Slicing through tension: Enhanced precision from cosmological weak lensing
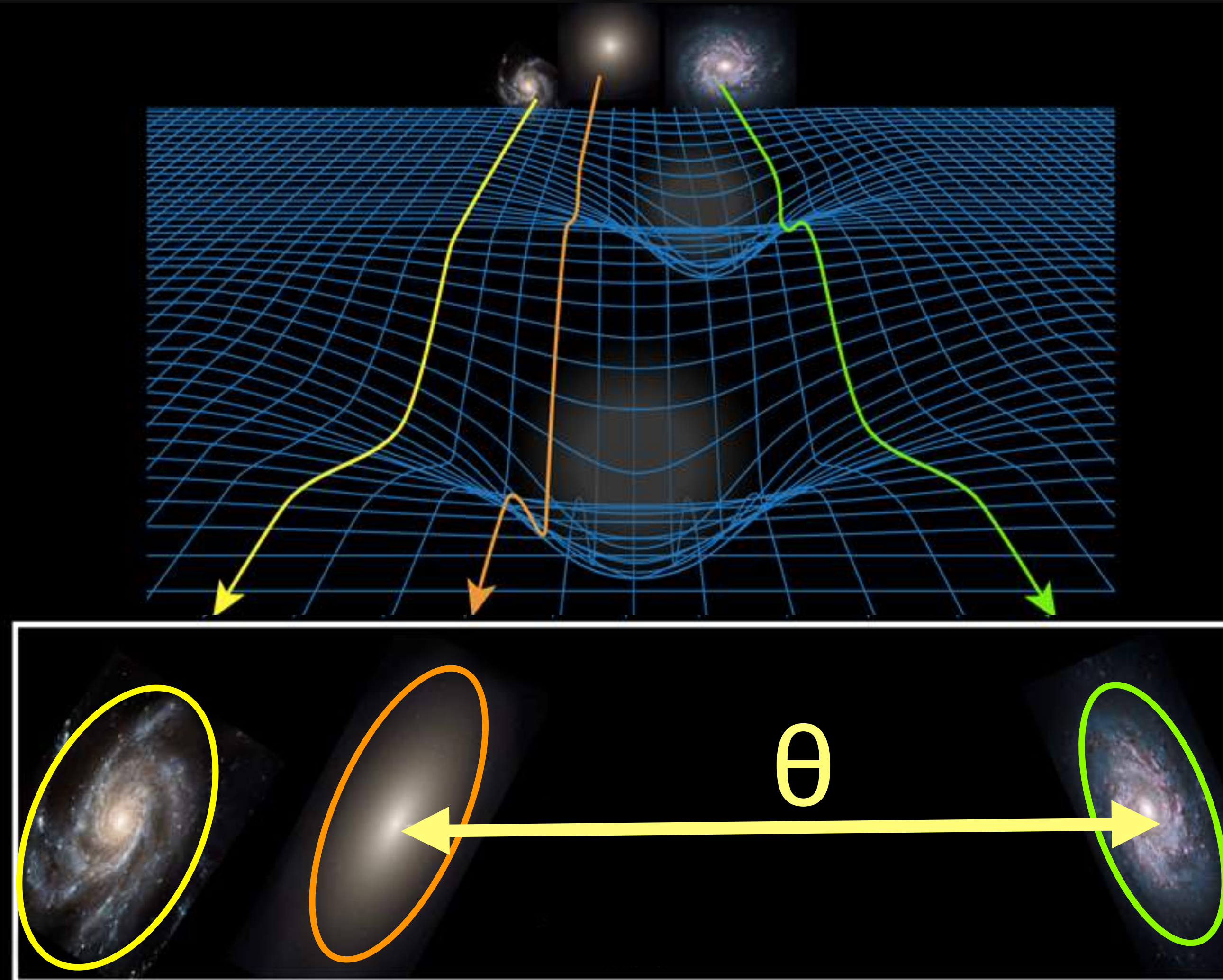
Benjamin Giblin,
Yanchuan Cai,
Joachim Harnois-Déraps
(arXiv: 2211.05708)
