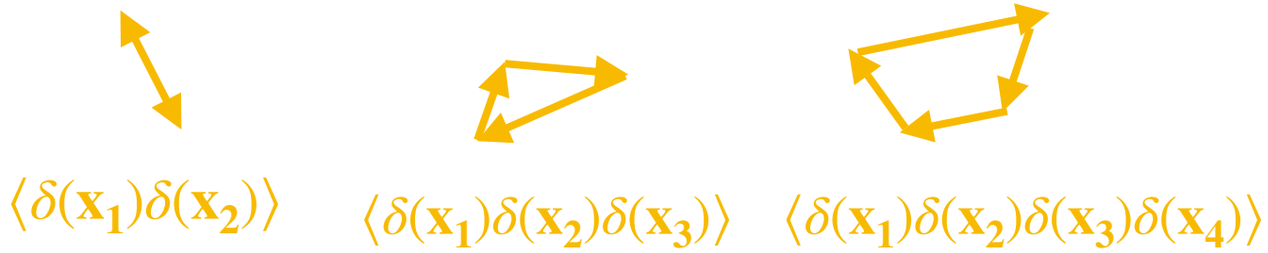


$\langle \delta_g^3 \rangle, \langle \delta_g^4 \rangle$



Going Beyond 2-point Statistics

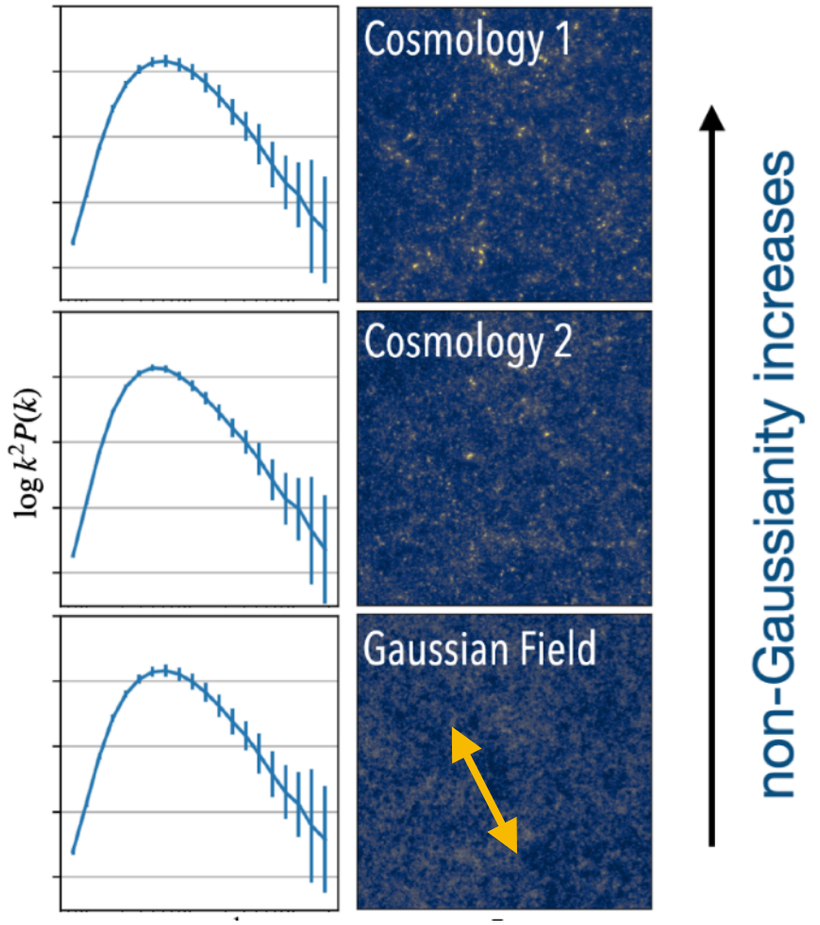
- Two-point statistics are **lossy compression** of the nonlinear large-scale structure



- Parameter **degeneracies** limit the constraining power
  (cosmo & nuisance params: galaxy biases, stochasticity, …)

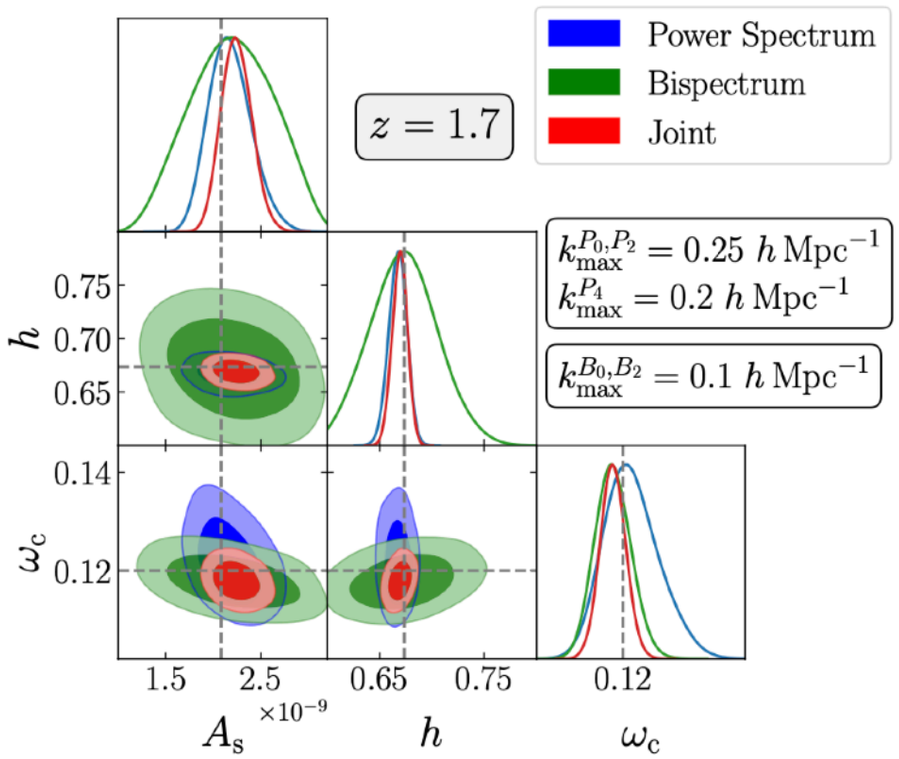
- **Additional information** in higher-order statistics
  (e.g. multi-field inflation)

- **Lack of sensitivity** of 2pt statistics to some imprints of new physics
  (e.g., field content and symmetries during inflation)



Cheng et al (2020)

Lossy Compression & Degeneracies



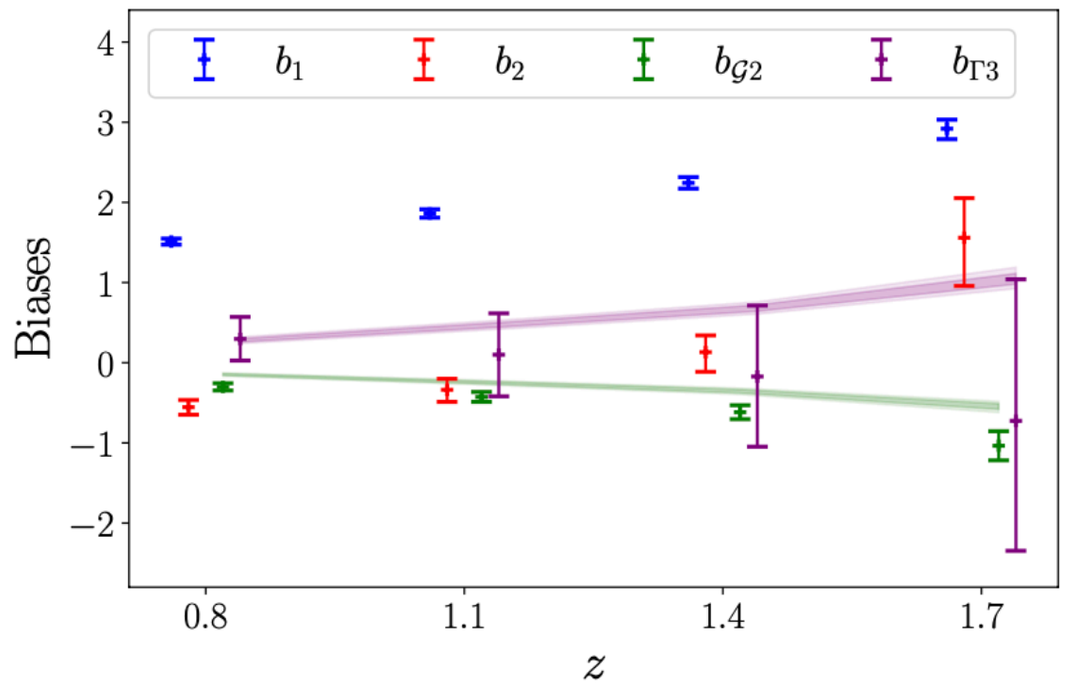


Dennis Linde

ΛCDM (on Euclid-like H-alpha HOD mocks)

- Considerable improvement by P+B on A_s, ω_c (reduced degeneracy)
- Negligible improvement on h (high-significance detection of baryon acoustic oscillations in P)

- Tight constraints on nonlinear galaxy biases
  - degeneracies (biases & cosmo params)
  - insight into galaxy properties (?)



Euclid Consortium: Linde & Moradinezhad et al (internal review)

Additional Information: Local PNG

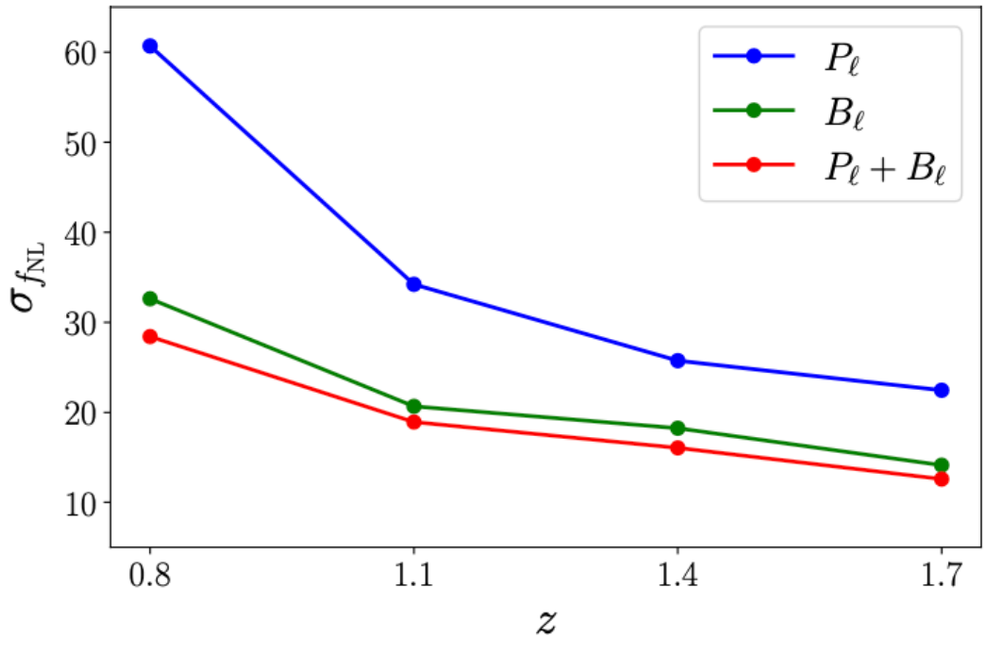
Account for poorly-understood galaxy formation and $\{f_{\rm NL}, b_\phi\}$ degeneracy

