Colloque national du WG Dark Energy 2025 - 9ème édition
Montpellier

The DESI Peculiar Velocity Survey: growth rate measurements with DR1

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on behalf of the DESI Peculiar Velocity team

November 6th, 2025

Plan

Motivation (dark energy or modified gravity)

Measuring growth rate at low-z with peculiar velocities

The DESI Peculiar Velocity survey

DR1 batch of papers

DR1 data and mock catalogs

Methodologies and results

Cosmological implications

Accelerated expansion: dark energy or modified gravity?

Accelerated expansion: **dark energy** or modified gravity?

Cosmological constant Λ

$$w = w_0 + (1 - a)w_a$$

Tension with the cosmological constant

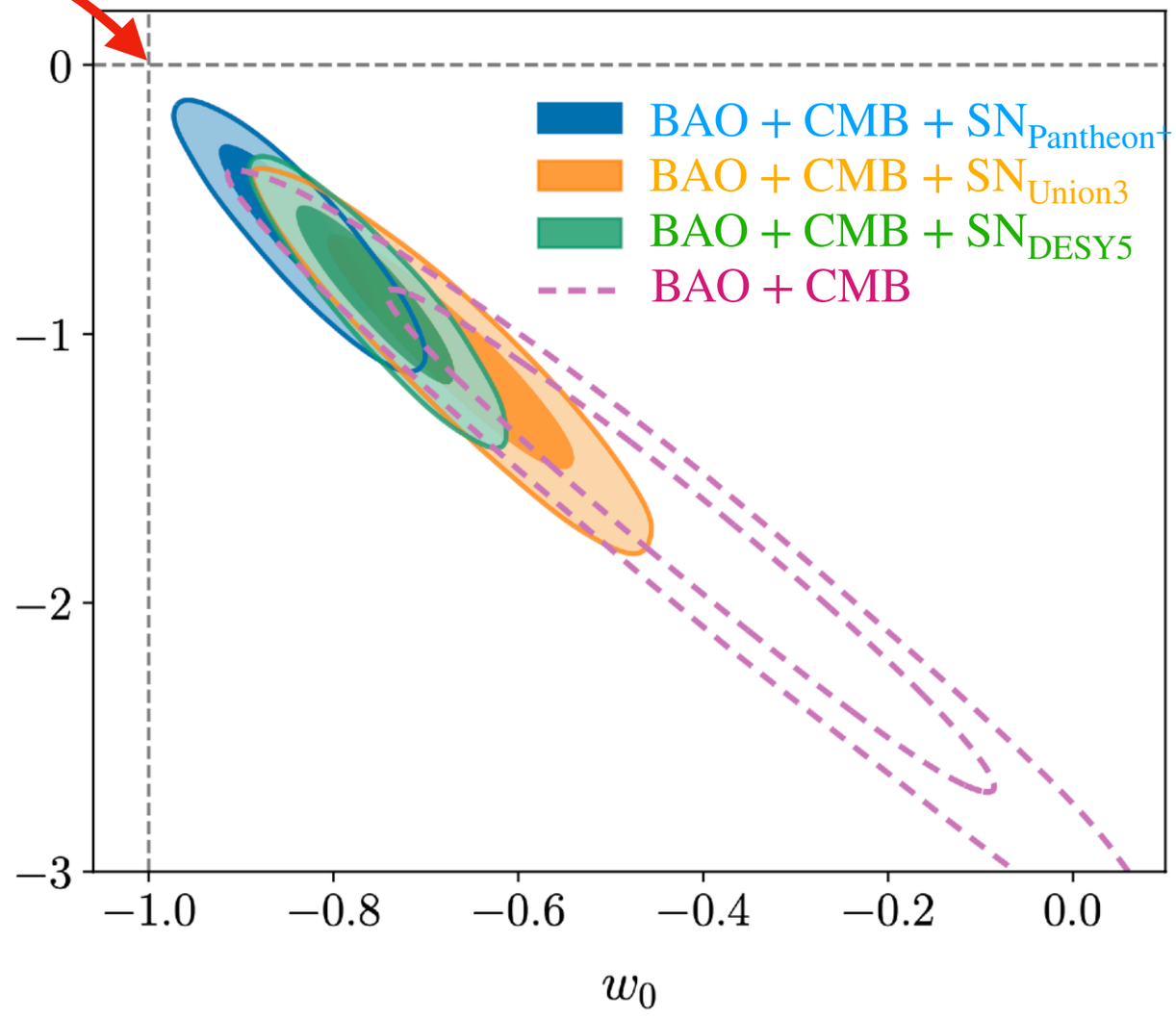
$\mathrm{BAO} + \mathrm{CMB} \Rightarrow 3.1\sigma$

$\mathrm{BAO} + \mathrm{CMB} + \mathrm{SN}_{\mathrm{Pantheon^+}} \Rightarrow 2.8\sigma$

$\mathrm{BAO} + \mathrm{CMB} + \mathrm{SN}_{\mathrm{Union3}} \Rightarrow 3.8\sigma$

$\mathrm{BAO} + \mathrm{CMB} + \mathrm{SN}_{\mathrm{DESY5}} \Rightarrow 4.2\sigma$

DESI DR2 Results II (2025)



Will this tension remain?

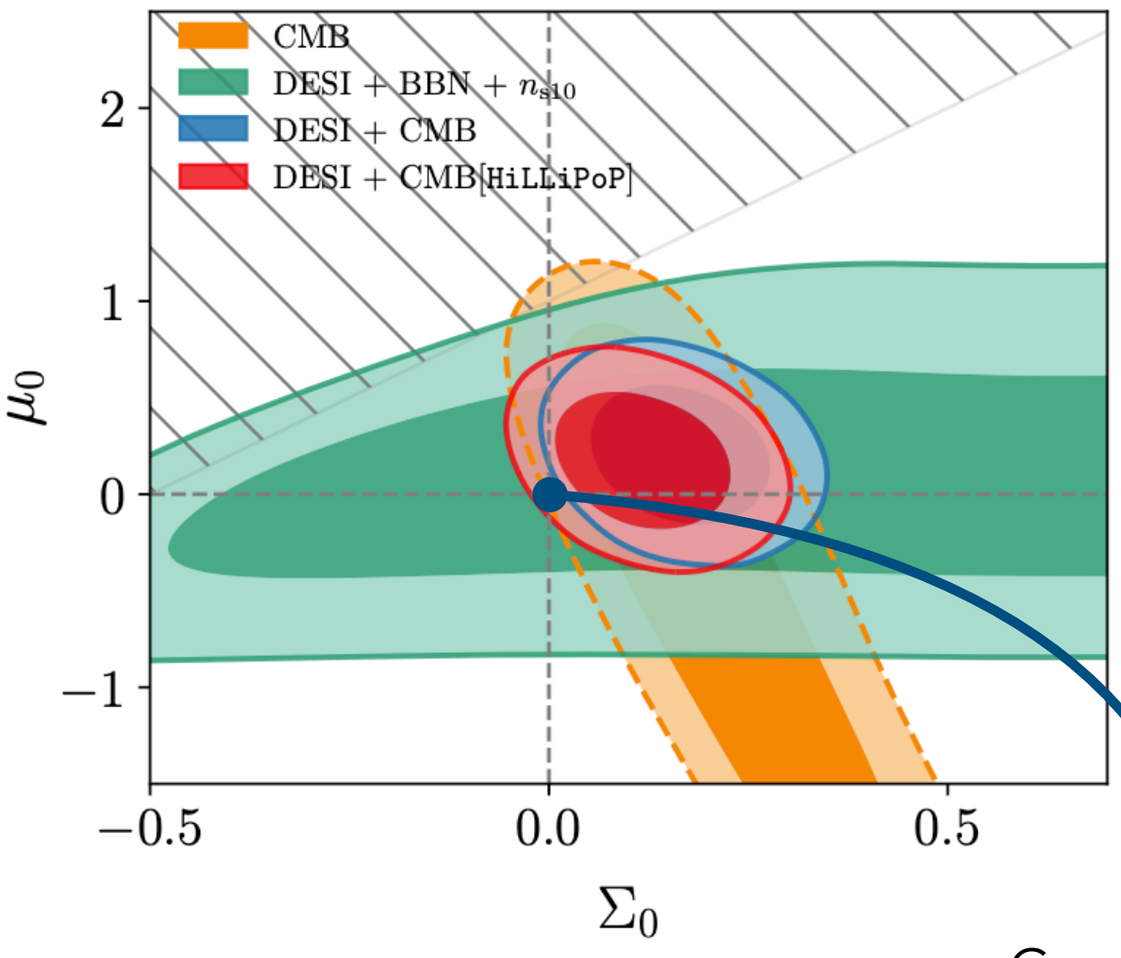
What is causing it?

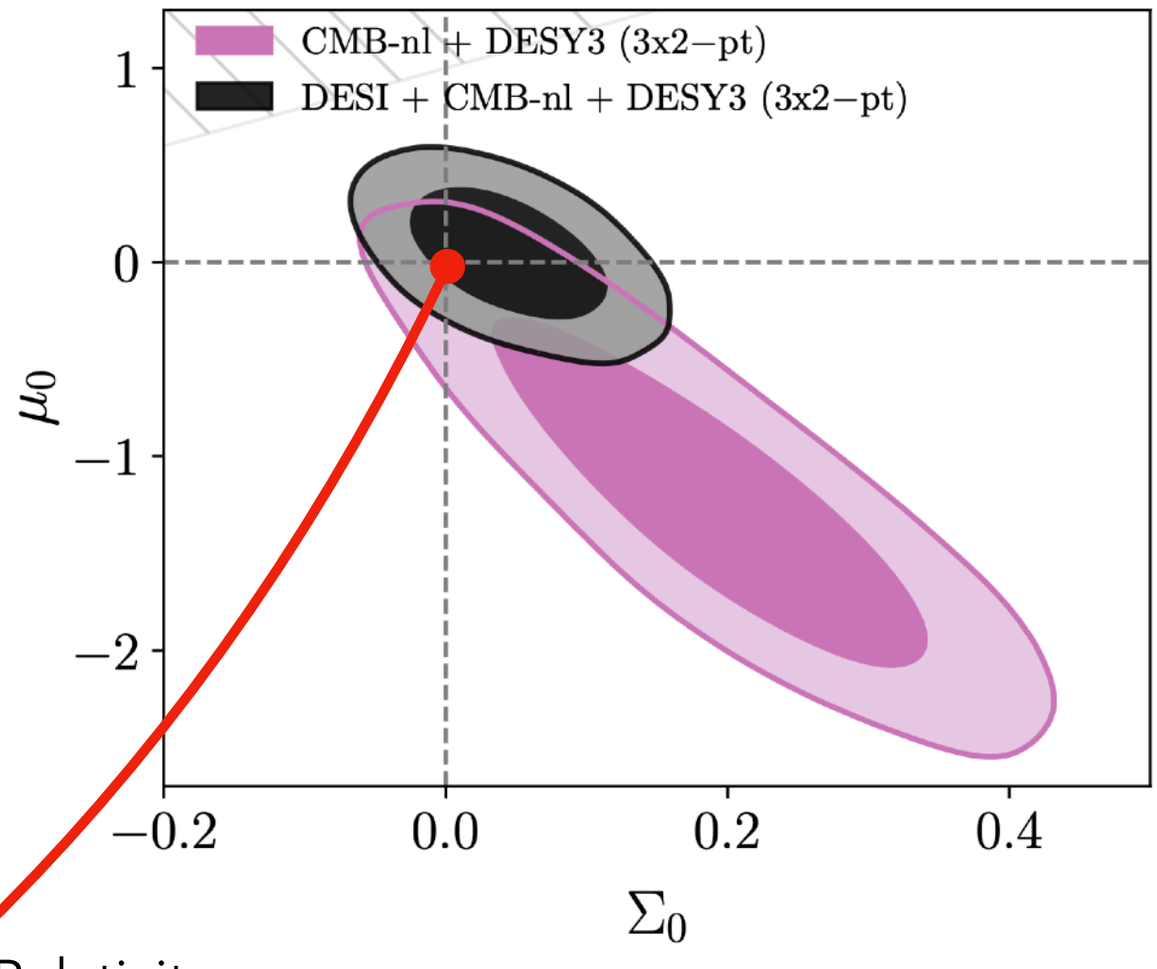
What is the meaning of life?

Accelerated expansion: dark energy or **modified gravity**?

Modified Poisson equations:

$$\begin{cases} -k^2\Psi = 4\pi G a^2 \mu \delta\rho \\ -k^2(\Phi+\Psi) = 4\pi G a^2 \Sigma \delta\rho \end{cases}$$





General Relativity

DESI DR1 Results VII (2024)

Will cosmology show departures from Einstein's theory of gravity?

