DESI (edited)

An *Unofficial* DESI Analysis

Turning 5 million galaxies into 3 numbers…

Oliver H. E. Philcox

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Acknowledgements

Reanalyzing DESI DR1:
1. ΛCDM Constraints from the Power Spectrum & Bispectrum

Anton Chudaykin,[1,*] Mikhail M. Ivanov,[2,3,†] and Oliver H. E. Philcox[4,5,6,7,‡]

(ChatGPT)

arXiv:2507.13433

Additional thanks

- **"East Coast" team**: Marko Simonovic, Matias Zaldarriaga, Giovanni Cabass, Kazu Akitsu, Stephen Chen
- **"West Coast" team:** Guido D'Amico, Leonardo Senatore, Pierre Zhang, Matt Lewandowski

and, of course, the **DESI collaboration!**

Galaxy Clustering Experiments

The Past

- BOSS [2009 — 2014]

The Present

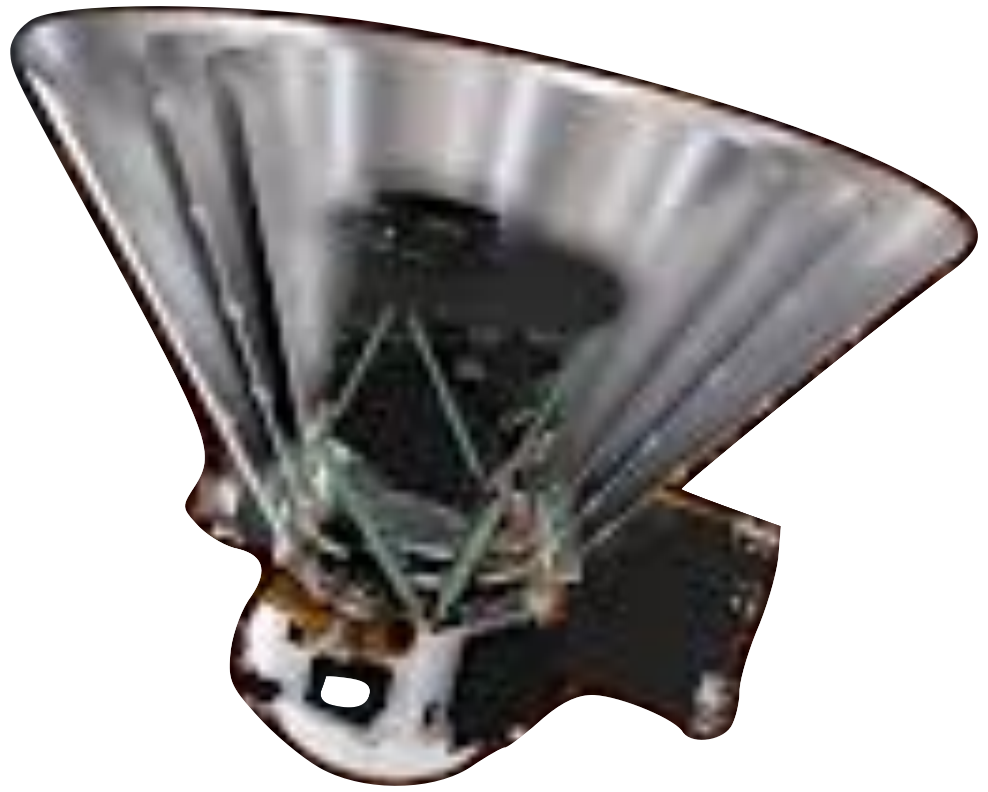
- DESI [2021 — 2026]
- Euclid [2024 — 2030]

The Nearly

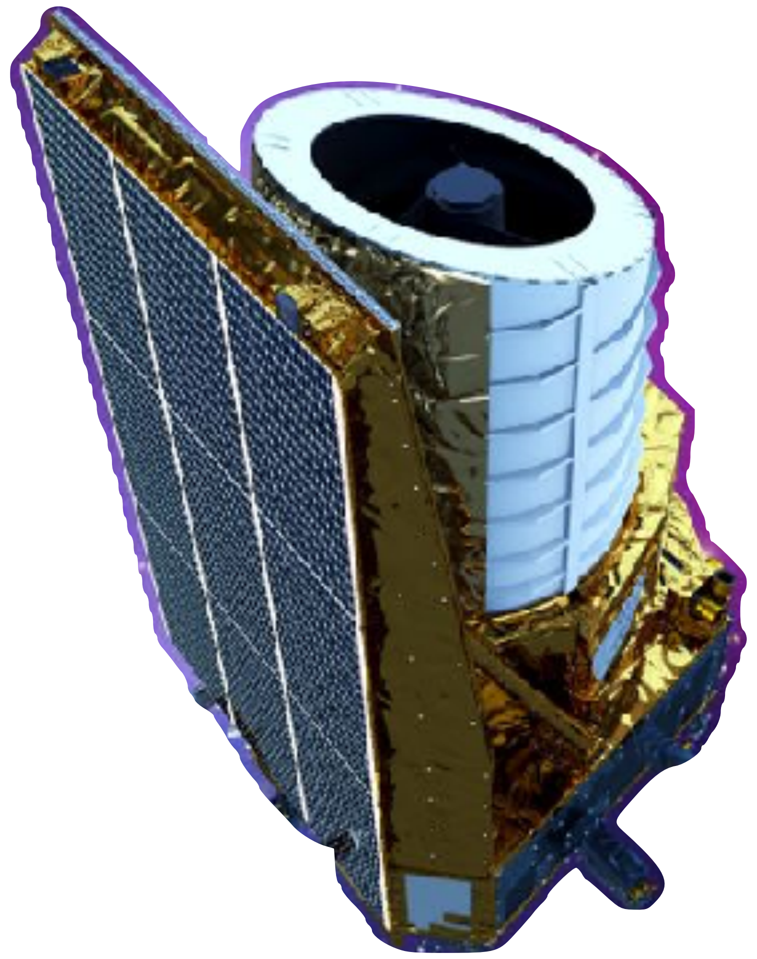
- SphereX [2025 — 2027]
- Rubin [2025 — 2035]
- Roman [launches 2027]

The Future

- Spec-S5? [planning]



SPHEREx



Euclid

DESI

Roman

Rubin

What Do These Probe?

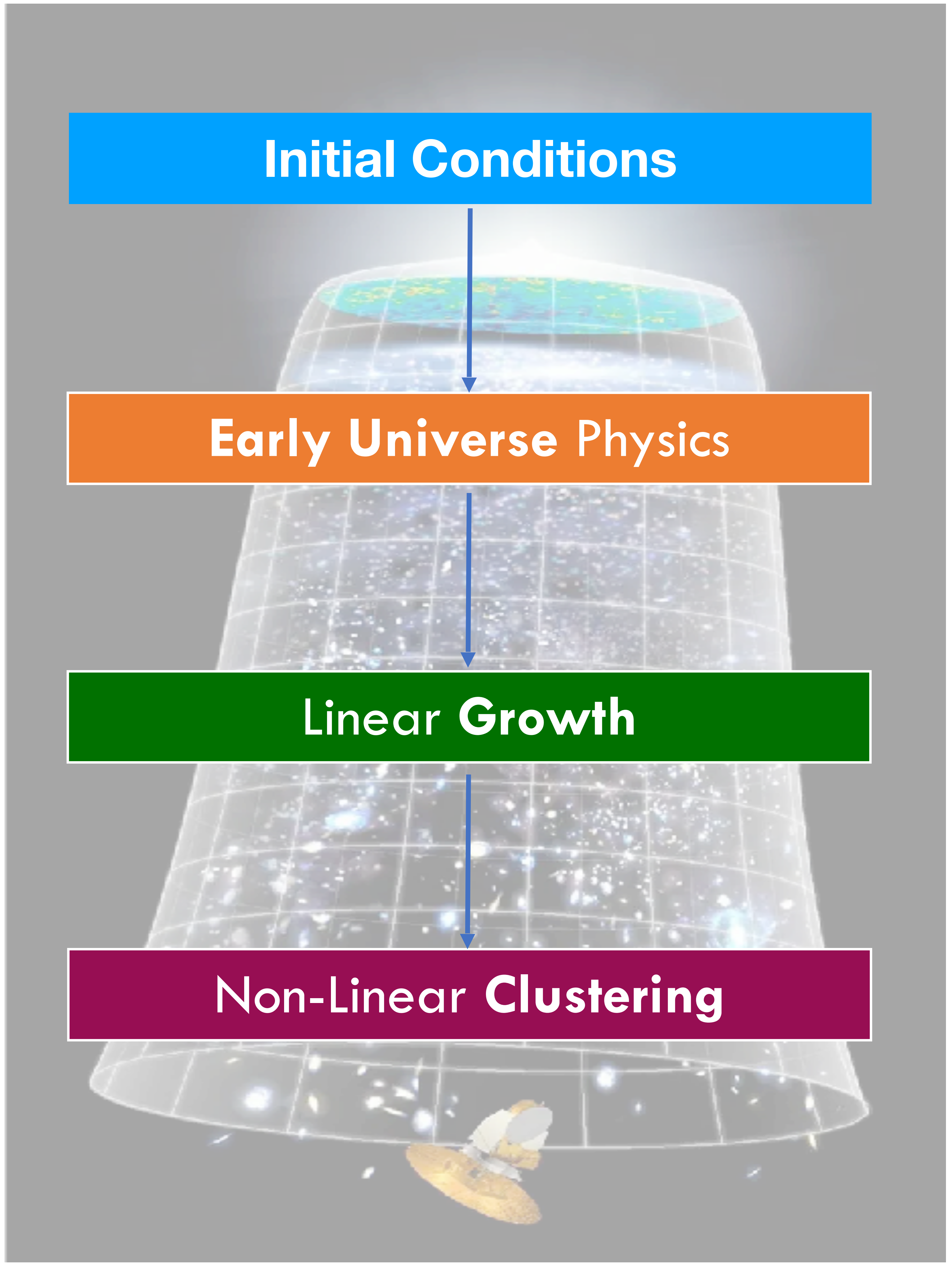
Major Goal: map the distribution of galaxies, $\delta_g(\mathbf{x}, z)$ across space and time

- Surveys range from low-**redshift** ($z \lesssim 0.1$) to high-redshift ($z \lesssim 3$)
    - *Low-z* — magnitude limited
    - *High-z* — large volume
- The surveys range from **ultra-large** to **ultra-deep**
    - *Large* — GR and non-Gaussianity
    - *Deep* — Non-linearities and structure formation

Each blob is a 3D galaxy position!

How to Model A Galaxy Survey

- **Initial Conditions**
    - **Gaussian**, with $\zeta \sim \mathcal{N}(0, P_\zeta)$
    - (Almost) **Scale-invariant**, with $P_\zeta(k) \sim A_s k^{n_s - 4}$
    - **Adiabatic** — all fields have the same initial conditions!
- **Early Universe Physics**
    - Standard expansion history including **matter-radiation** equality $k_{\mathrm{eq}} \sim \Omega_m H_0$
    - Recombination physics, including **sound horizon** $r_d \sim \Omega_b H_0^2, \Omega_m H_0^2, \cdots$
- **Linear Growth**
    - Background — $H(z), D_A(z)$ set by $H_0, \Omega_m, \Omega_r, \Omega_\Lambda$
    - Perturbations — $D(z), f(z) \sim \Omega_m(z)^\gamma$ set by $\Omega_m, \Omega_r, \Omega_\Lambda$ + GR
- **Non-Linear Clustering**
    - Collapse of **dark matter** into bound structures
    - Formation of **galaxies** around dark matter halos ← *This is the hard bit!*



How to Model A Galaxy Survey — beyond ΛCDM

- **Initial Conditions**
  - **Gaussian**, with $\zeta \sim \mathcal{N}(0, P_\zeta)$
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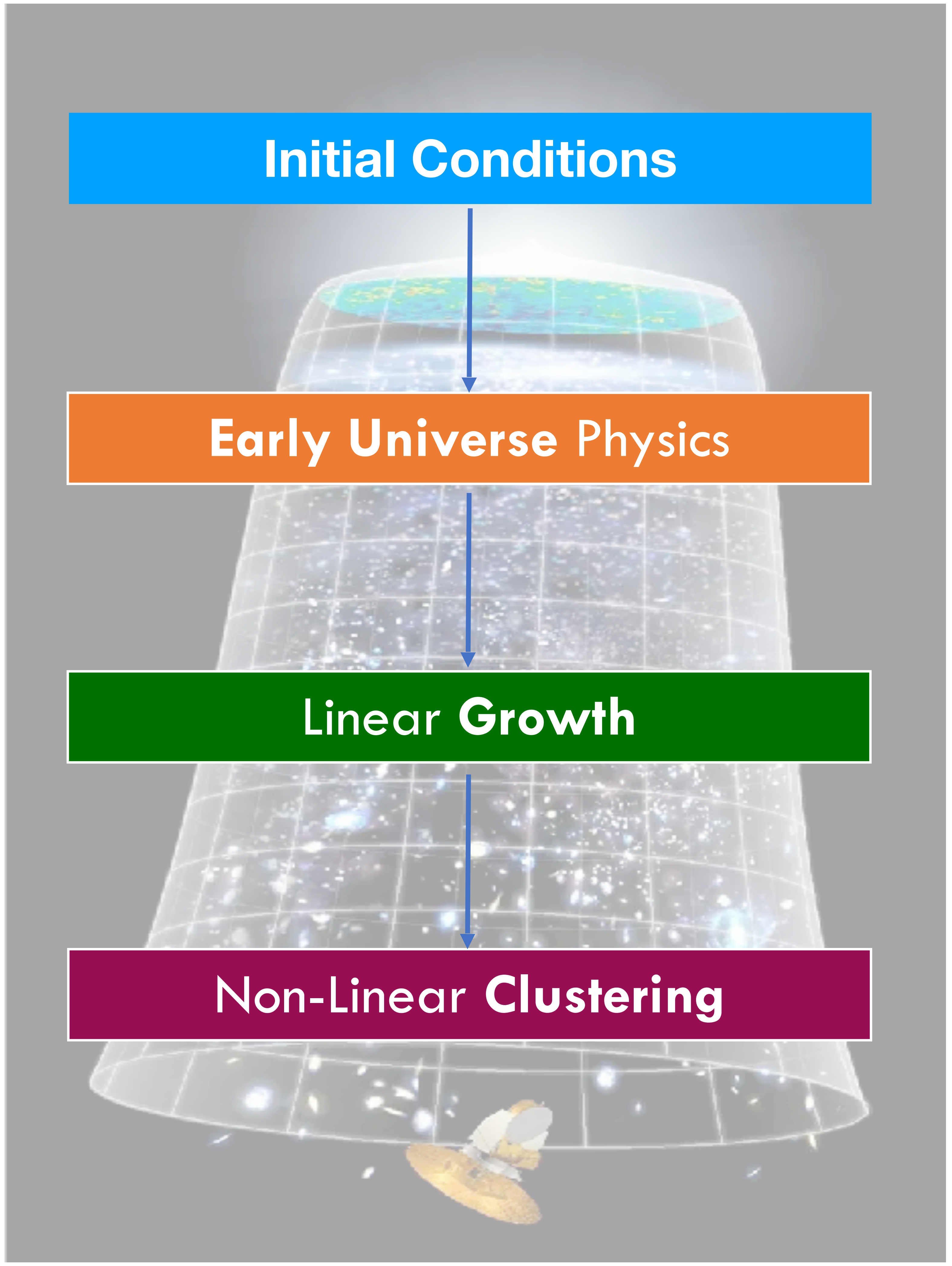
Modified Inflation

Modified Early Universe

Modified Expansion History

Modified Structure Formation



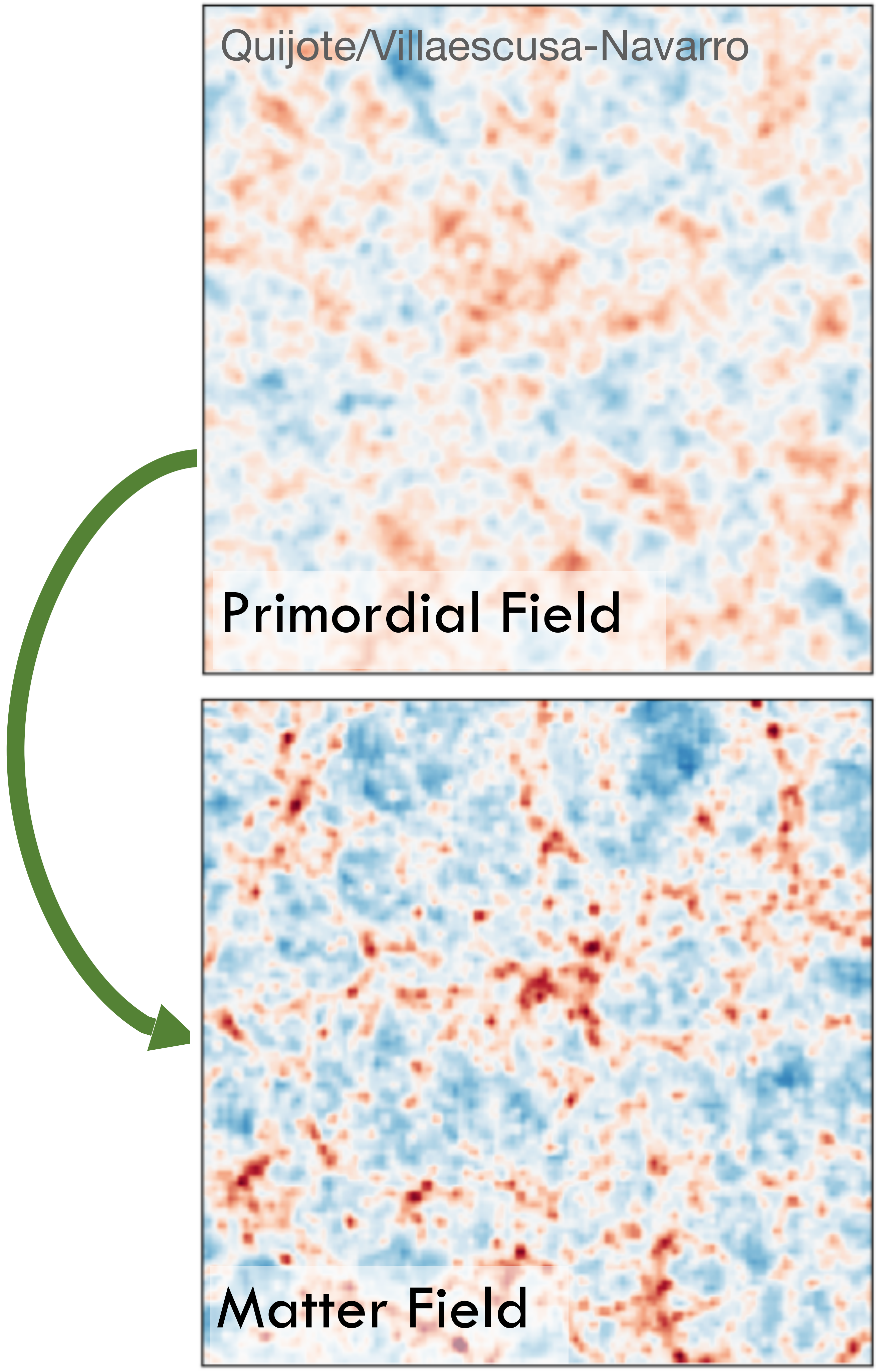
Modeling Non-Linearities

Step 1: predict the distribution of dark matter $\delta_m(\mathbf{x}, z)$

- This can be done either **analytically** or **numerically**
- Most modern analyses use the "Effective Field Theory of Large-Scale Structure"
  - This *smoothes* ("coarse-grains") the dark matter on some scale $R \gtrsim 10\,\mathrm{Mpc}$
    $\delta_m \to \delta_m \star \text{smoothing}[R]$
  - We can compute δ_m as a **perturbation series** in the initial conditions

$$\delta_m \sim K_1 \zeta + \int K_2 \zeta^2 + \int\int K_3 \zeta^3 + \cdots$$

  - The coupling kernels are set by **gravity**
  - Free **counterterms** account for **small-scale** physics ("renormalization")
- **Alternative** — run **N-body simulations** and **emulate** the statistics of interest



Cabass+, **Philcox**+, Chen+, d'Amico+, Assassi, Zaldarriaga, Simonovic, Senatore, White, Castorina, Vlah,…