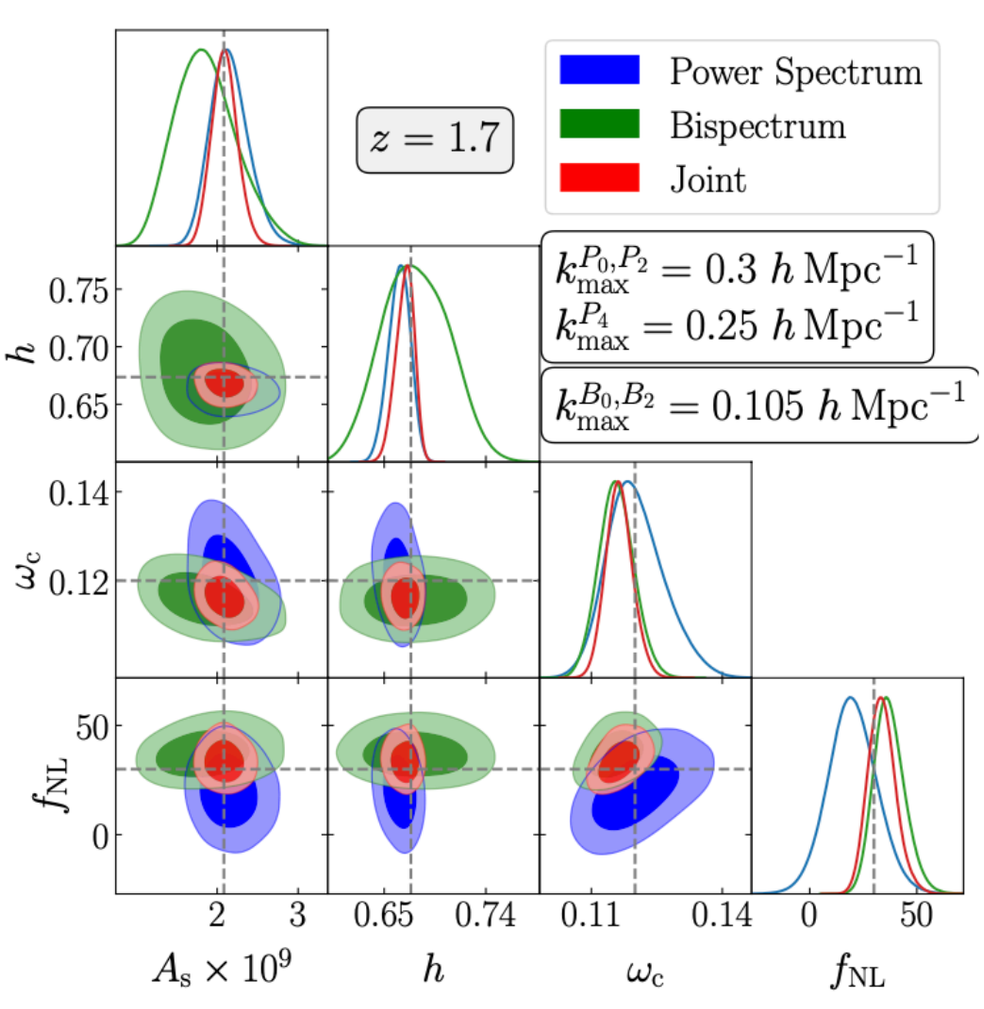
- Tighter constraints at higher z where b_ϕ is larger:

  larger P response, enhanced PNG to Gaussian ratio in B

- B outperform P (30-45)%, P+B improves P by (38-53)% ~ 2x larger survey volume

- (1 - 2.3)σ detection of $f_{\rm NL}$ from P+B

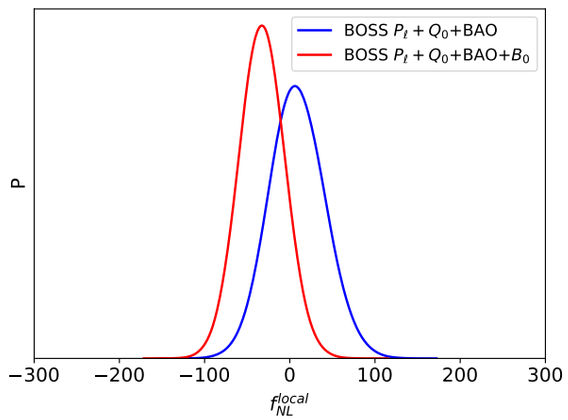


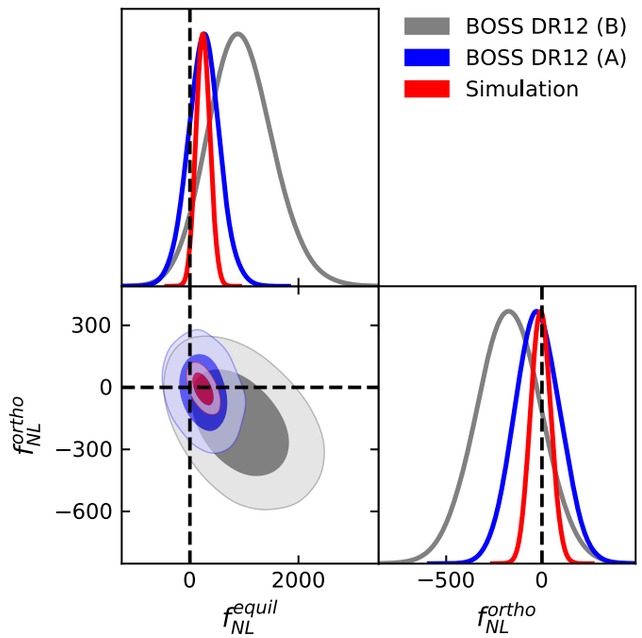


Euclid Consortium: Linde & Moradinezhad et al (2026)

Lack of Sensitivity to New Physics

Primordial Non-Gaussianity

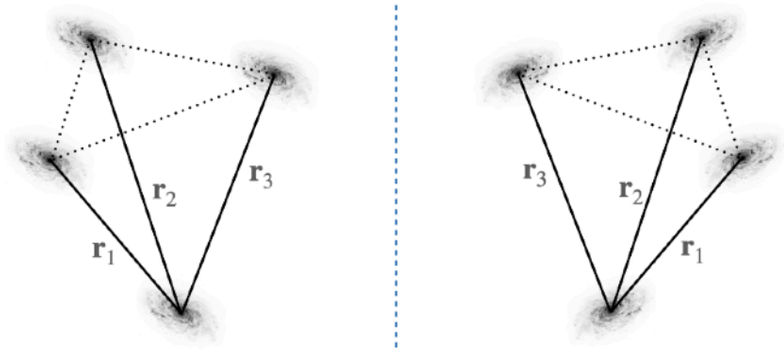




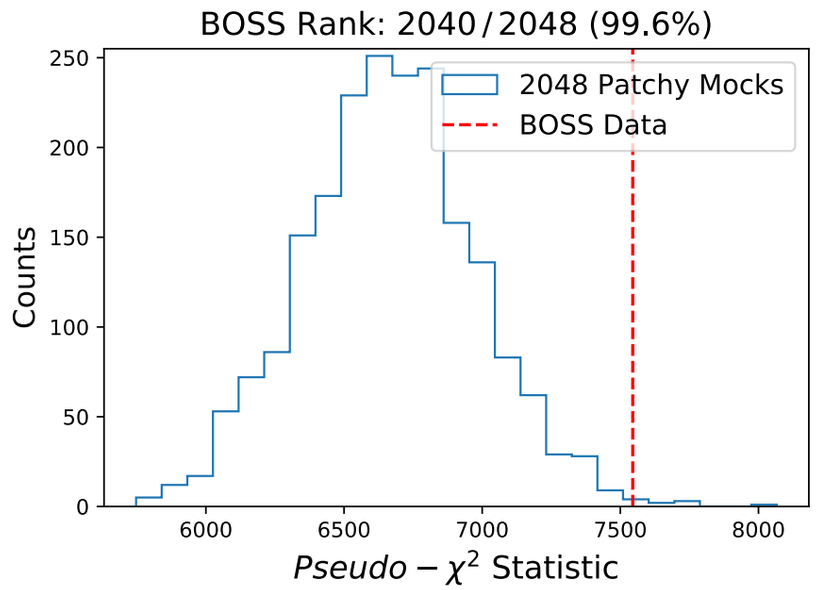
Cabass et al (2022a, 2022b)

[see also D'Amico et al (2022a, 2022b)]

Parity Violation



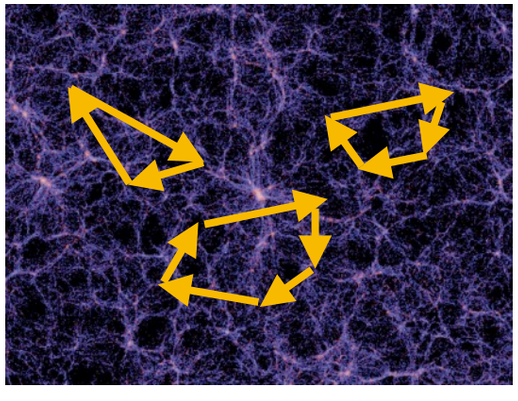
$$\tilde{\chi}^2 \equiv \left[\zeta^T \tilde{C}^{-1} \zeta\right]_{\mathrm{NGC}} + \left[\zeta^T \tilde{C}^{-1} \zeta\right]_{\mathrm{SGC}}$$



Philcox (2022) [see also Hou et al (2022)]

Higher-Order Statistics in Stage-IV Galaxy Surveys

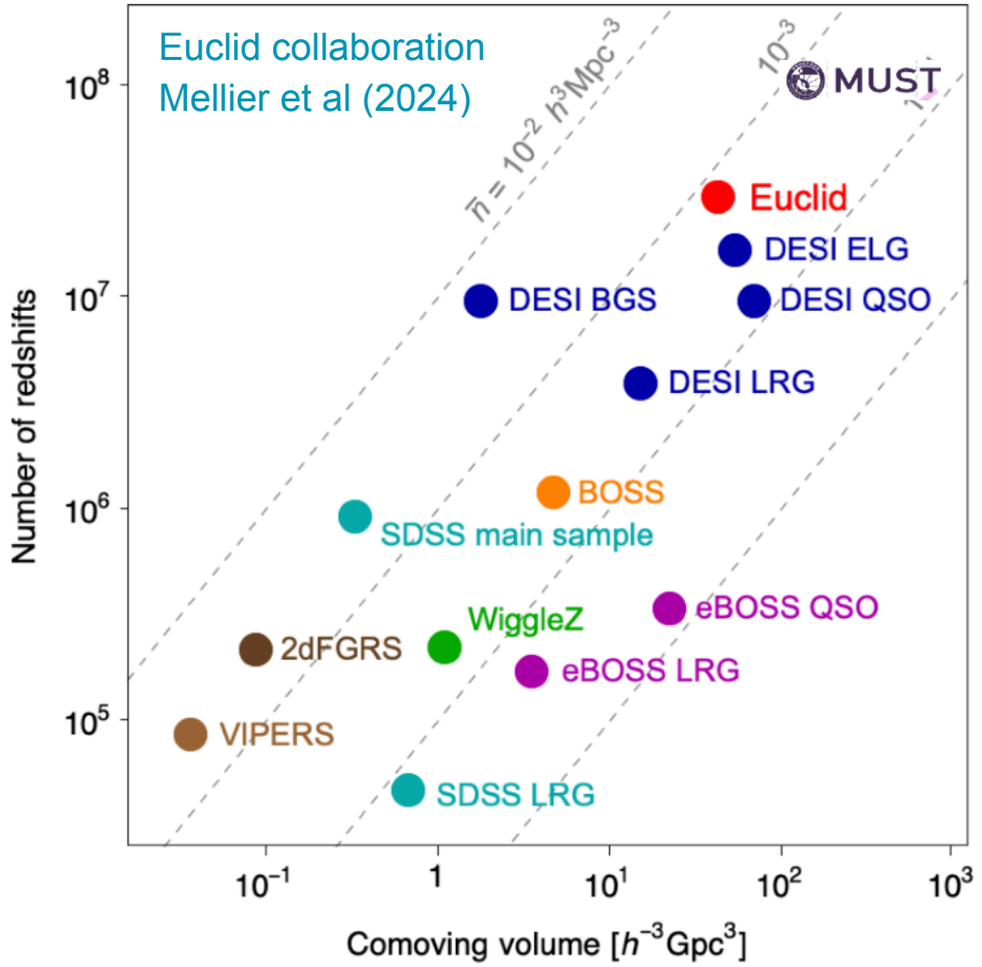
- Challenges:
  - **Computational** cost due to dimensionality of the observables (measurement, theoretical prediction, covariance estimation, inference)
  - **Observational** systematics, survey geometry, …



- Increasing volume of survey and size of samples:
  - Higher S/N detection of the higher-order statistics
  - Enhanced computational challenge and robust modeling of systematics

Limited by observational/theoretical systematics instead of statistical error

(often not well-tested beyond 2pt statistics)



Challenges of Survey Analysis

- Untreated observational systematics can
  - ❖ Bias inferred cosmological parameters
  - ❖ Mimic signatures of new physics