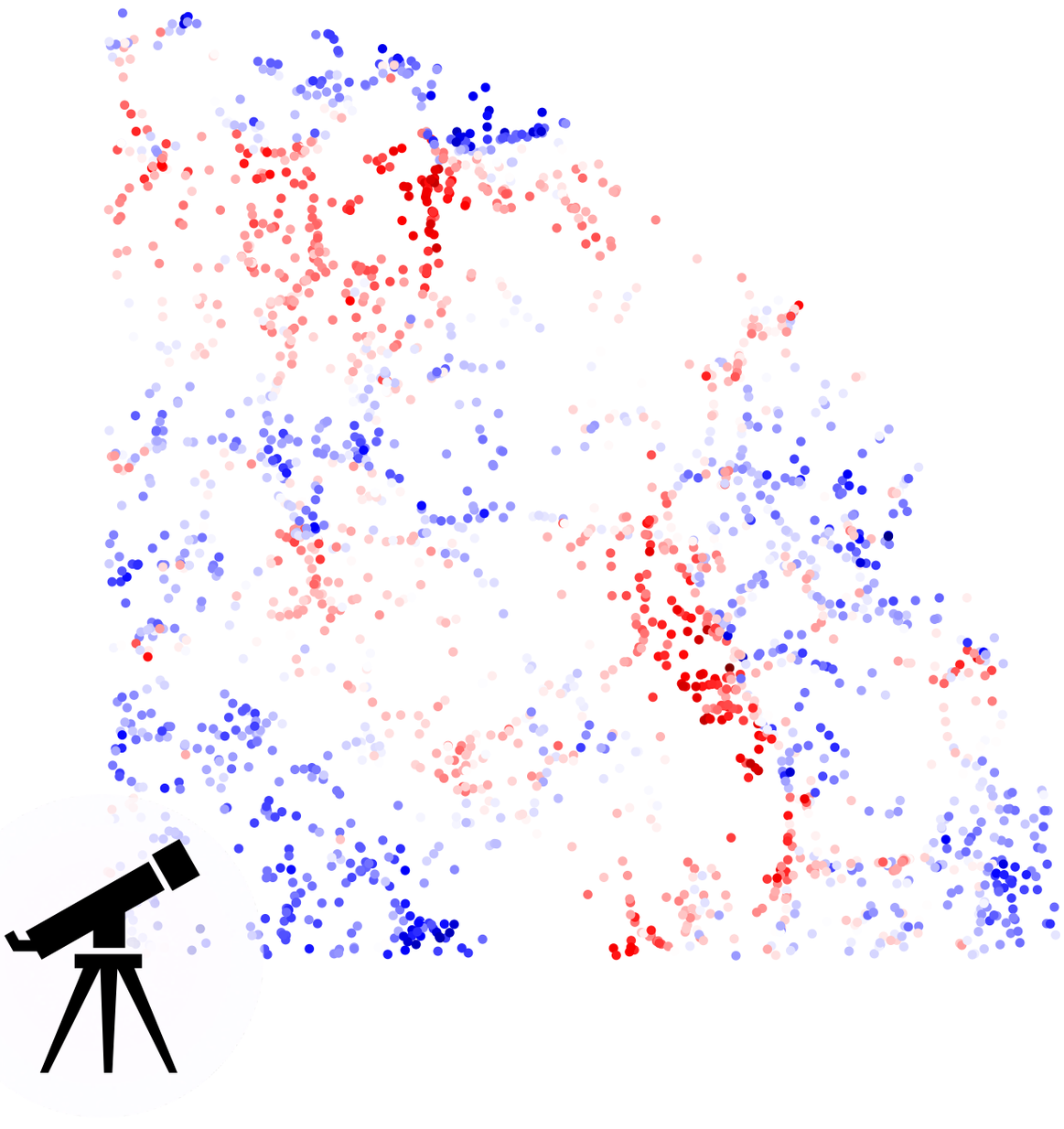
Measuring the growth rate of structures

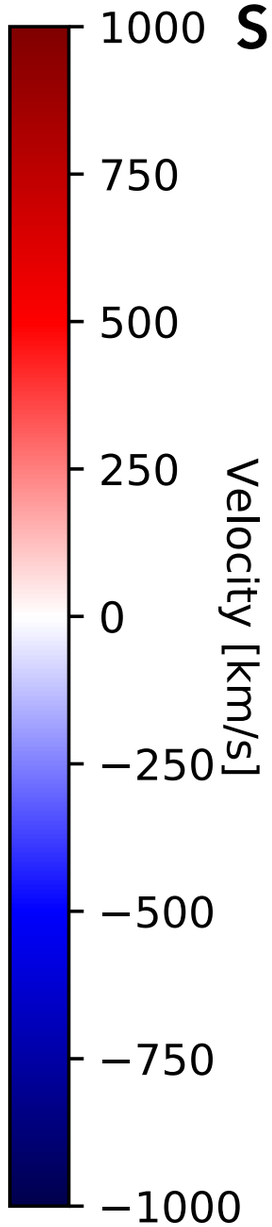
Redshift survey

$\{\theta_i, \phi_i, z_i\}$

Density field in redshift-space

$\delta_g(\vec{s})$





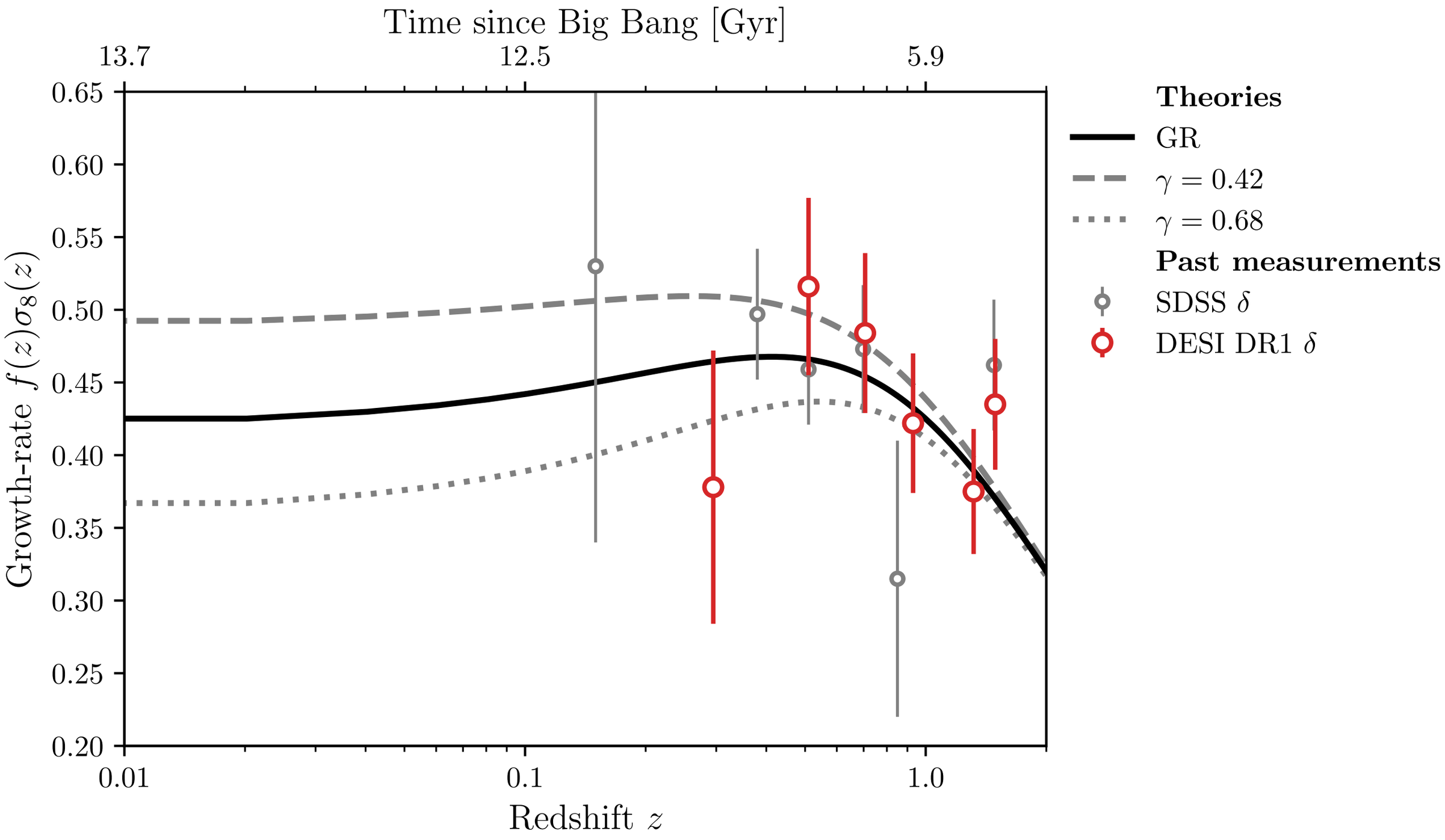
Spatial correlations

$\langle \delta_g(\vec{s}) \delta_g(\vec{s} + \Delta\vec{s}) \rangle$

Growth rate of structures

$f\sigma_8$

Growth rate measurements



RSD: $\langle \delta_g \delta_g \rangle$

Measuring the growth rate of structures

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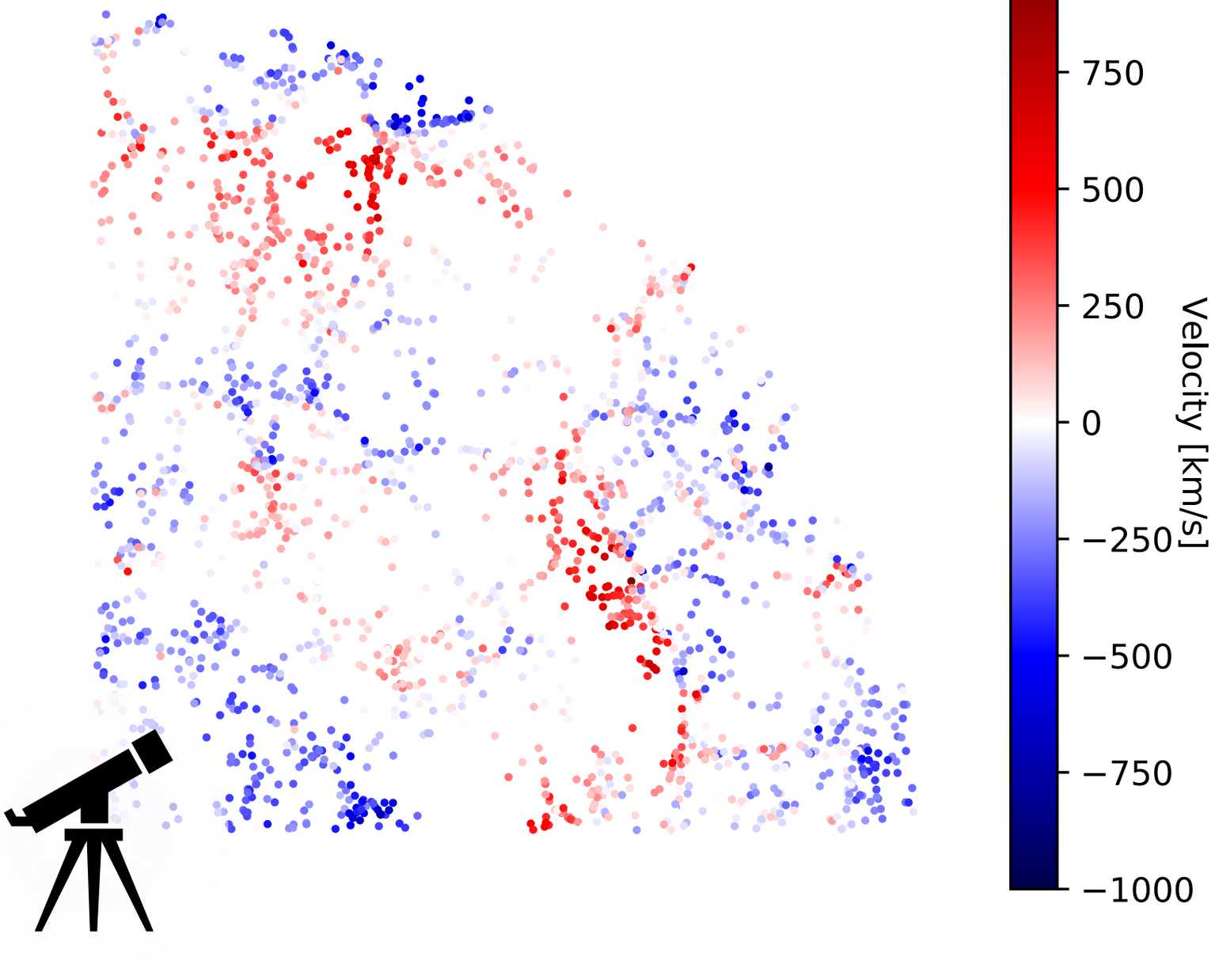

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Measuring the growth rate of structures