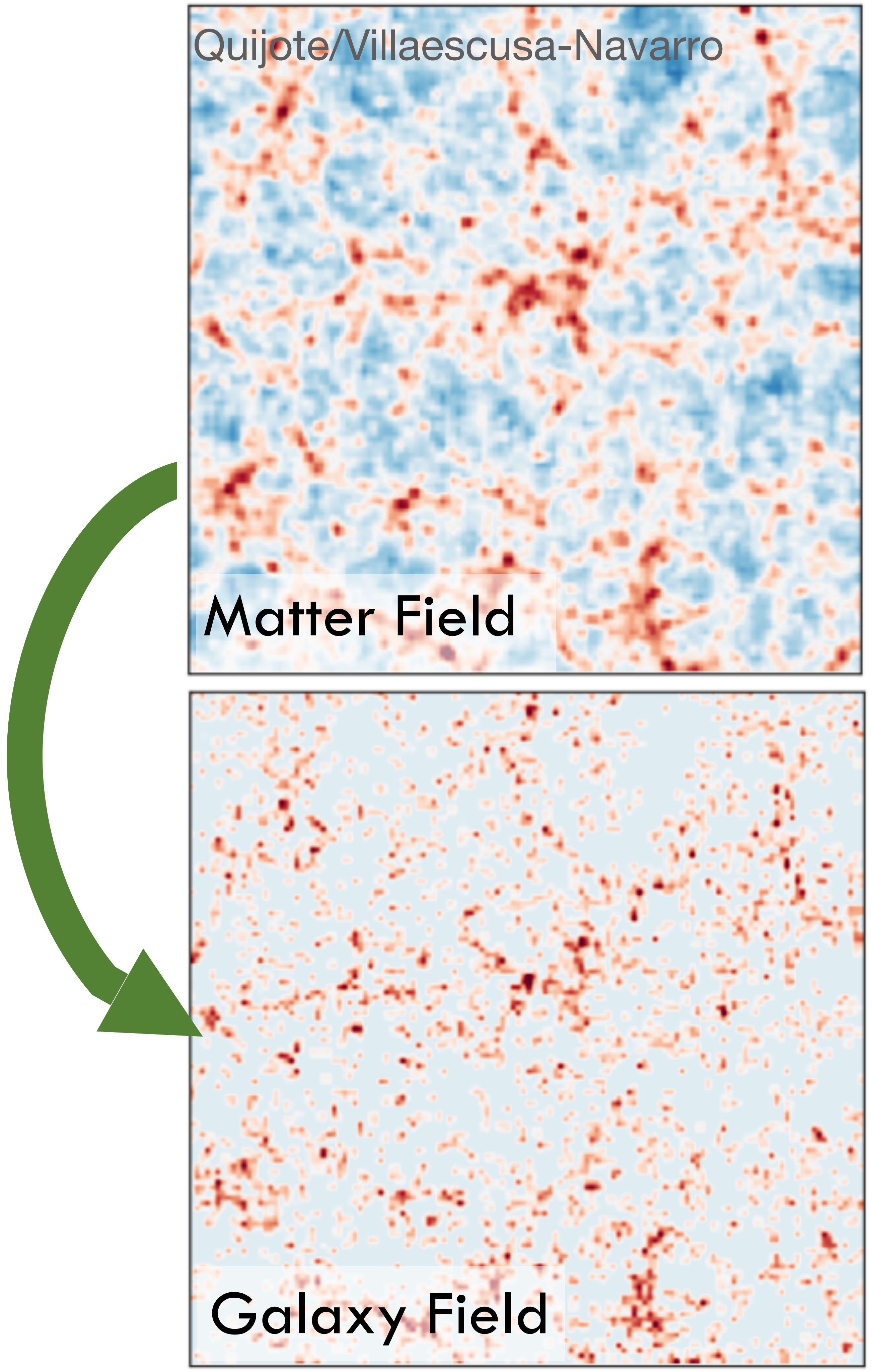
Modeling Non-Linearities

Step 2: predict the distribution of galaxies $\delta_g[\delta_m](\mathbf{x}, z)$

- This can be done **analytically**, **semi-analytically** or **numerically**
- **Effective Field Theory** approach:
  - Compute δ_g as a **perturbation series** in the dark matter density, δ_m
  - Use **symmetries** to account for **any galaxy formation** effects [e.g., homogeneity, isotropy, Galilean invariance]:

$$\delta_g = b_1\delta + b_2\delta^2 + b_s s_{ij}s^{ij} + b_\nabla \nabla^2\delta + \cdots$$

  - The **bias parameters** encode galaxy formation physics
  - This is **robust** but limited to large-scales ⇒ *loss of information*
  - Can model δ_m either from **theory** or **simulations** (Hybrid EFT)
- **Alternatives:**
  - Post-process **simulations** to add galaxies, with an HOD or Semi-Analytic Model
  - Perform a full hydrodynamical simulation!

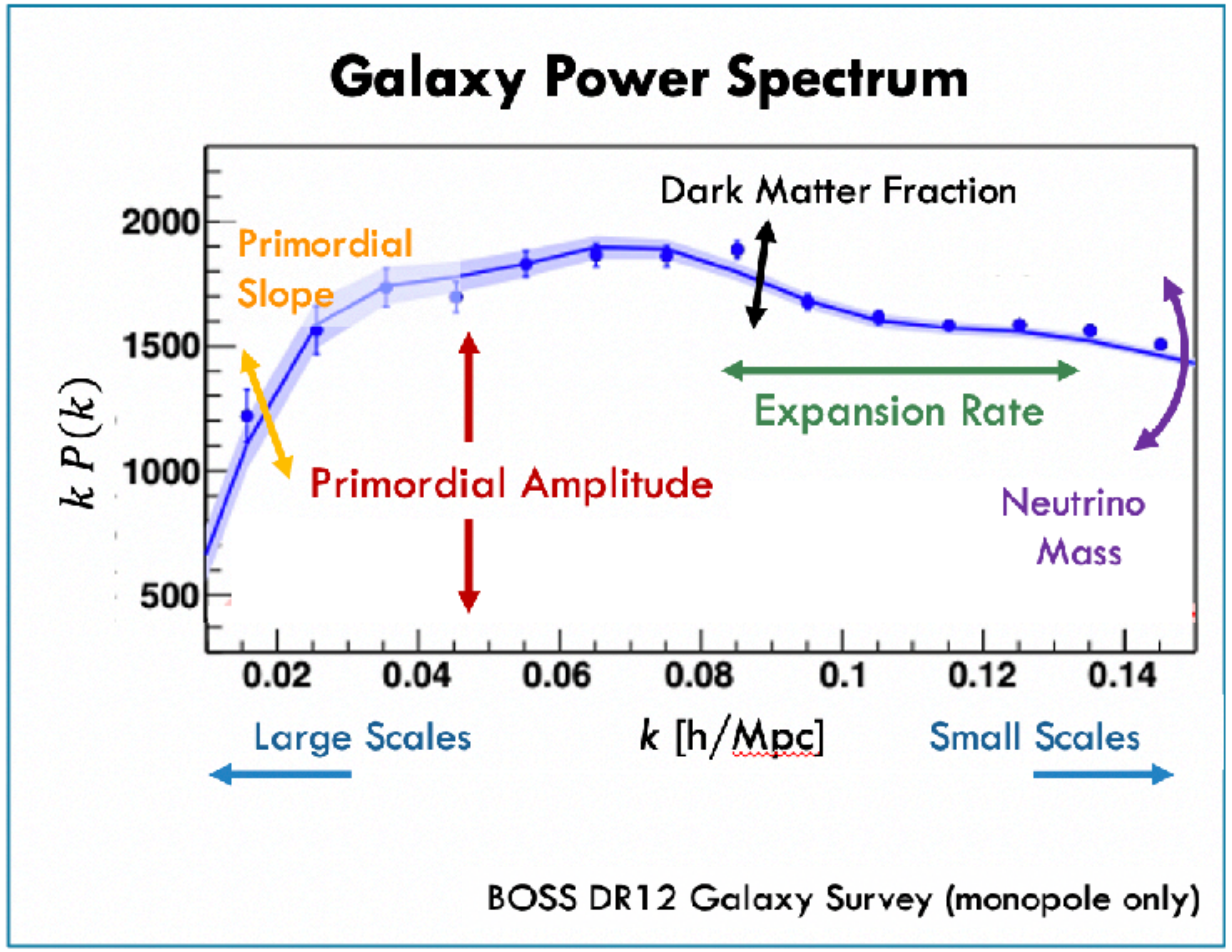


Cabass+, **Philcox**+, Chen+, d'Amico+, Assassi, Zaldarriaga, Simonovic, Senatore, White, Castorina, Vlah, Kokron, Modi, Angulo…

What Statistics Should We Use?

Most analyses focus on the simplest statistics

- The **B**aryon **A**coustic **O**scillations (BAO)
  - Good for tracing the **expansion history** across time
- The **Galaxy Power Spectrum** (or correlation function)
  - This is a **powerful** probe of ΛCDM!



(Many **many** references here!)

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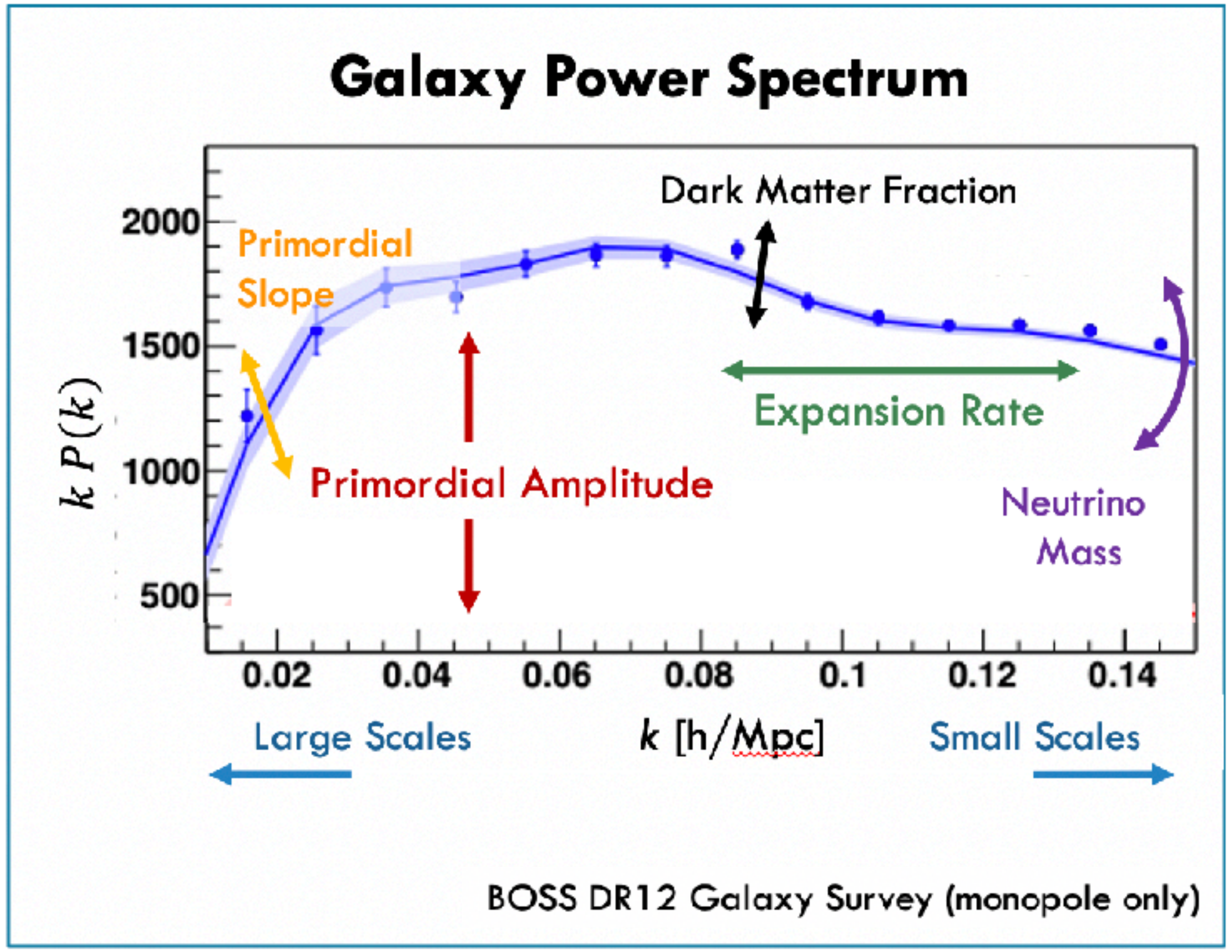
Other options include:

- ***Bispectra*** and ***Trispectra*** (3-Point and 4-Point Functions)
  - Traces non-linear information and **inflation** *but* more expensive!
- ***Galaxy bias*** and ***halo mass functions*** $n_{\rm gal}(M_{\rm halo})$
  - These probe halo-scale physics ($R \lesssim 10h^{-1}{\rm Mpc}$) but are difficult to model!
- ***Wavelets, kNNs, CNNs, marked statistics, density-split statistics, …***
  - These are **non-linear** probes that must be modeled numerically!
- Cross-Correlations with **weak lensing**
  - Strong probes of **gravity**
- Galaxy **spins**, galaxy **shapes**
  - Higher-order physics including **tensors**



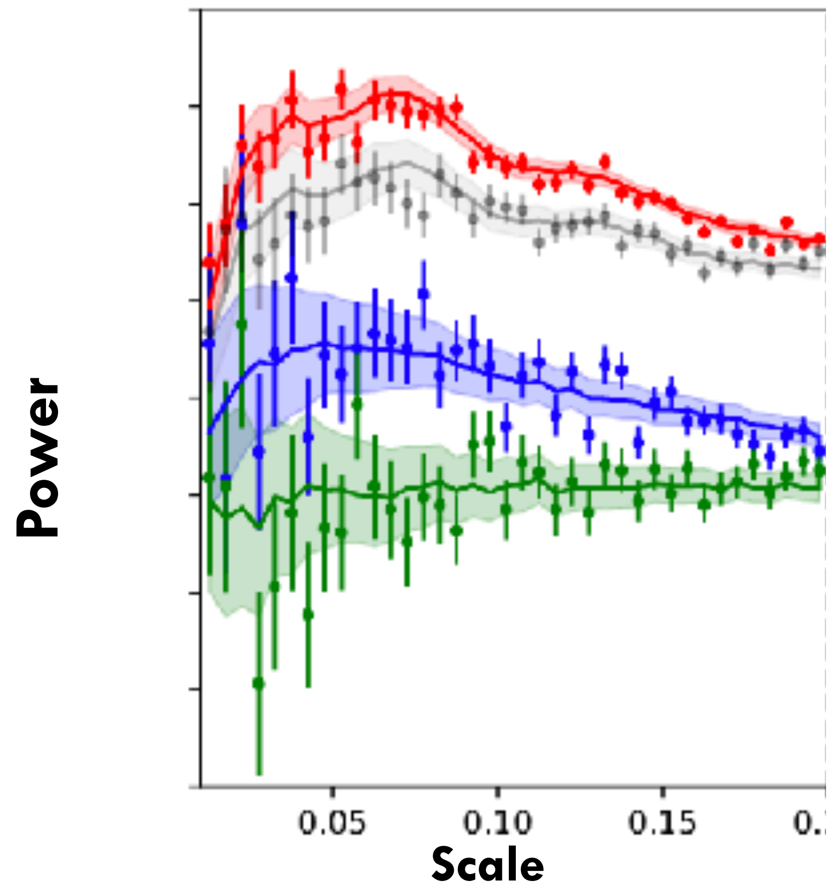
(Many **many** references here!)

Theory In Practice

- There are **fast codes** implementing the theory predictions:
  - CLASS-PT, Velocileptors, PyBird, PBJ, Class OneLoop, FOLPS-ν,…
- These predict the **power spectrum** or **bispectrum** of galaxies
- By combining with an **observed dataset** and a **Gaussian likelihood** we can constrain any ΛCDM parameter entering the model!

Cosmology Parameters

Perturbation Theory Code



Predictions for Statistics

Ivanov, **Philcox**, Cabass, Chen, Vlah, Zhang, d'Amico, Simonovic, Zaldarriaga, Senatore, Moretti, Lesgourges, Werth, Aviles, Gil-Marin, Beutler, …

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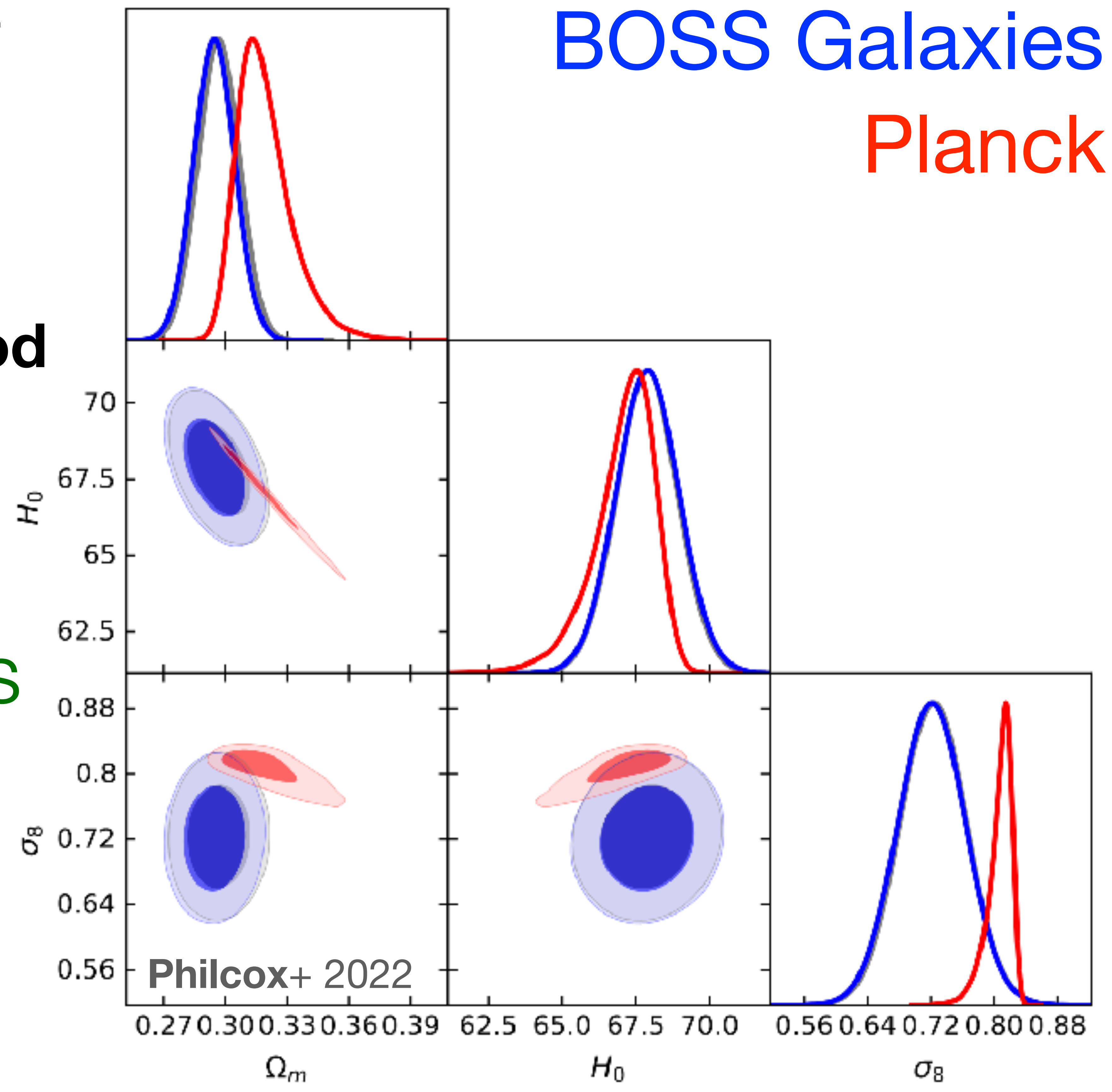
- These predict the **power spectrum** or **bispectrum** of galaxies
- By combining with an **observed dataset** and a **Gaussian likelihood** we can constrain any ΛCDM parameter entering the model!
- This has been used to measure $\Omega_m, H_0, \sigma_8, \cdots$ from BOSS / eBOSS in **full-shape / direct modeling** analyses
  - *(See also ShapeFit and $f\sigma_8$ measurements)*
- Recently, it has been applied to the **Year 1 DESI dataset**

Can we reproduce this?