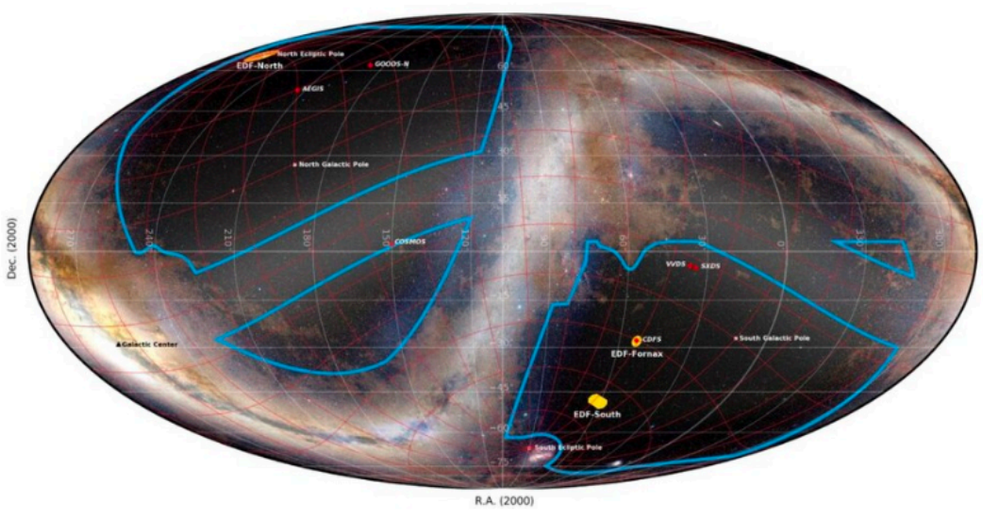
Louis Christoph
PhD @ LAPTh



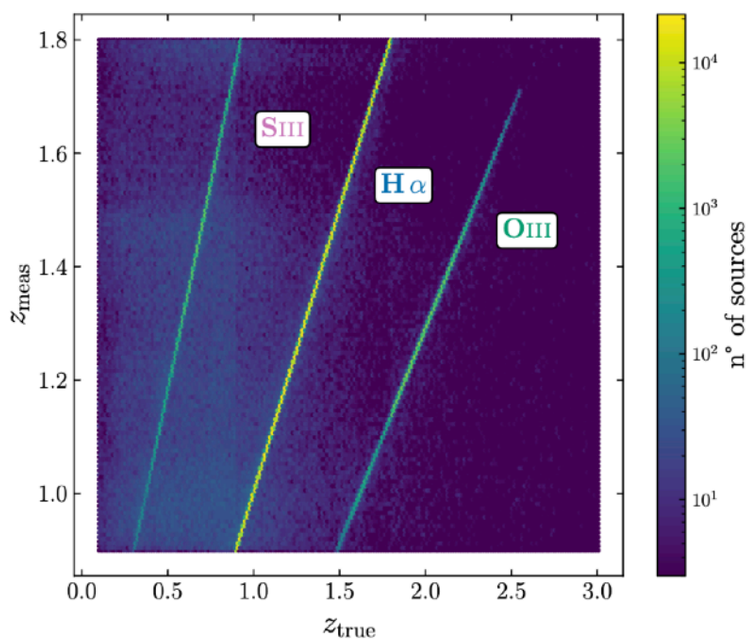
Marina Cagliari
Postdoc @ LAPTh

- For now, focus on three types of systematics for Euclid first data release (DR1)

survey geometry

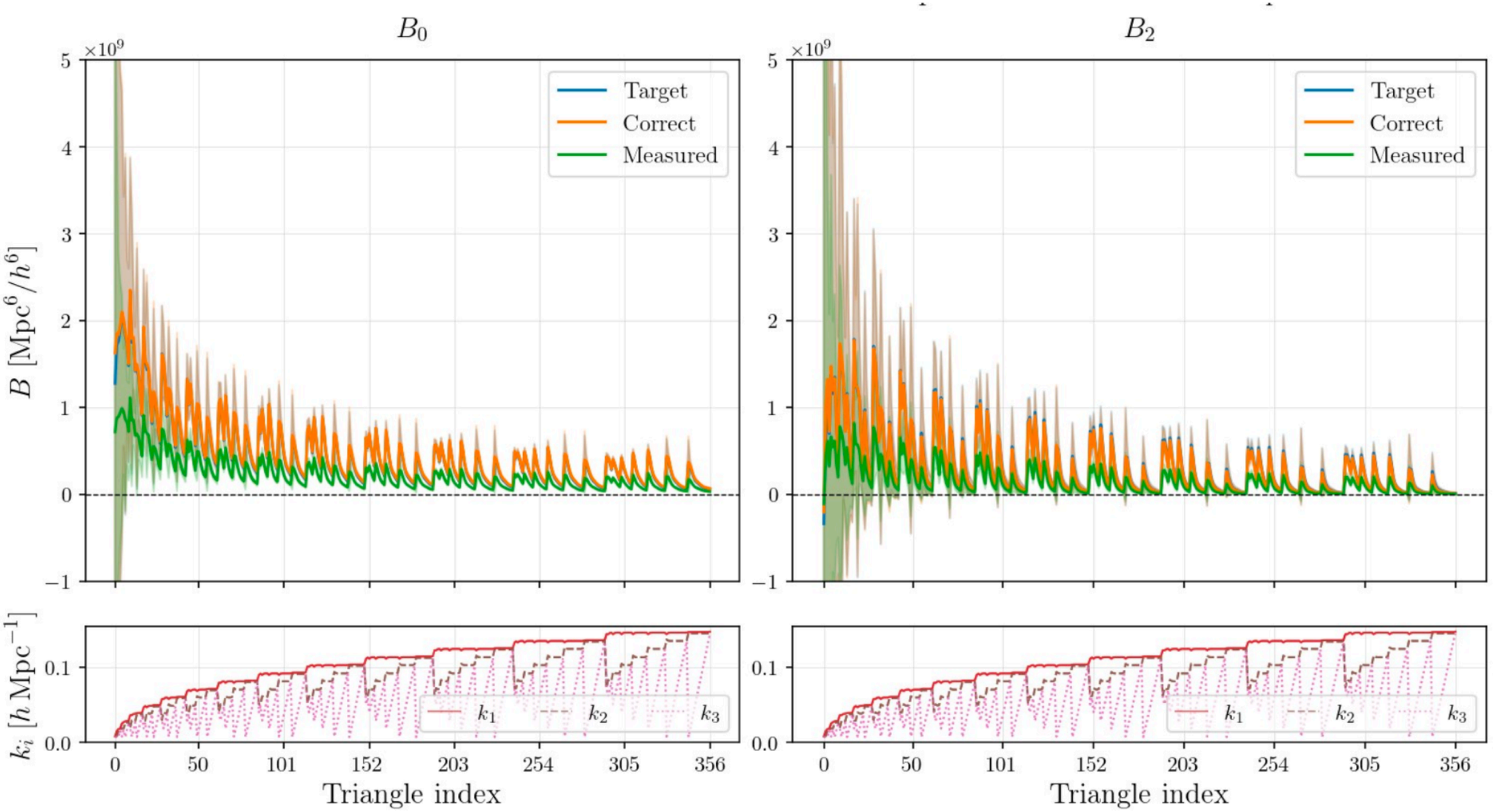


redshift errors: noise and line interlopers

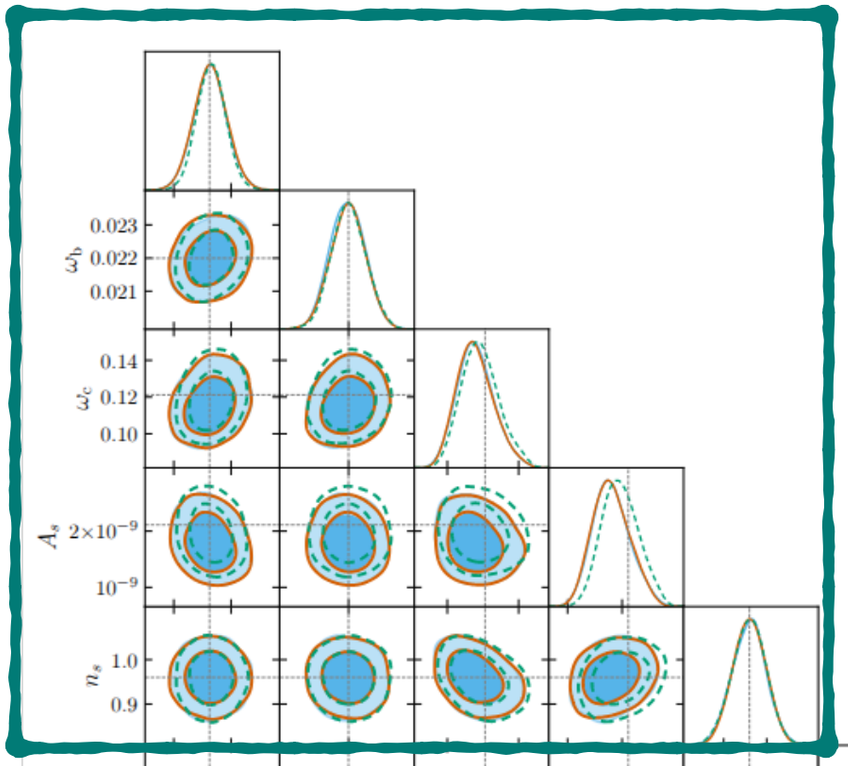


Extensive Tests on Simulated Data

Euclid Large Mocks (ELMs): 1000 simulations with expected systematics of data



Extensive Tests on Simulated Data



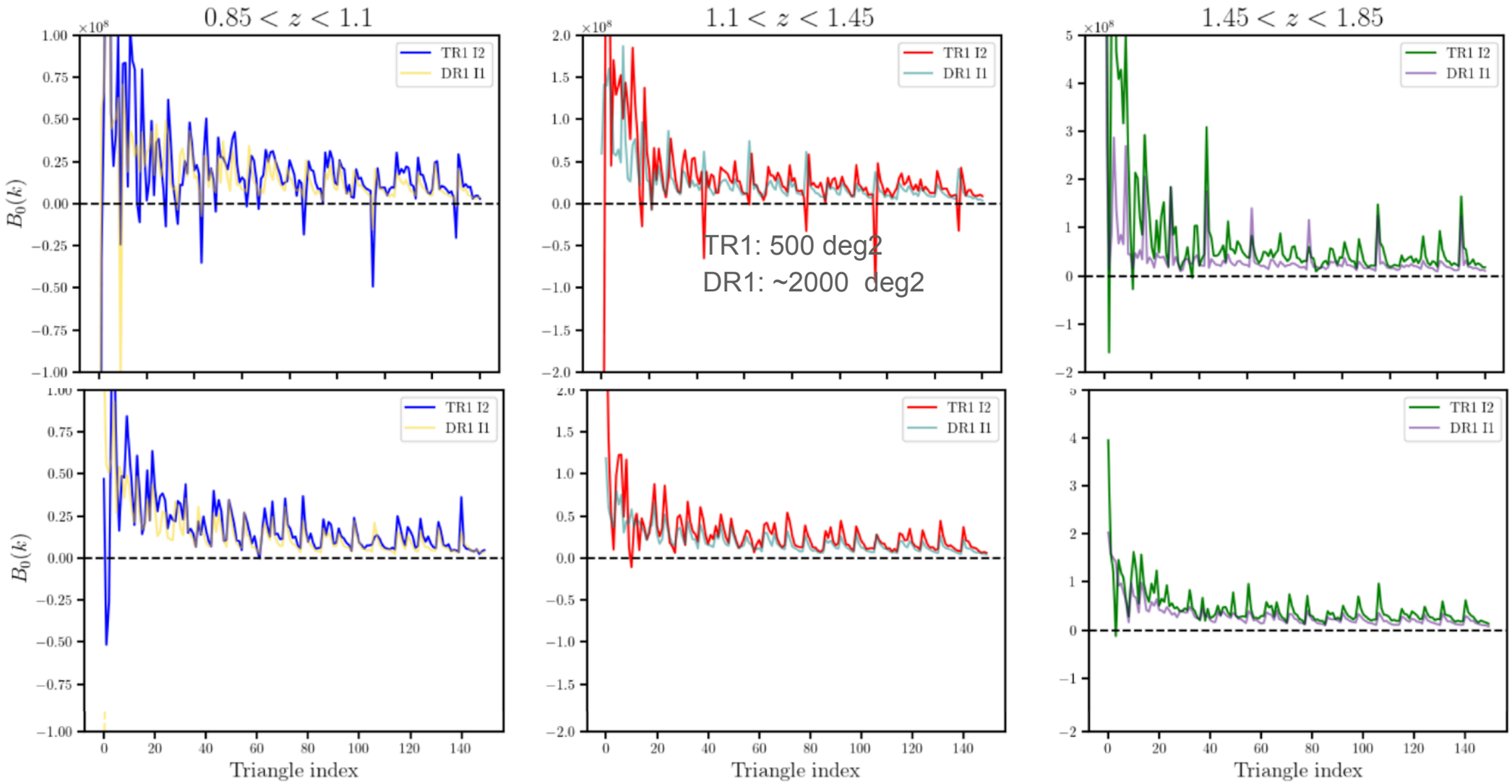
: $\mathcal{P} + \mathcal{B}$ measured, with varying $f_{\rm interl}$
: $\mathcal{P} + \mathcal{B}$ correct, (no interlopers)
: $\mathcal{P} + \mathcal{B}$ measured, with fixed $f_{\rm interl}$
: simulation cosmology

First Look at the Euclid DR1

First measurements in, preparing for analysis (summer 2027)
(efficient and robust pipeline, accurate noise estimation, cosmological inference)