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$\{\theta_i, \phi_i, z_i\}$

Density field in redshift-space

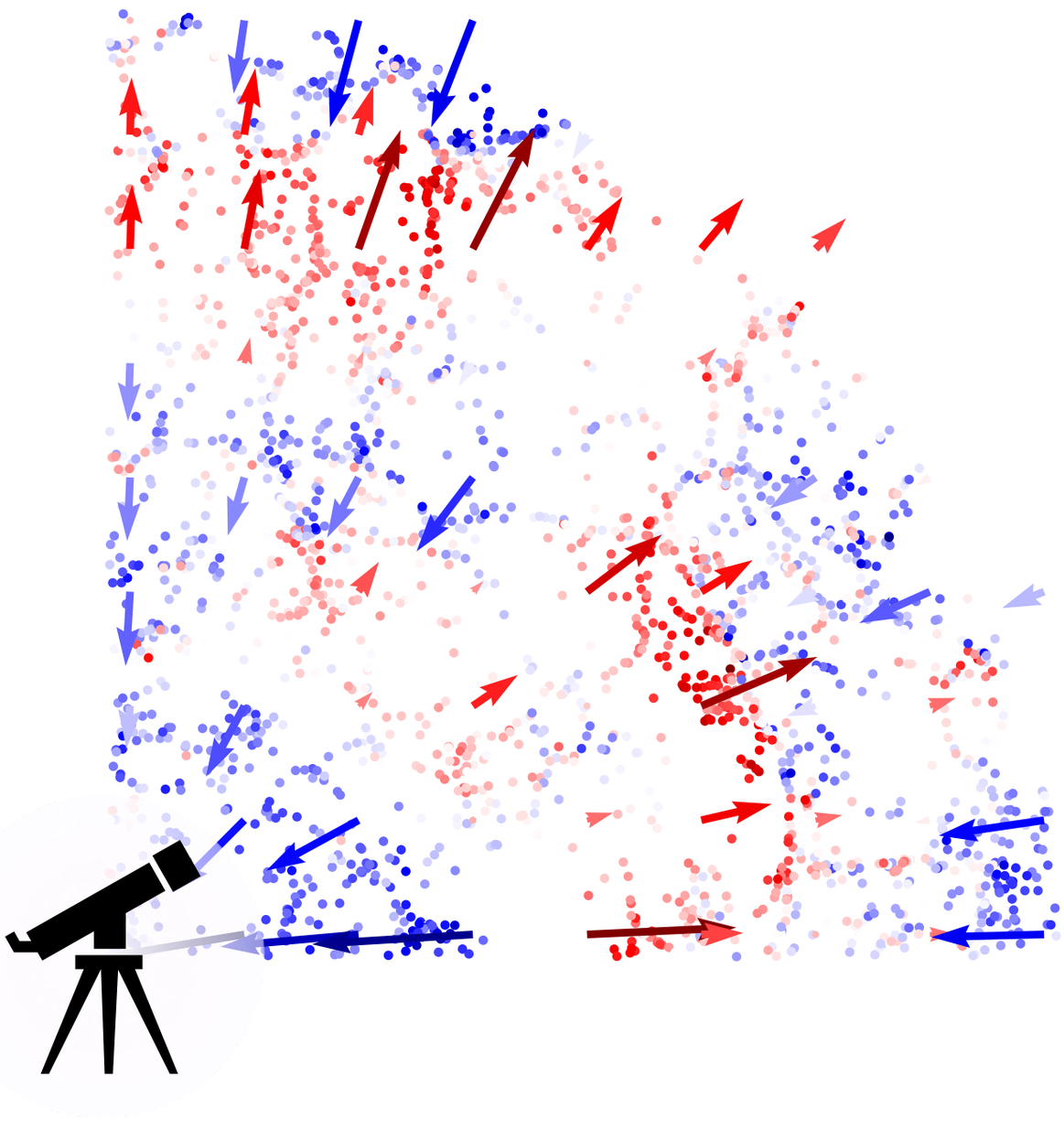
$\delta_g(\vec{s})$

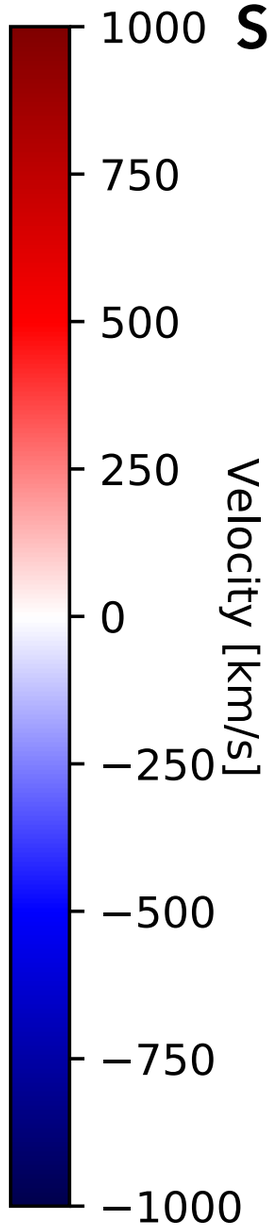
Distance survey

$\{\theta_j, \phi_j, z_j\} + \{D_j\}$

Radial velocity field in redshift space

$v_r(\vec{s})$





Spatial correlations

$\langle \delta_g(\vec{s}) \delta_g(\vec{s} + \Delta\vec{s}) \rangle$

$\langle \delta_g(\vec{s}) v_r(\vec{s} + \Delta\vec{s}) \rangle$

$\langle v_r(\vec{s}) v_r(\vec{s} + \Delta\vec{s}) \rangle$

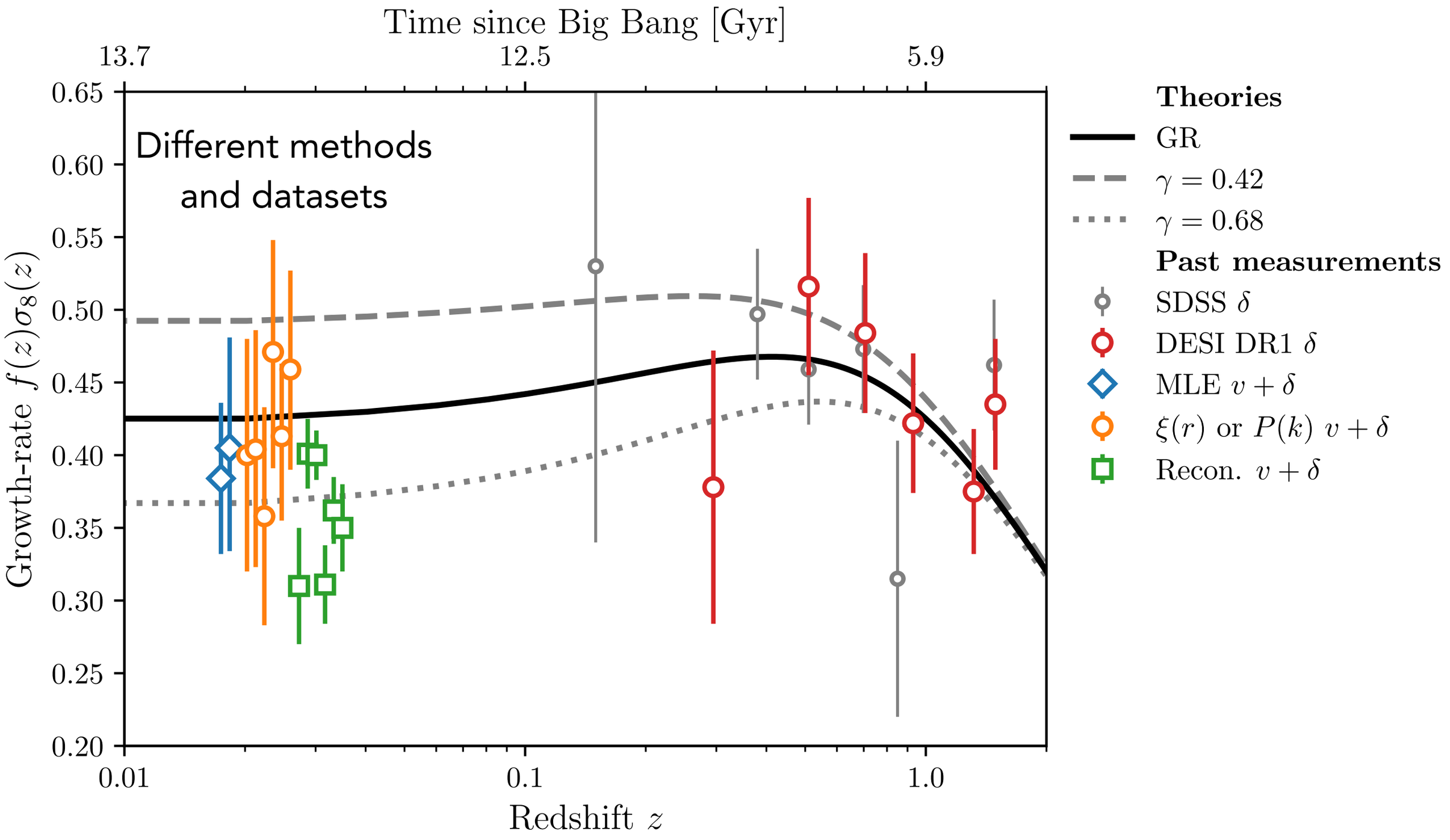
3 x 2pt functions

BETTER

Growth rate of structures

$f\sigma_8$

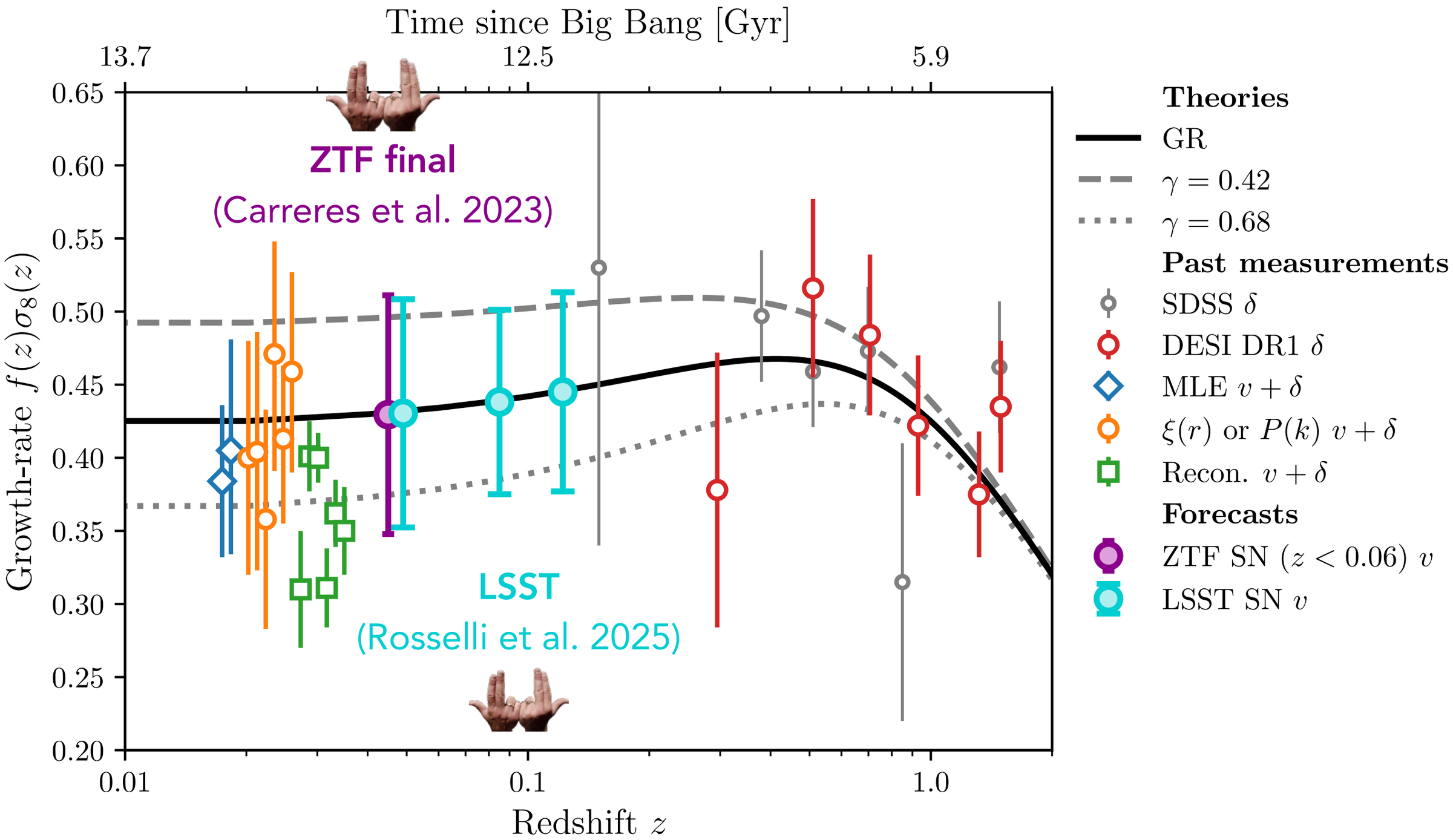
Growth rate measurements



RSD + PV: $\langle \delta_g \delta_g \rangle, \langle \delta_g v_r \rangle, \langle v_r v_r \rangle$

RSD: $\langle \delta_g \delta_g \rangle$

Growth rate measurements



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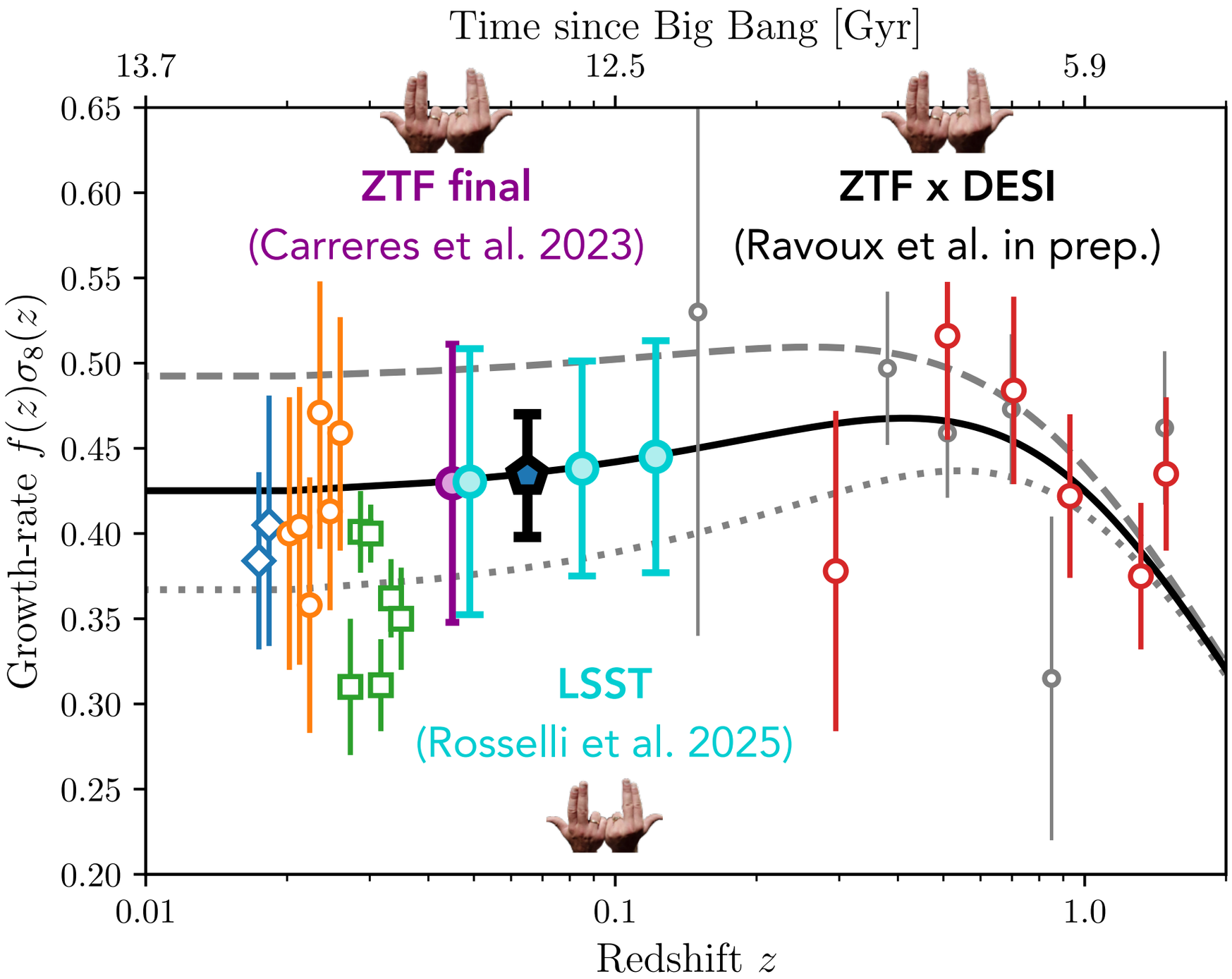


Theories
- GR
- $\gamma = 0.42$
- $\gamma = 0.68$

Past measurements
- SDSS δ
- DESI DR1 δ
- MLE $v + \delta$
- $\xi(r)$ or $P(k)$ $v + \delta$
- Recon. $v + \delta$

Forecasts
- ZTF SN ($z < 0.06$) v
- LSST SN v
- ZTFxDESI $v + \delta$

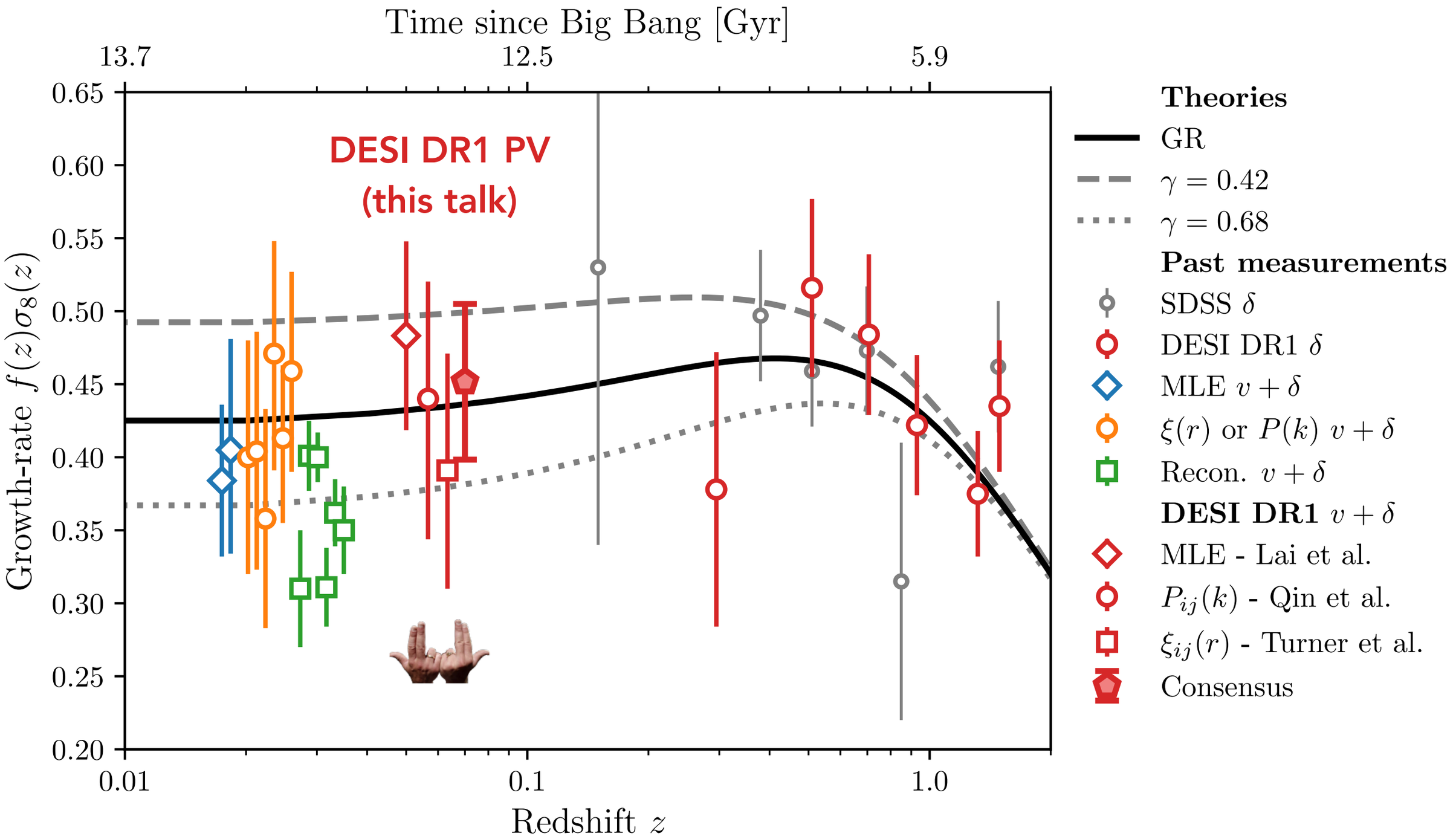
RSD + PV: $\langle \delta_g \delta_g \rangle, \langle \delta_g v_r \rangle, \langle v_r v_r \rangle$

RSD: $\langle \delta_g \delta_g \rangle$

Preliminary !

Growth rate measurements

Preliminary !



RSD + PV: $\langle \delta_g \delta_g \rangle, \langle \delta_g v_r \rangle, \langle v_r v_r \rangle$

RSD: $\langle \delta_g \delta_g \rangle$

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Peculiar velocity measurements

Observed redshift is :

$$(1 + z_{\rm obs}) = (1 + z_{\rm cosmo})(1 + z_v)$$

Spectroscopic survey

Distance indicator

Radial peculiar velocity

	Tully-Fisher	**Fundamental plane**	**Type-Ia supernova**
Intrinsic scatter (in distance)	$\frac{\sigma_D}{D} \sim 20\,\%$	$\frac{\sigma_D}{D} \sim 20\,\%$	$\frac{\sigma_D}{D} \sim 7\,\%$
Future datasets	WALLABY ~ 30k **DESI ~ 53k**	Taipan ~ 50k 4HS ~ 500k **DESI ~ 133k**	**ZTF ~ 5k** LSST ~ 30 to 100 k (?)