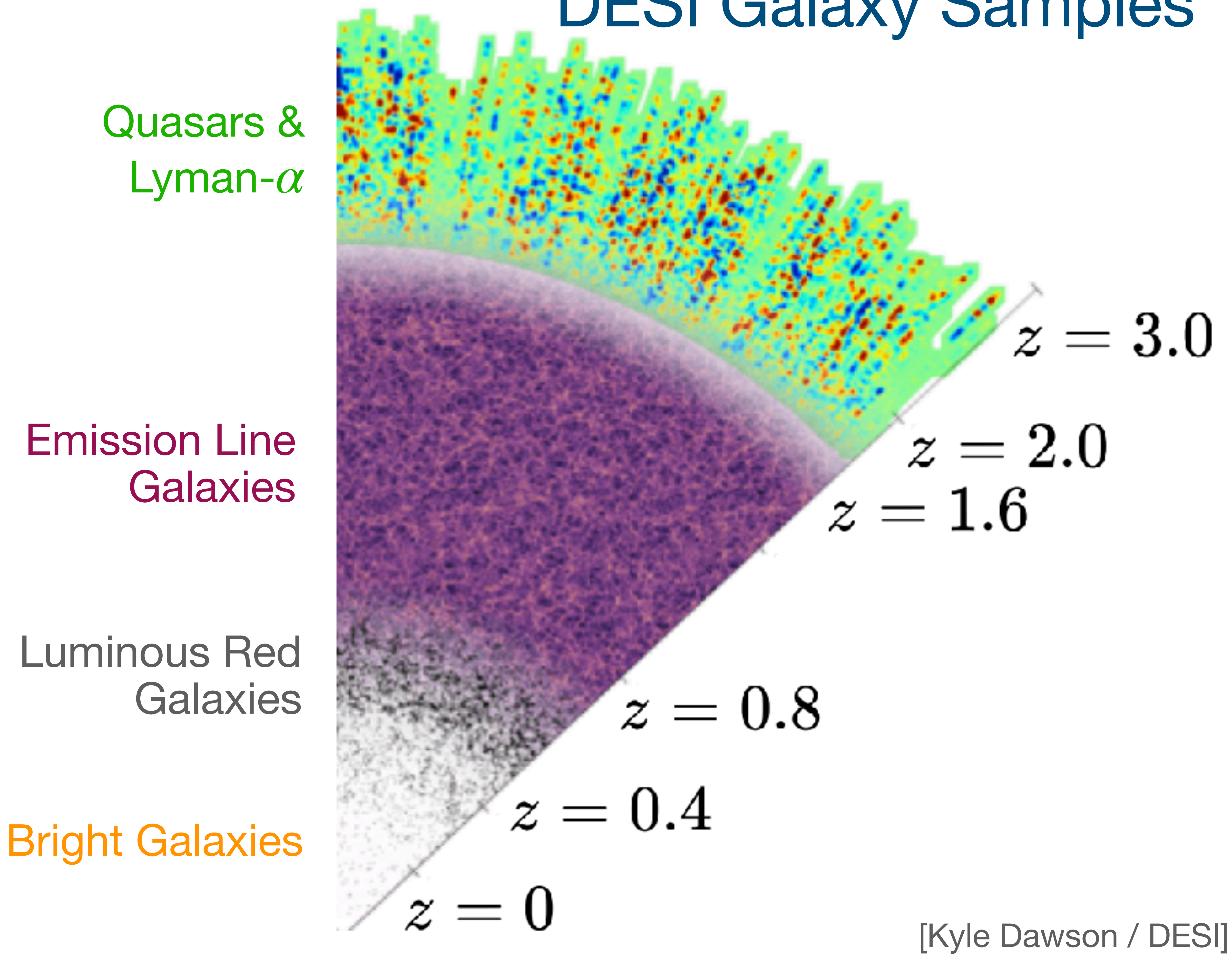


Ivanov, **Philcox**, Cabass, Chen, Vlah, Zhang, d'Amico, Simonovic, Zaldarriaga, Senatore, Moretti, Lesgourges, Werth, Aviles, Gil-Marin, Beutler, …

The DESI Universe

- We analyze **six** DESI chunks:
  - BGS: Bright Galaxy Sample ($0.1 < z < 0.4$)
    - Low redshift, magnitude limited
  - LRG: Luminous Red Galaxies ($0.4 < z < 1.1$)
    - Similar to previous surveys!
  - ELG: Emission Line Galaxies ($1.1 < z < 1.6$)
    - Low-redshift tail dropped due to systematic contamination
  - QSO: Quasars ($0.8 < z < 2.1$)
    - High redshift, **large** shot-noise
  - Lyman-alpha Emission
    - Not included in DR1
- Each is split into **north** and **south** regions

DESI Galaxy Samples

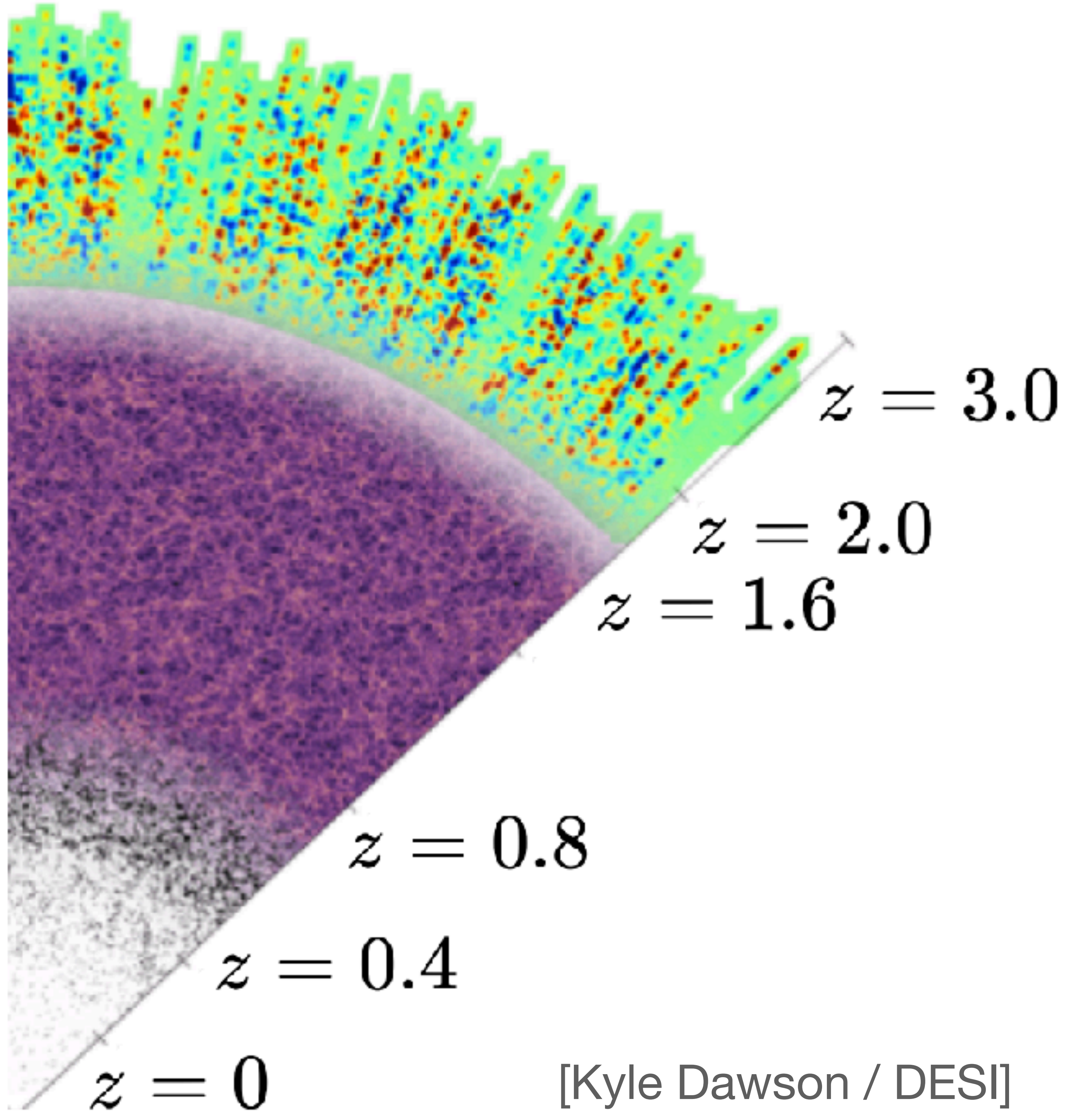


[Kyle Dawson / DESI]

DESI 2024 II, V, DESI Data Release 1

Reanalyzing DESI

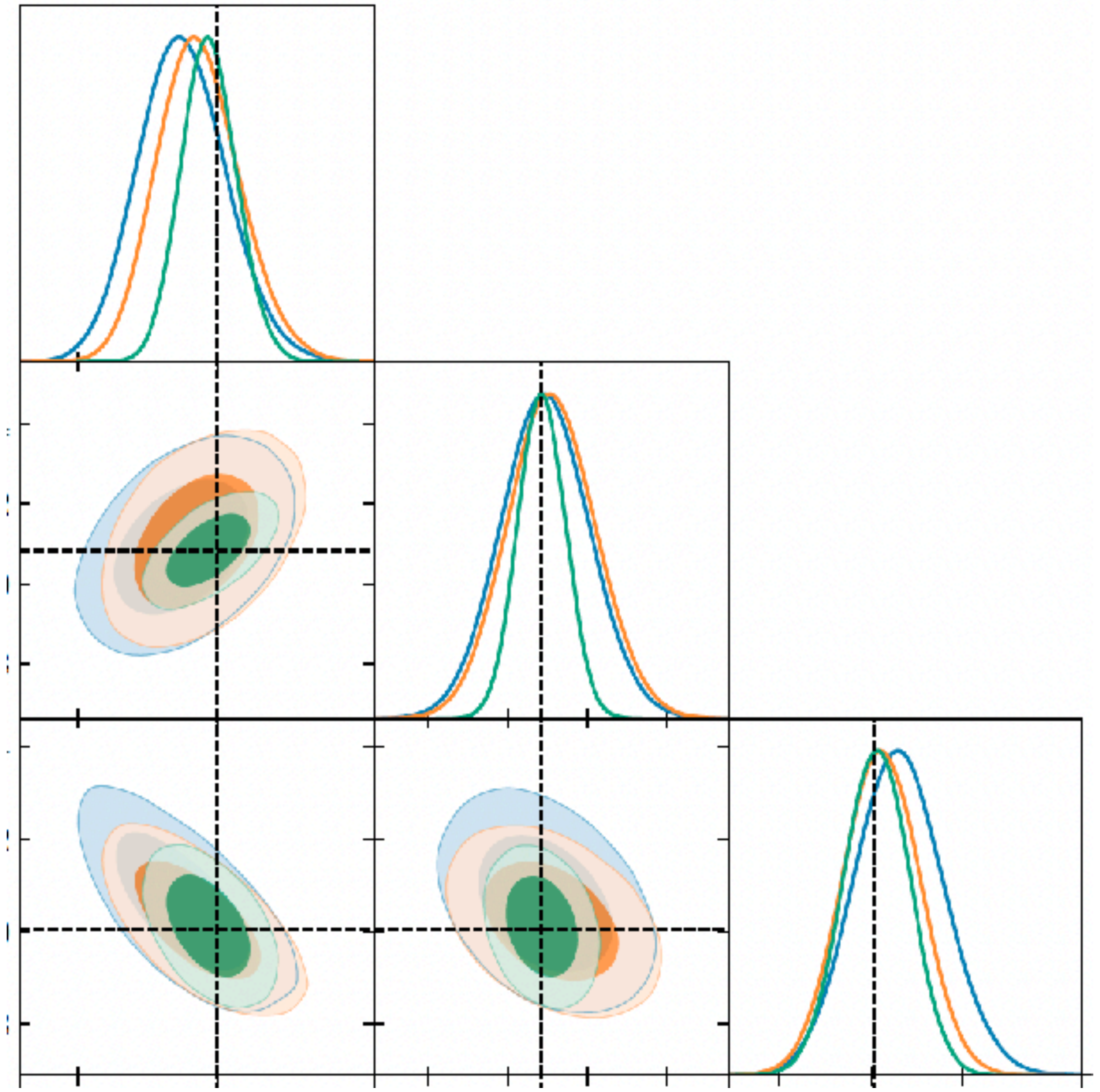
DESI Galaxies



[Kyle Dawson / DESI]

???

Cosmological Parameters



DESI 2024 II, V, DESI Data Release 1, Chudaykin, Ivanov, **Philcox** 2025

Reanalyzing DESI

DESI Data Release 1 (LRGs)

TARGETID	Z	NTILE	RA	DEC	...
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39627546844726132	0.8129116729090922	1	158.76343950179967	-9.912671320450734	...
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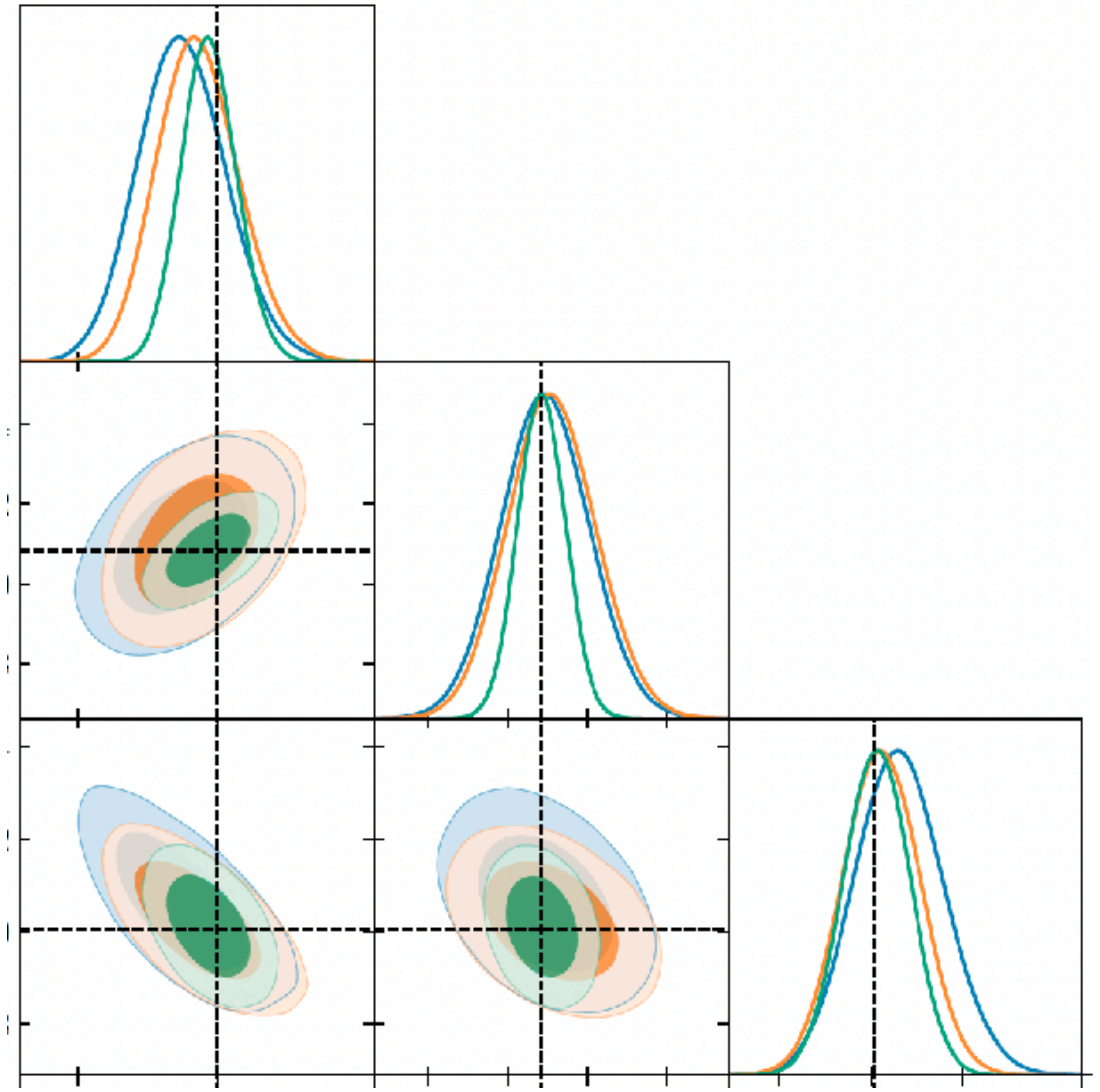
???

Cosmological Parameters



DESI 2024 II, V, DESI Data Release 1, Chudaykin, Ivanov, **Philcox** 2025

Reanalyzing DESI

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39627546848922139	0.7200341373651288	
39627546848922621	0.7606337242857438	
39627546848922874	0.7198972751282844	
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39627546853114634	0.8131126675553368	
39627546853115304	0.5559672054059013	
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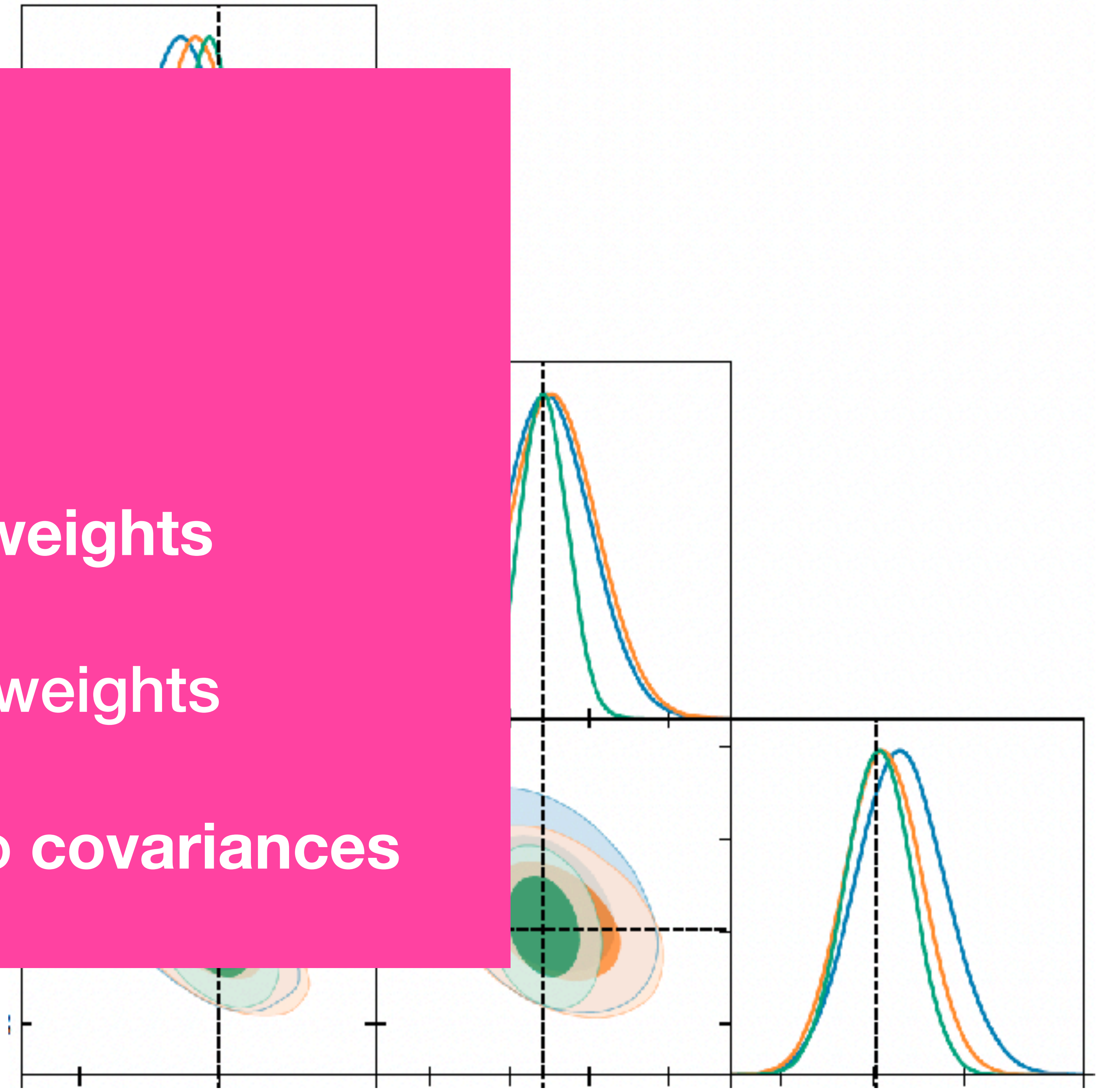
...	...	...