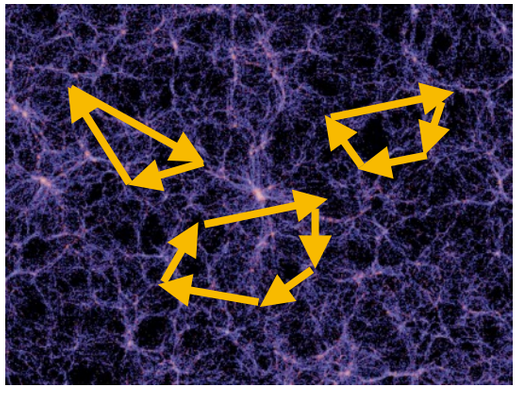
NGC

SGC



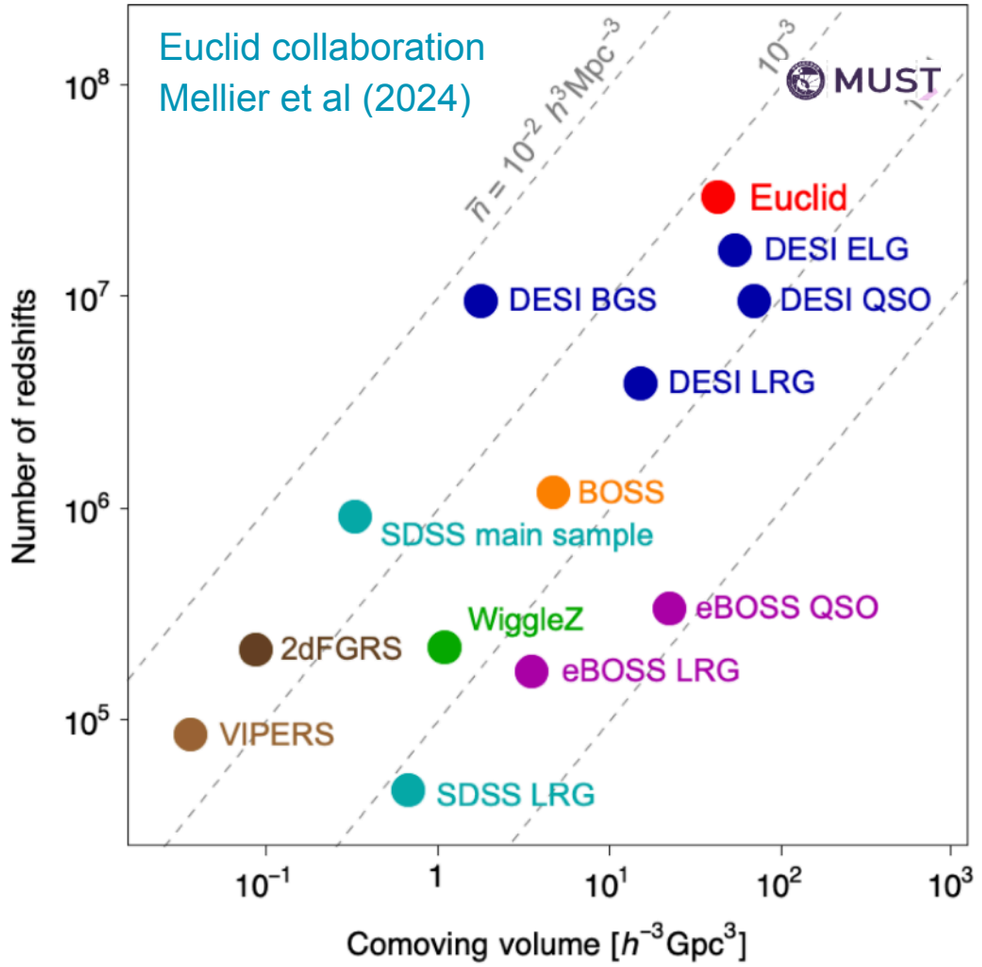
Higher-Order Statistics in Stage-IV Galaxy Surveys

- Challenges:
  - **Computational** cost due to dimensionality of the observables (measurement, theoretical prediction, covariance estimation, inference)
  - **Observational** systematics, survey geometry, …

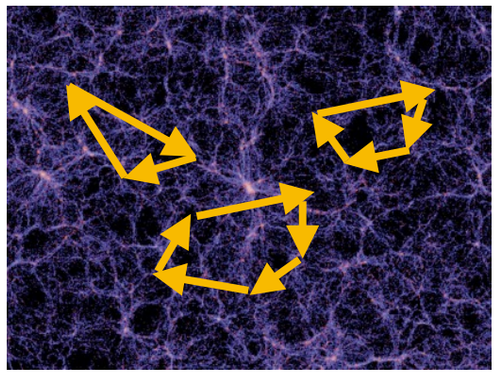


- Increasing volume of survey and size of samples:
  - Higher S/N detection of the higher-order statistics
  - Enhanced computational challenge and robust modeling of systematics

Alternative proxy statistics for N-point functions?



Composite-Field Spectra: Efficient Proxies



- Low dimensional observables as proxies for N-point functions

$$\mathscr{D}_n[\delta](\mathbf{x}) = \prod_{i=1}^{n} \mathscr{D}_i(\mathbf{x})\delta(\mathbf{x})$$

$$\langle D_n[\delta](\mathbf{k}) D_m[\delta](\mathbf{k}')\rangle = (2\pi)^3 \delta_D(\mathbf{k}+\mathbf{k}')\mathscr{P}_{D_n[\delta],D_m[\delta]}(\mathbf{k})$$

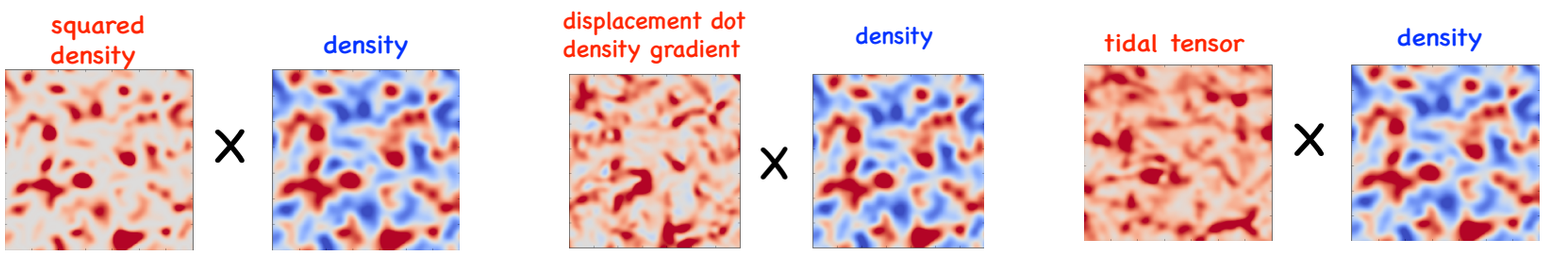
$$D_n[\delta](\mathbf{k}) = \int_{\mathbf{k}_1} \cdots \int_{\mathbf{k}_{n-1}} D_n(\mathbf{q}_1 \cdots \mathbf{q}_{n-1} \mathbf{k} - \mathbf{q}_1 - \cdots - \mathbf{q}_{n-1}) \delta_R(\mathbf{q}_1) \cdots \delta_R(\mathbf{q}_{n-1}) \delta_R(\mathbf{k}_1 - \cdots - \mathbf{q}_{n-1})$$

?

- **Bispectrum**: skew spectra:

  Schmittfull et al (2015), Schmittfull & Moradinezhad (2020)

$$B : \langle \delta\delta\delta \rangle \rightarrow \langle D_2[\delta] D_1[\delta] \rangle$$



Moradinezhad et al (2019),
Hou & Moradinezhad et al (2022),
SimBIG Collaboration: Hou & Moradinezhad et al (2024)

- **Trispectrum**: kurto spectra

$$T : \langle \delta\delta\delta\delta \rangle \rightarrow \langle D_2[\delta] D_2[\delta] \rangle \ \& \ \langle D_3[\delta] D_1[\delta] \rangle$$

Measure galaxy biases: Abidi & Baldauf (2018),
Lazeyras & Schmidt (2018)

Parity-odd trispectrum?

Probing Parity with Scalar Observables

- Full analysis of 4pt CF is very challenging (measurement, noise estimation, inference)

- Instead perform a non-parametric test to examine the hypothesis of zero parity-odd 4PCF by comparing data and mock $\tilde{\chi}^2$

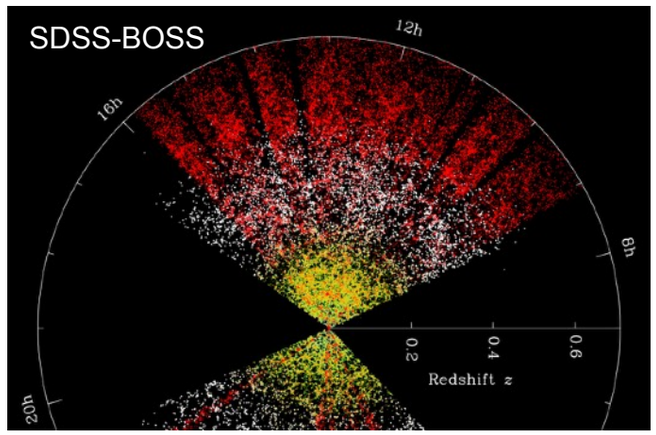
Hou et al (2022), Philcox (2022)
Hou et al (2025), Slepian et al (2025)

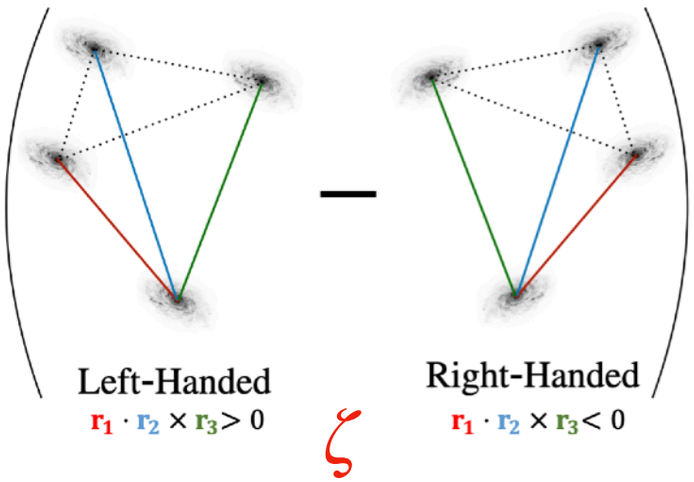
$$\tilde{\chi}^2 \equiv \zeta^T \tilde{C}^{-1} \zeta$$

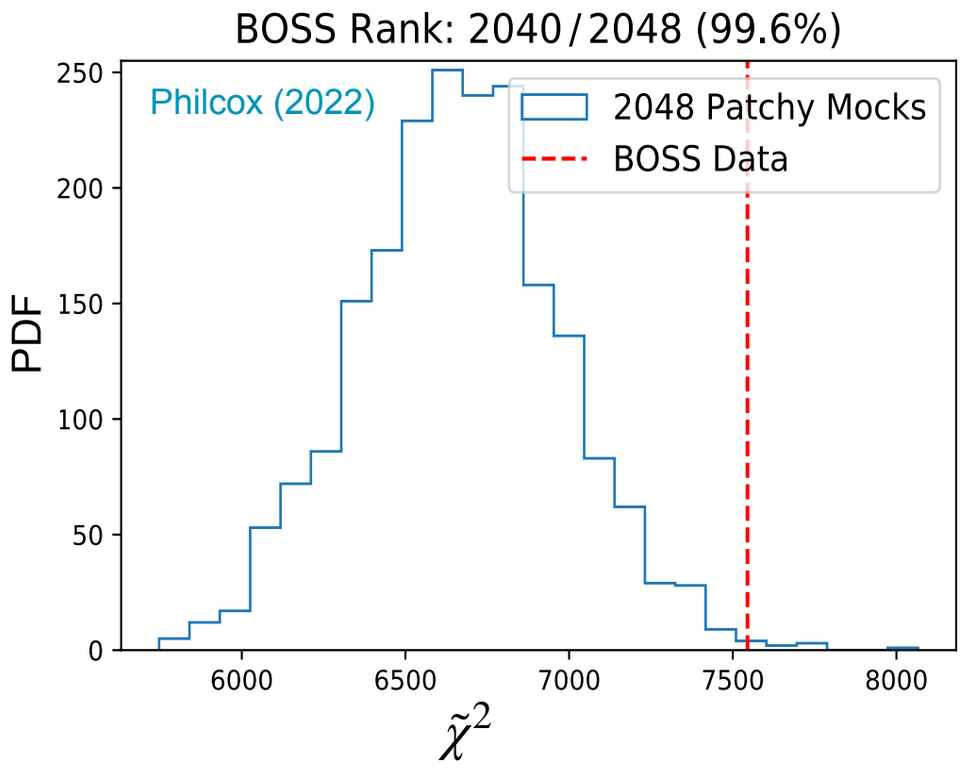
Alternative Summary Statistics?

rely on analytic covariance: dimensionality of 4pt CF (under-estimated error)

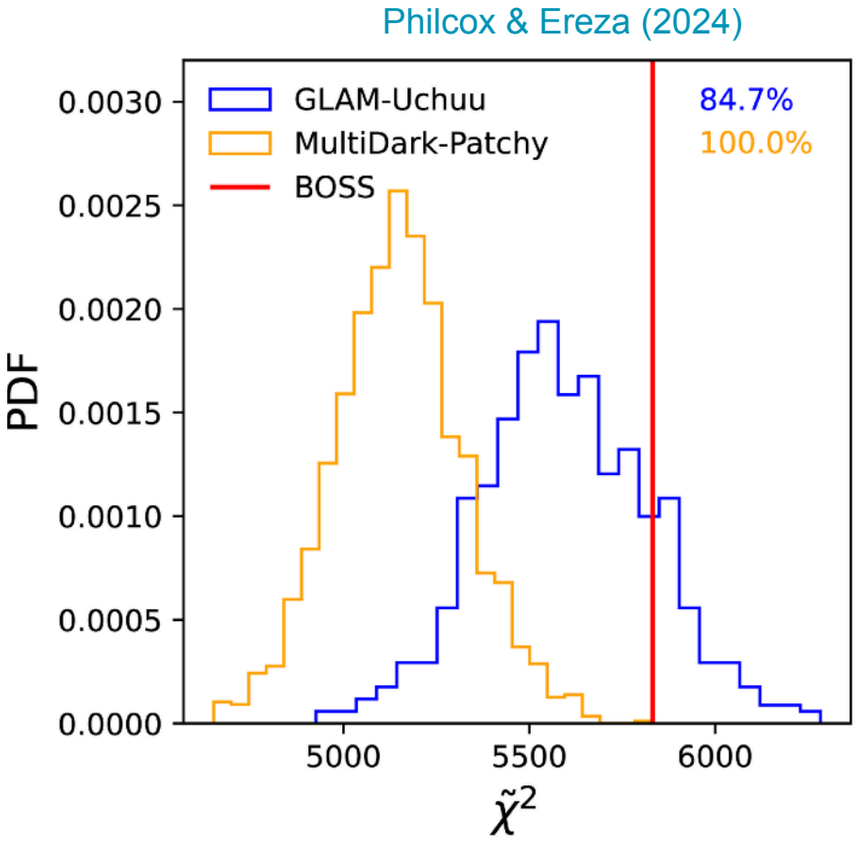
highly sensitive to the employed mocks (data-mock mismatch)