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DESI Peculiar Velocity Survey

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DESI Peculiar Velocity Program

Saulder et al 2023

Tully-Fisher

~ 53k

Fundamental plane

~ 133k

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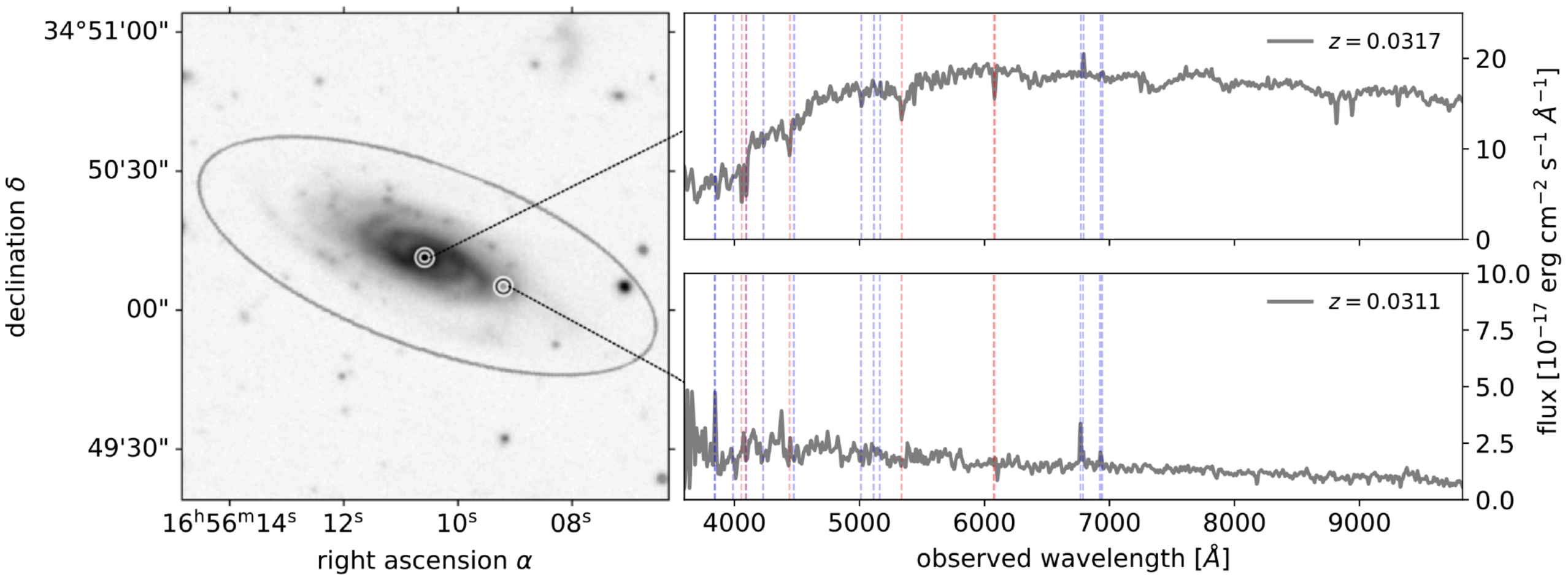

DESI spectra yield **rotational velocities of spiral galaxies**

(BenZvi, Douglass, Kim et al. in prep)

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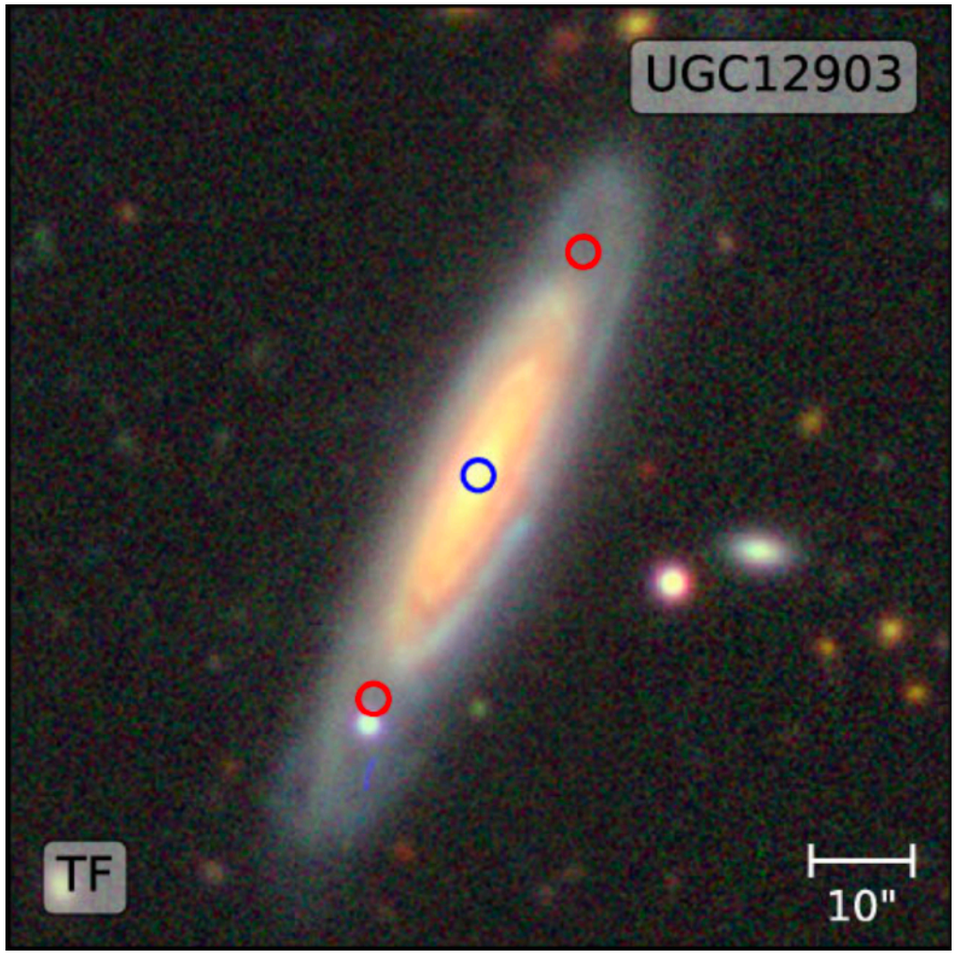
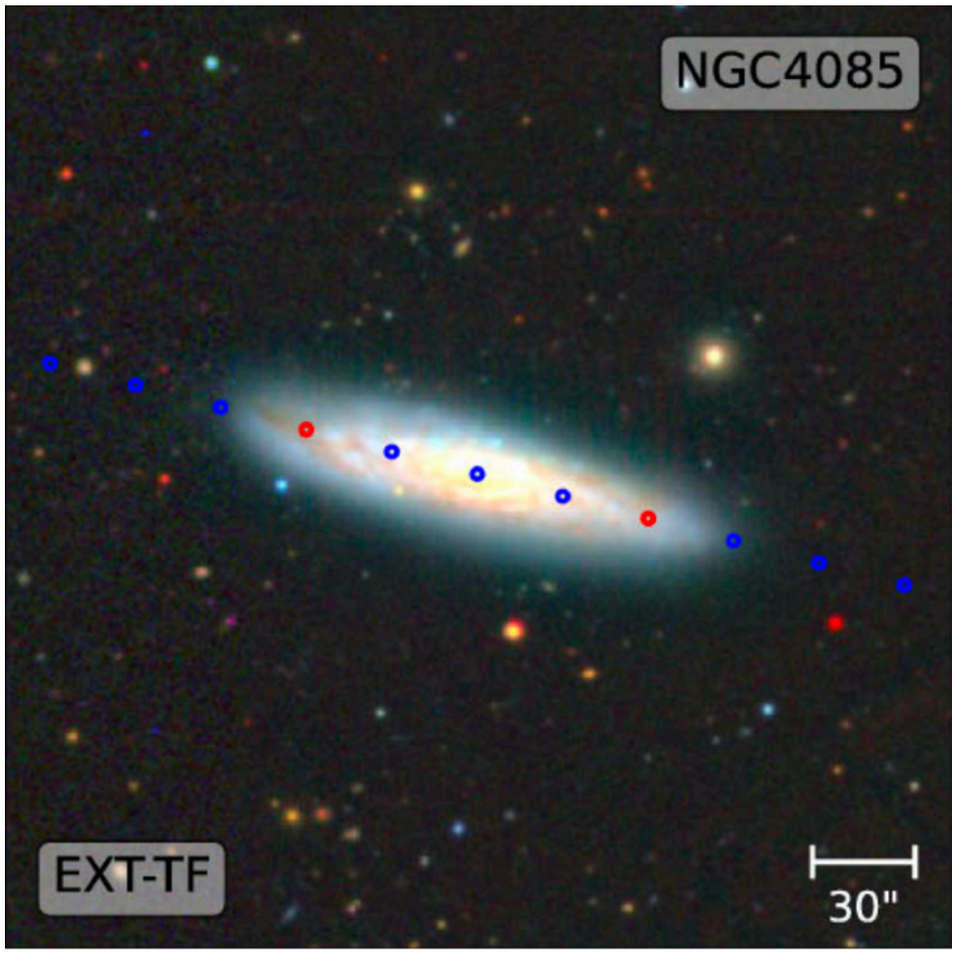
Tully-Fisher

~ 53k





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Saulder et al 2023

Tully-Fisher

~ 53k

Fundamental plane

~ 133k

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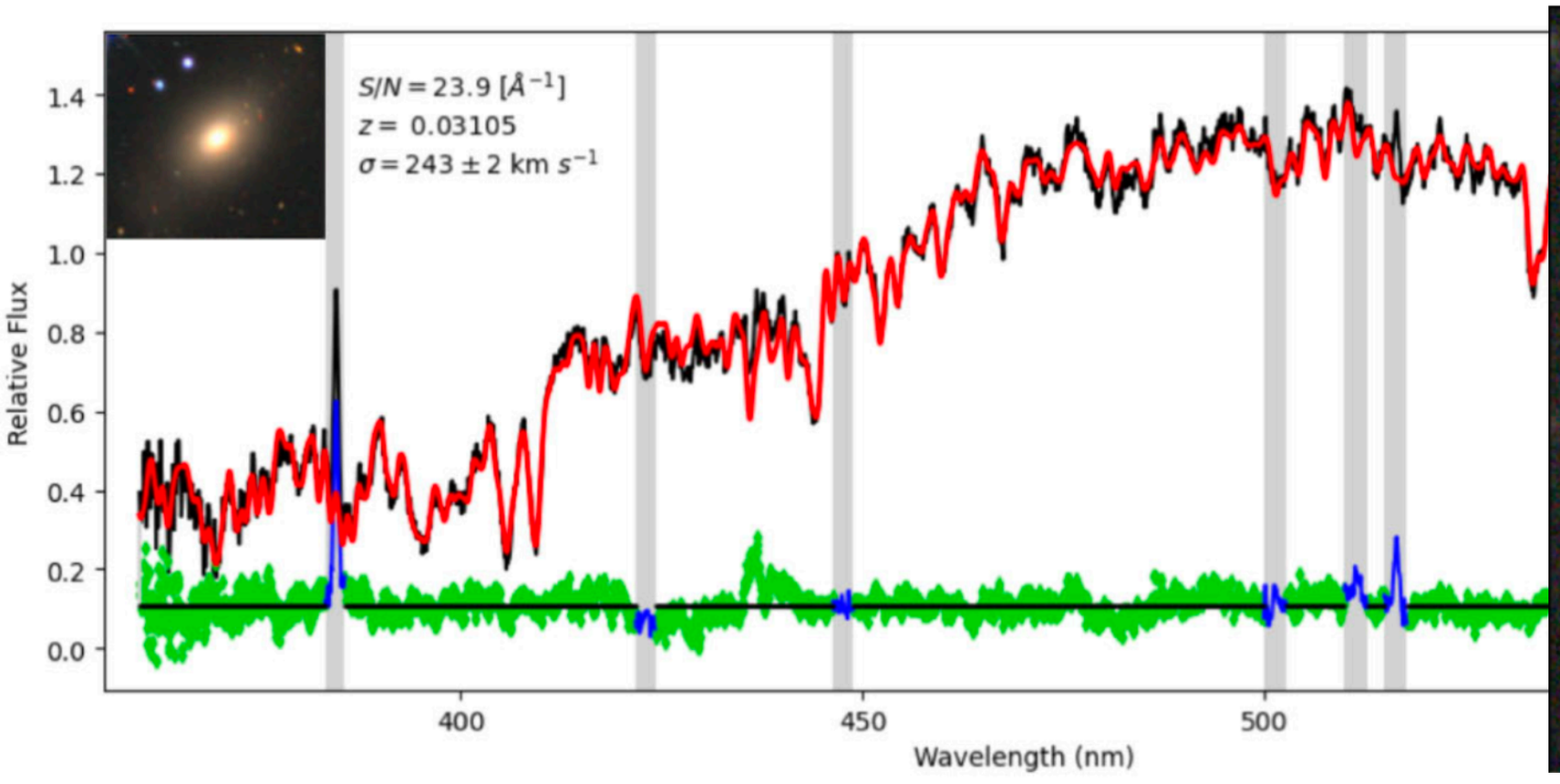
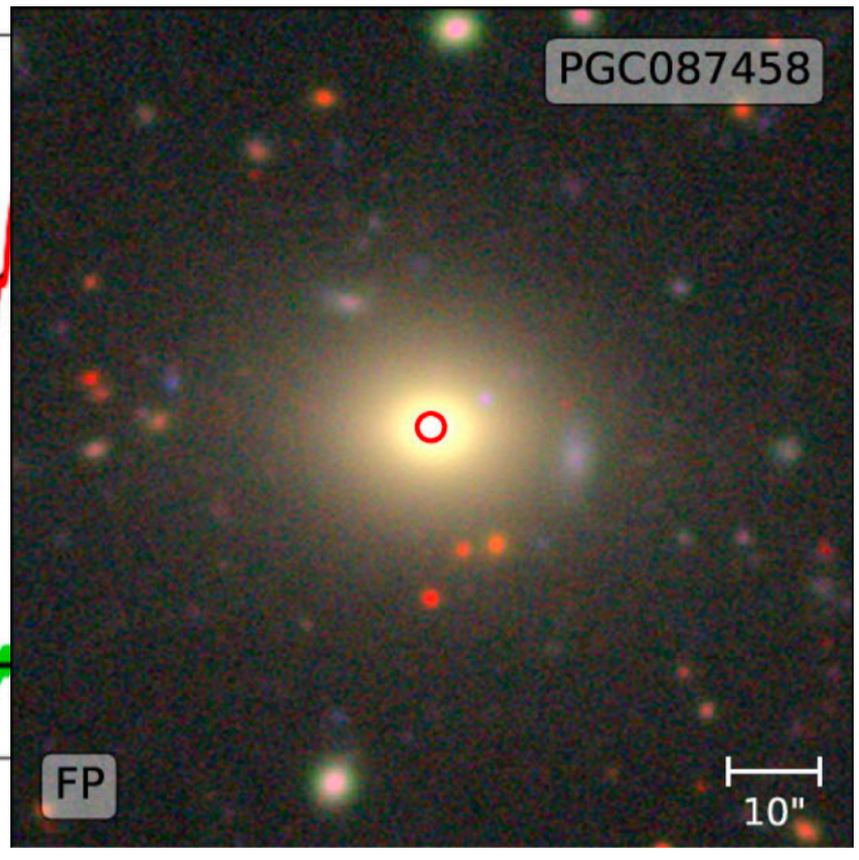
DESI Peculiar Velocity Program

Saulder et al 2023, Said et al. 2024

Fundamental plane

~ 133k





DESI spectra yield **velocity dispersions of elliptical galaxies**

(Caitlin Ross, Said, Howlett et al. in prep)

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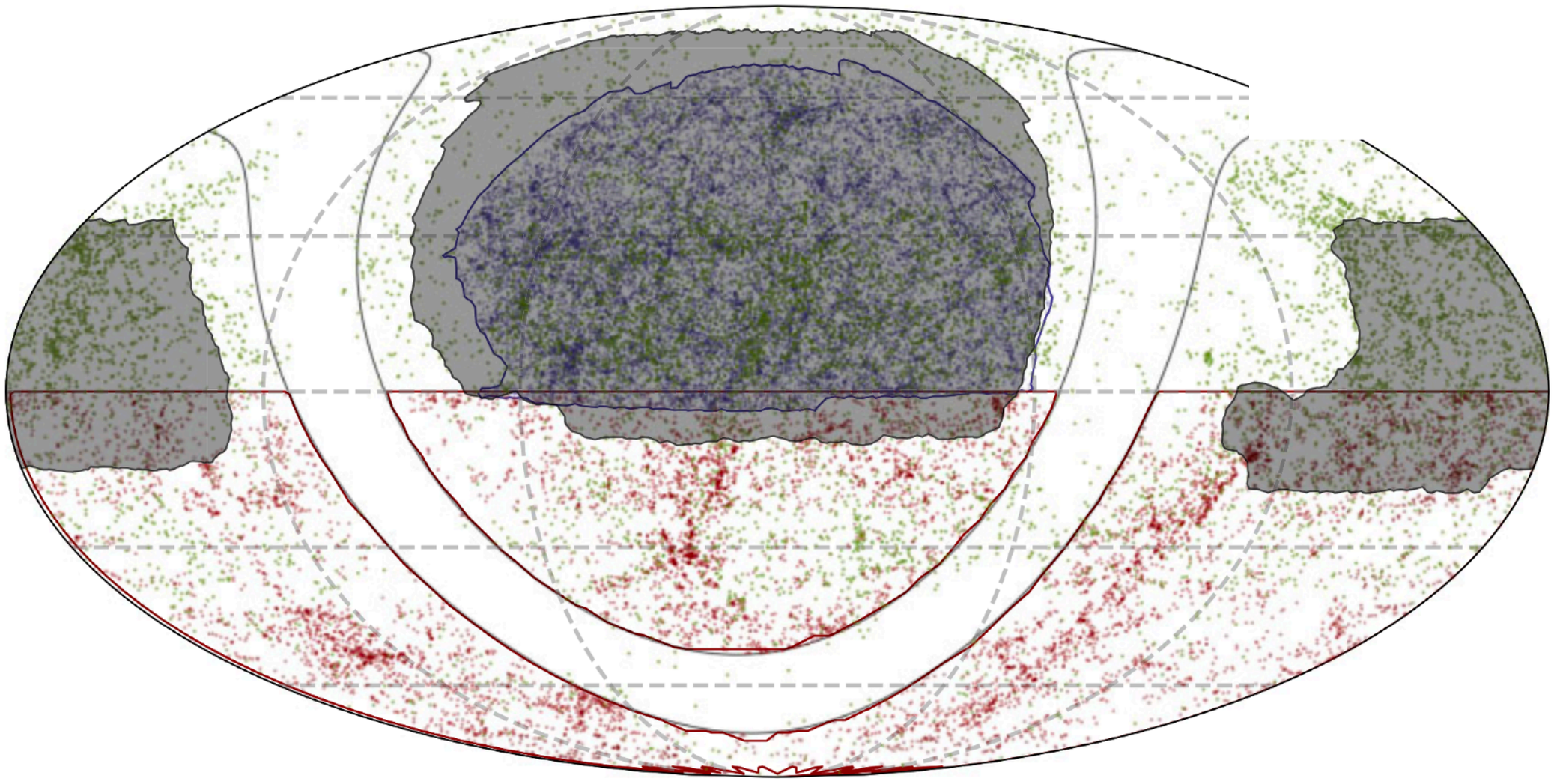
DESI Peculiar Velocity Program