Cosmological Parameters



This is hard

The data release only contains:

- **Galaxy positions, redshifts and systematic weights**
- Random positions, redshifts and systematic weights

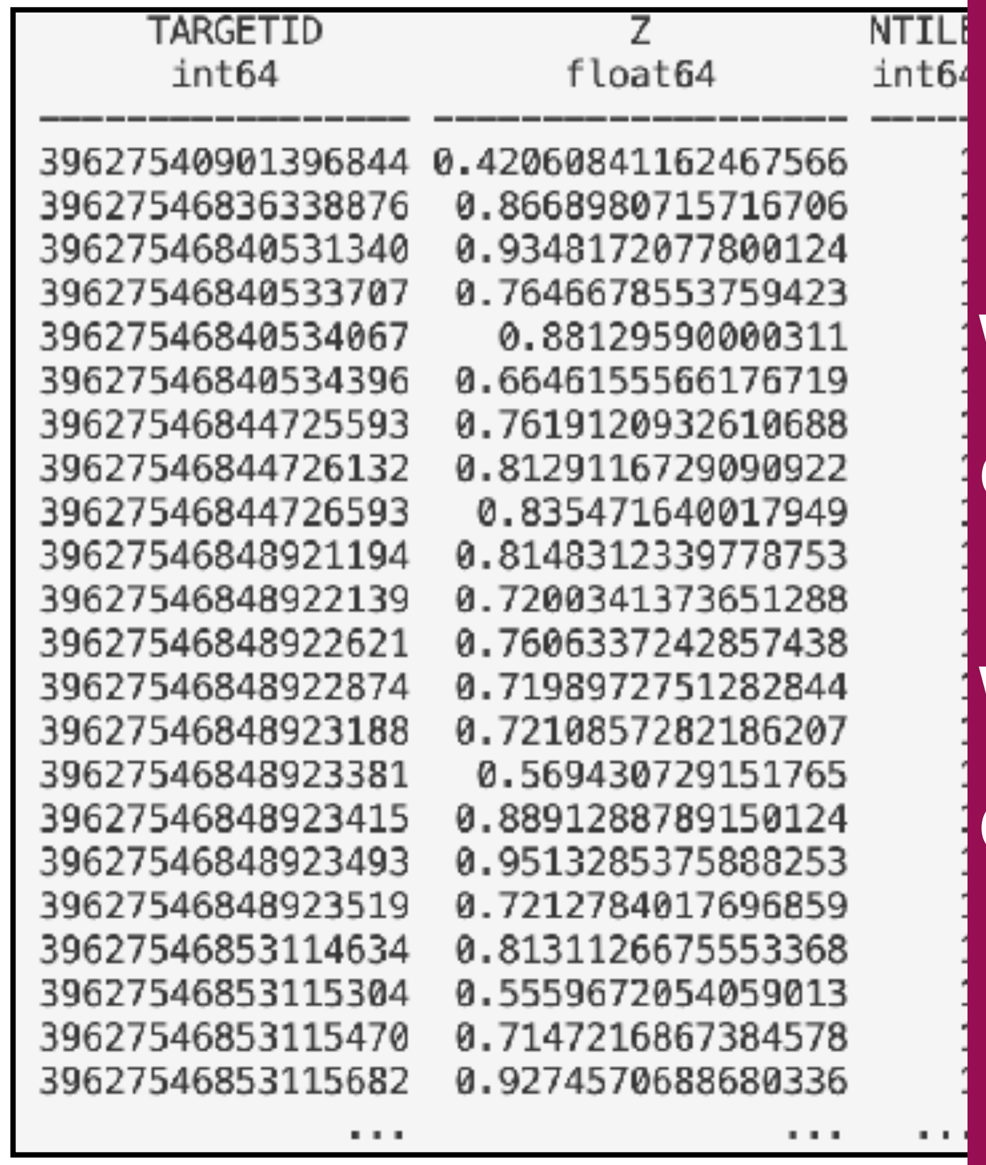
There are no **simulations**, no **power spectra** and no **covariances**

DESI 2024 II, V, DESI Data Release 1, Chudaykin, Ivanov, **Philcox** 2025

Reanalyzing DESI

DESI Data Release 1 (LRGs)

Cosmological Parameters



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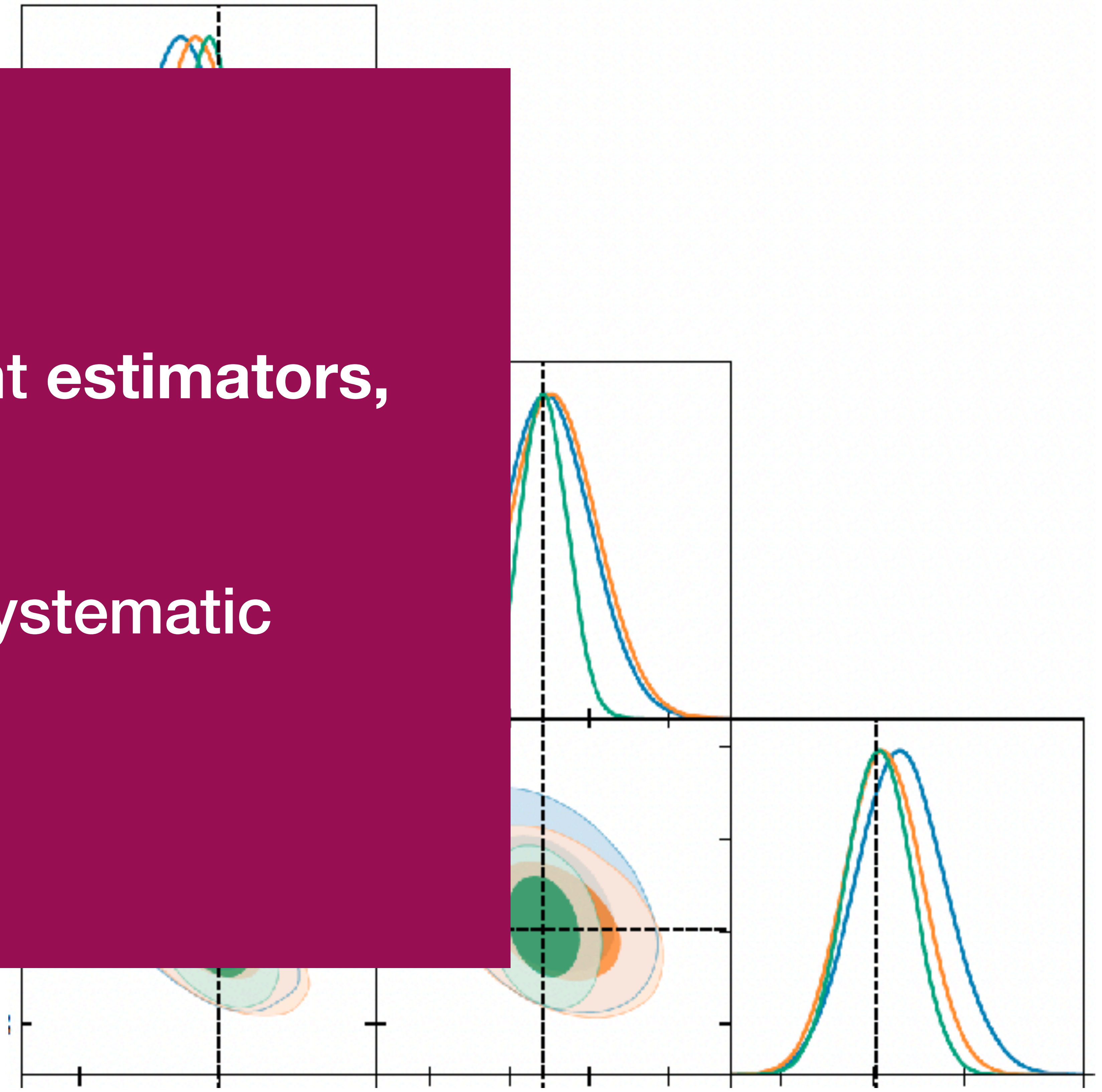
...	...	...



This is important

We develop an **independent** pipeline, using different **estimators**, **covariance estimates**, and **theory codes**

We can include **more data with new methods for systematic** corrections

DESI 2024 II, V, DESI Data Release 1, Chudaykin, Ivanov, **Philcox** 2025

Two-Point Estimators

- The DESI data is a **point cloud** of positions and weights for **galaxies** and **randoms**

$$n_g(\mathbf{x}) \sim \sum_{i=1}^{N_g} w_{g,i}\delta_{\rm D}(\mathbf{x}-\mathbf{x}_{g,i}), \quad n_r(\mathbf{x}) \sim \sum_{i=1}^{N_r} w_{r,i}\delta_{\rm D}(\mathbf{x}-\mathbf{x}_{r,i})$$

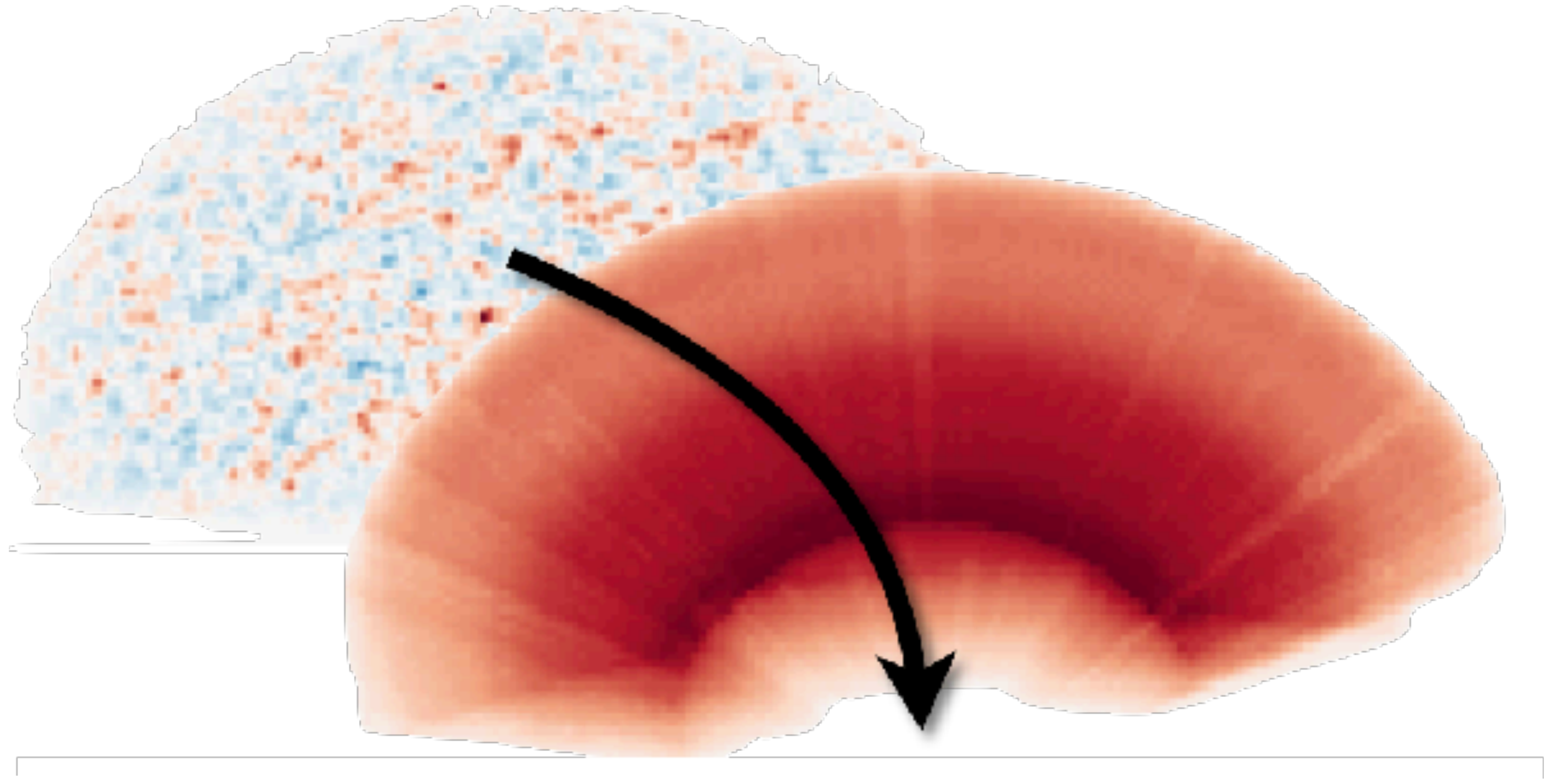
- We want to turn this into a **power spectrum**

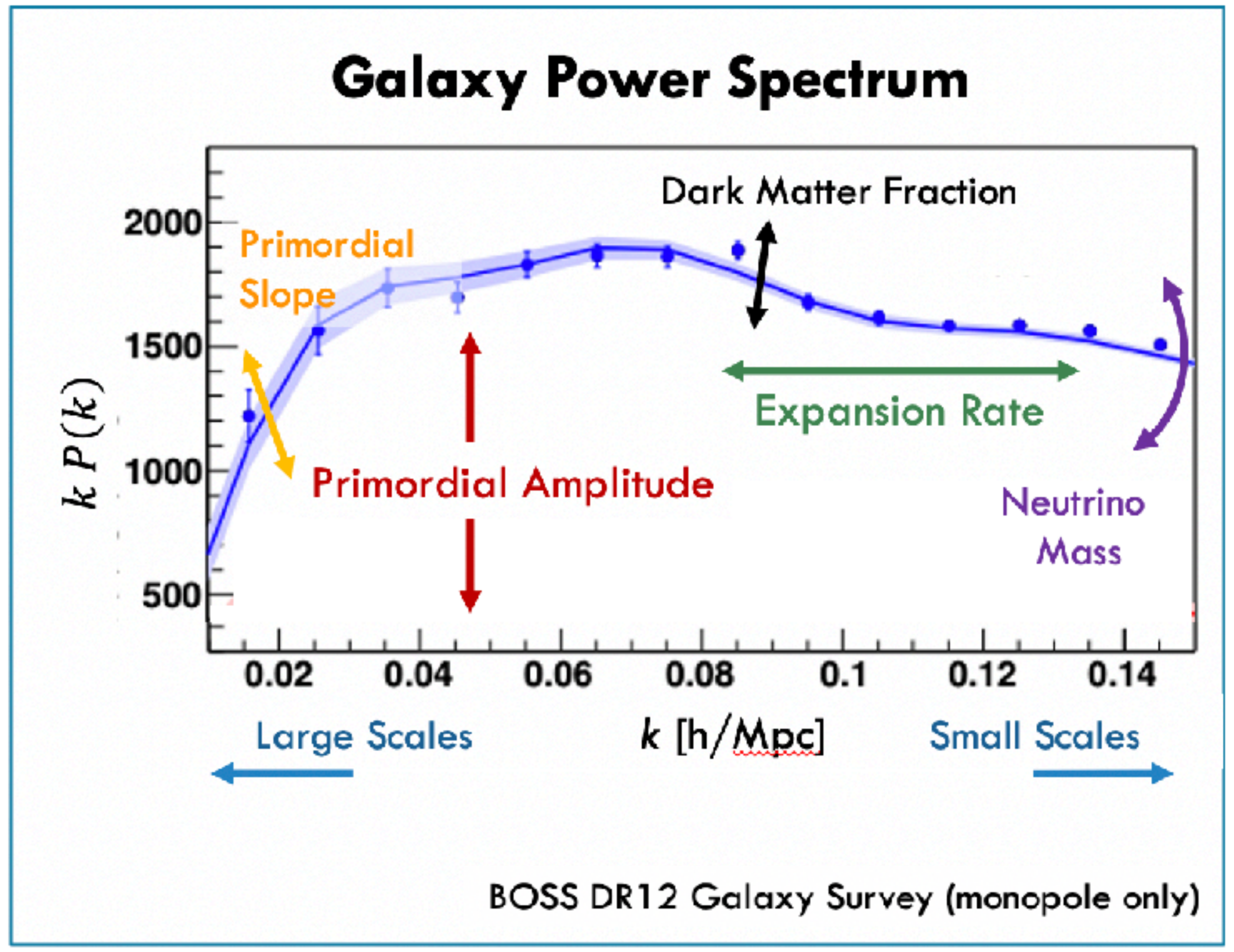
1. **FKP** estimator ← Used by DESI

$$P_{\rm FKP}(\mathbf{k}) \sim \left| n_g(\mathbf{k}) - \frac{N_g}{N_r} n_r(\mathbf{k}) \right|^2 / \langle n^2 \rangle$$

- This is (almost) optimal
- The output is convolved with the mask:

$$P_{\rm FKP}(\mathbf{k}) \sim \int d\mathbf{q}\ \left| n(\mathbf{k}-\mathbf{q}) \right|^2 P_{\rm true}(\mathbf{q}) / \langle n^2 \rangle$$





Feldman, Kaiser, Peacock 1980s, BOSS DR12, Beutler+, Gil-Marin+, McDonald+, Ivanov+19, **Philcox**+20,21, **Philcox** & Floss 2025

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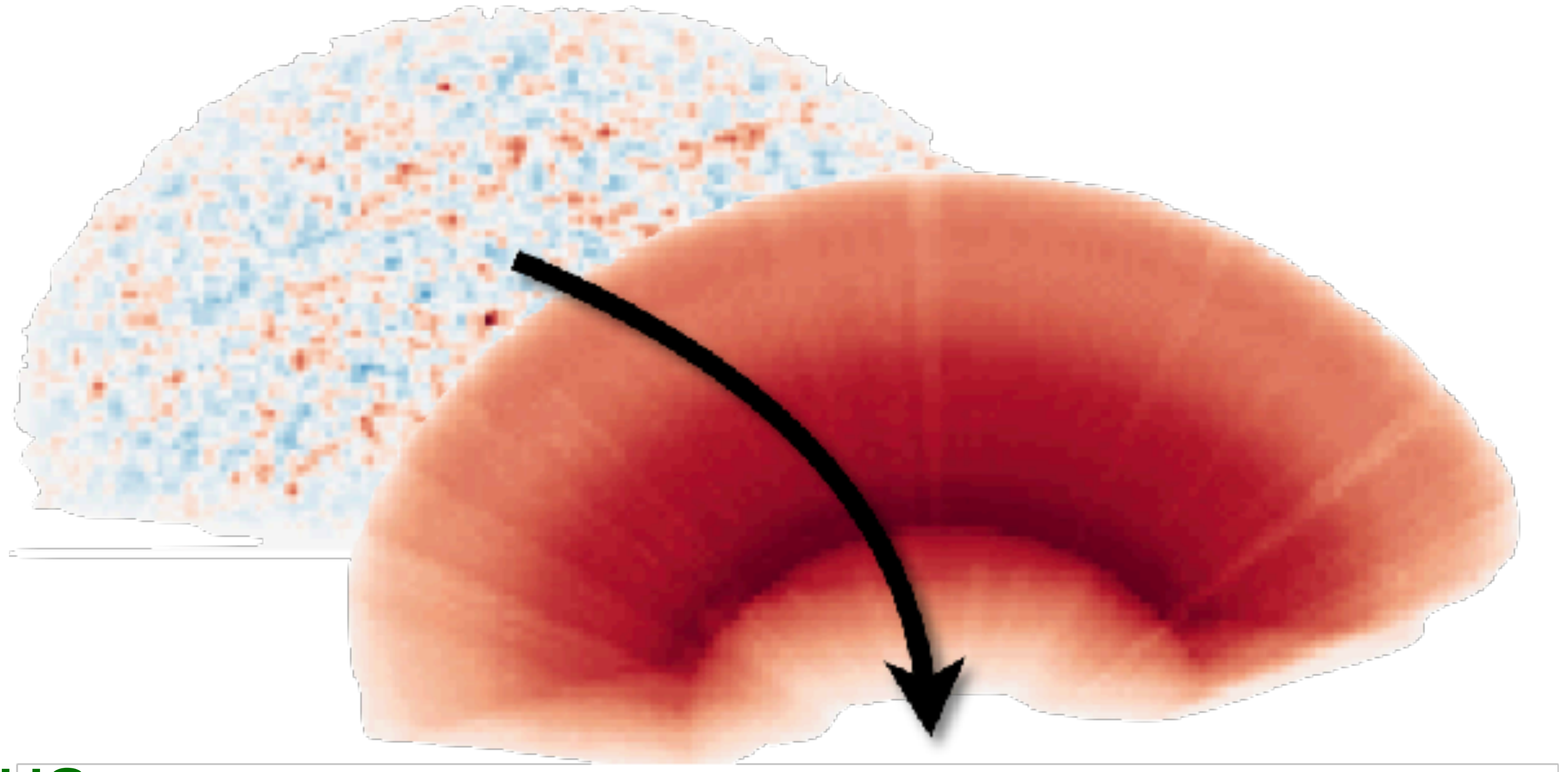


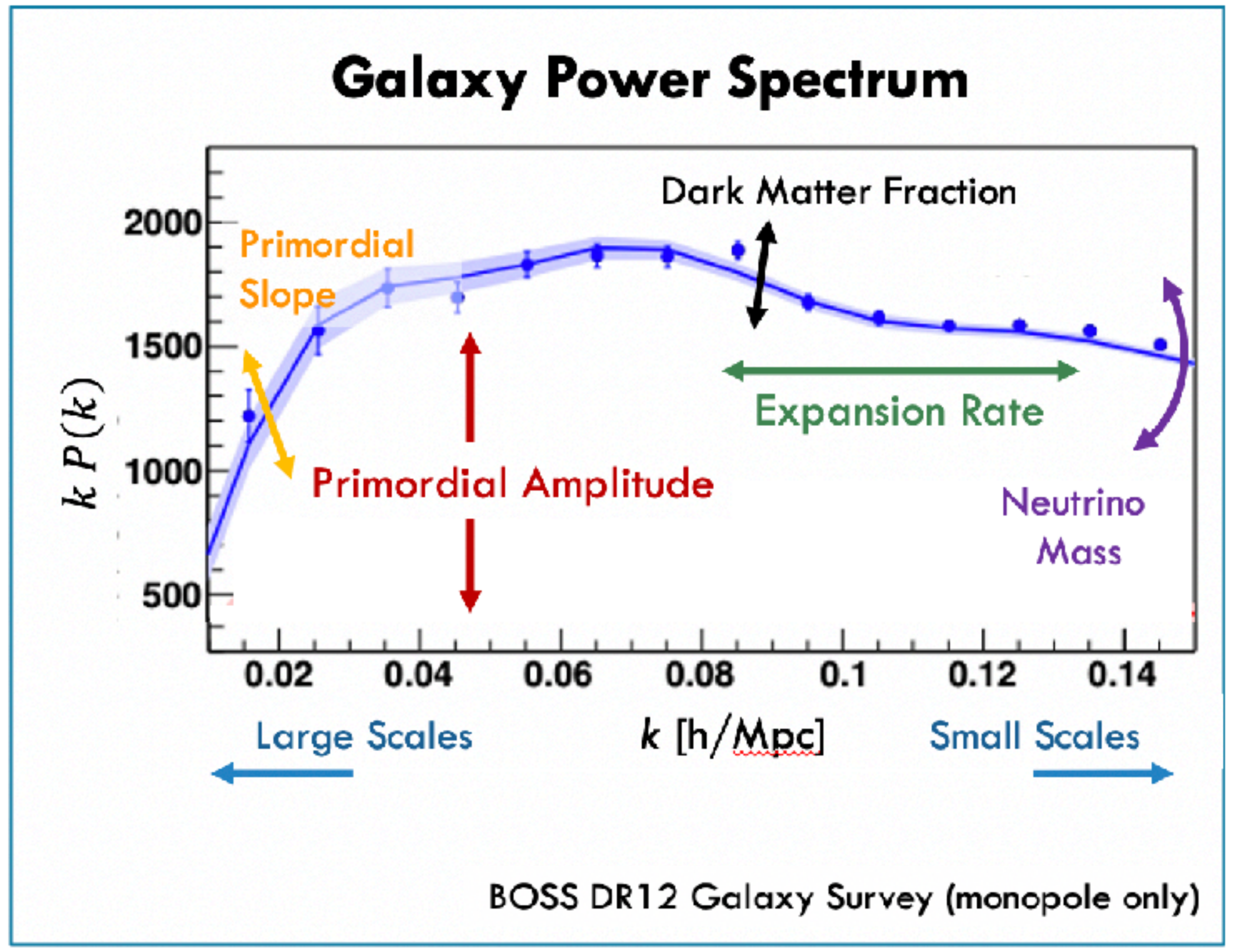
- We want to turn this into a **power spectrum**