$3\sigma - 7\sigma$ **detection of parity violation ??**



Parity-Odd Kurto Spectra



Zucheng Gao
Postdoc @ LAPTh

$$T : \langle \delta\delta\delta\delta \rangle \rightarrow \langle D_2[\delta] D_2[\delta] \rangle \ \& \ \langle D_3[\delta] D_1[\delta] \rangle$$

$$T_{\rm PO} \rightarrow \langle D_2^i[\delta] D_2^j[\delta] \rangle \ \& \ \langle D_3[\delta] D_1[\delta] \rangle$$

See also Jaimieson et al (2024)

$$V_i^{ab}(\vec{x}) = \delta^a(\vec{x}) \partial_i \delta^b(\vec{x})$$

$$A_i^{ab}(\vec{x}) = \epsilon_{ijk} \partial_j \partial^{-2} V_k^{a'b'}(\vec{x})$$

$$\rightarrow \quad \mathscr{P}^{\rm PO}_{2\times 2}(k) = \int \frac{d\Omega_k}{4\pi} \langle \mathbf{V}^{ab}(\mathbf{k}) \cdot \mathbf{A}^{cd}(-\mathbf{k}) \rangle$$

vector, pseudo-vector

$$\Psi^{abc}(\mathbf{x}) = \nabla \delta^a(\mathbf{x}) \cdot \mathbf{B}^{bc}(\mathbf{x})$$

$$\mathbf{B}^{bc}(\mathbf{x}) = \nabla \delta^b(\mathbf{x}) \times \nabla \delta^c(\mathbf{x})$$

$$\rightarrow \quad \mathscr{P}^{\rm PO}_{3\times 1}(k) = \int \frac{d\Omega_k}{4\pi} \langle \delta(\mathbf{k}_2) \Psi^{abc}(\mathbf{k}_1) \rangle$$

pseudo-scalar

- Apply to Nbody simulations with parity-odd ICs (Quijote parity-odd suite) Coulton et al (2023)

Gao, Moradinezhad, Vlah (2025)

Quijote Parity-odd Simulations

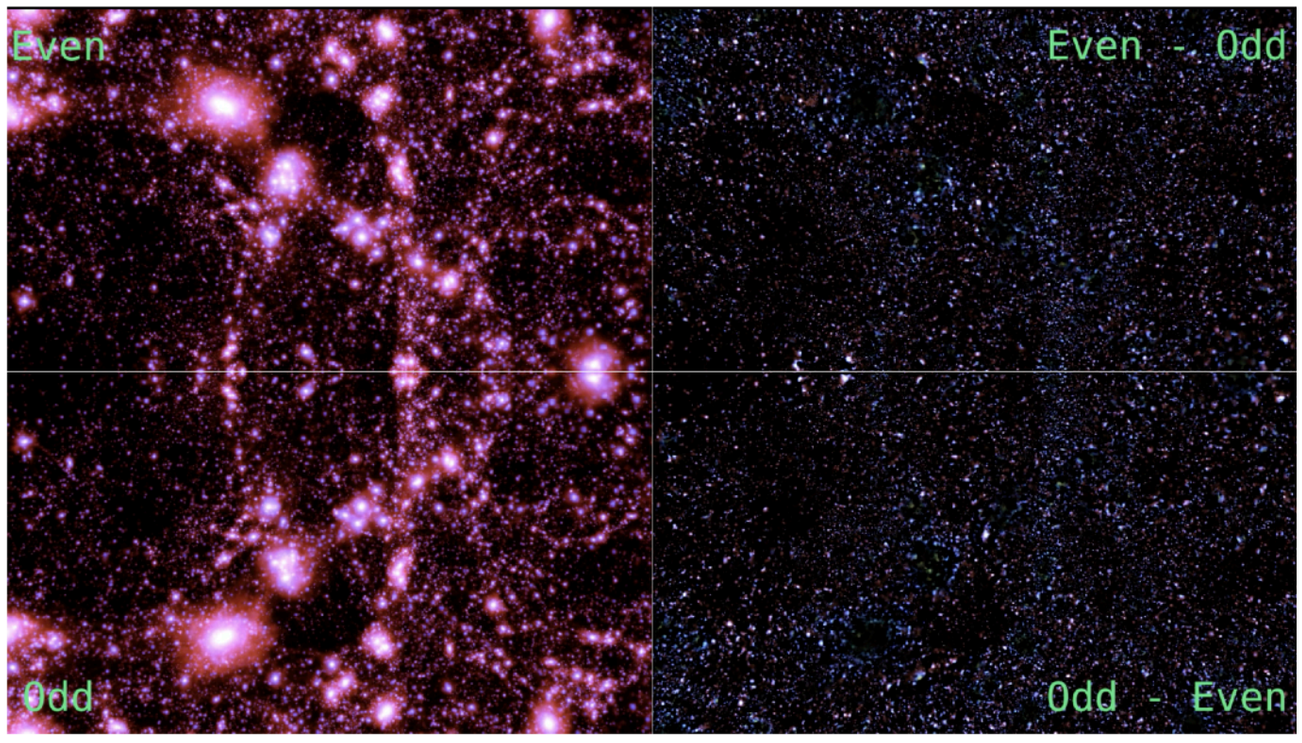
- Parity-odd initial conditions

Depends on derivative structure of the couplings, model

$$\phi(\mathbf{k}) = \phi_{\rm G}(\mathbf{k}) + \phi^{(3)}_{\rm NG}(\mathbf{k}) \qquad K^{(3)}_{\rm NL,PO}(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3) = \mathbf{k}_1\cdot\left(\mathbf{k}_2\times\mathbf{k}_3\right) S(k_1,k_2,k_3)$$

$$T_\phi(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3,\mathbf{k}_4) = i\, g^{\rm PO}_{\rm NL}\, K^{(3)}_{\rm NL,PO}(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3)\, P_\phi(k_1)\, P_\phi(k_2)\, P_\phi(k_3) \;+\; 23 \text{ perms},$$

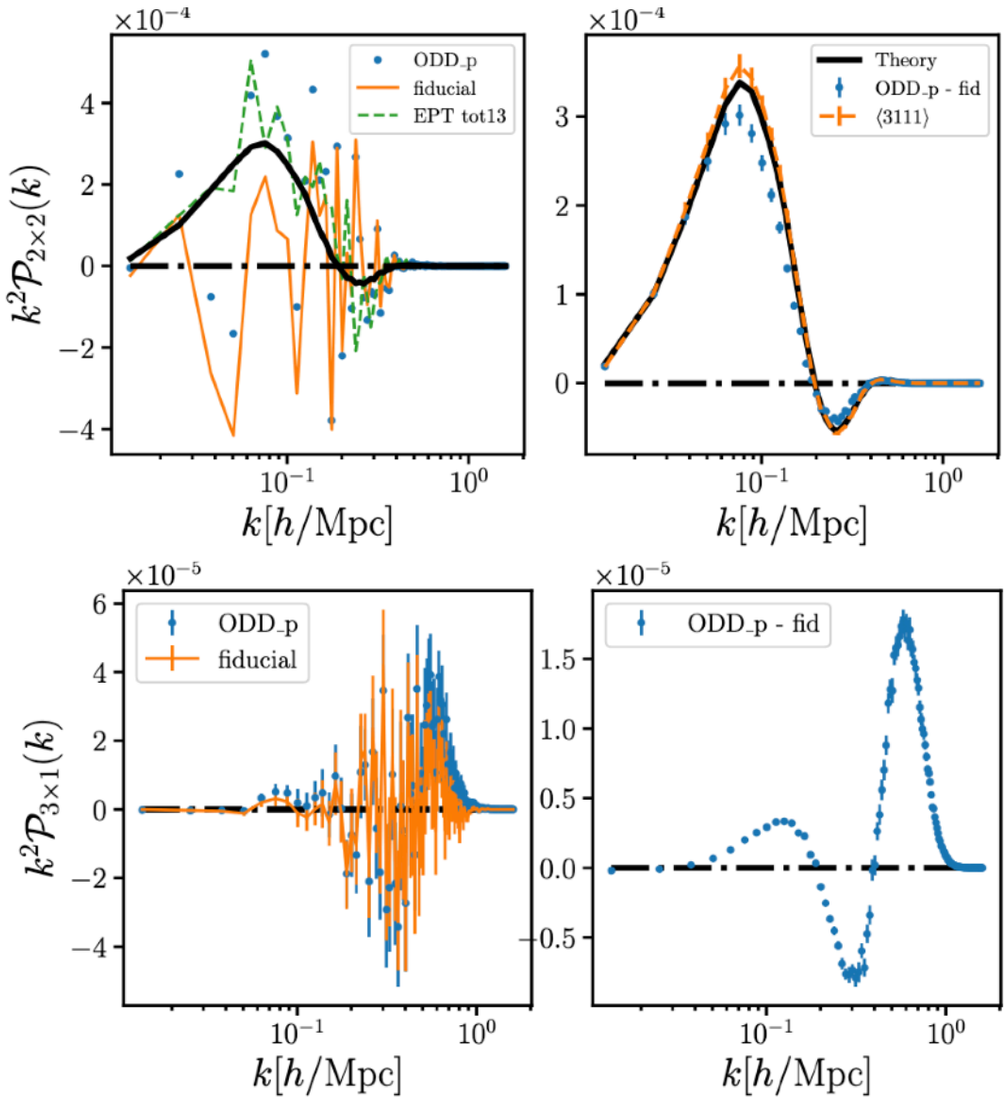
- Nobody simulations (Gadget), box of $V = 1\ (\mathrm{Gpc}/h)^3$, evolving 512^3 particles
- Total of 1000 simulations with $g^{\rm PO}_{\rm NL} = \{+10^6, -10^6\}$ and their corresponding phase-matched $g^{\rm PO}_{\rm NL} = 0$



Matter & Halo Parity-Odd Kurto Spectra

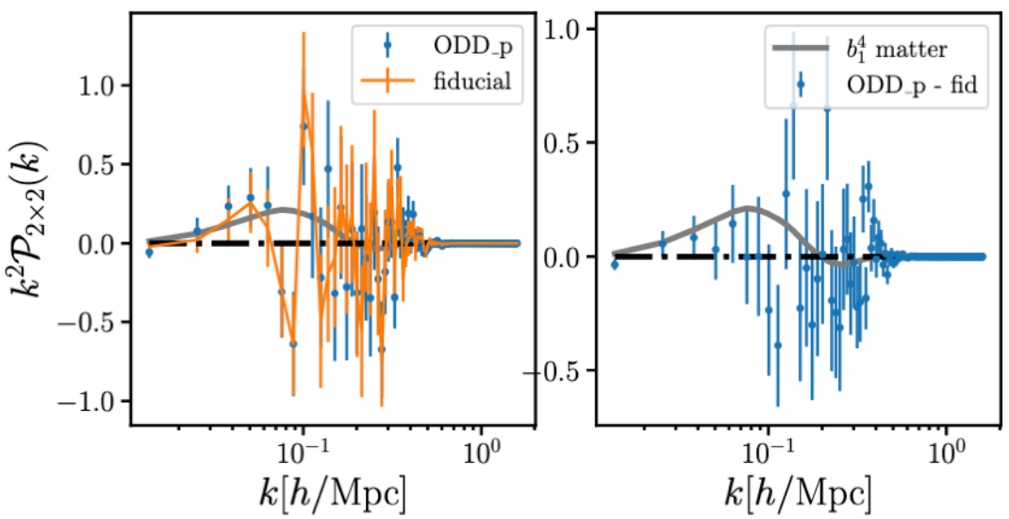
- Dark matter: substantial noise from parity-even contributions on a single realization
- Averaged over 40 realizations still noisy, fiducial subtraction brings out the signal
- Distinct shapes of kurto spectra, sensitivity to different trispectrum configurations

Dark matter, 40 realizations ~ full Euclid Volume



- Halos: very noisy [even in a volume of 500 (Gpc/h)^3]
- Origin of noise: differing stochasticity

Halos, 500 realization



Gao, Moradinezhad, Vlah (2025)

Non-Parametric Tests on Galaxy Survey Data

Gao, Cagliari, Moradinezhad, Vlah (2026)

- Null hypothesis: no cosmological parity violating (PV) signal

- Use a χ^2 statistics to verify null hypothesis: $\chi^2 = \xi^{\mathrm{T}} \mathbf{C}^{-1} \xi$

Signal: $\{\mathscr{P}_{2\times2}, \mathscr{P}_{3\times1}\}$ covariance; numerical

Compare its value on **observed** and **simulated** galaxy mocks



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Survey Data: Measurements

SDSS-BOSS (DR12)