Saulder et al 2023

Sky distribution



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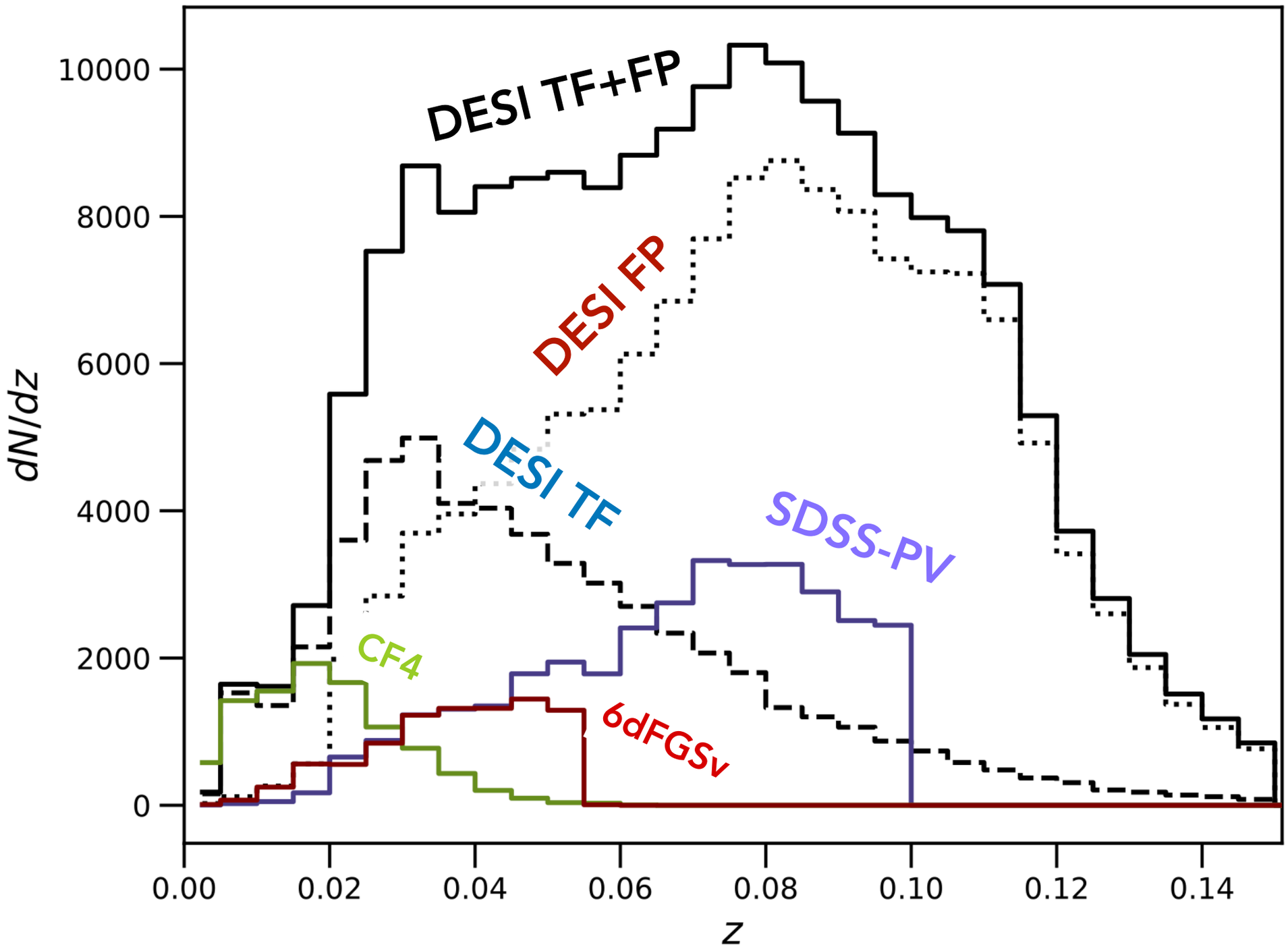
Saulder et al 2023

Redshift distribution



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DESI PV Data Release 1

Batch of 7 papers coming end of 2025

Data sets

Caitlin Ross et al.: **Fundamental Plane** sample
Kelly Douglass et al.: **Tully-Fisher** sample
Anthony Carr et al.: Zero-point calibration and H_0

Mocks

JB et al.: **Mock catalogs** from n-body simulations

Measurements of $f\sigma_8$

Yan Lai et al.: Growth rate with maximum likelihood fields
Fei Qin et al.: Growth rate with momentum power spectra
Ryan Turner et al.: Growth rate with correlation functions
Nguyen et al. 2025: Growth rate with DESI and Pantheon+ SN

Internal combination of FP and TF samples
675 n-body based mock catalog realisations
First ever consistency check among methodologies

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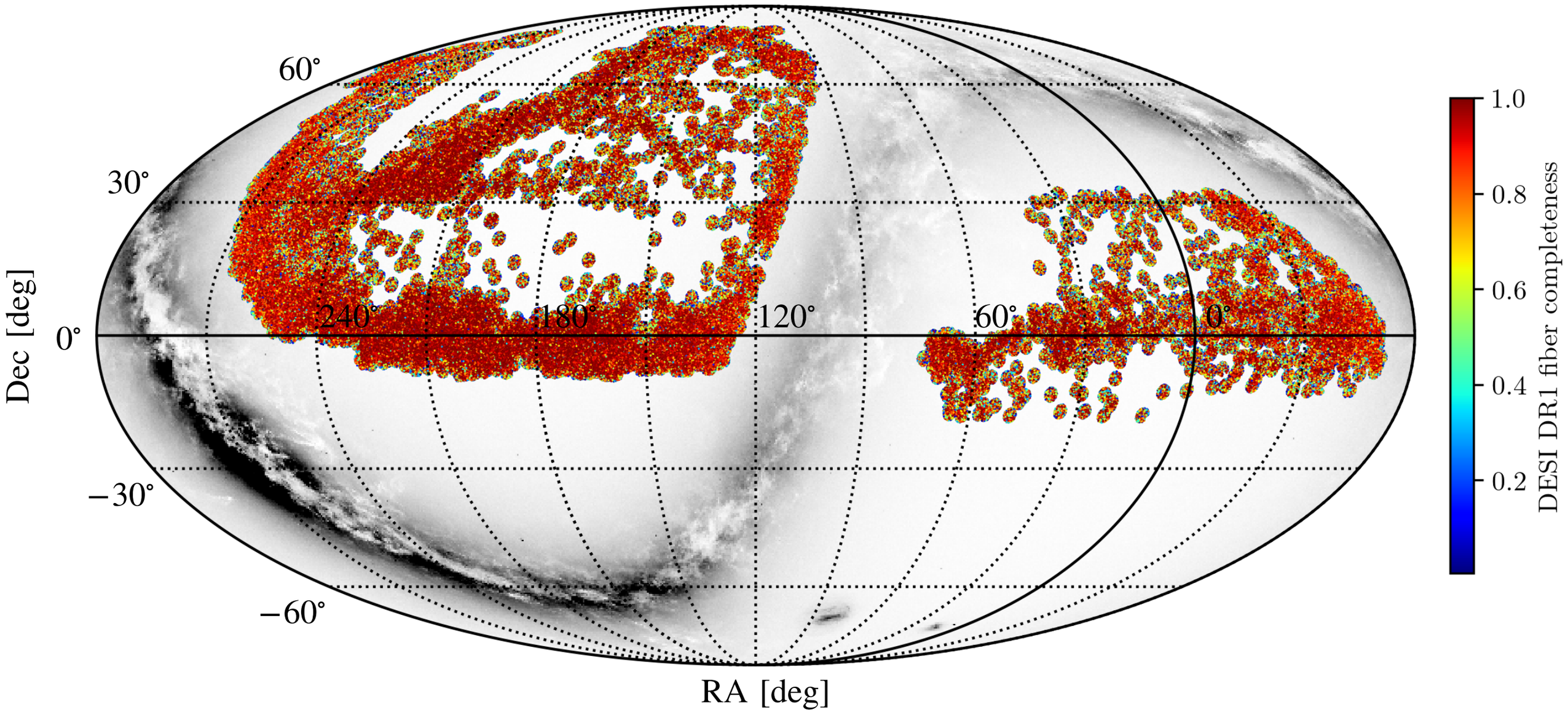
DESI PV Data Release 1



DR1 Fundamental Plane sample: 98 292 velocities

DR1 Tully-Fisher sample: 10 262 velocities

DR1 density sample at z < 0.1: 415 523 galaxies

Already surpassed past PV samples

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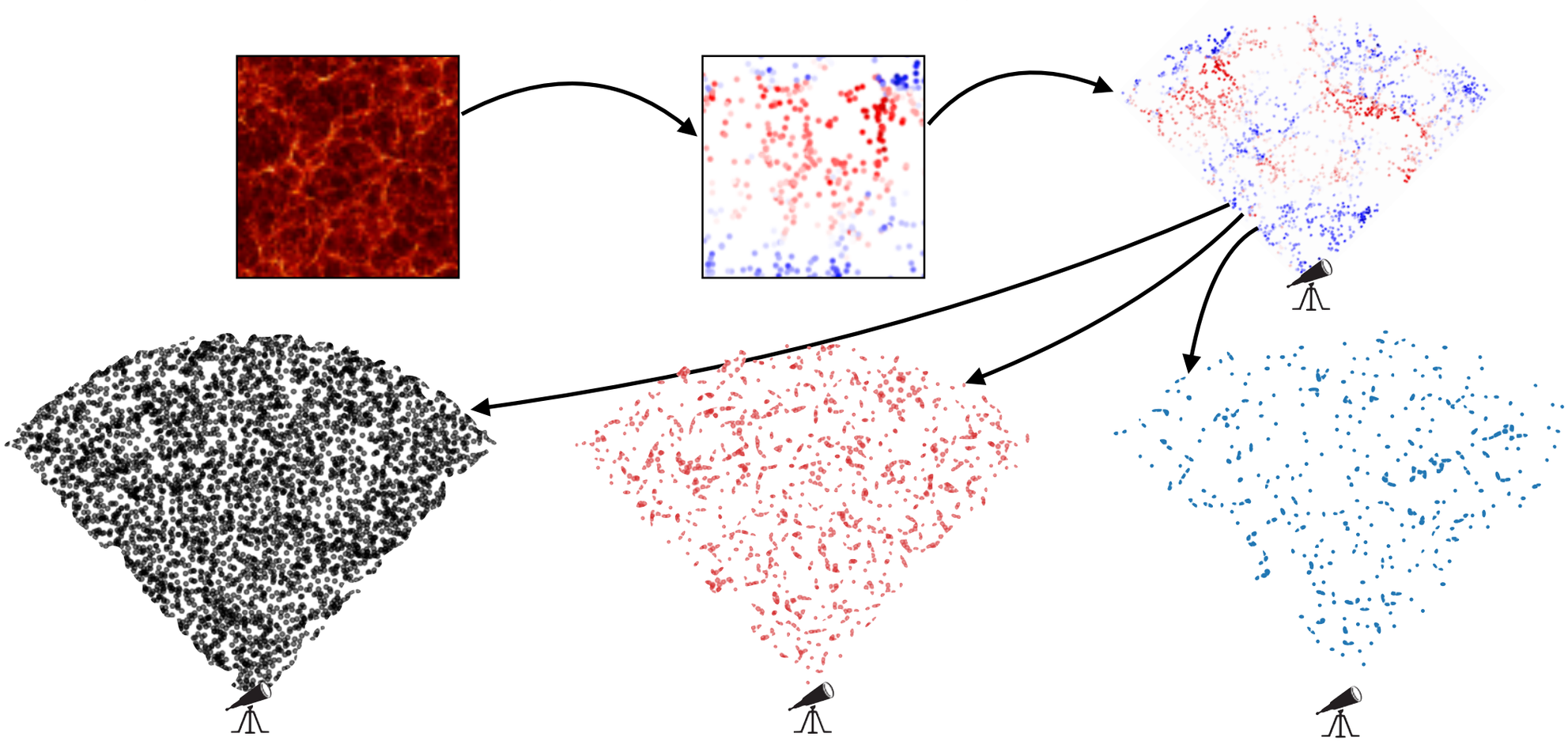
DESI PV DR1 Mock catalogs

JB et al.

AbacusSummit n-body simulations (Maksimova et al. 2021)

Evolving HOD model based on DESI BGS (Smith et al. 2024)

DR1 geometry and completeness with observer



BGS density

Fundamental plane

Tully-Fisher

675 realisations

Largest and most accurate set of mocks for PV cosmology

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DESI PV Methodologies

Maximum likelihood estimator (MLE)

Lai et al.

Configuration space $\xi(r)$

Turner et al.

Fourier space $P(k)$

Qin et al.

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Assign galaxies and velocities to a 3D mesh

$$\mathbf{d} = \left[\delta_g(\vec{x}_1), \ldots, \delta_g(\vec{x}_n), v_r(\vec{x}_1), \ldots, v_r(\vec{x}_n)\right]$$

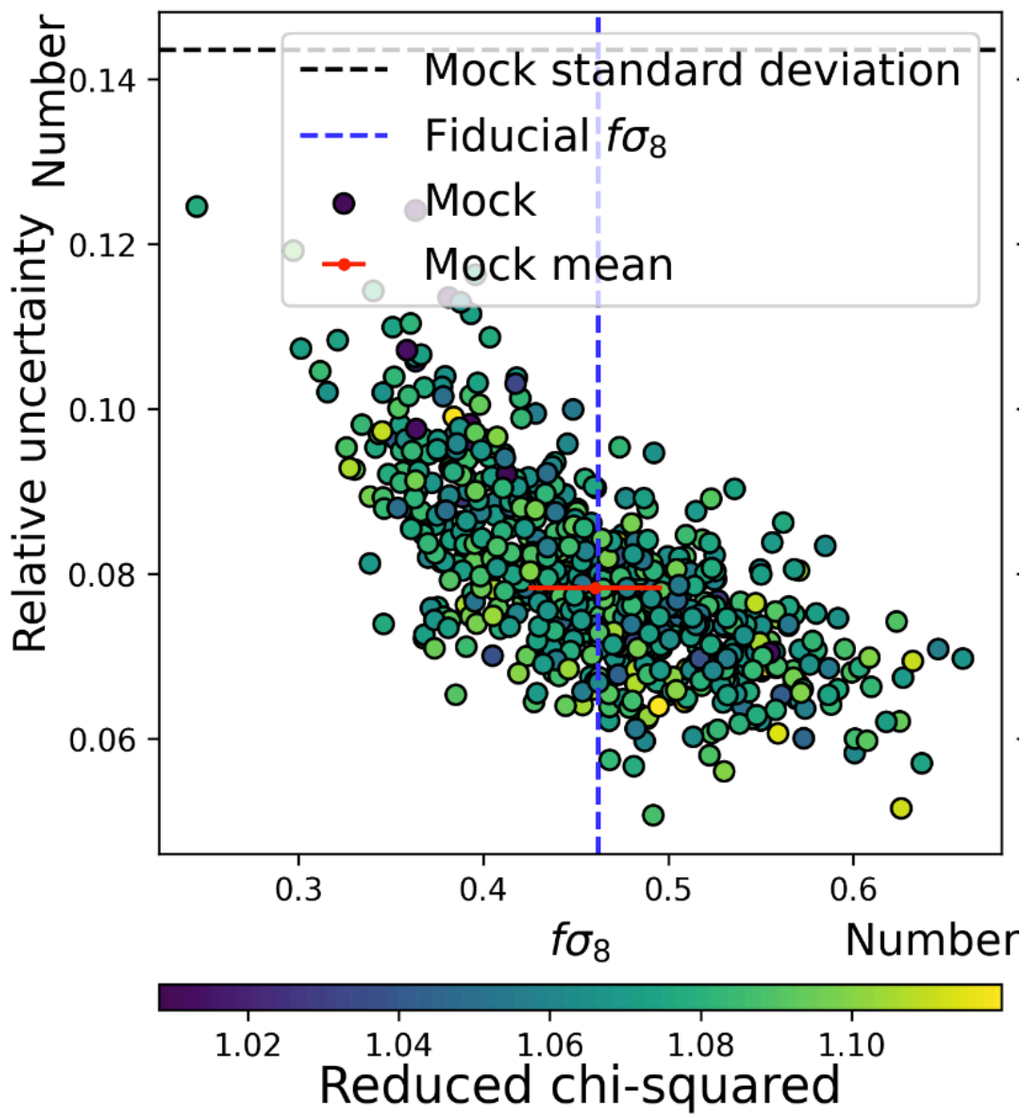
Model covariance between voxels at field level assuming Gaussian

$$P(\theta \,|\, \mathbf{d}) = \frac{1}{(2\pi)^n \,|\, \mathbf{C} \,|} \exp\left(-\frac{1}{2}\mathbf{d}\ \mathbf{C}\ \mathbf{d}^T\right)$$

$$\text{where } \mathbf{C} = \begin{pmatrix} C_{11} & \cdots & C_{1n} \\ \vdots & \ddots & \vdots \\ C_{n1} & \cdots & C_{nn} \end{pmatrix}$$