2. Quasi-Optimal “**Unwindowed**” estimator ⟵ Used by us

$$P_{\mathrm{unwin}}(\mathbf{k}) \sim \int d\mathbf{q}\, \mathbf{W}^{-1}(\mathbf{k},\mathbf{q}) \left| n_g(\mathbf{q}) - \frac{N_g}{N_r} n_r(\mathbf{q}) \right|^2 / \langle n^2 \rangle$$

- At leading order, the output is **not** convolved with the mask:

$$P_{\mathrm{unwin}}(\mathbf{k}) \sim P_{\mathrm{true}}(\mathbf{k})$$



Feldman, Kaiser, Peacock 1980s, BOSS DR12, Beutler+, Gil-Marin+, Ivanov+19, **Philcox**+20,21, **Philcox** & Floss 2025

Two-Point Estimators

- In practice, we compute the **binned power spectrum** in a set of k-bins and redshift-space **multipoles**, plus a (square) **2D normalization matrix**

$$P_\ell^{\mathrm{unwin}}(k) \sim \sum_{\ell' k'} \mathscr{W}^{-1}_{\ell\ell'}(k,k') \left| n_g(\mathbf{k}') - \frac{N_g}{N_r} n_r(\mathbf{k}') \right|^2_{\ell'}$$

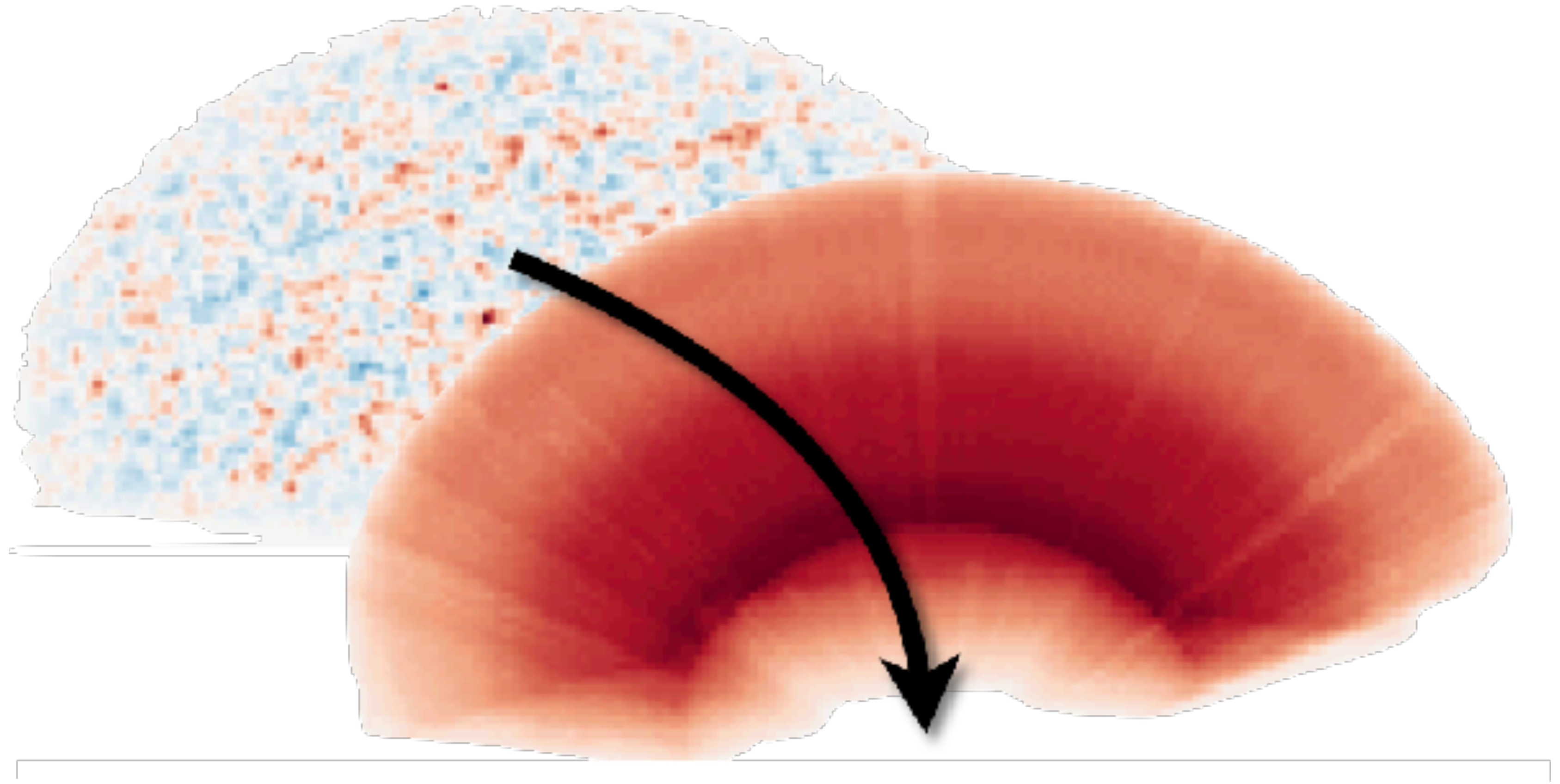
- The **numerator** is the standard FKP numerator (up to an user-defined weight)

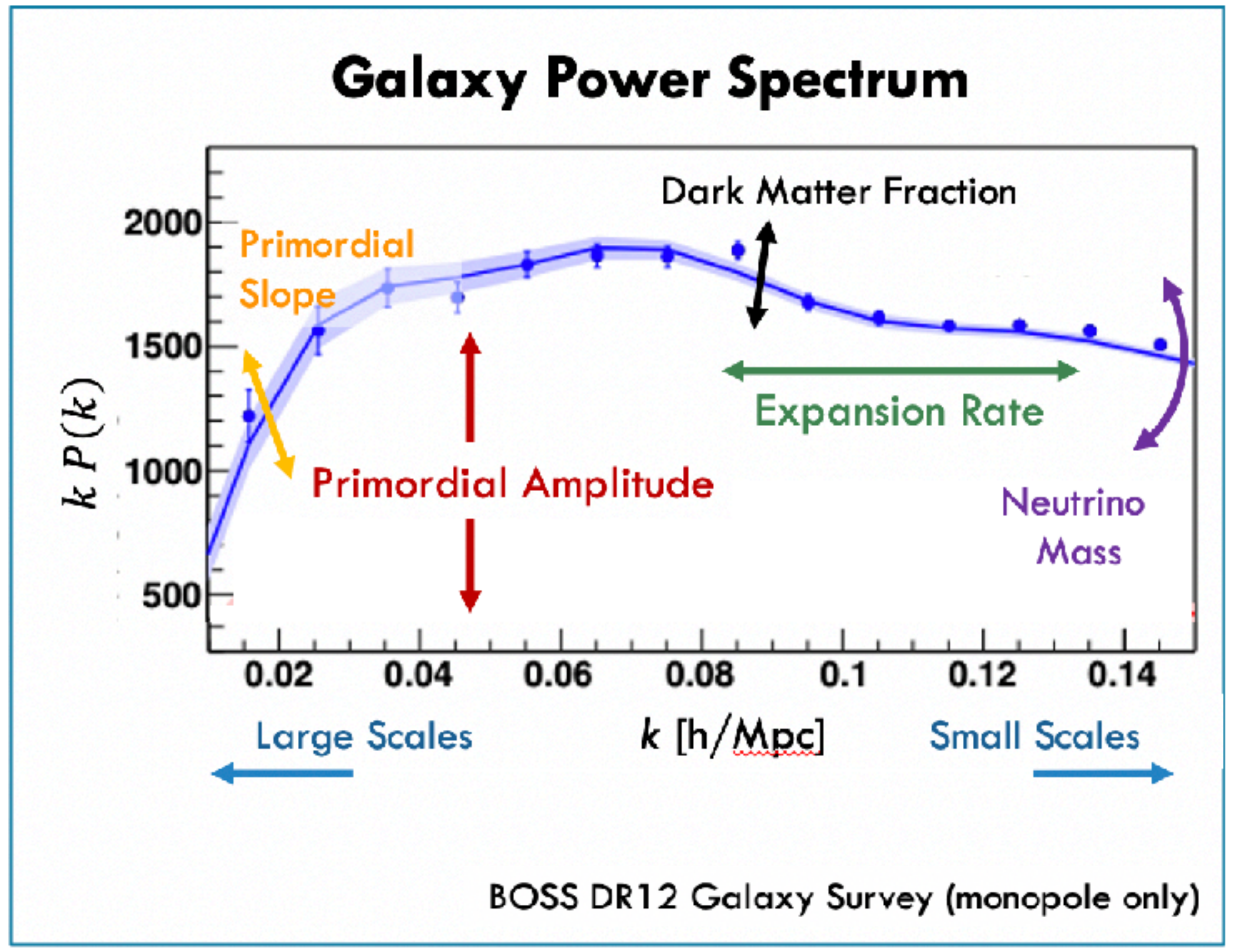
- The **normalization** can be computed using **Monte Carlo** methods and **FFTs**
(Stochastic Trace Estimation; See **Philcox**, Floss 2025)

- We account for **residual corrections** using a rectangular ***theory matrix*** (computed stochastically)

- This is equivalent to the **pseudo-C_ℓ scheme** used in the CMB!

- Up to scale-cuts, it is **equivalent** to the standard estimators





Feldman, Kaiser, Peacock 1980s, BOSS DR12, Beutler+, Gil-Marin+, McDonald+, Ivanov+19, **Philcox**+20,21, **Philcox** & Floss 2025

Three-Point Estimators

- We also want to compute **bispectra**

- These are usually computed using **FKP-like** estimators:

$$B_{\mathrm{FKP}}(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3) \sim \left\langle \prod_{i=1}^{3}\left(n_g(\mathbf{k}_i) - \frac{N_g}{N_r}n_r(\mathbf{k}_i)\right)\right\rangle \Big/ \langle n^3\rangle$$

- The theory needs to be convolved with the **mask**

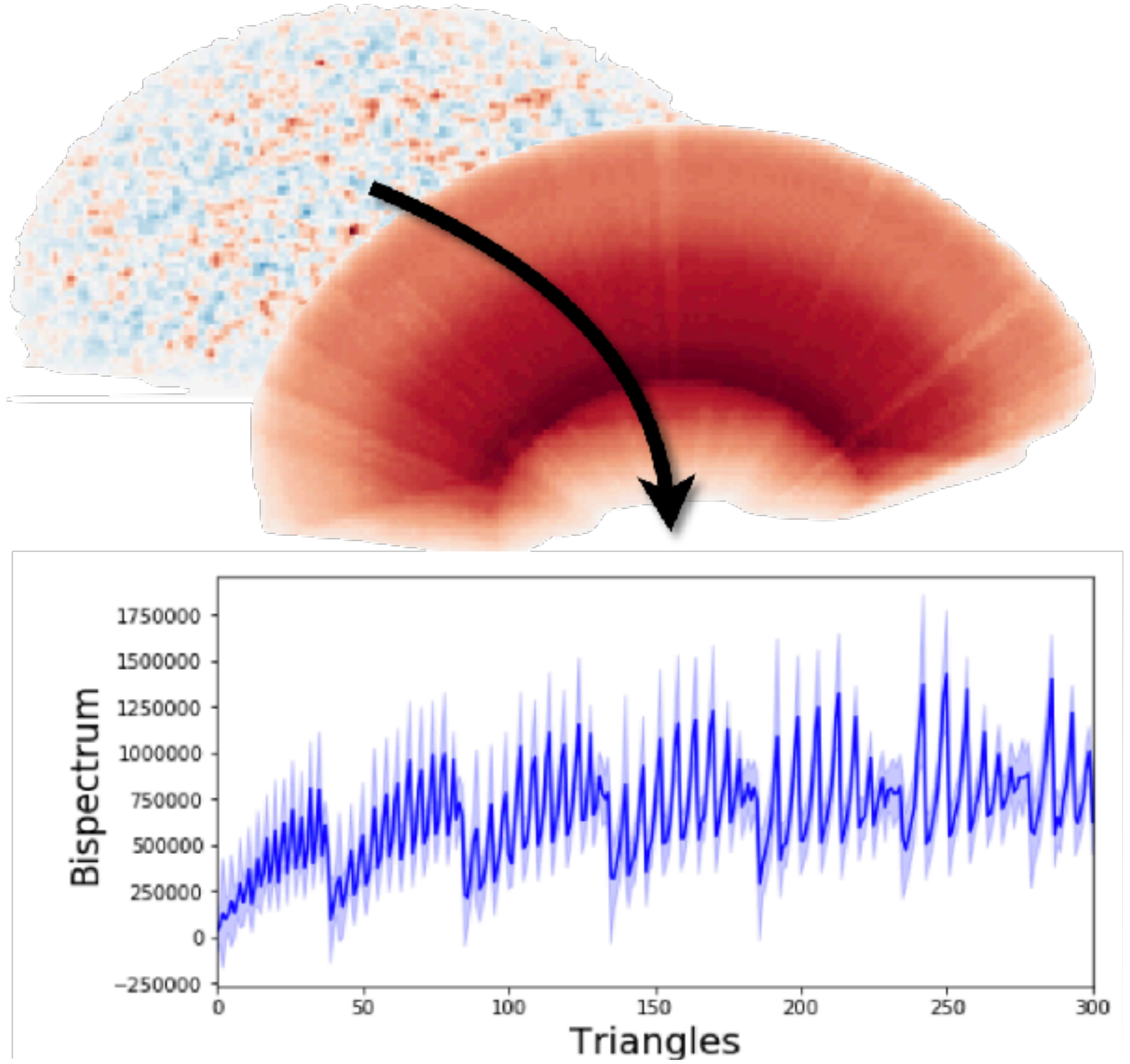
$$B_{\mathrm{FKP}}(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3) \sim \int_{\mathbf{q}_1+\mathbf{q}_2+\mathbf{q}_3=\mathbf{0}} n(\mathbf{k}_1-\mathbf{q}_1)n(\mathbf{k}_2-\mathbf{q}_2)n(\mathbf{k}_3-\mathbf{q}_3)B_{\mathrm{true}}(\mathbf{q}_1,\mathbf{q}_2,\mathbf{q}_3)$$

- This is a **difficult** 6-dimensional integral to compute at **every** step of the MCMC chain

(See Pardede++)

- Various approximations exist, but they can **break down**

(See Gil-Marin+, Chen+)



Feldman, Kaiser, Peacock 1980s, BOSS DR12, Beutler+, Gil-Marin+, McDonald+, Ivanov+19, **Philcox**+20,21, **Philcox** & Floss 2025

Three-Point Estimators

- We compute bispectra using quasi-optimal **“unwindowed”** estimators:

$$\color{blue}{B^{\rm unwin}_{{\rm bin}\,a}} \sim \sum_{b \in bins} \mathscr{W}^{-1}_{ab} \left\langle \prod_{i=1}^{3} \left(n_g(\mathbf{k}_i) - \frac{N_g}{N_r} n_r(\mathbf{k}_i) \right) \right\rangle_{{\rm bin}\,b} \quad \text{(+ linear term)}$$

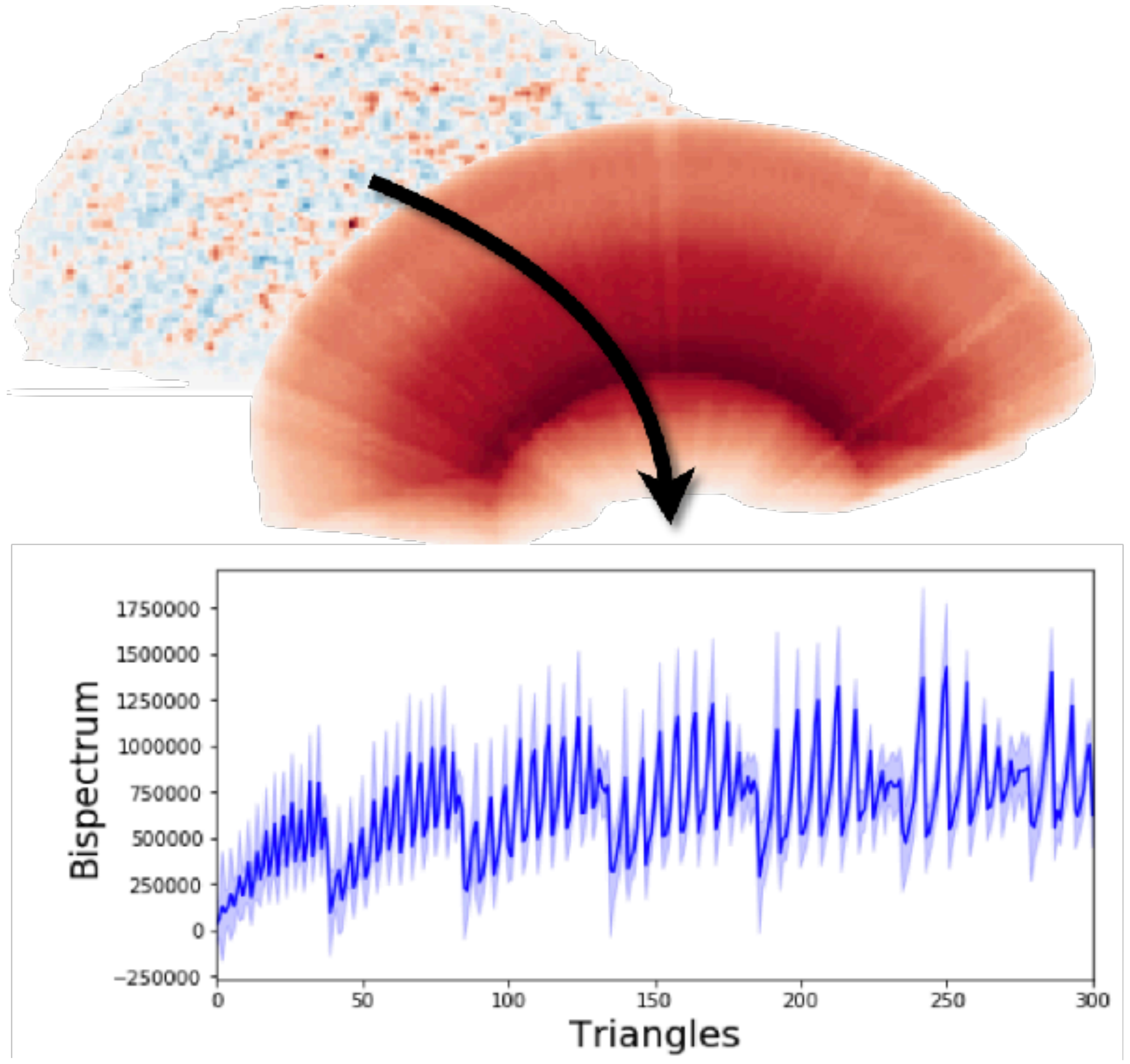
- At leading-order (a good approximation), this does **not** need to be convolved with the mask

$$\color{blue}{B^{\rm unwin}_{{\rm bin}\,a}} \sim B^{\rm true}_{{\rm bin}\,a}$$

- ***Plus**,* it’s almost optimal, even on **large-scales**

- Instead of **mask-convolving** the theory, we **mask deconvolve** the data!