Area (deg2): 7429 (NGC) + 2823 (SGC)

Redshift range: 0.43 < z < 0.7

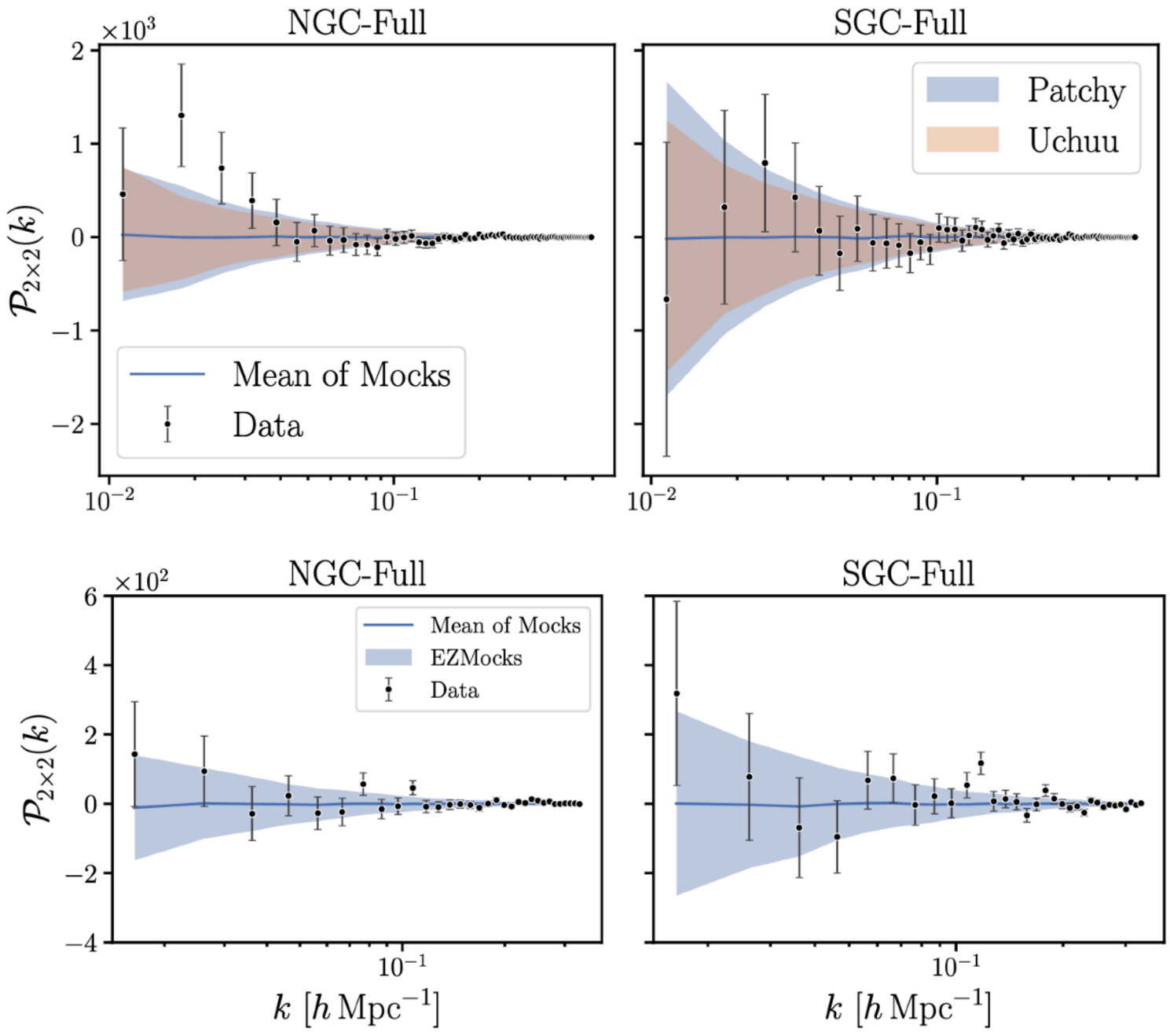
Mean number density: $3.5 \times 10^{-4}\ (h/\mathrm{Mpc})^3$

DESI (DR1)

Area (deg2): 3650 (NGC) + 2089 (SGC)

Redshift range: 0.4 < z < 1.1

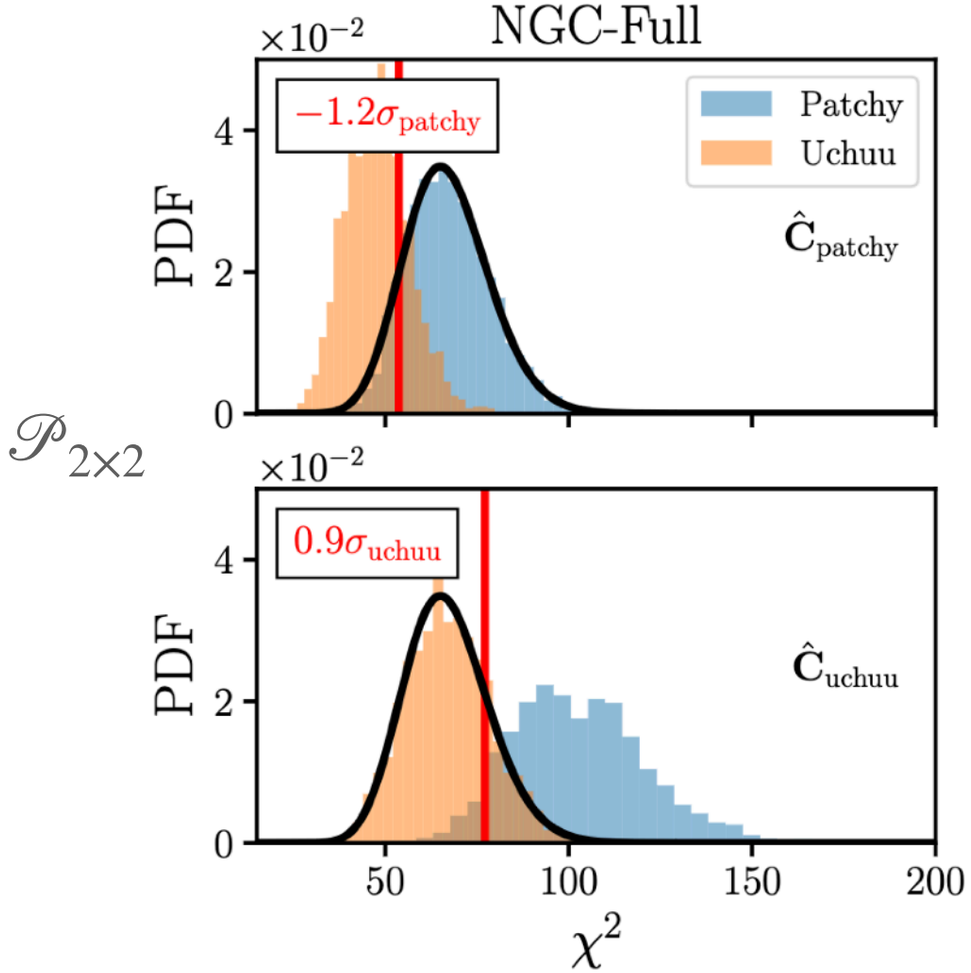
Mean number density: $5 \times 10^{-4}\ (h/\mathrm{Mpc})^3$



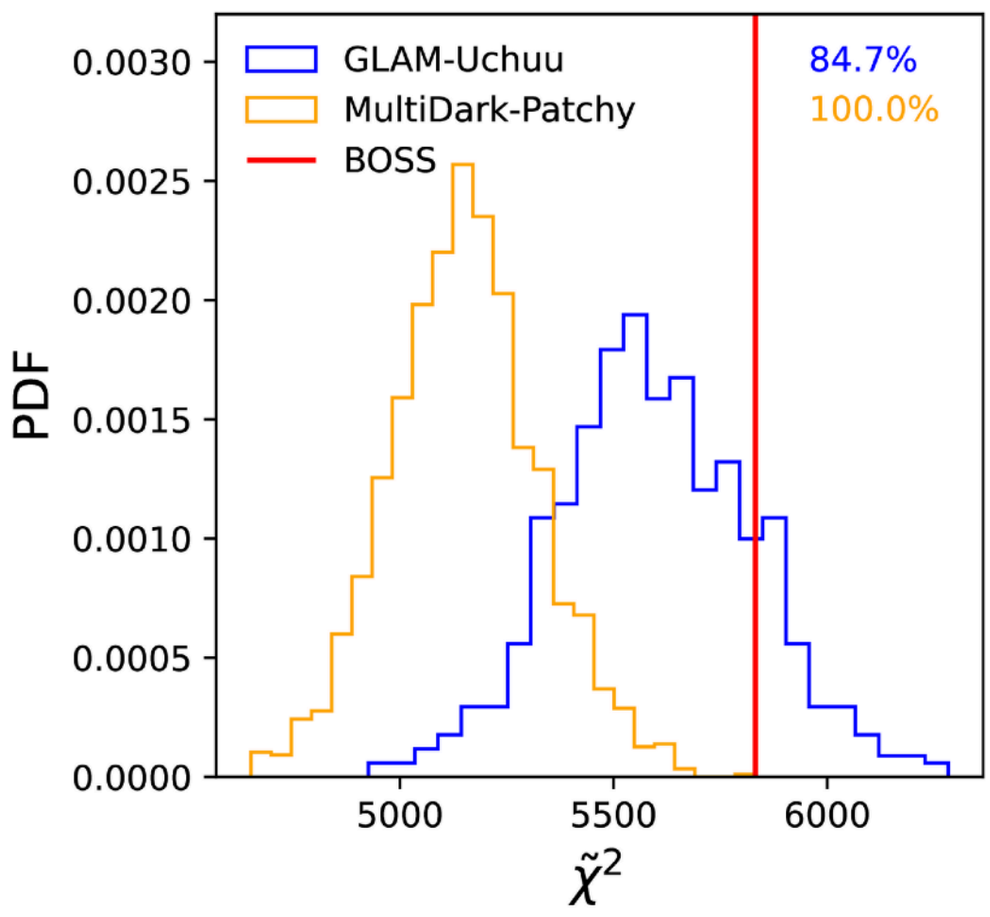
Gao, Cagliari, Moradinezhad, Vlah (2026)

Survey Data (BOSS): Testing Null Hypothesis

- Substantially lower-dimensional than 4pt CF: directly use mocks for covariance estimation
- More robust (less sensitive) to the choice of mocks compared to 4pt CF
- $\chi^2_\times$ perfectly consistent with zero independent of the mock, confirming no PO signal



Gao, Cagliari, Moradinezhad, Vlah (2026)

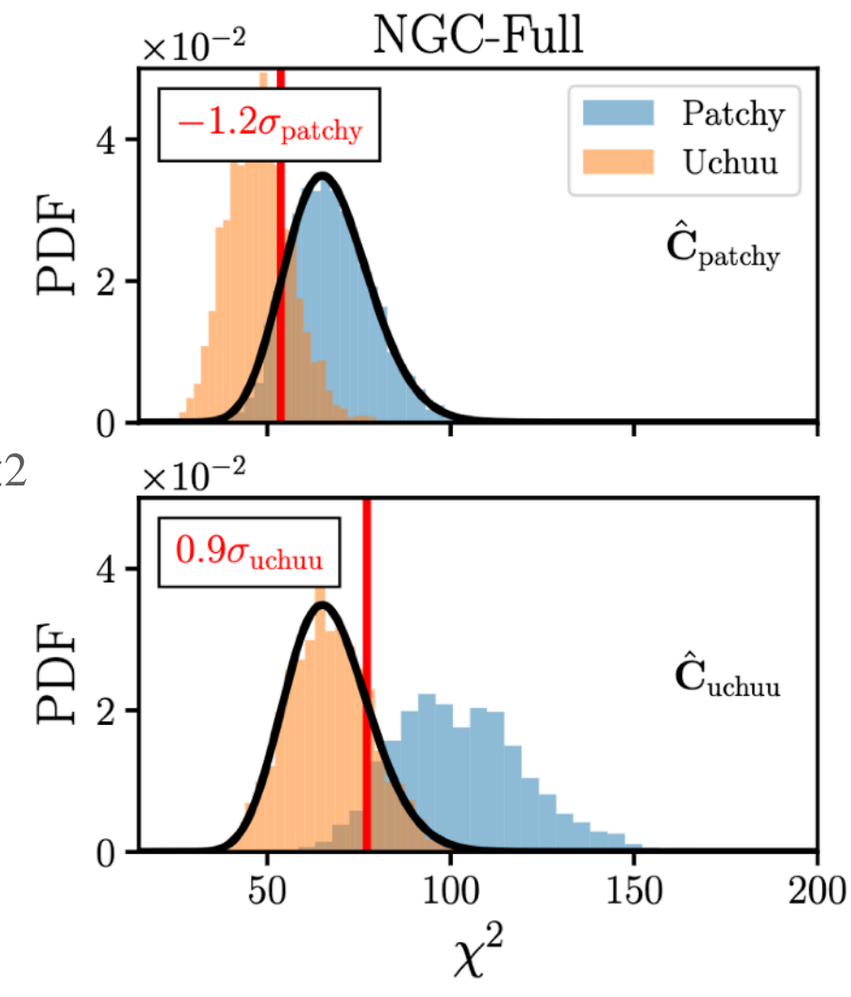


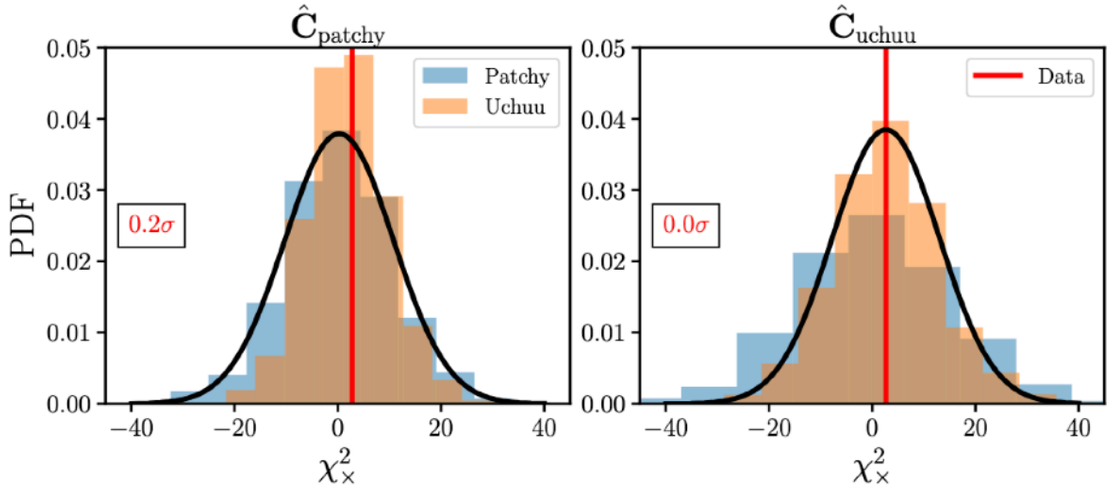
Philcox & Ereza (2024)