(cf. Rafael's talk)

Fits to 675 mocks: **no bias**



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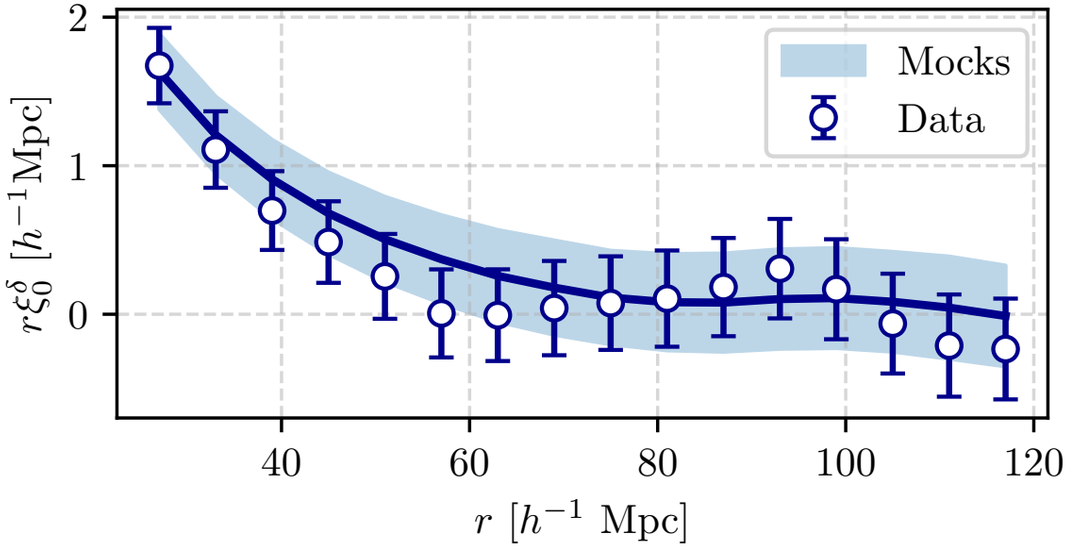
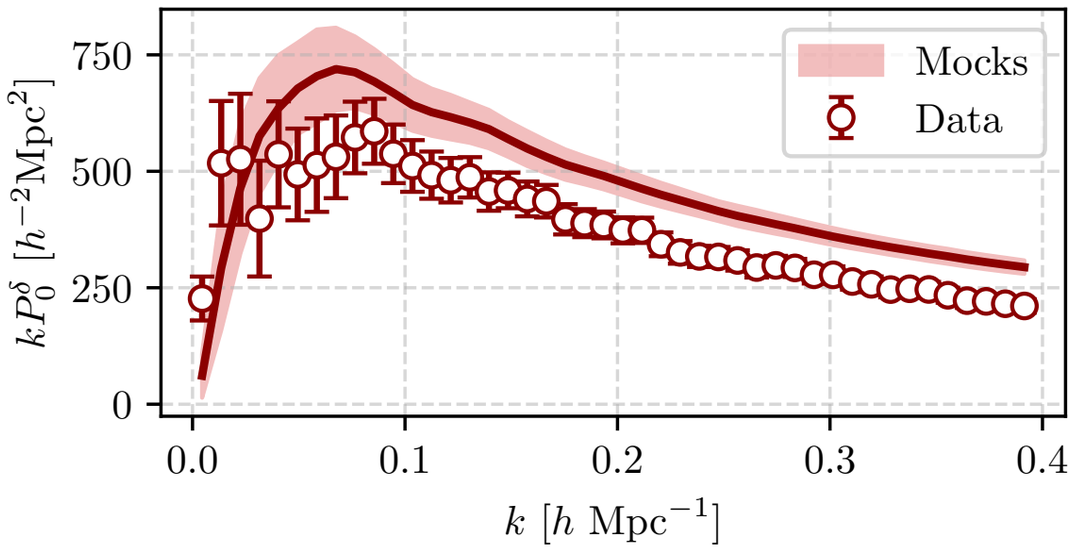
Density-density





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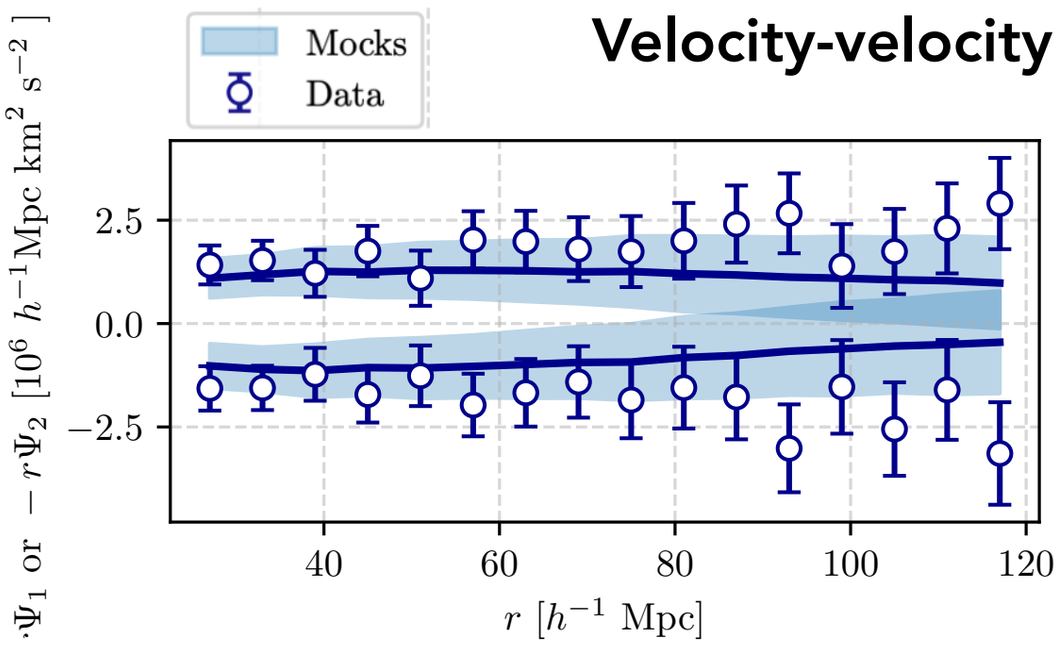
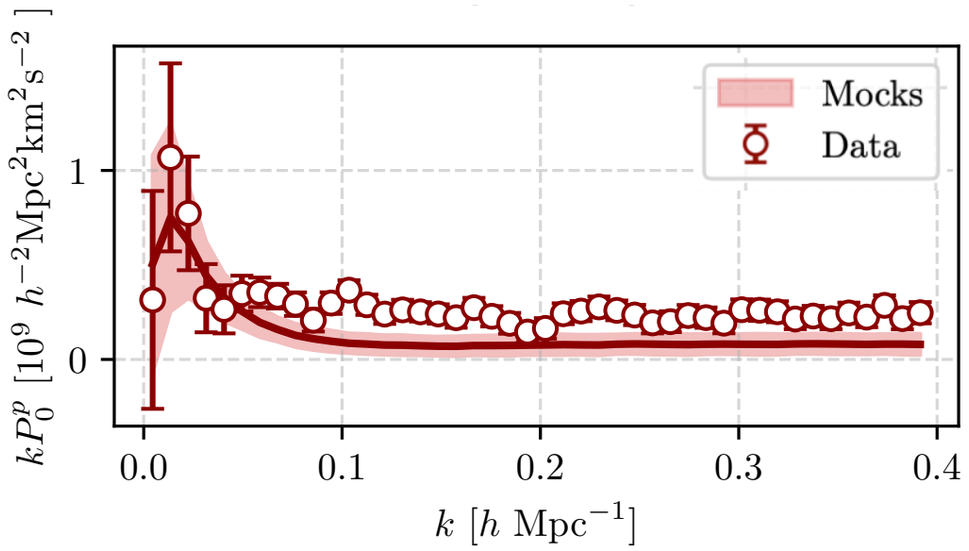
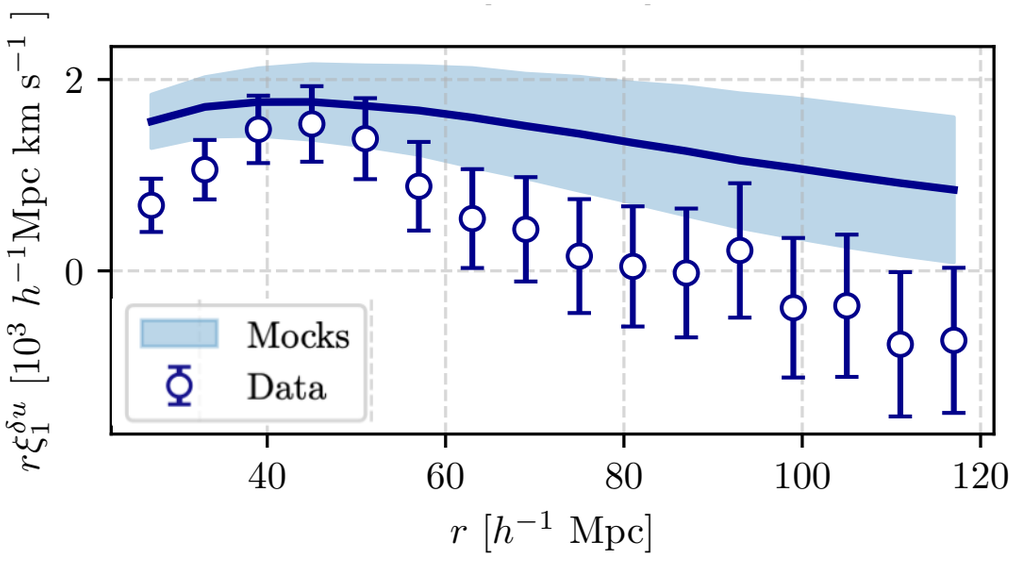
Qin et al.

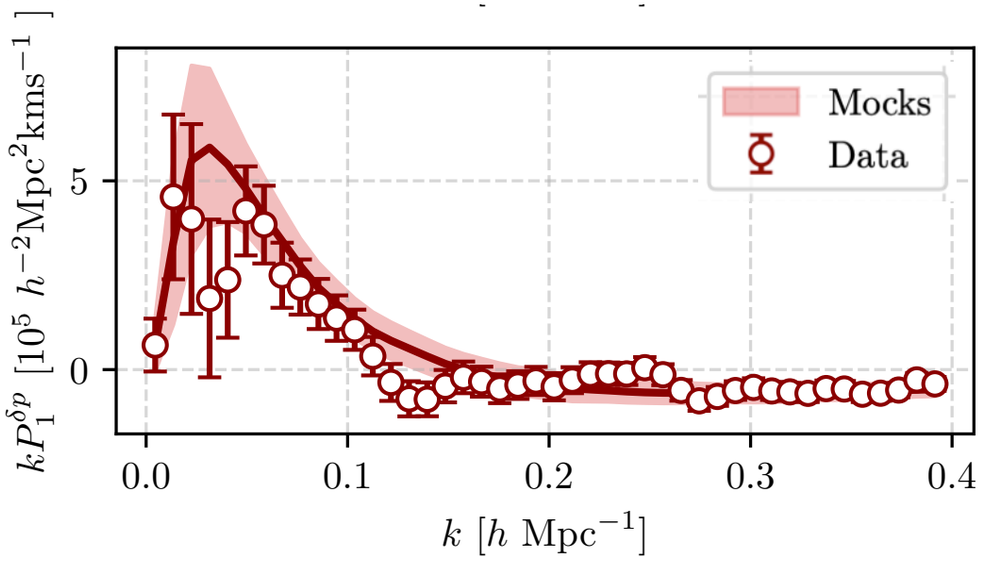
Velocity-velocity or momentum-momentum





Density cross velocity/momentum





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Lai et al.

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Fourier space $P(k)$

Qin et al.

Model based on perturbation theory + higher order bias expansion

Density-density $$P^{\delta}(k,\mu) = P_{00} + \mu^2(2P_{01} + P_{02} + P_{11}) + \mu^4(P_{03} + P_{04} + P_{12} + P_{13} + \frac{1}{4}P_{22})$$

Velocity-velocity $$P^{p}(k,\mu) = \frac{[a(z)H(z)]^2}{k^2}[P_{11} + \mu^2(2P_{12} + 3P_{13} + P_{22})]$$

Density-velocity $$P^{\delta p}(k,\mu) = \frac{a(z)H(z)}{k}\mu\left[P_{01} + P_{02} + P_{11} + \mu^2\left(\frac{3}{2}P_{03} + 2P_{04} + \frac{3}{2}P_{12} + 2P_{13} + \frac{1}{2}P_{22}\right)\right]$$

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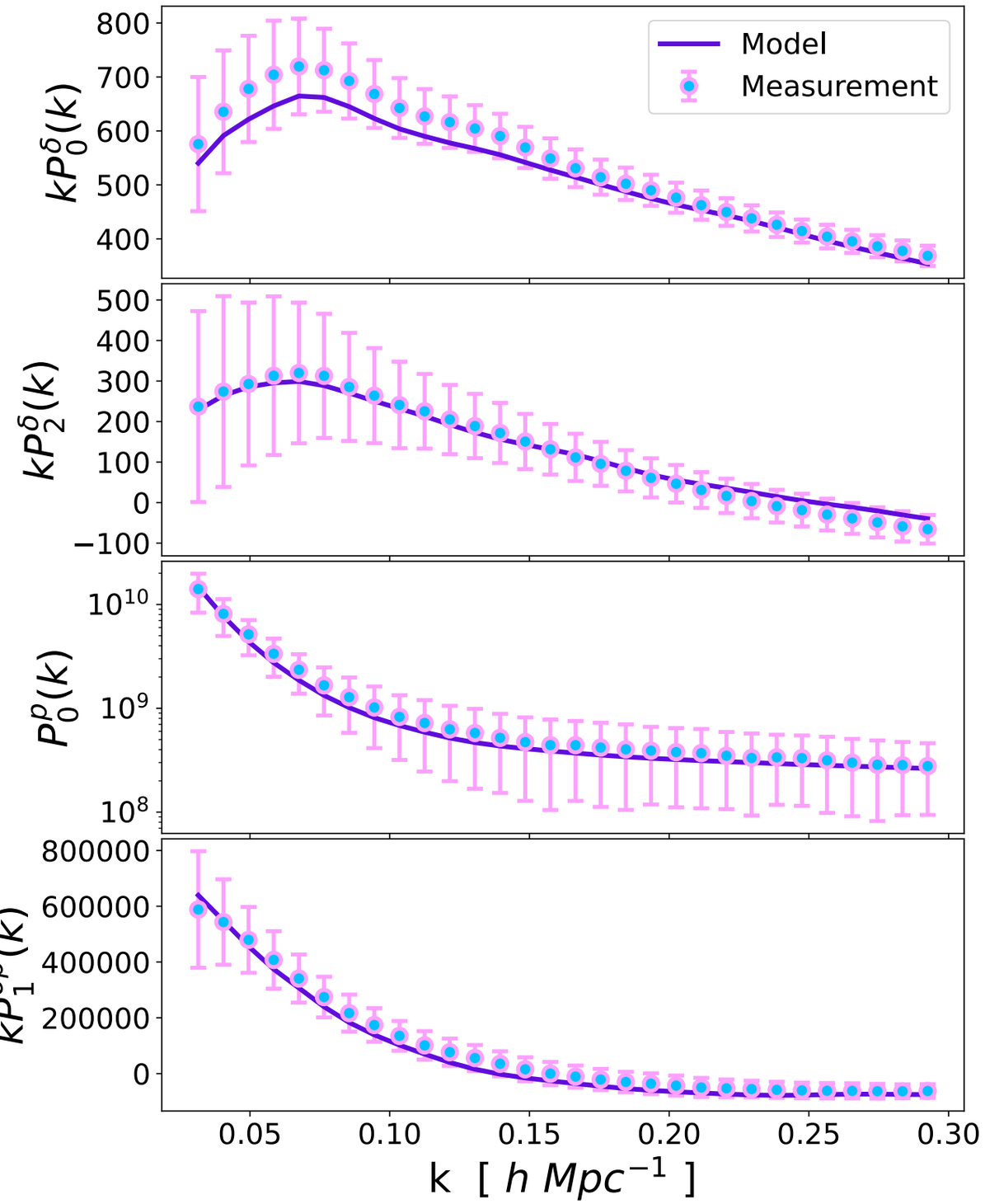
DESI PV Methodologies