- The **normalization** can be efficiently computed using **Monte Carlo** methods and FFTs
  (**Philcox**, Floss 2025)



Both $P + B$ are computed using the **PolyBin3D** code
(**Philcox**, Floss 2025)

Feldman, Kaiser, Peacock 1980s, BOSS DR12, Beutler+, Gil-Marin+, McDonald+, Ivanov+19, **Philcox**+20,21, **Philcox** & Floss 2025

Accounting for Systematics

- **Radial integral constraint**
  - [missing line-of-sight fluctuations]
  - Included in **normalization** and **theory matrix**
- **Imaging systematics**
  - [the Galaxy contaminates angular modes]
  - Included in **weights** (as in DESI)
  - Template marginalized out over for ELG2 and QSO
- **Stochasticity**
  - [the sample is discrete]
  - Subtract **Poisson** shot-noise

$$P_{\rm shot} \sim \bar{n}_g^{-1}, B_{\rm shot} \sim \bar{n}_g^{-2} + \bar{n}_g^{-1} P(k)$$

- **Wide-angle effects**
  - Included in power spectrum **theory matrix**

$$[\mathrm{Window} \star P^{\rm WA}_{\ell=1,3}] \sim [\mathrm{Window}' \star P^{\rm true}_{\ell}]$$

Chudaykin, Ivanov, **Philcox** 2025

Fiber Collisions

- **Small** angular scales in DESI are **contaminated** by observational systematics, *i.e.* **fiber collisions**

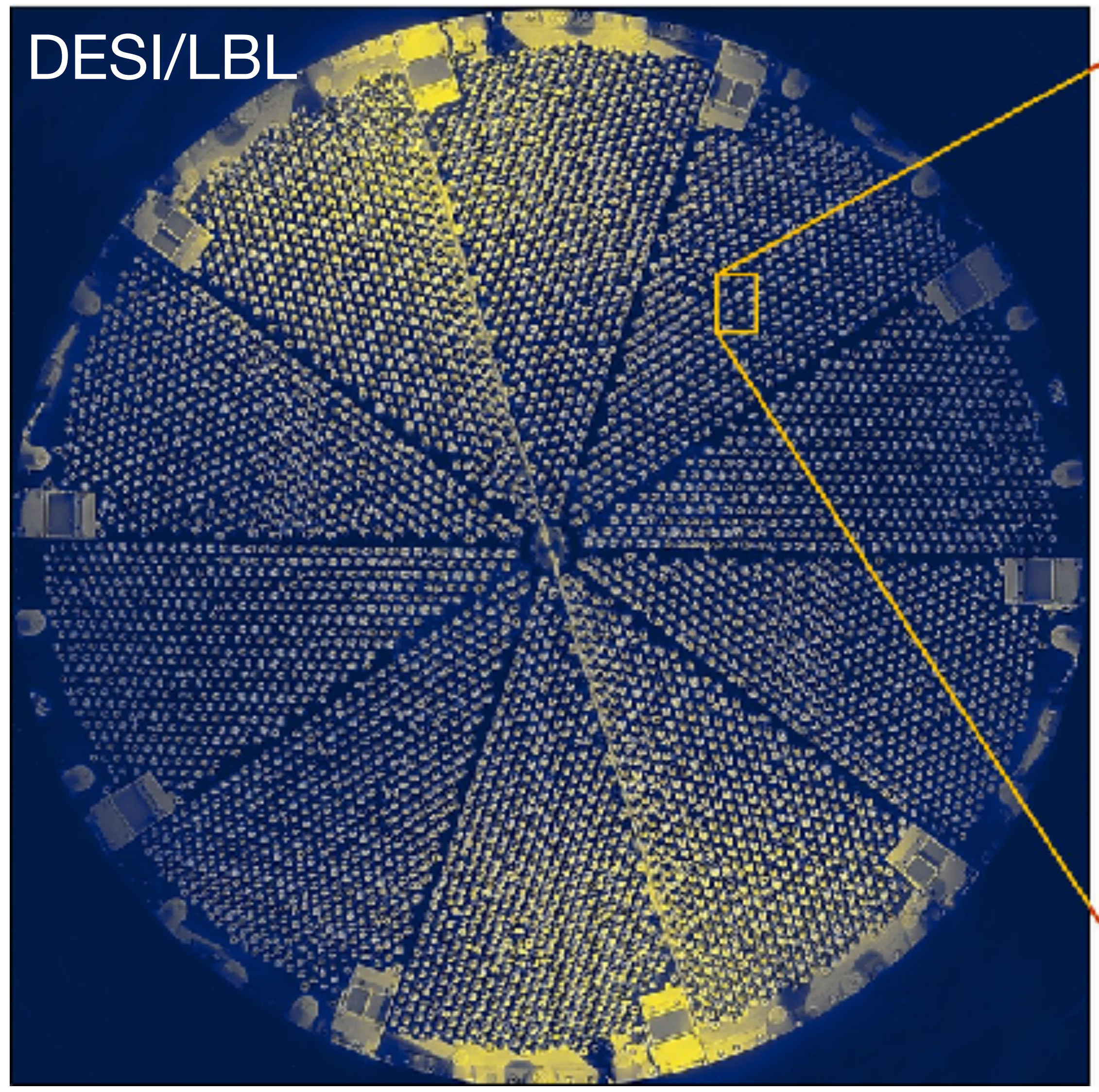
- DESI accounted for this by **removing** pairs of galaxies with small angular separations

$$P(\mathbf{k}) \sim \sum_{\text{galaxy } i} \sum_{\text{galaxy } j} w_i w_j e^{i\mathbf{k}\cdot(\mathbf{x}_i - \mathbf{x}_j)} \times \begin{cases} 1 & \text{if } \theta_{ij} > 0.05^\circ \\ 0 & \text{else} \end{cases}$$

- The correction can be computed by explicit **pair-counting**

- We do the same, correcting the **numerator**, the **normalization,** and the **theory matrix** [*i.e.* residual window]

- DESI applied a **rotation** since the new window is strongly off-diagonal
  - This is **automatically** accounted for in our normalization matrix!



DESI Focal Plane

DESI Fibers

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Fiber Collisions

- Fiber collisions are **harder** for the bispectrum

- To remove all close **pairs** (or triplets), we'd need to count all **triplets** of galaxies, which is $\sim 10^6$ times more expensive!

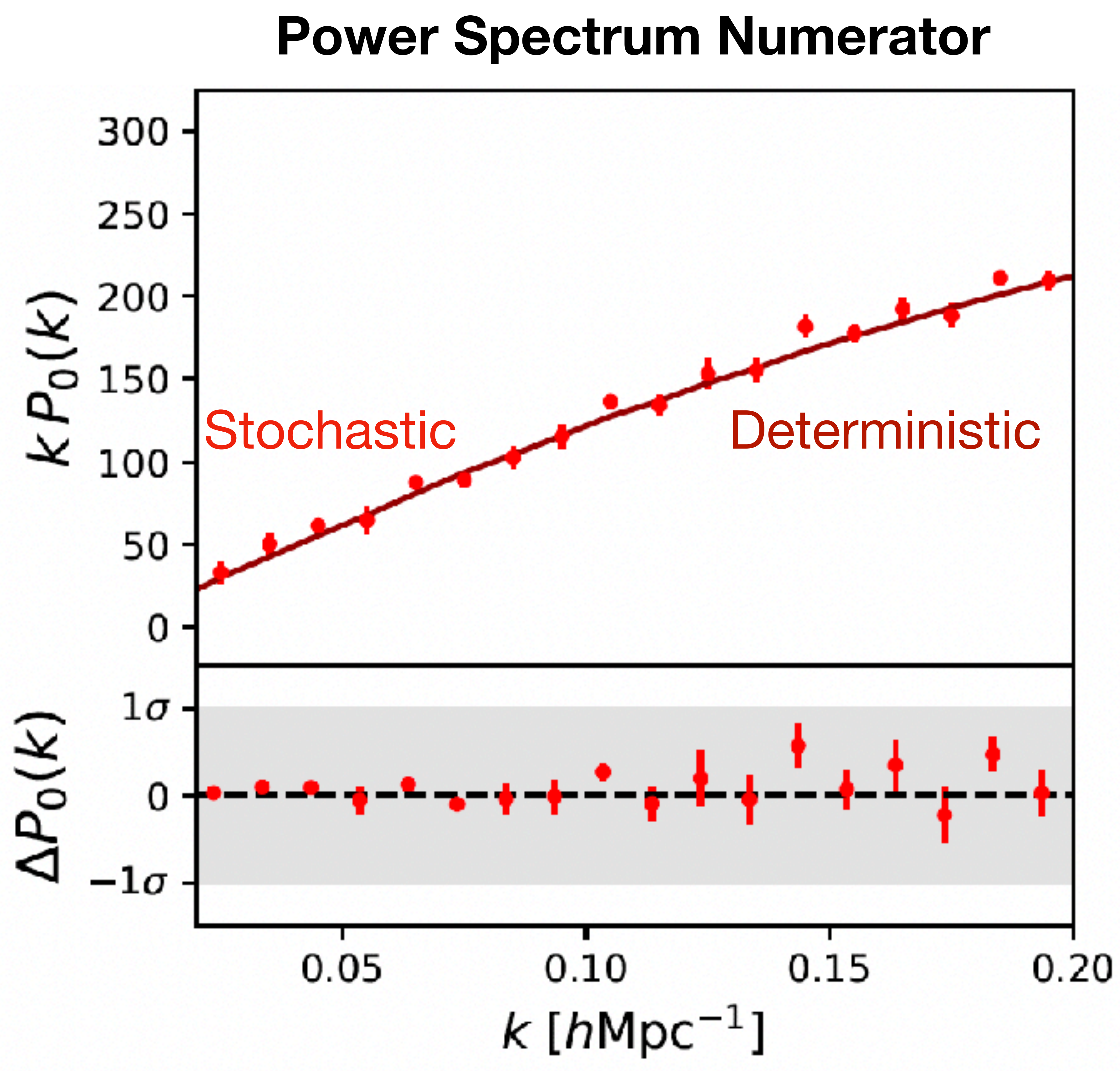
$$B(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3) \sim \sum_{\text{galaxy } i} \sum_{\text{galaxy } j} \sum_{\text{galaxy } k} w_i w_j w_k (\cdots) \times \begin{cases} 1 & \text{if } \left(\theta_{ij} \text{ and } \theta_{jk} \text{ and } \theta_{ki}\right) > 0.05^\circ \\ 0 & \text{else} \end{cases}$$

- We introduce a novel **stochastic** method for removing these, involving **cross-bispectra**

Power spectrum example:

$$\sum_i w_i \epsilon_i \sum_j w_j \sum_k \epsilon_k \begin{cases} 1 & \text{if } \theta_{jk} > 0.05^\circ \\ 0 & \text{else.} \end{cases} \Rightarrow \sum_i w_i \sum_j w_j \begin{cases} 1 & \text{if } \theta_{ji} > 0.05^\circ \\ 0 & \text{else.} \end{cases}$$

average over $\epsilon_i \sim \mathcal{N}(0,1)$



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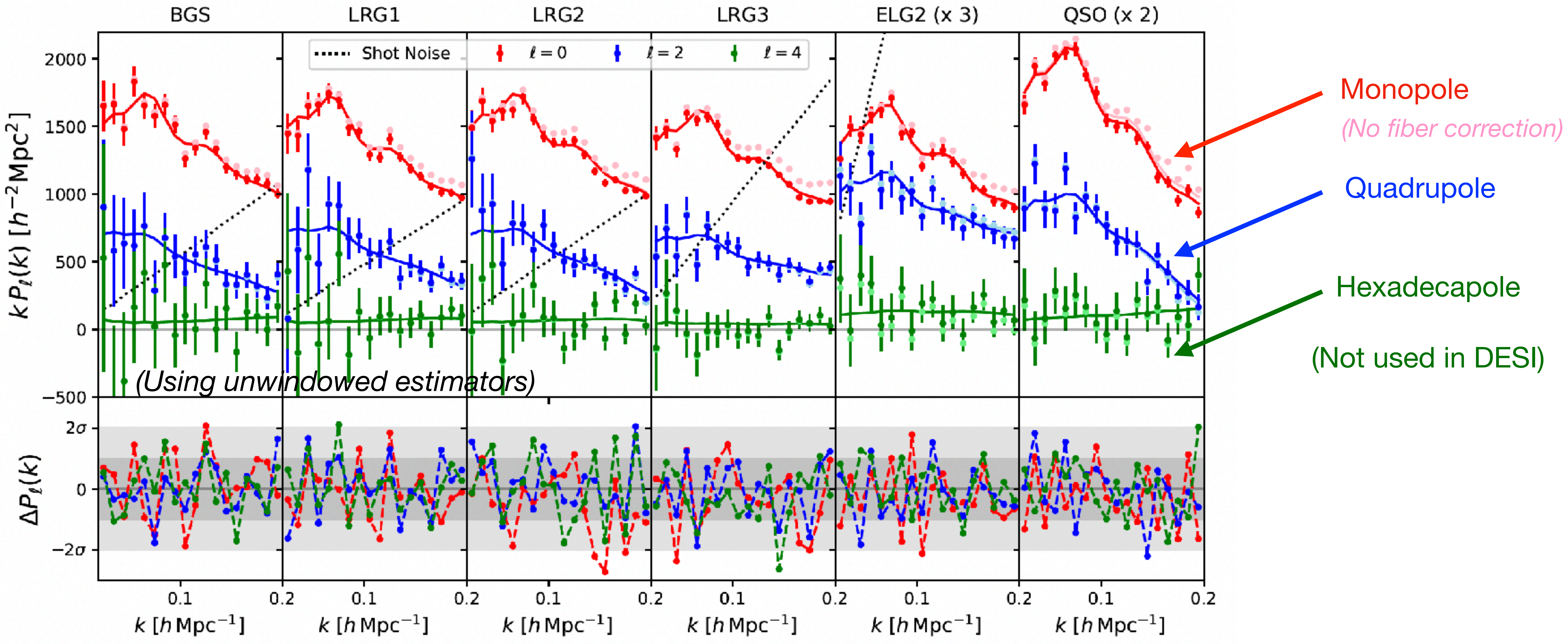
Power Spectrum Data-Set

$P_\ell(k)$ for $\ell = 0{,}2{,}4$ and $0.02\,h\mathrm{Mpc}^{-1} \le k \le 0.20\,h\mathrm{Mpc}^{-1}$



(Maximum SNR: 230σ)

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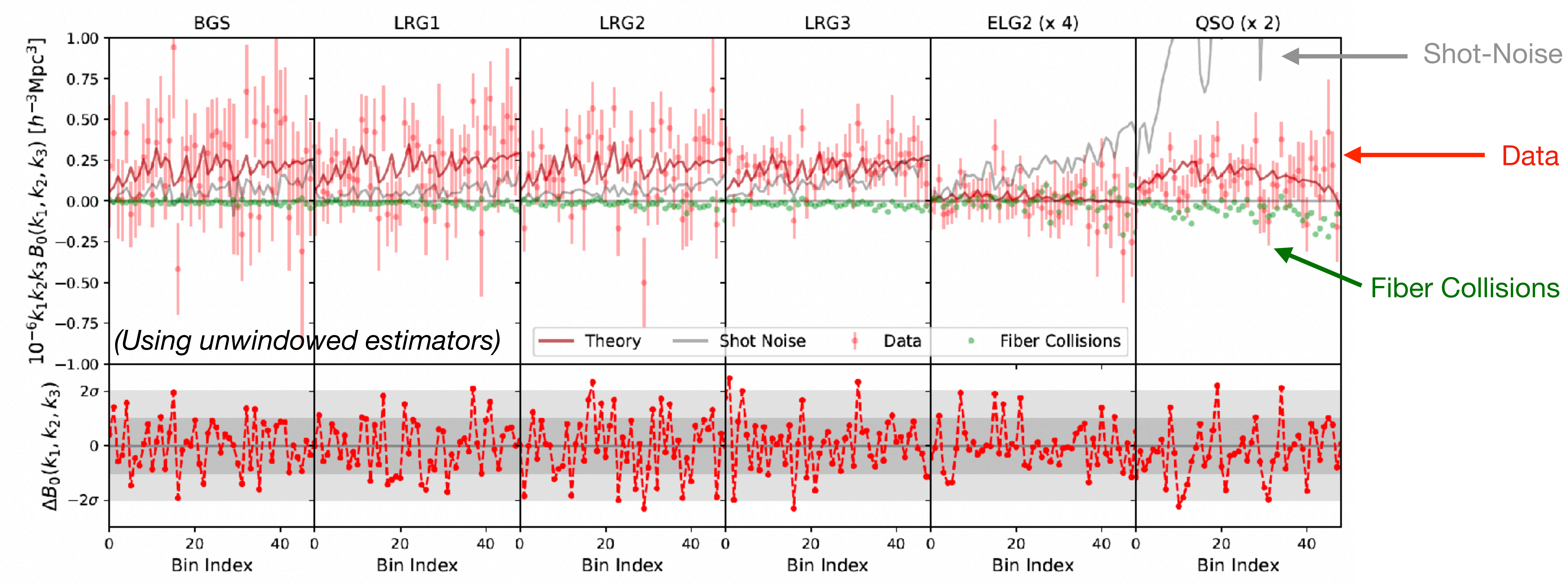
Bispectrum Data-Set

$B_0(k)$ for $0.02\,h\mathrm{Mpc}^{-1} \leq k \leq 0.08\,h\mathrm{Mpc}^{-1}$



(Maximum SNR: 9σ)

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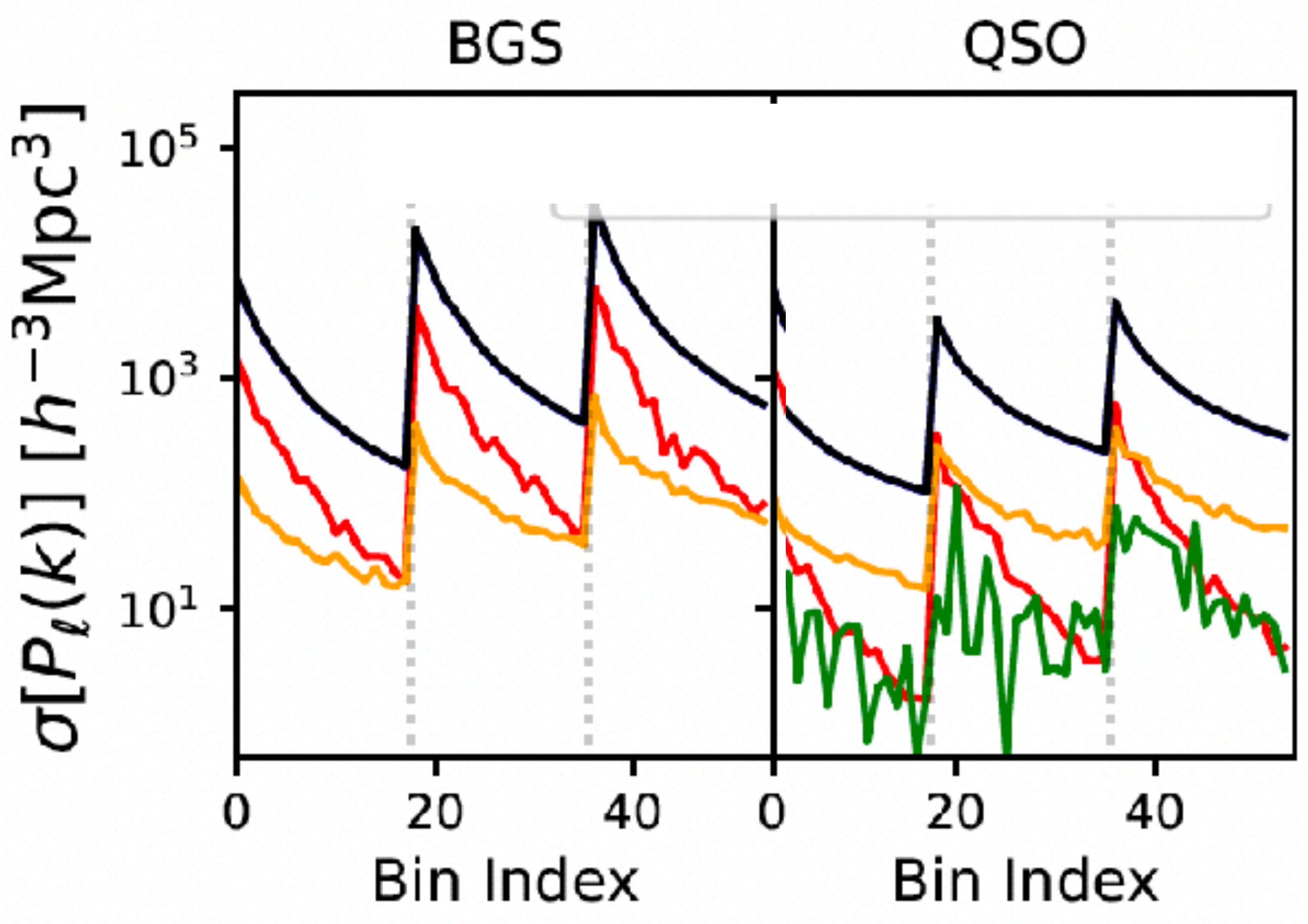
Covariance Matrix

- DESI computed the covariances using **simulations**
- We compute covariance **analytically**

$$\mathrm{cov}[P] \sim P^2(k) \star \mathrm{mask}^4, \qquad \mathrm{cov}[B] \sim P^3(k) \star \mathrm{mask}^6$$

  - This is computed on a **grid**, accounting for the **mask**
  - **PolyBin3D** measures this similarly to the **normalization** and **theory matrix**
  - This depends on a power spectrum **model** fit from the **data**
- **Note:** we do not include non-Gaussian terms…
- DESI rescaled the **simulation** covariance to match a **data-calibrated** theory covariance — we do not need to do this! (It also does not make a difference)
- We **inflate** covariance to include various sources of noise