Survey Data (BOSS): Testing Null Hypothesis

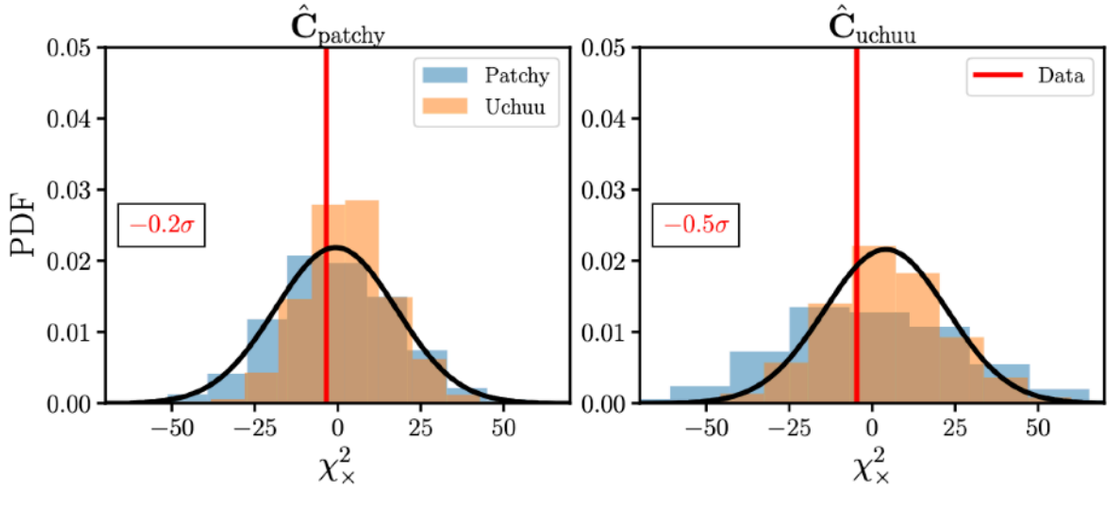
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$\mathscr{P}_{2\times2}$





(a) Cross-chi-square for the $\mathcal{P}_{2\times2}$ kurto spectra.



(b) Cross-chi-squared for the $\mathcal{P}_{3\times1}$ kurto spectra.

Gao, Cagliari, Moradinezhad, Vlah (2026)

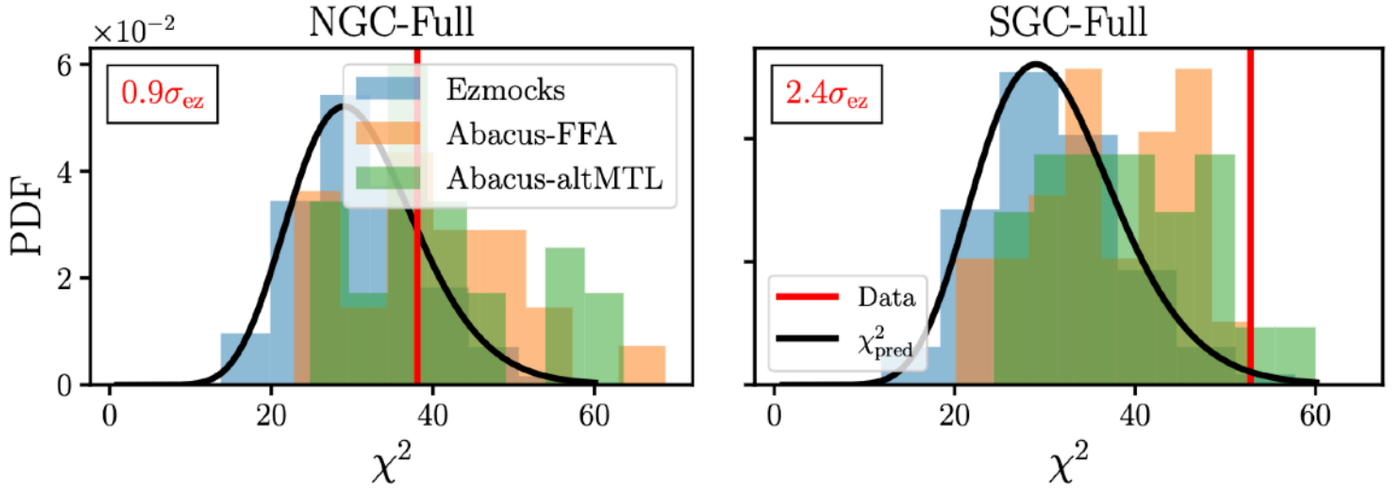
Survey Data (DESI): Testing Null Hypothesis

- Here $\chi^2_{\rm data} > \chi^2_{\rm mocks}$, mocks are better representation of data compared to BOSS (?)
- No detection of parity-odd signal (up to 3σ discrepancy due to a few points on small scales)
- Kurto spectra less sensitive than 4pt-CF to small-scale modeling (e.g. fiber collision)

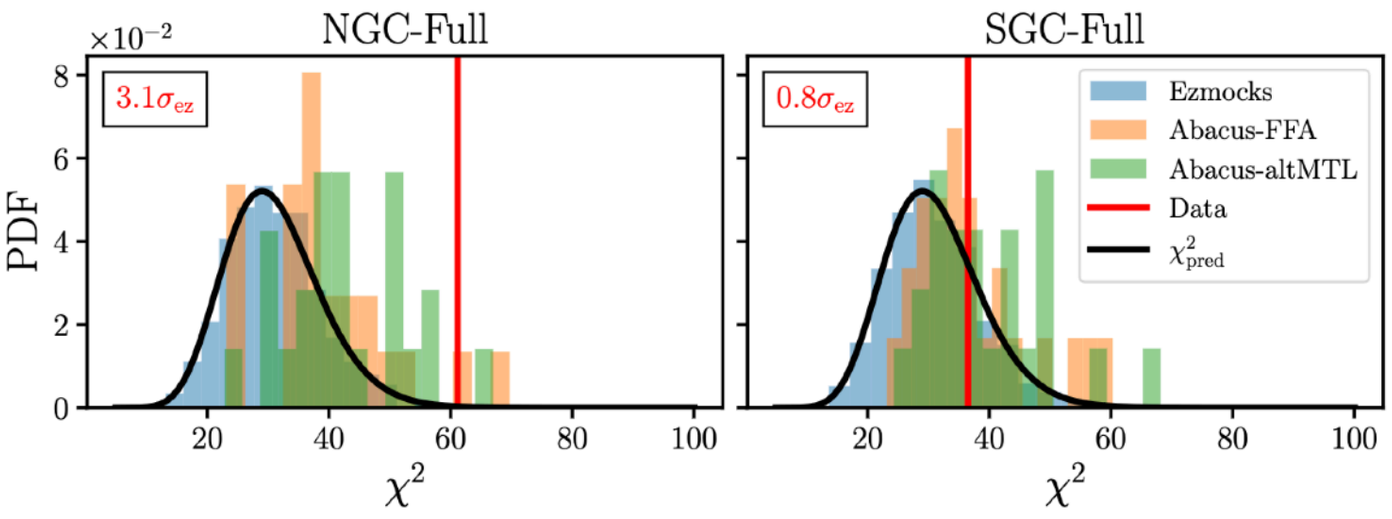
DESI 4pt-CF: Hou et al (2025)

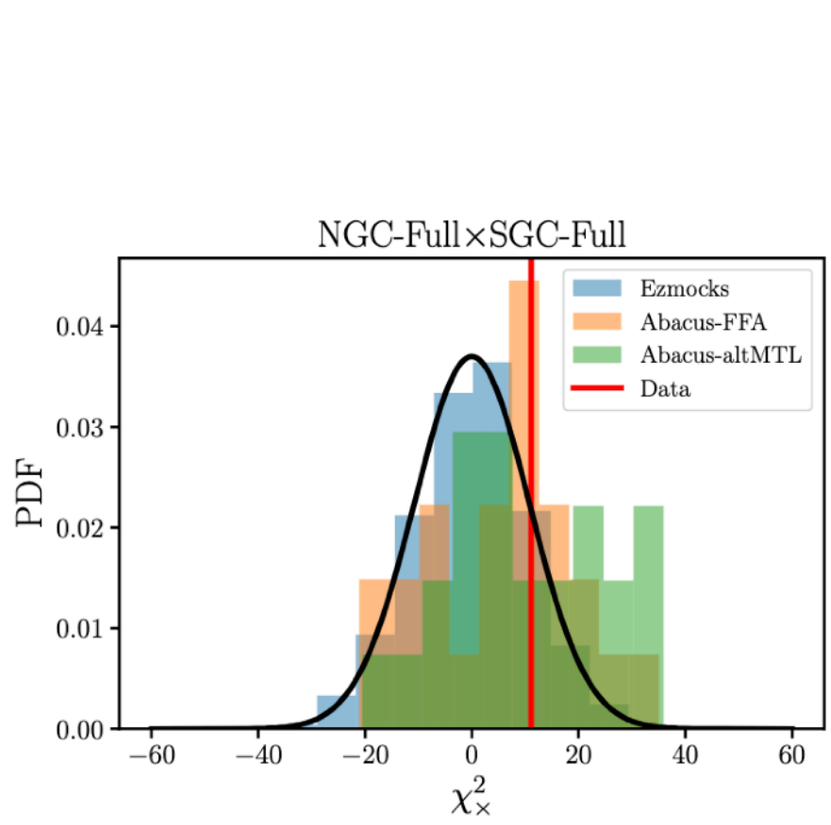
- $\chi^2_\times$ consistent with zero independent of the mock used

$\mathscr{P}_{2\times2}$

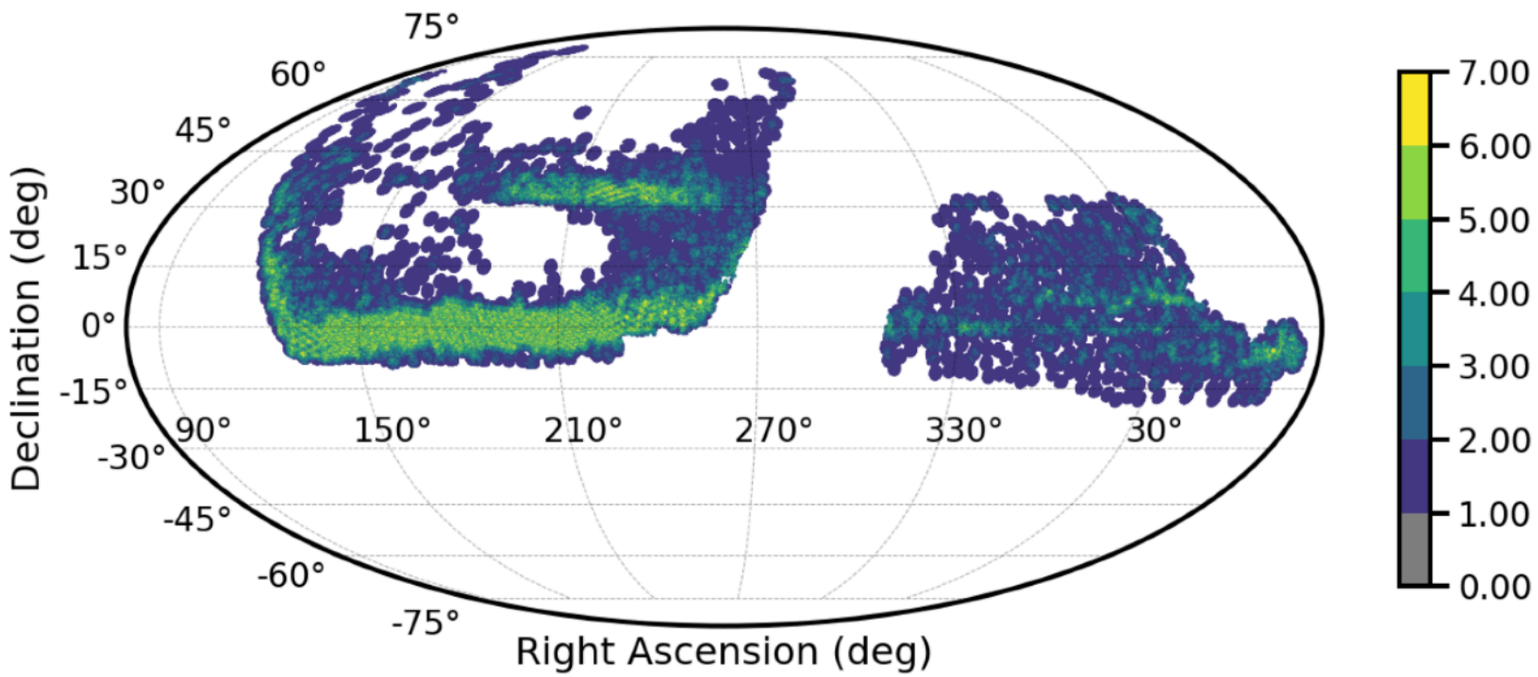


$\mathscr{P}_{3\times1}$





Future Detection/Tighter Constraints?