Density-density

Velocity-velocity

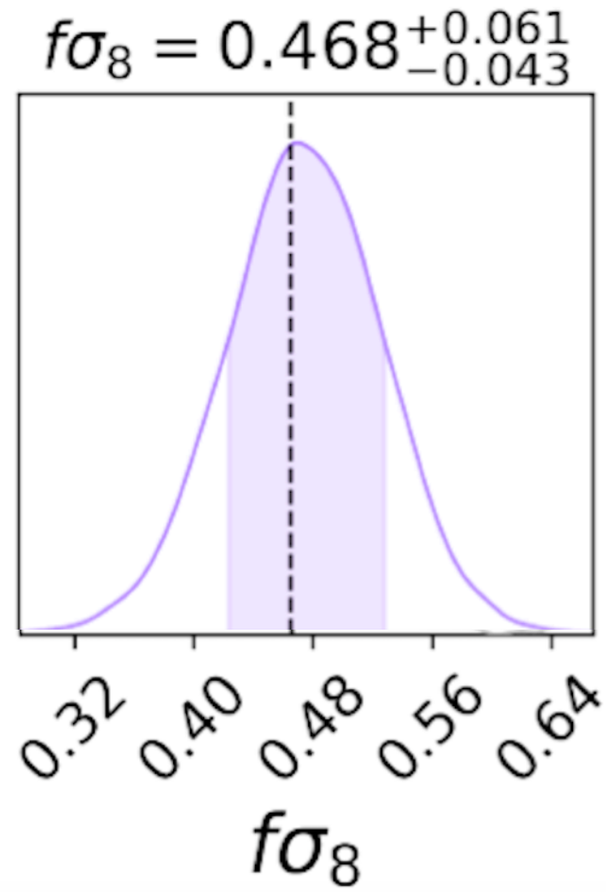
Density-velocity



Excellent fit to mocks

Fourier space $P(k)$

Qin et al.



No bias on $f\sigma_8$

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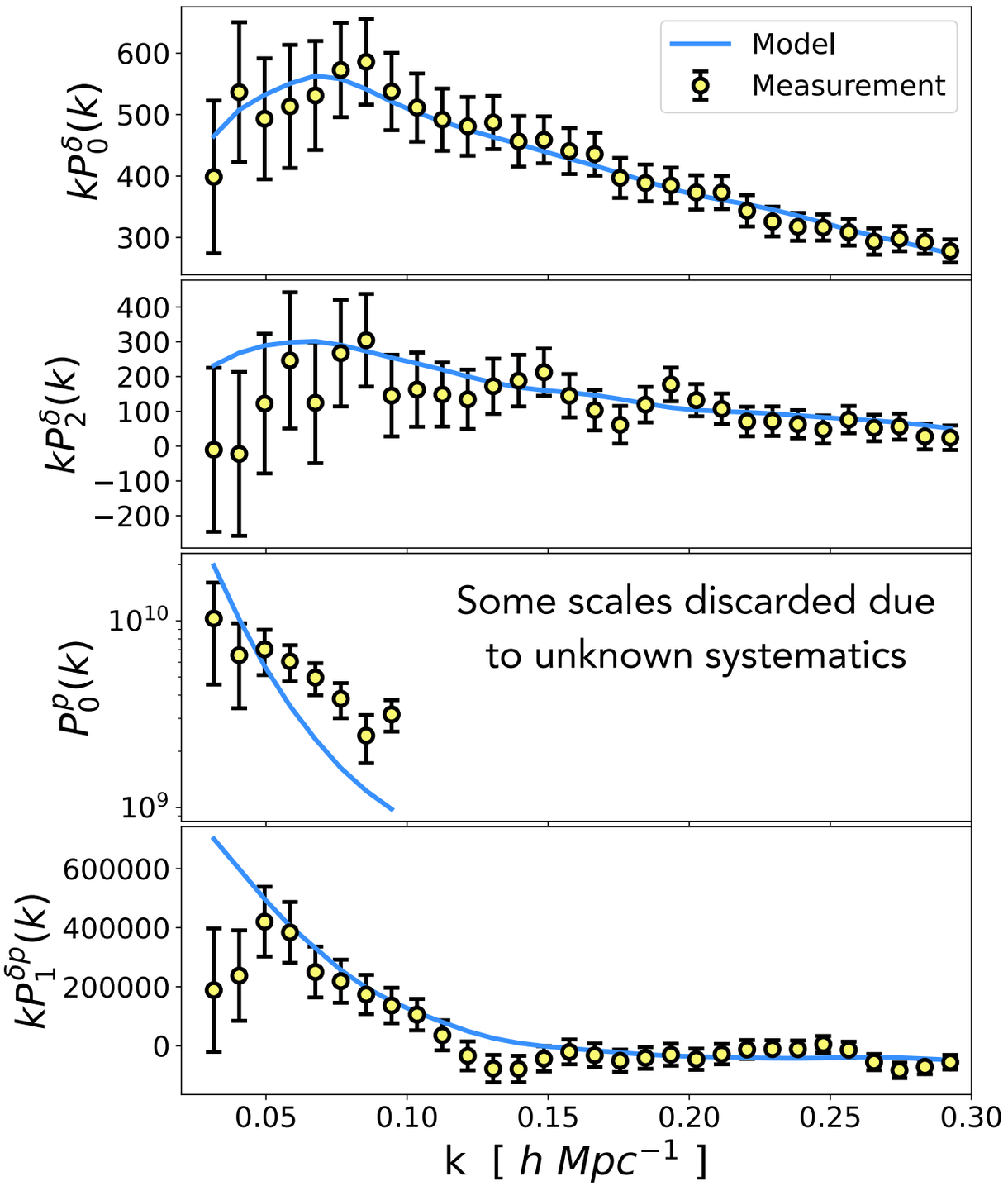
DESI PV Methodologies

Density-density

Velocity-velocity

Density-velocity

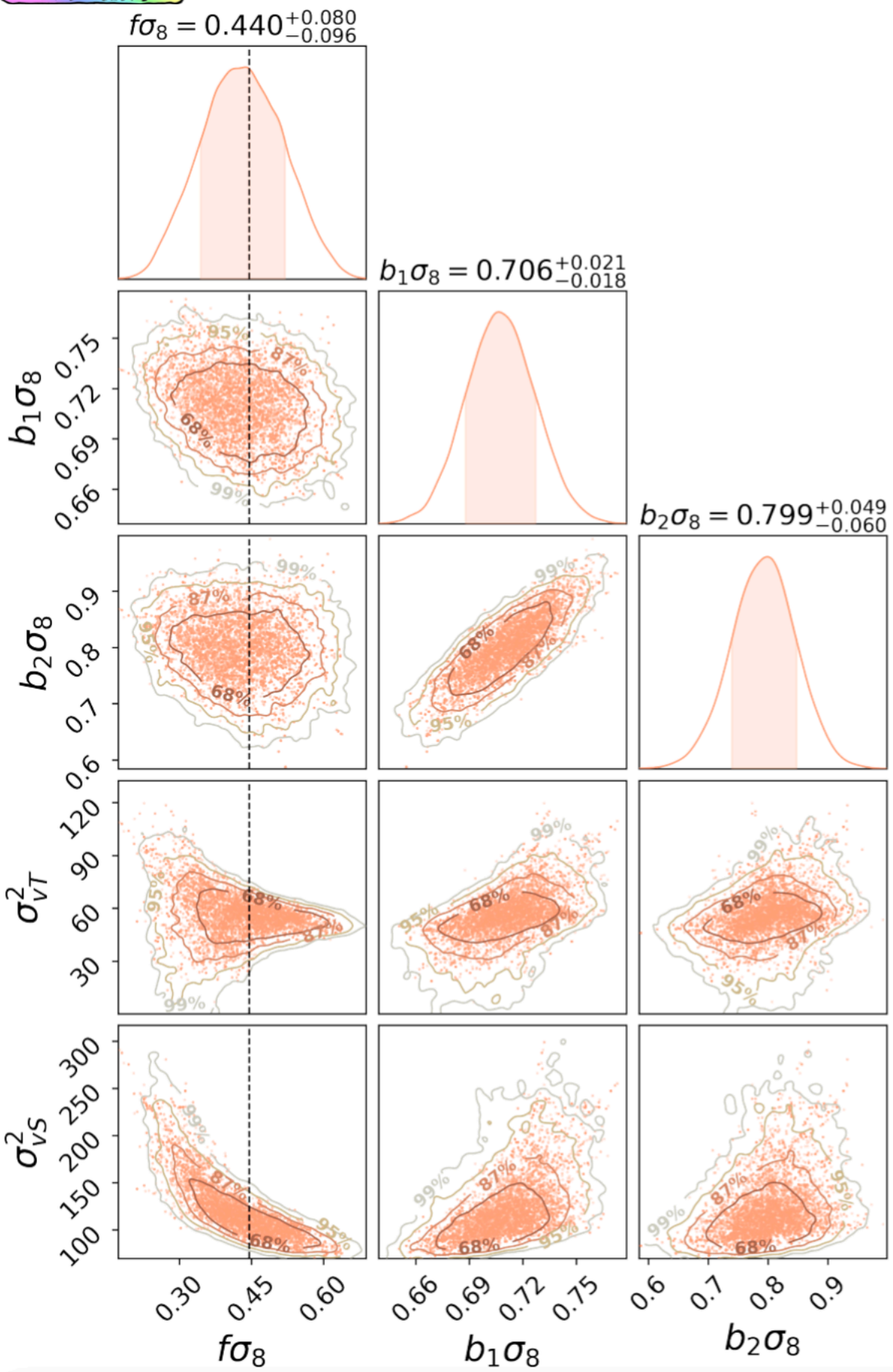


Fourier space $P(k)$

Qin et al.

Best-fit on data

DESI PV Methodologies



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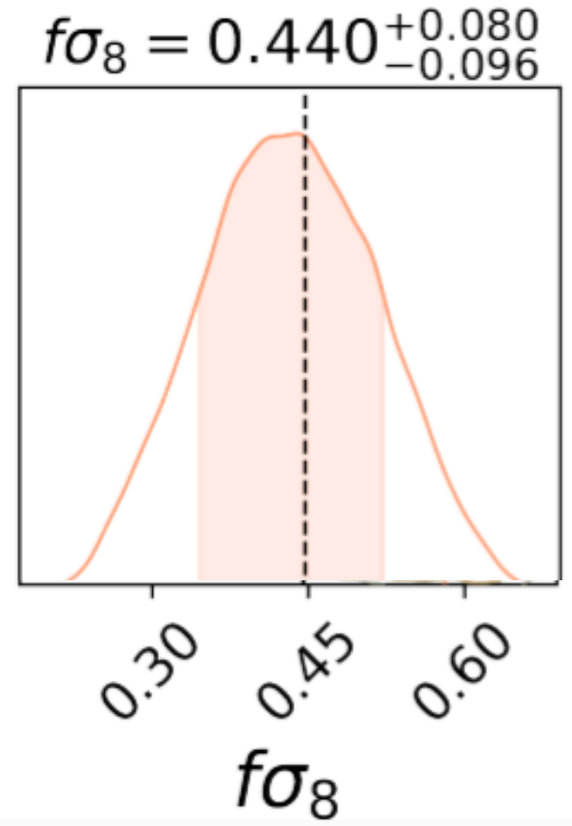

Consistency with GR+LCDM

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DESI PV DR1 Growth rates

Maximum likelihood estimator (MLE)

Lai et al.

$$f\sigma_8 = 0.483 \pm 0.065$$

Preliminary !

Configuration space $\xi(r)$

Turner et al.

$$f\sigma_8 = 0.391 \pm 0.081$$

Preliminary !

Fourier space $P(k)$

Qin et al.

$$f\sigma_8 = 0.440 \pm 0.080$$

Preliminary !

Compute consensus results accounting for correlations estimated from 675 mocks

	MLE	$P_{ij}(k)$
$P_{ij}(k)$	$(38.8 \pm 3.4)\%$	
$\xi_{ij}(r)$	$(27.3 \pm 5.6)\%$	$(29.0 \pm 4.3)\%$

Consensus

$$f\sigma_8 = 0.452 \pm 0.053$$ (12% uncertainty)

Preliminary !

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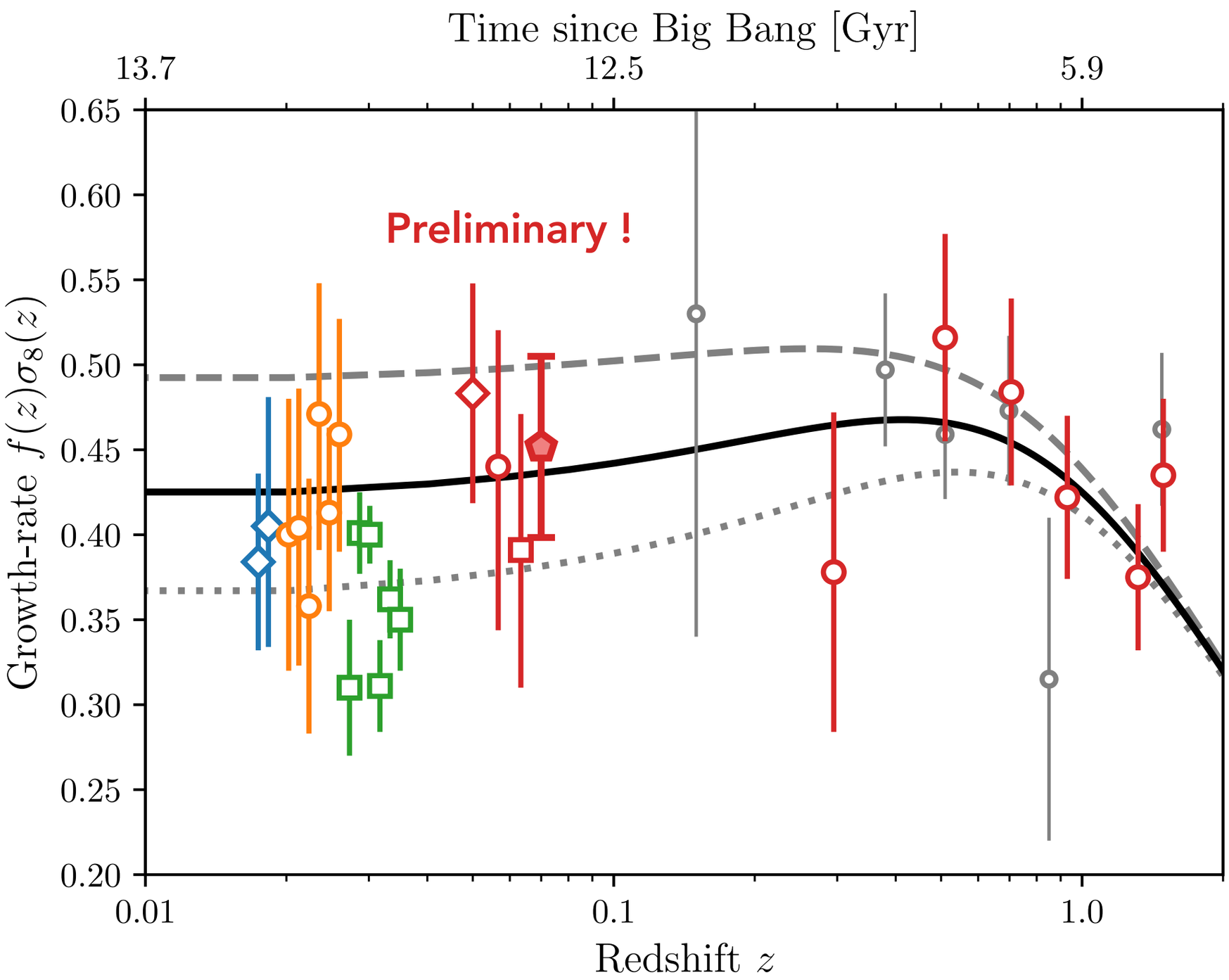
DESI PV DR1 Growth rates