DESI $P(k)$ Covariance

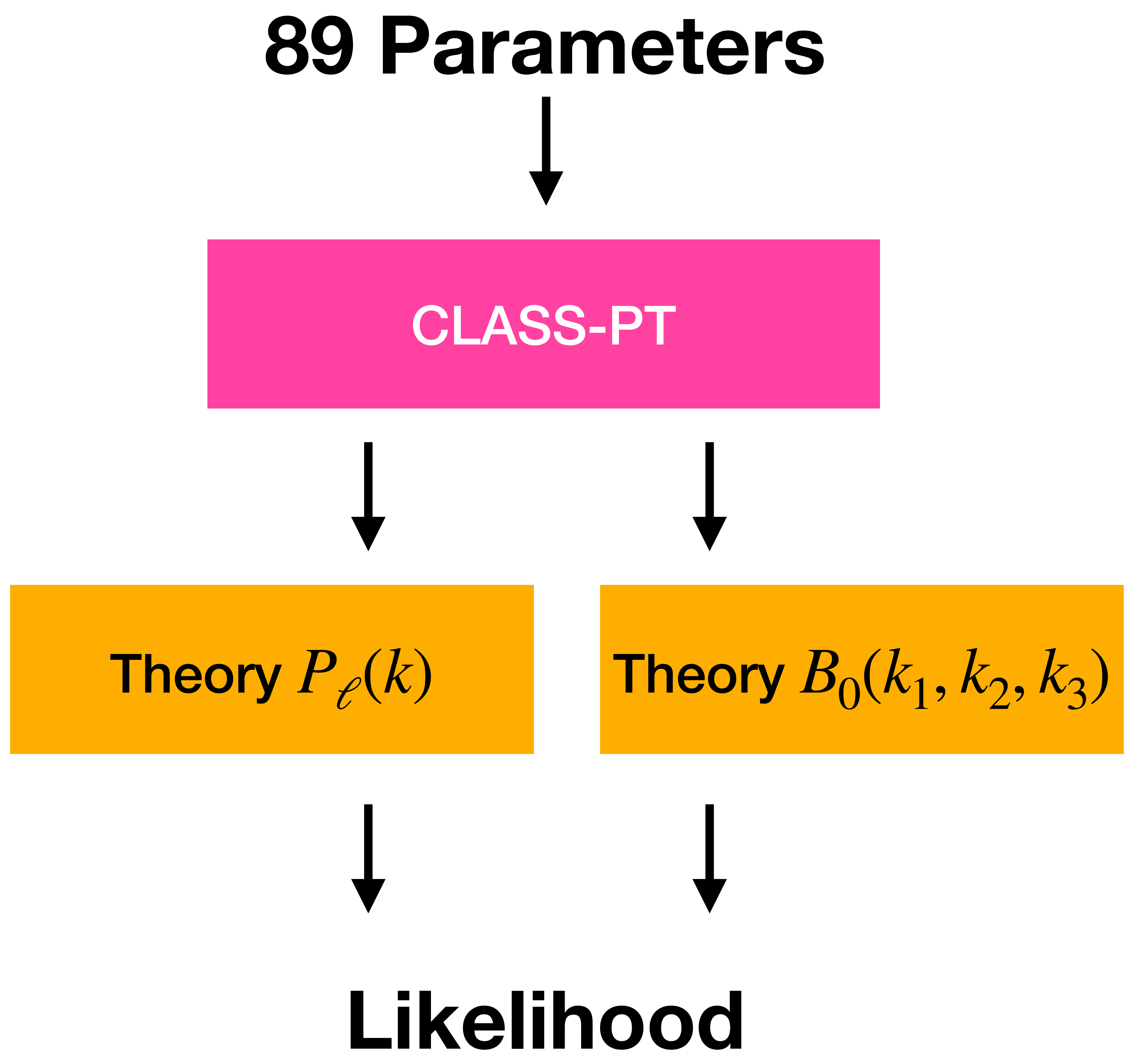


Total *vs* Theory Matrix *vs* Shot *vs* Systematics

DESI 2024 V, Rashkovetskyi+, Forero-Sanchez+, Chudaykin, Ivanov, **Philcox** 2025

Theoretical Model

- We fit the data with the **Effective Field Theory** of **Large Scale Structure** at **one-loop** for P and **tree-level** for B
- **Parameters** (assuming ΛCDM):
  - Cosmology: free $(H_0, \omega_{\rm cdm}, \log A_s)$, plus priors on (ω_b, n_s)
  - Bias: free $(b_1, b_2, b_{\mathcal{G}_2}, b_{\Gamma_3})$
  - Stochasticity: free $P_{\rm shot}, B_{\rm shot}, A_{\rm shot}, a_0, a_2$
  - Counterterms: free $c_0, c_2, c_4, \tilde{c}, c_1$
- Most parameters are **analytically marginalized**
- We rescale parameters by σ_8 according to degeneracies



DESI 2024 V, Maus+, Chudaykin, Ivanov, **Philcox** 2025

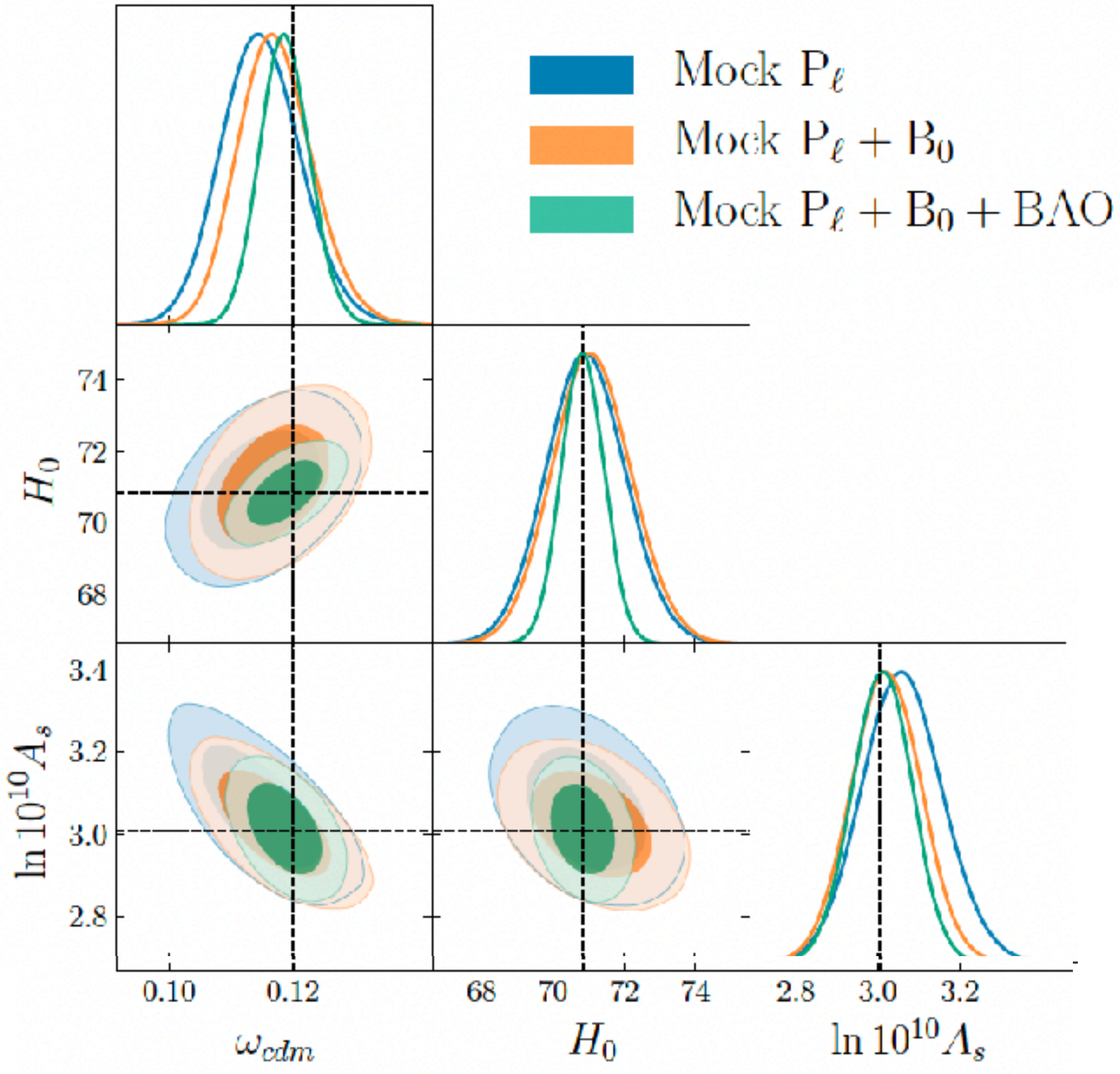
Projection Effects

- When analyzing synthetic data, do we recover the input cosmology?
  - The best-fit can be shifted due to **non-Gaussian** posteriors and **parameter degeneracies**
  - This is a consequence of **Bayes' theorem**, but minimizing these helps to interpret **posteriors**

- We find **good consistency** with inputs, particularly when **extra data** is added ($< 0.4\sigma$)

- The **rescaled biases** (e.g., $b_1 \to b_1\sigma_8$) help a lot!

  e.g. Maus+24



DESI 2024 V, Maus+, Chudaykin, Ivanov, **Philcox** 2025

Constraints on ΛCDM

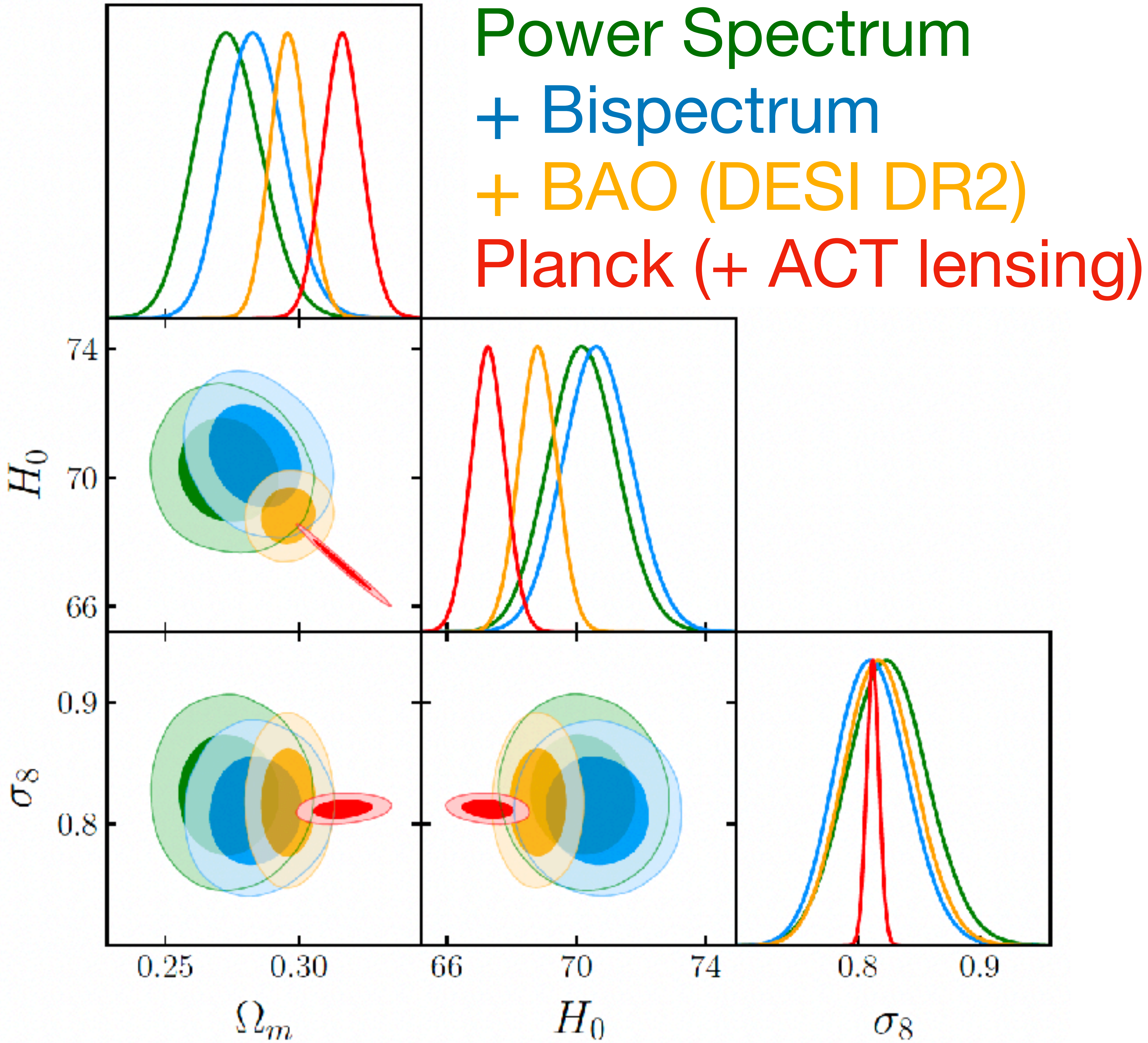
DESI alone finds **strong constraints** on Ω_m, H_0, σ_8

- Adding the **bispectrum** improves constraints by $\sim$10%
- Adding the (official) DESI DR2 BAO gives **significant** improvements in Ω_m, H_0
- No evidence for H_0 tension or S_8 tension $(S_8 = 0.813 \pm 0.031)$

Our constraints are **broadly consistent** with Planck

- $P + B + \mathrm{BAO}$ dataset matches CMB to 2σ (1.8σ with PR4)

Dataset	Ω_m	H_0	σ_8
$P_\ell(k)$	$0.274^{+0.012}_{-0.013}$	$70.22^{+1.06}_{-1.06}$	$0.825^{+0.033}_{-0.033}$
$P_\ell(k) + B_0(k)$	$0.284^{+0.010}_{-0.012}$	$70.67^{+1.05}_{-1.05}$	$0.811^{+0.028}_{-0.031}$
$P_\ell(k) + B_0(k) + \mathrm{BAO}$	$0.296^{+0.007}_{-0.007}$	$68.82^{+0.58}_{-0.58}$	$0.818^{+0.029}_{-0.029}$
CMB	$0.316^{+0.007}_{-0.007}$	$67.28^{+0.53}_{-0.53}$	$0.812^{+0.005}_{-0.005}$



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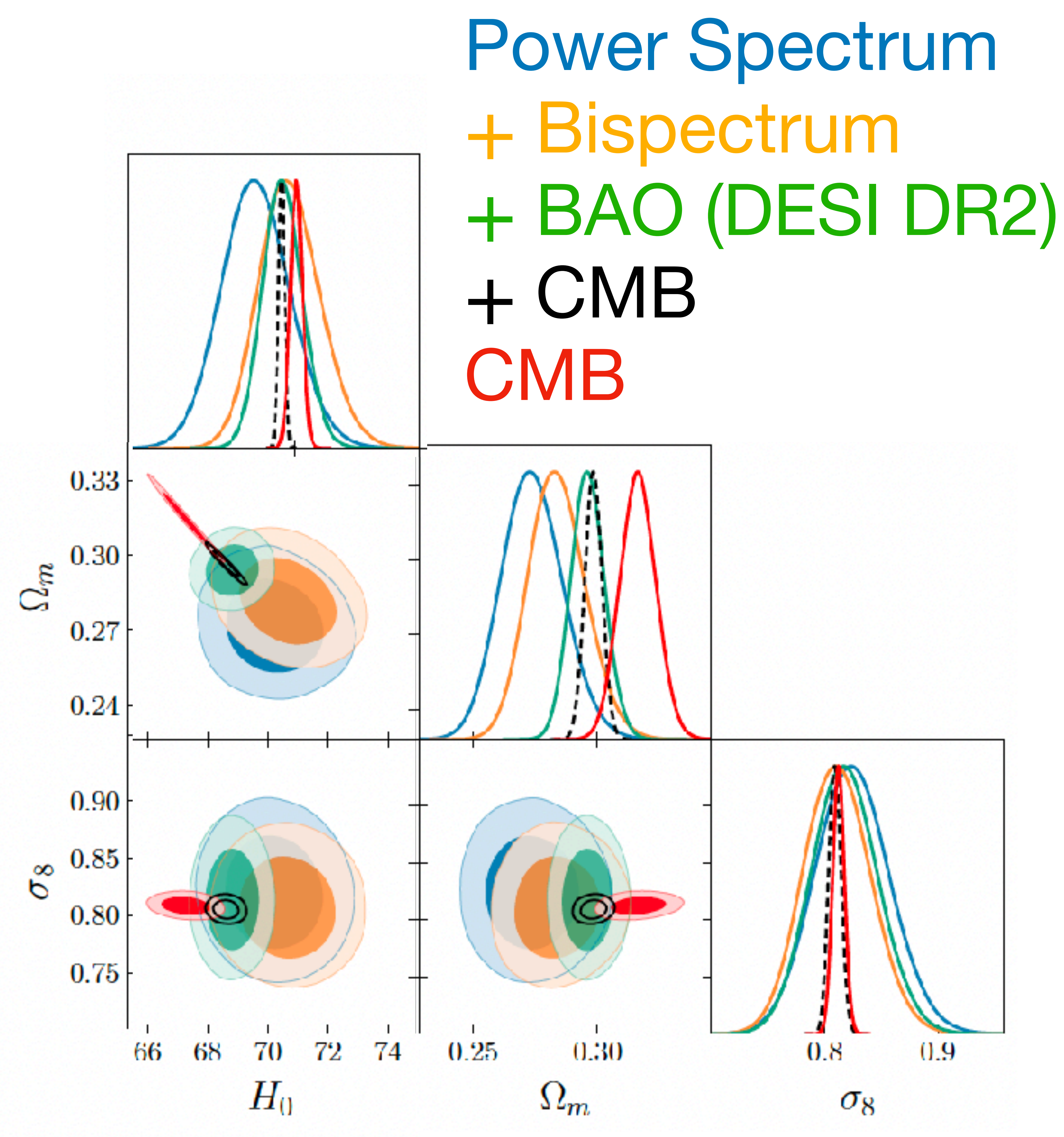
Constraints on ΛCDM

We find even **stronger** constraints combining with the CMB:

- DESI **enhances** Planck constraints up to $2\times$
  - $\Omega_m = 0.298 \pm 0.003$
  - $H_0 = 68.61 \pm 0.28$
  - $\sigma_8 = 0.809 \pm 0.005$
- Ω_m is still a **bit low** *but* it shifts towards Planck as more data is added