DESI collaboration: Hou et al (2025)

Data

- More complete sample
- More dense sample
- Multiple tracers: BGS, ELG, LRG, Quasars
- Higher redshift sample (e.g. DESI-II & S5)

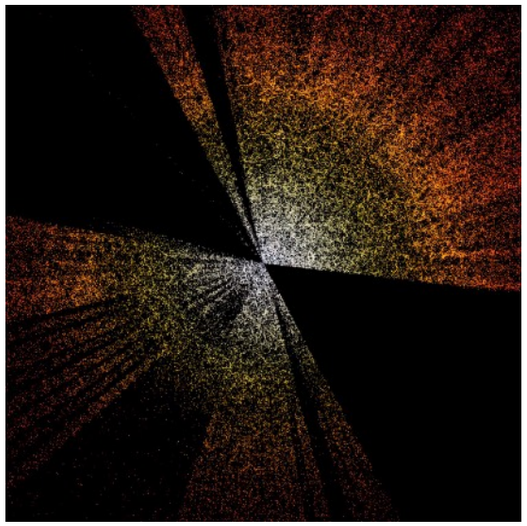
Analysis

- Optimal weighting of galaxies
- Template search for broader classes of inflation model
- Beyond null detection: inference

Simulation-Based Inference (SBI)

$\boldsymbol{x}$

Observed Galaxy Distribution

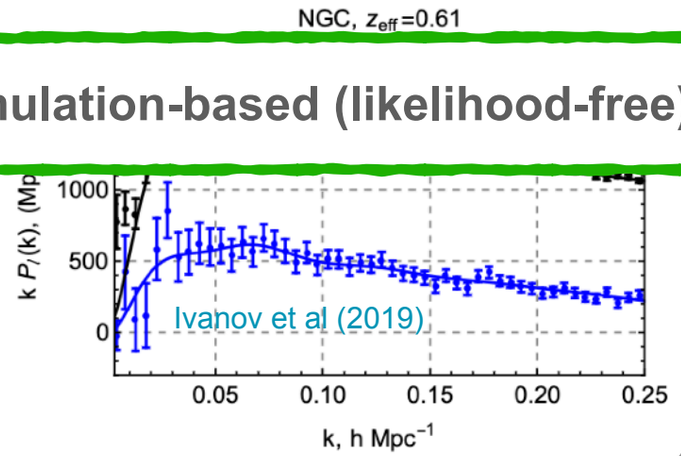


$$\underbrace{p(\boldsymbol{\theta}\,|\,\mathbf{x})}_{\text{Posterior}} \propto \underbrace{p(\mathbf{x}\,|\,\boldsymbol{\theta})}_{\text{Likelihood}} \underbrace{p(\boldsymbol{\theta})}_{\text{Prior}}$$

Data Compressi

Summary Statistics

- 2-point correlation function



Simulation-based (likelihood-free) Inference

Theoretical Model

- perturbation theory

Likelihood

$\boldsymbol{\theta}$

Inferred Cosmology

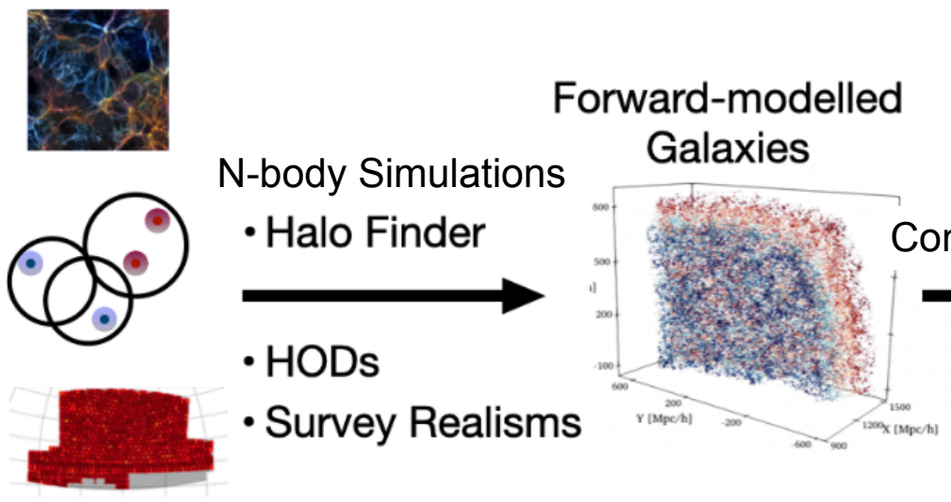
A_s $N_{\rm eff}$
n_s Σm_ν
h $f_{\rm NL}$
Ω_c …
Ω_b

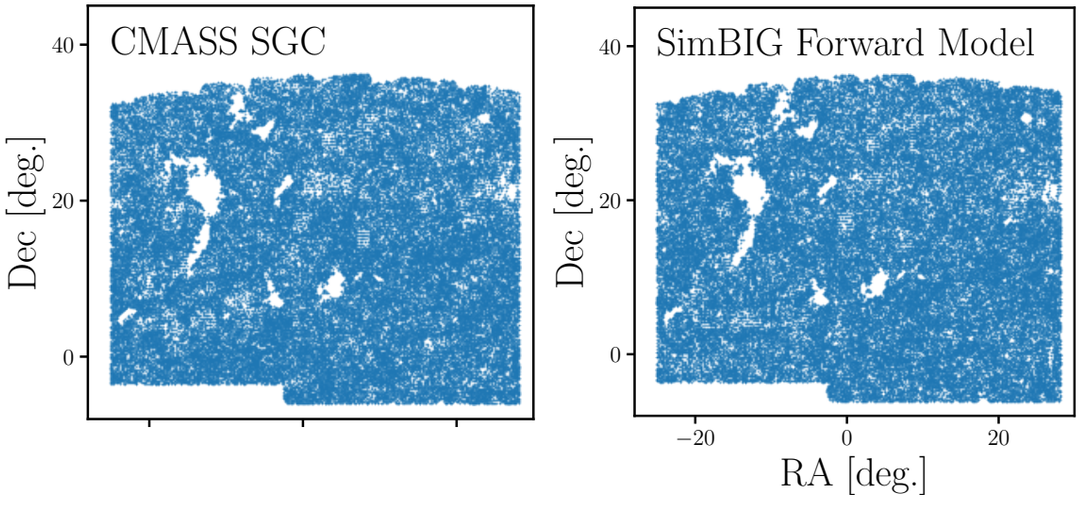
- **SBI** addresses three shortcomings of traditional analysis by
  - Using high-fidelity simulations to model the signal instead of PT-based models
  - No strong assumption on the form of the likelihood instead of Gaussian form
  - Accurate forward modeling of the observational systematics instead of applying approximate correction schemes

Simulation-Based Inference on BOSS Data

SimBig: framework for performing forward modeling + simulation-based inference

performance and specific challenges of each statistics





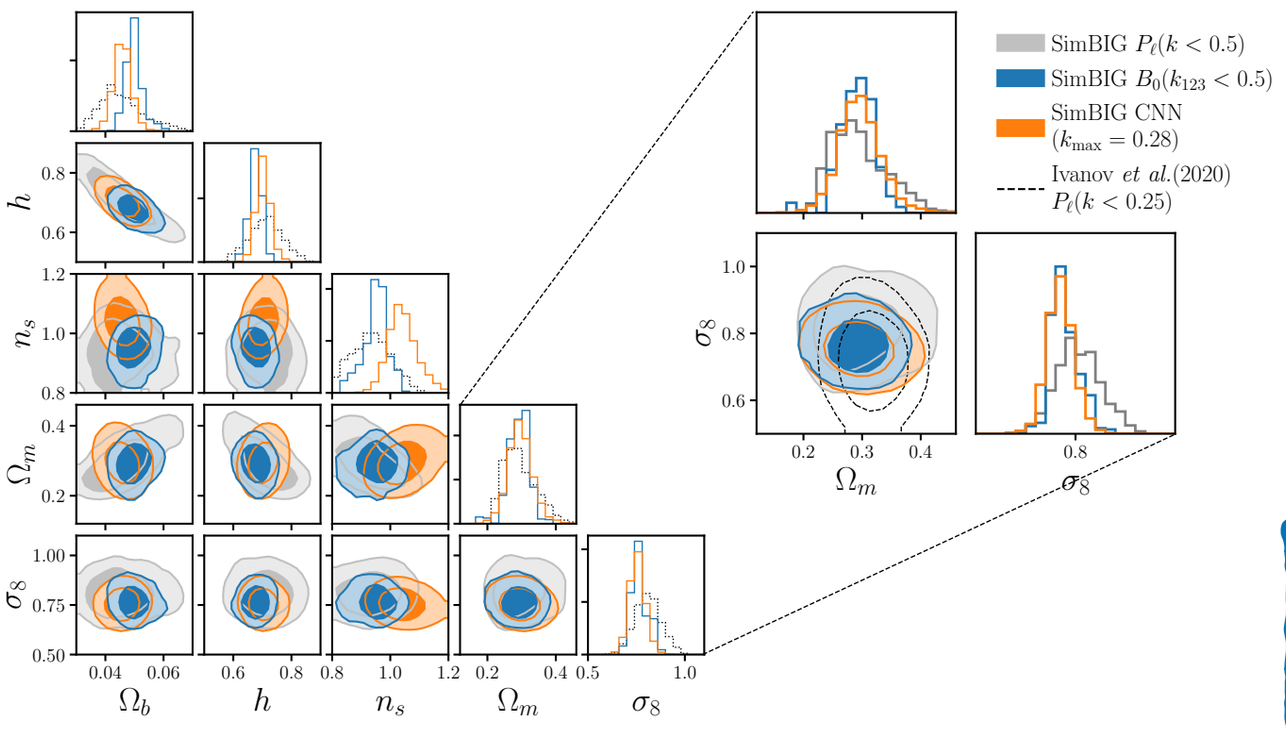
BOSS-CMASS analysis (10%) $0.45 < z < 0.6$

Power spectrum: Hahn et al (incl. Moradinezhad) (2022a, 2022b)
Bispectrum: Hahn et al (incl. Moradinezhad) (2023c, 2023d)
CNN: Lemon & Parker et al (incl. Moradinezhad) (2023)
WST: Regaldo et al (incl. Moradinezhad) (2023)
Skew spectra: Hou & Moradinezhad et al (2024)
Marked power spectrum: Massara et al (incl. Moradinezhad) (2024)

SimBIG: Power Spectrum, Bispectrum, CNN

Analyzing 10% of BOSS survey (CMASS-SGC)

- Significant improvement over P_ℓ (x3 in h, x1.8 in σ_8)
- Notable improvement over standard P_ℓ analysis (x1.5 in h, x2 in σ_8)



Hahn et al (including **Moradinezhad)** et al (2023b)

Challenges moving to Stage-IV surveys

- ❖ Simulations with larger volume and better mass resolution
- ❖ Increasingly accurate forward models

- Specs for SimBIG-I (Quijote simulations)
  - ❖ Cost of 10 million CPU hours,
  - ❖ Small volume of 1Gpc/h
  - ❖ Coarse resolution (restricted to HOD and not more accurate galaxy models)
  - ❖ Limited to LCDM

SimBIG-II : New simulation suite for DESI-LRG & cross correlation w. CMB lensing

$(w_0 w_a M_\nu - \mathrm{CDM})$

Conclusions

- **Large-scale structure is becoming a precision lab for fundamental physics**
  Constrain early-Universe physics, nature of dark components, and law of gravity

- **Extracting non-Gaussian information is essential**
  Nonlinear structure information and some new physics imprints

- **The central challenge is robust and efficient extraction of information**
  Interpretable summary statistics and robust inference

- **Looking ahead: rapidly-growing simulation-based analysis w. machine learning**
  standard analysis (perturbative model + Gaussian likelihood) vs simulation-based Inference