RSD + PV: $\langle \delta_g \delta_g \rangle, \langle \delta_g v_r \rangle, \langle v_r v_r \rangle$

RSD: $\langle \delta_g \delta_g \rangle$

Plan

Motivation (dark energy or modified gravity)

Measuring growth rate at low-z with peculiar velocities

The DESI Peculiar Velocity survey

DR1 batch of papers

DR1 data and mock catalogs

Methodologies and results

Cosmological implications

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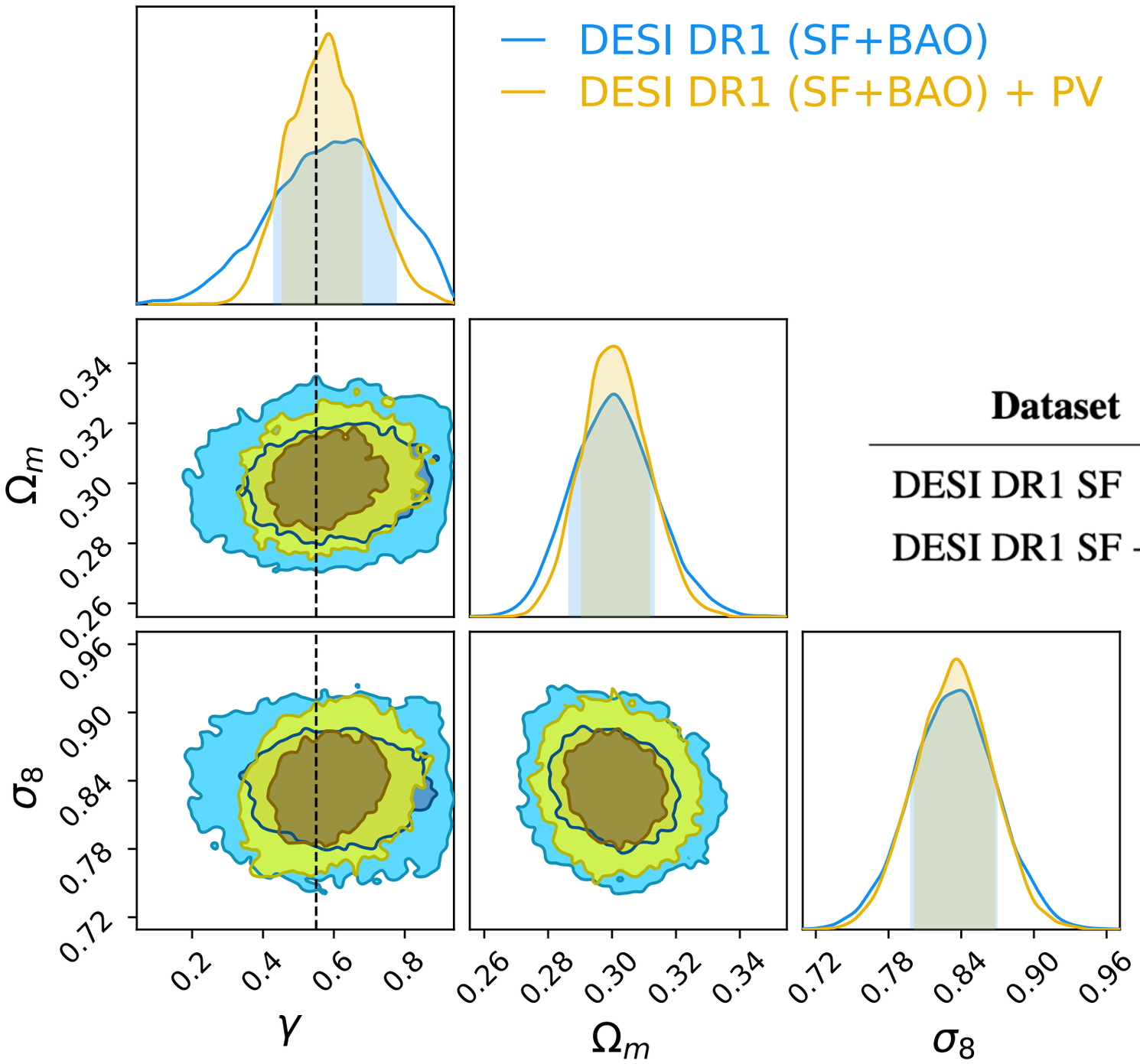
DESI PV DR1 Cosmology implications



Testing departures from GR

$$f(z) = \left[\Omega_m(z)\right]^{\gamma}$$

$$\gamma = 0.55 \text{ (GR)}$$

Preliminary !

Dataset	γ	Ω_m	σ_8
DESI DR1 SF	$0.610^{+0.160}_{-0.160}$	$0.301^{+0.013}_{-0.017}$	$0.832^{+0.039}_{-0.039}$
DESI DR1 SF + PV	$0.581^{+0.097}_{-0.120}$	$0.301^{+0.010}_{-0.010}$	$0.834^{+0.031}_{-0.031}$

50% improvement on γ and $\Omega_m$uncertainty thanks to PV

Consistency with GR

Conclusion

Low redshift growth rate measurements are important for dark energy

DESI DR1 Peculiar velocity survey is already the largest PV survey

Robust analysis: 675 n-body based mock catalogs and 3 methodologies

12% growth measurement with DR1

50% improvement on γ

DR2 analysis already started (expected September 2026)

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DESI PV DR1 Hubble Constant

Anthony Carr et al.

Distance ladder

Parallax
Masers
Eclipsing binaries

↓

Cepheids
Tip of Red Giant Branch (TRGB)

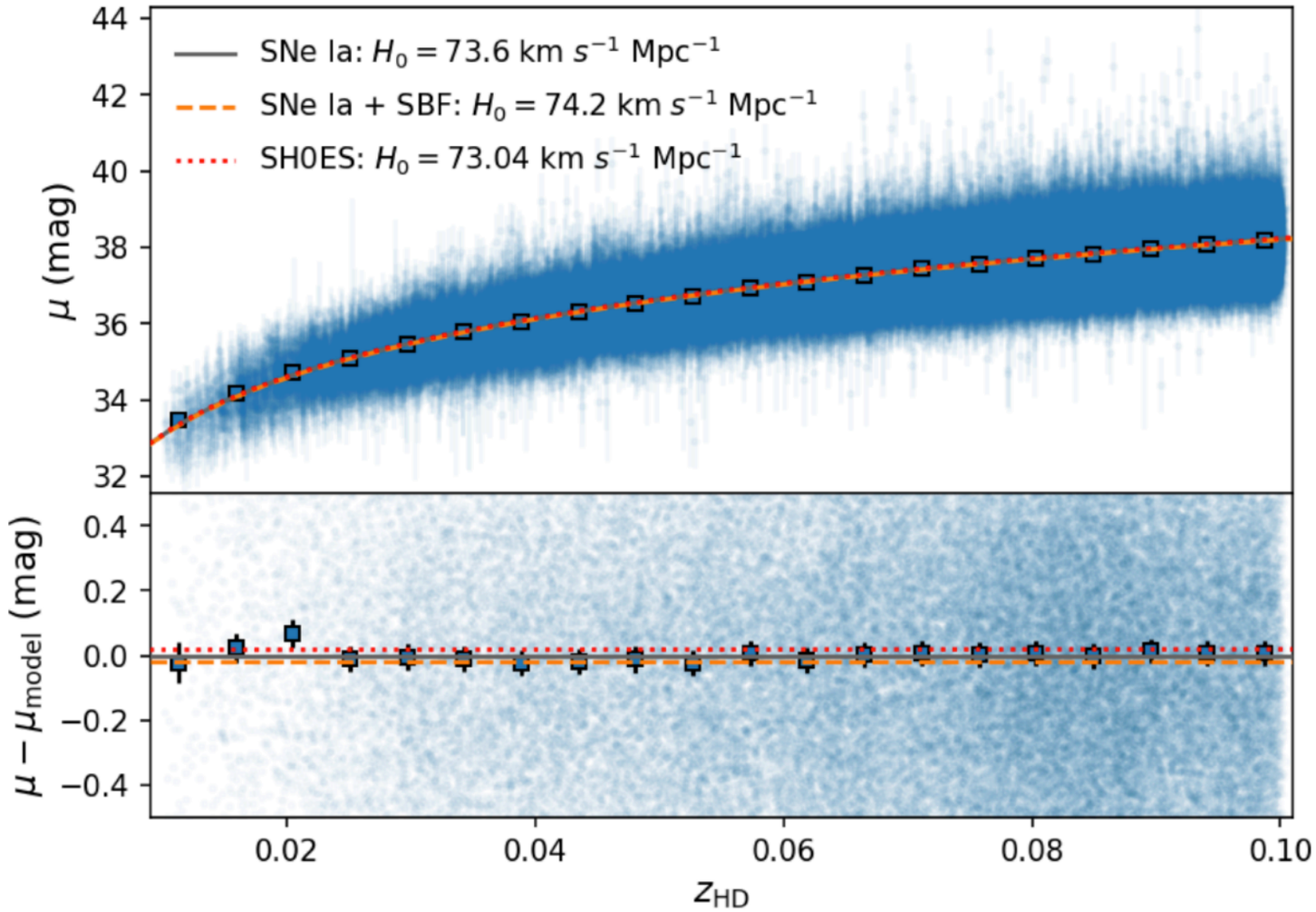
↓

Type-Ia Supernovae
Surface Brightness Fluctuations (SBF)

↓

DESI Fundamental Plane and Tully-Fisher distances

Preliminary !



Using 100 SH0ES/Pantheon+ Supernovae to calibrate distances:

$$H_0 = 73.60 \pm 0.06\ (\text{stat.}) \pm 1.10\ (\text{syst.})$$ **Preliminary !**

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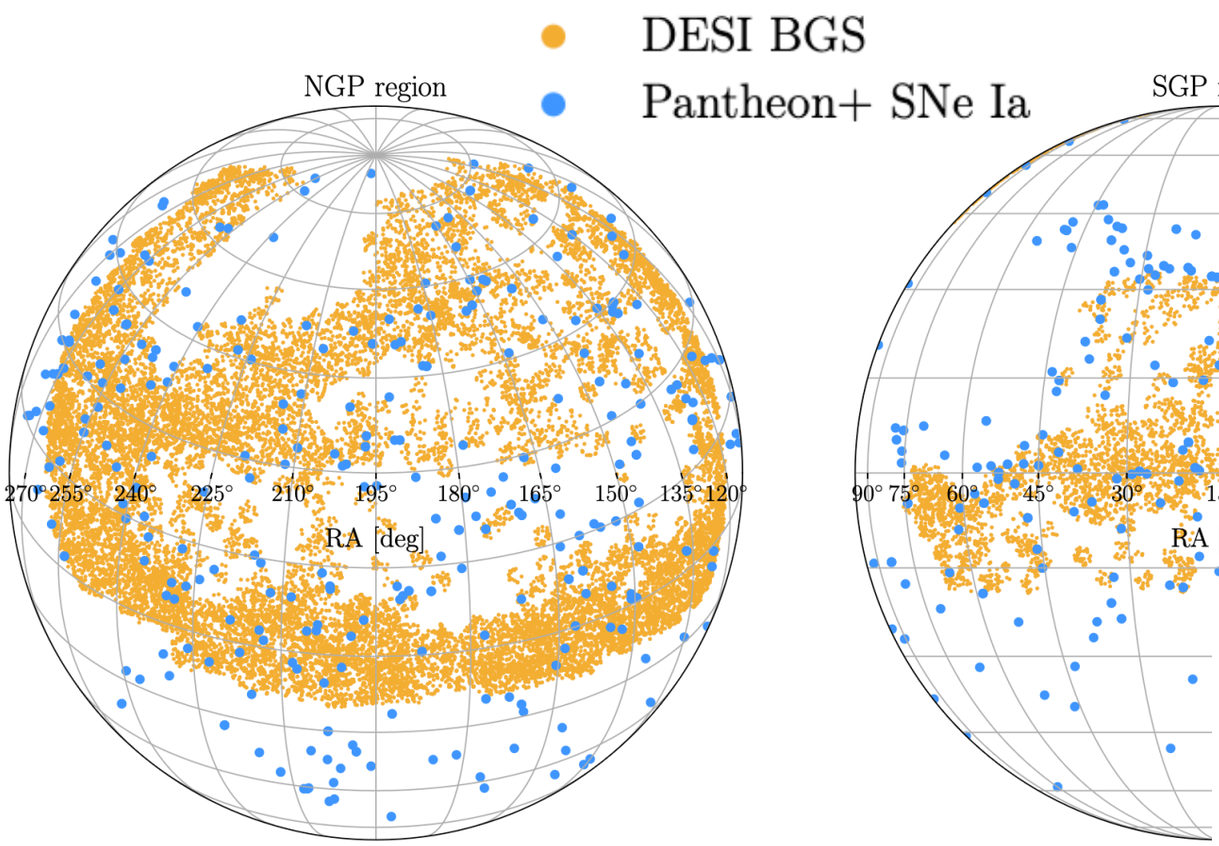
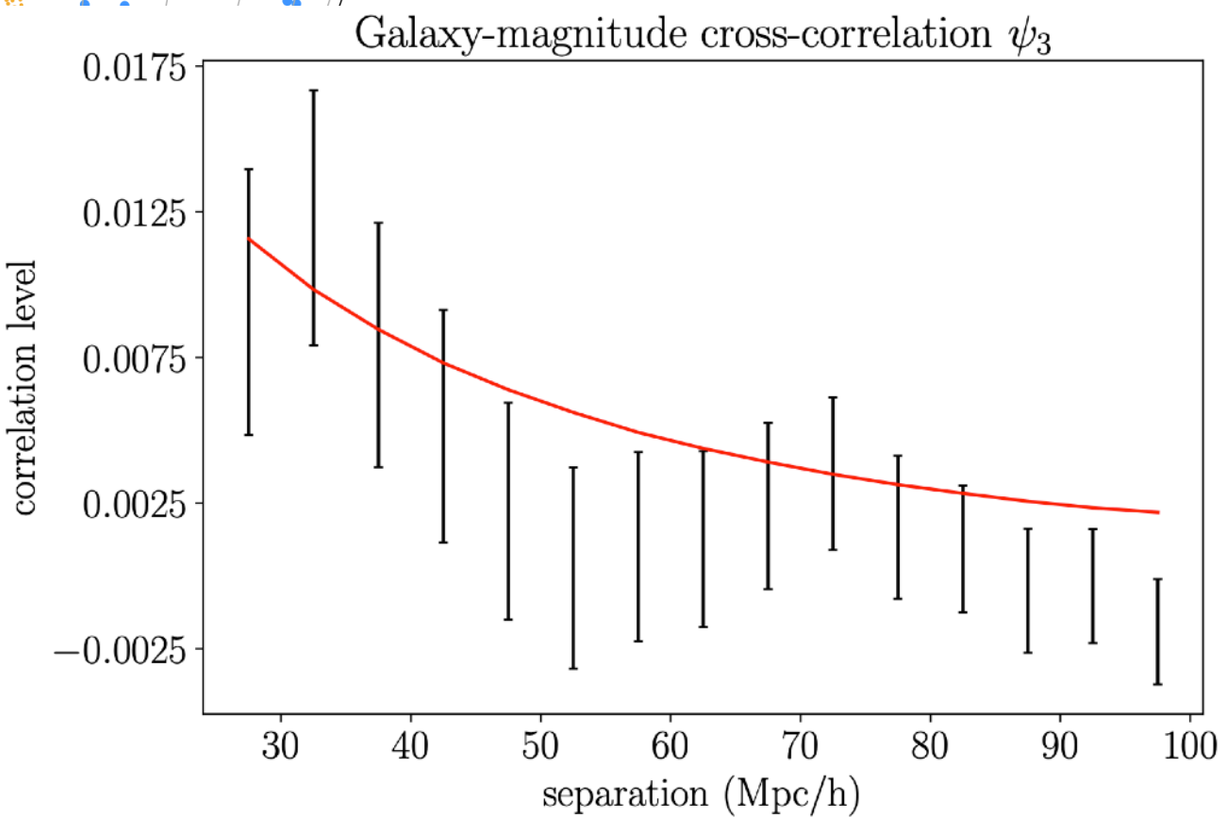
DESI PV DR1 x Pantheon+ SN

Andy Nguyen et al. 2025





$$f\sigma_8 = 0.384^{+0.094}_{-0.157}$$ (32% uncertainty)