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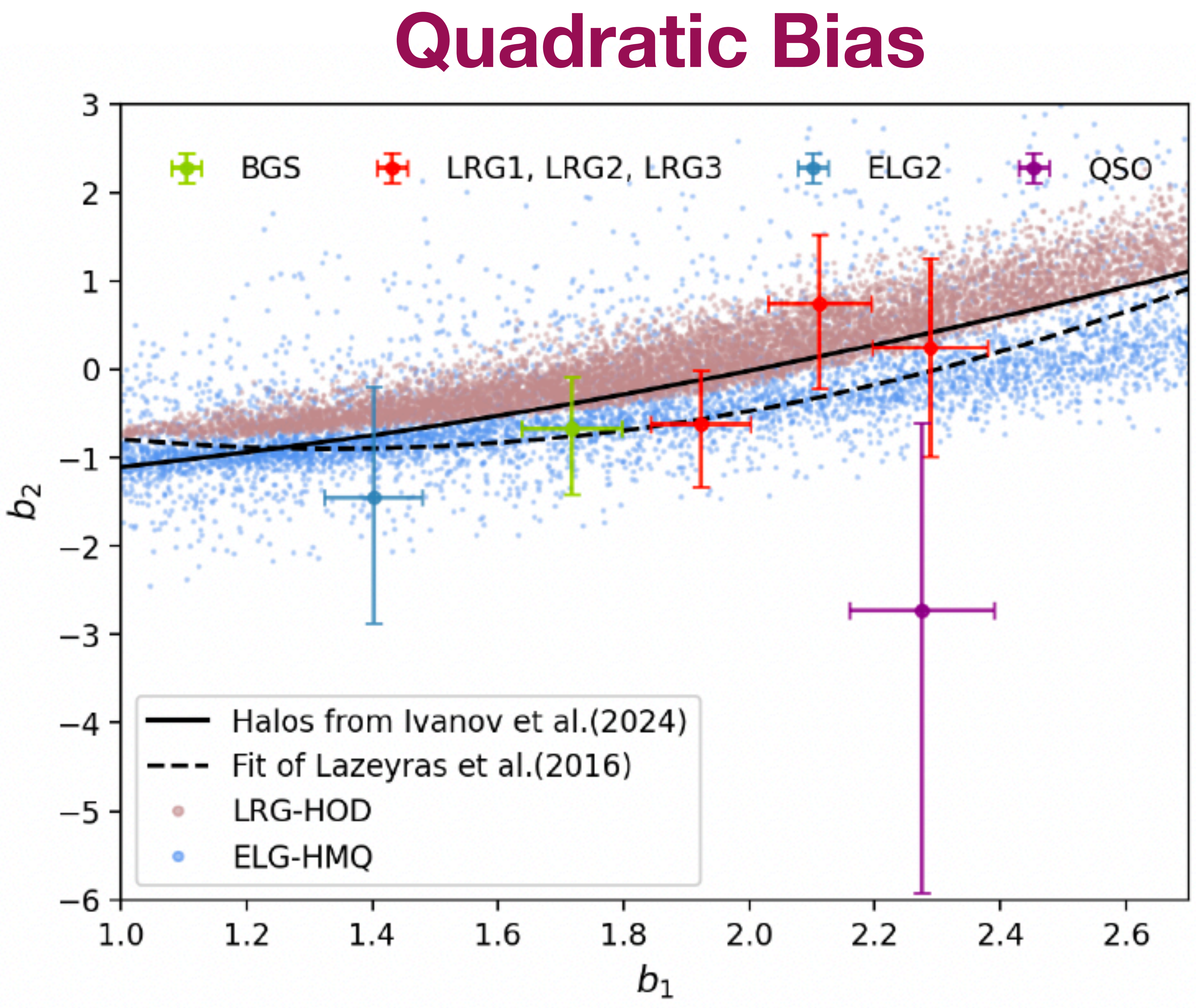
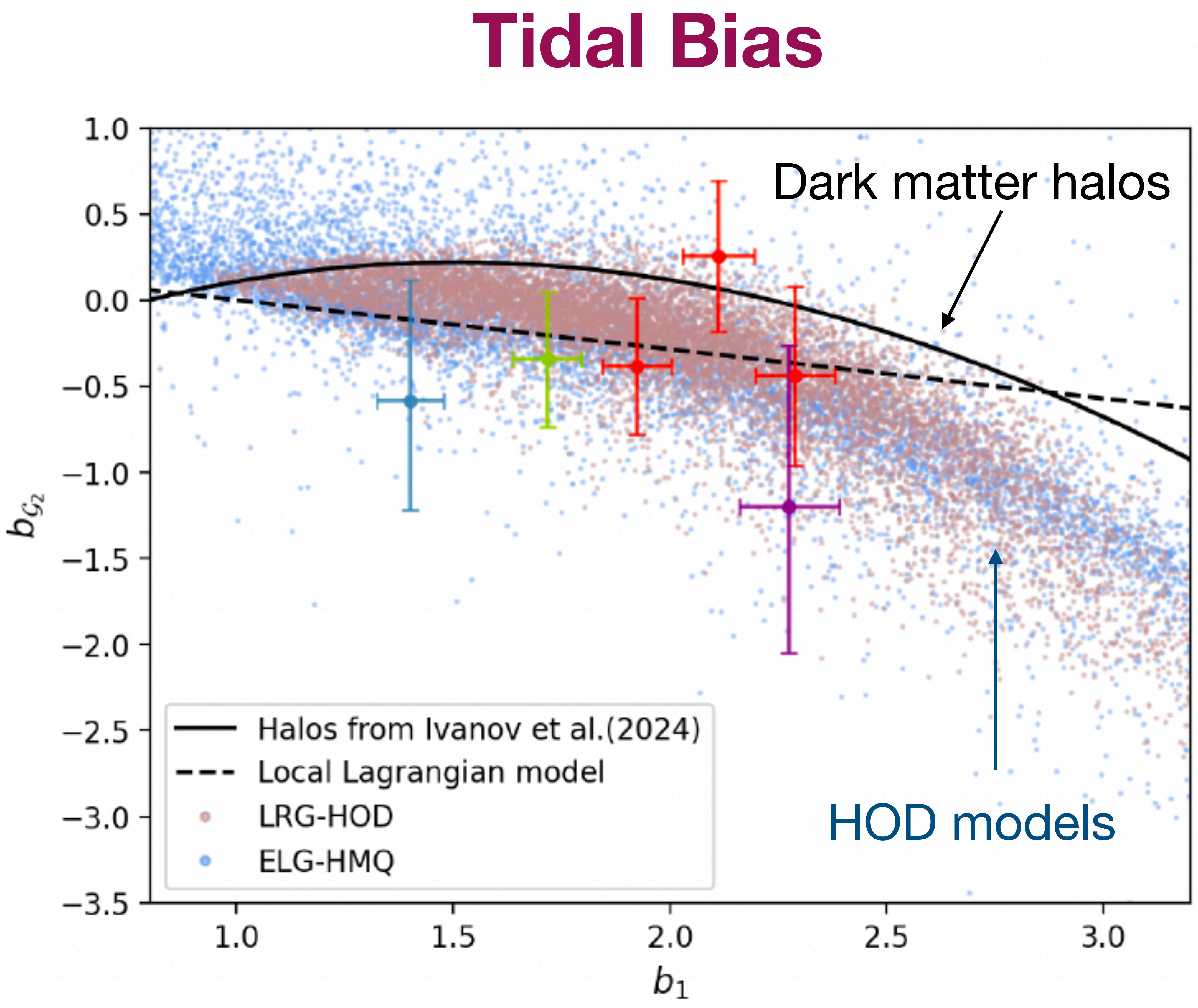
Constraints on Bias Parameters

- Adding the **bispectrum** leads to strong constraints on **bias parameters**
- These agree with HOD predictions, but not with **dark matter** predictions





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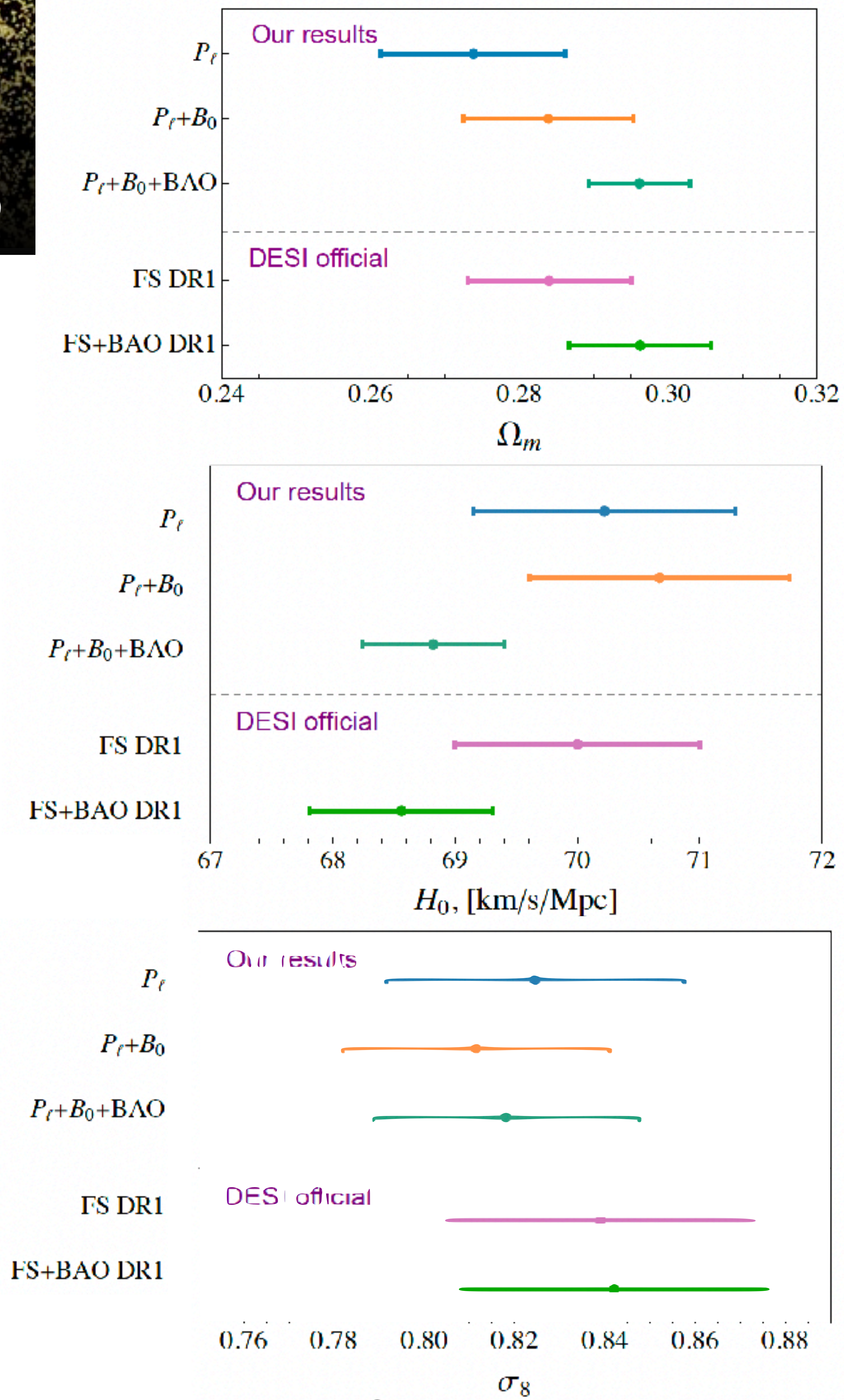
Comparison to Official Results

- We find **fairly good** agreement with DESI with $\Delta\Omega_m = -0.8\sigma, \Delta H_0 = +0.2\sigma, \Delta\sigma_8 = -0.4\sigma$
- The main differences are due to:
  - Addition of the **hexadecapole** (P_4)
  - Free **scale-dependent** shot-noise ($P \supset \frac{1}{\bar{n}}\left[1+a_0k^2\right]$)
  - Free higher-order **fingers-of-God** counterterm ($\tilde{c}$)
  - Free cubic bias (b_{Γ_3})
  - Analytic covariance
- And of course, the addition of the bispectrum and DR2 BAO



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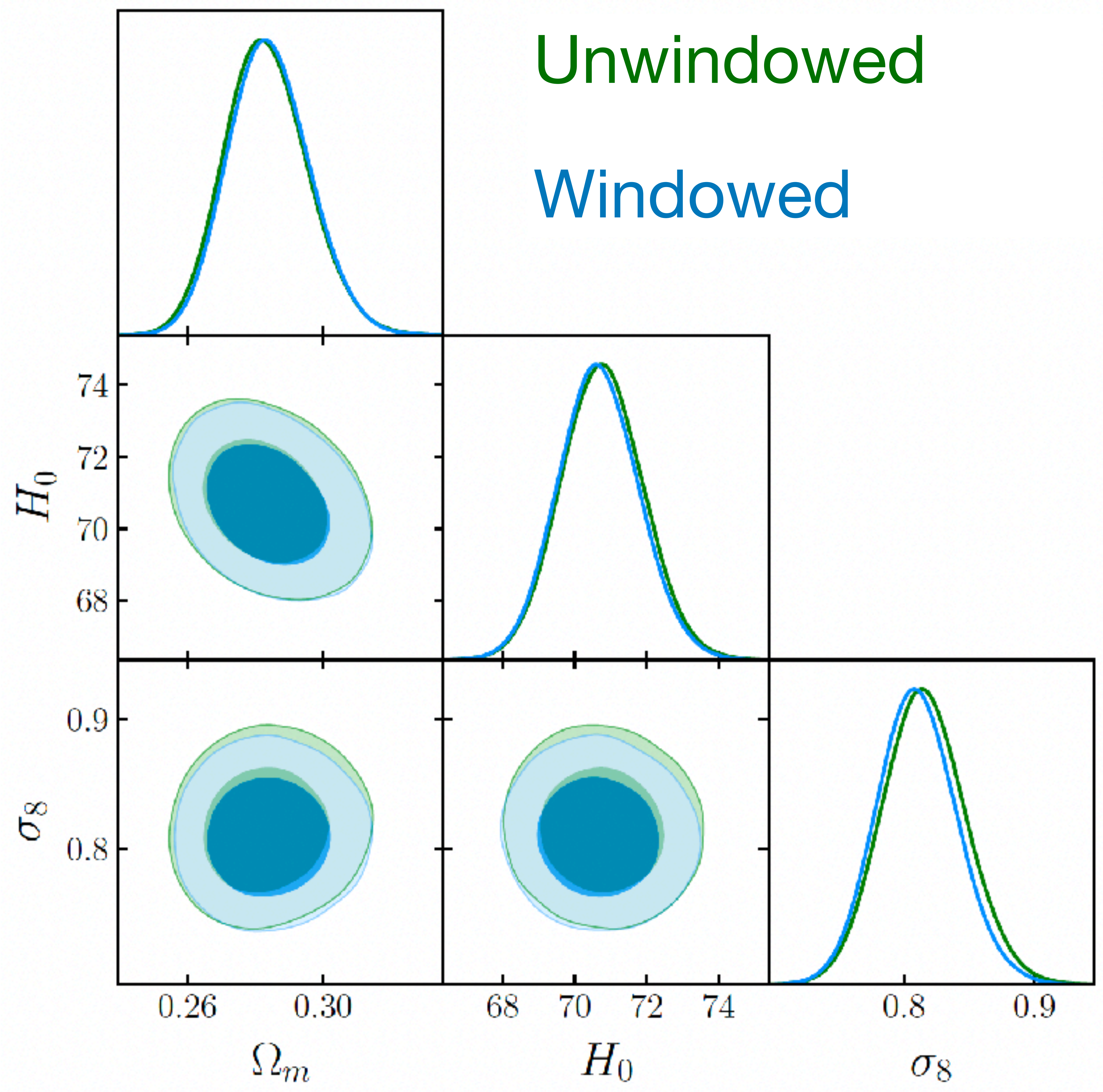
Other Systematic Checks

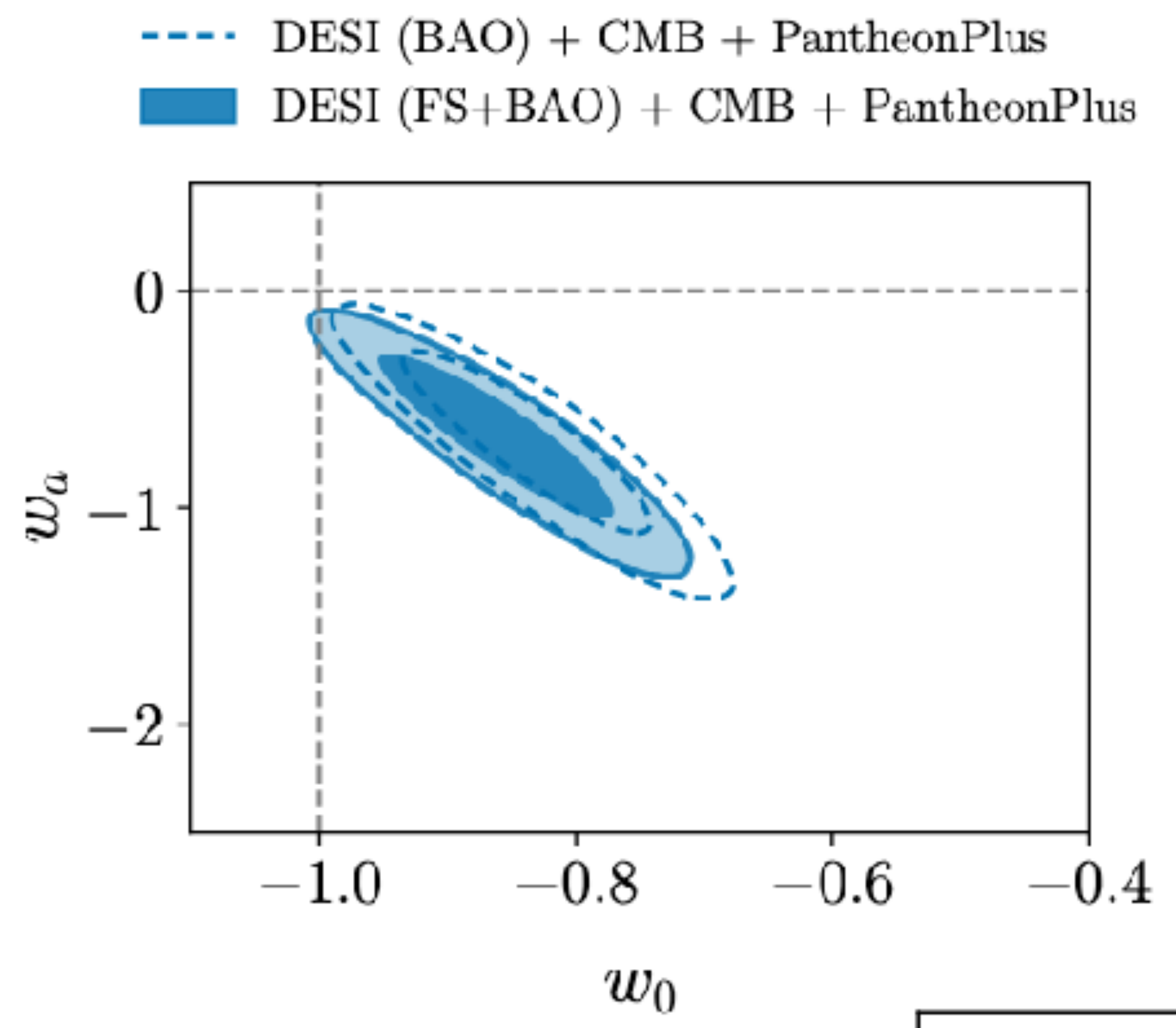
- Results are **stable** ($< 0.5\sigma$ shifts) under changes to the bias model
    - *i.e.* fixing $a_0, b_{\Gamma_3}, \tilde{c}$
    - *Or* removing the hexadecapole
- Results are **stable** under switching from **unwindowed** to (conventional) **windowed** estimators
    - (Windowed are much slower however!)

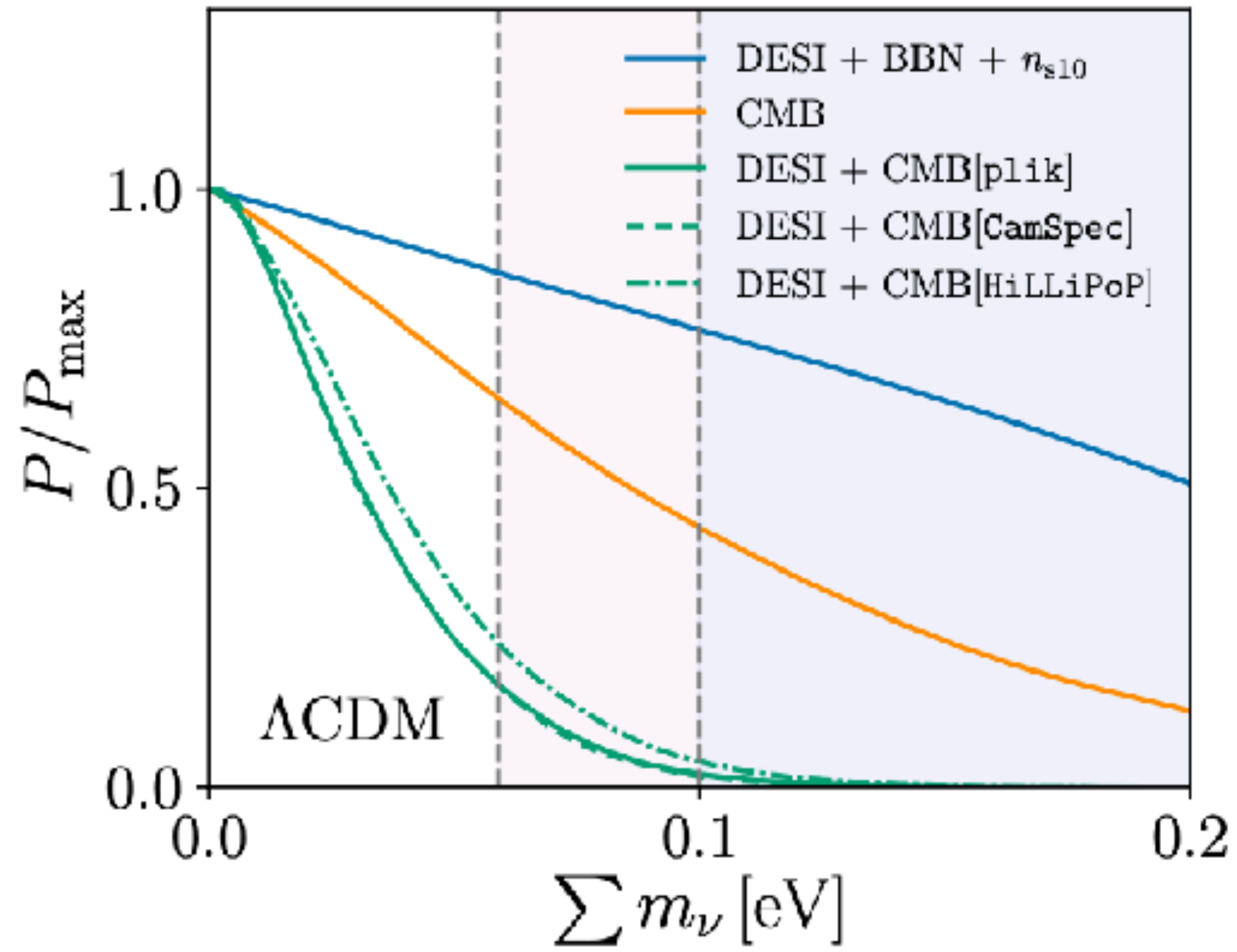


Next works

- There are **many** more models to explore, e.g.,
  - Curvature Ω_k
  - Dark Energy $w(a)$
  - Neutrinos $\sum m_\nu$
  - Primordial non-Gaussianity, $f_{\rm NL}^{\rm loc,\, eq,\, orth}$
- There are **many** more datasets to explore, e.g.,
  - Combined BAO and full-shape data
  - Bispectrum multipoles, B_ℓ
  - Smaller scale bispectra (one-loop)

Can we independently reproduce these?





SIMONS FOUNDATION

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

Stanford University

DESI (edited)

Summary

- We perform a **full renalysis** of the **public** DESI DR1 (full-shape), using **independent** *estimators*, *theory codes*, and *covariances*!

- We find **consistency** within $\approx 0.5\sigma$, and we add **new data** $(P_4 + B_0)$

- There's **a lot** more to explore with the data!

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