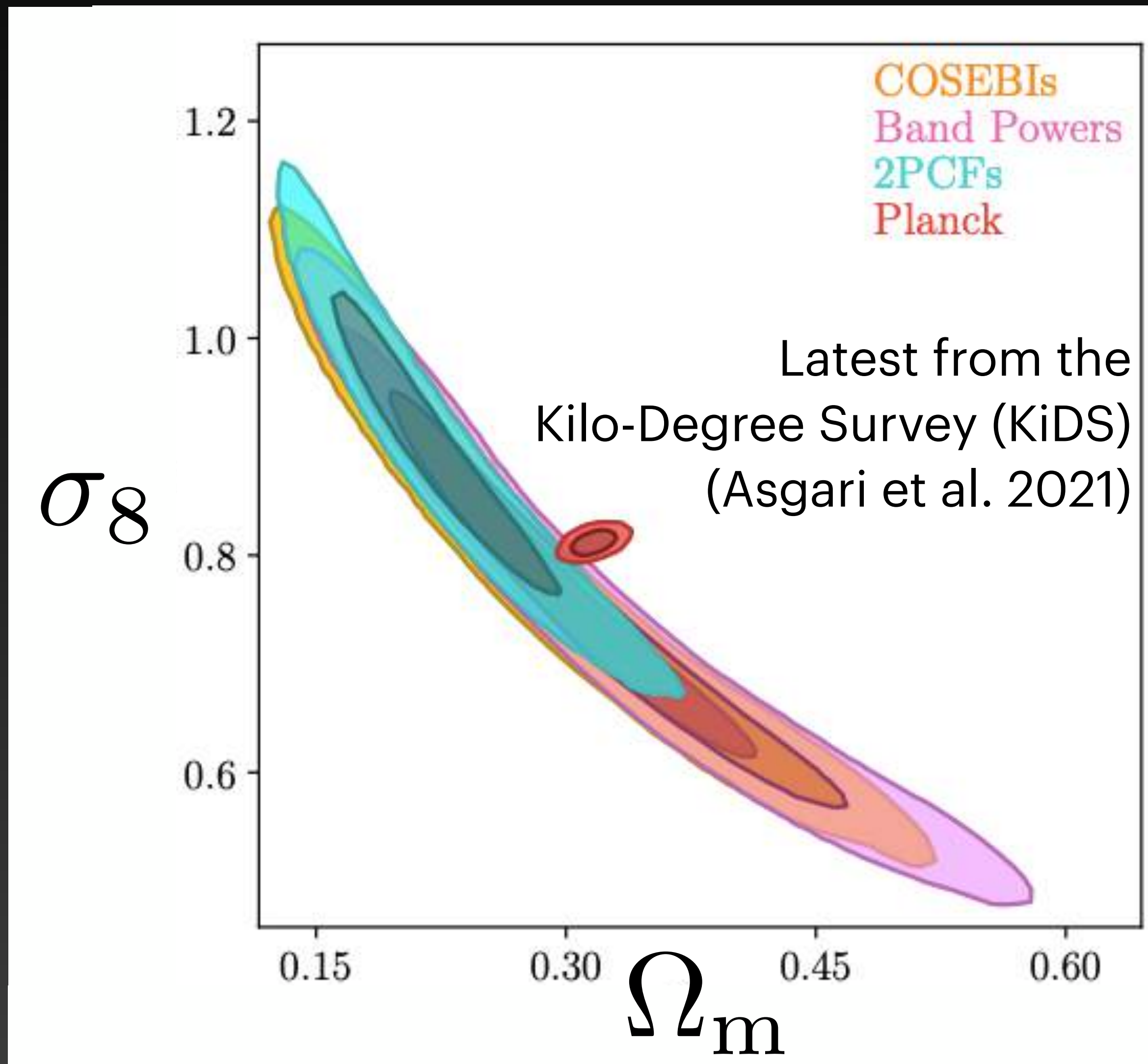
Cosmoverse, Lisbon
May 2023

Coming up...

- How does cosmological weak lensing (cosmic shear) work?

- How can we do better? (with the lensing PDF!)
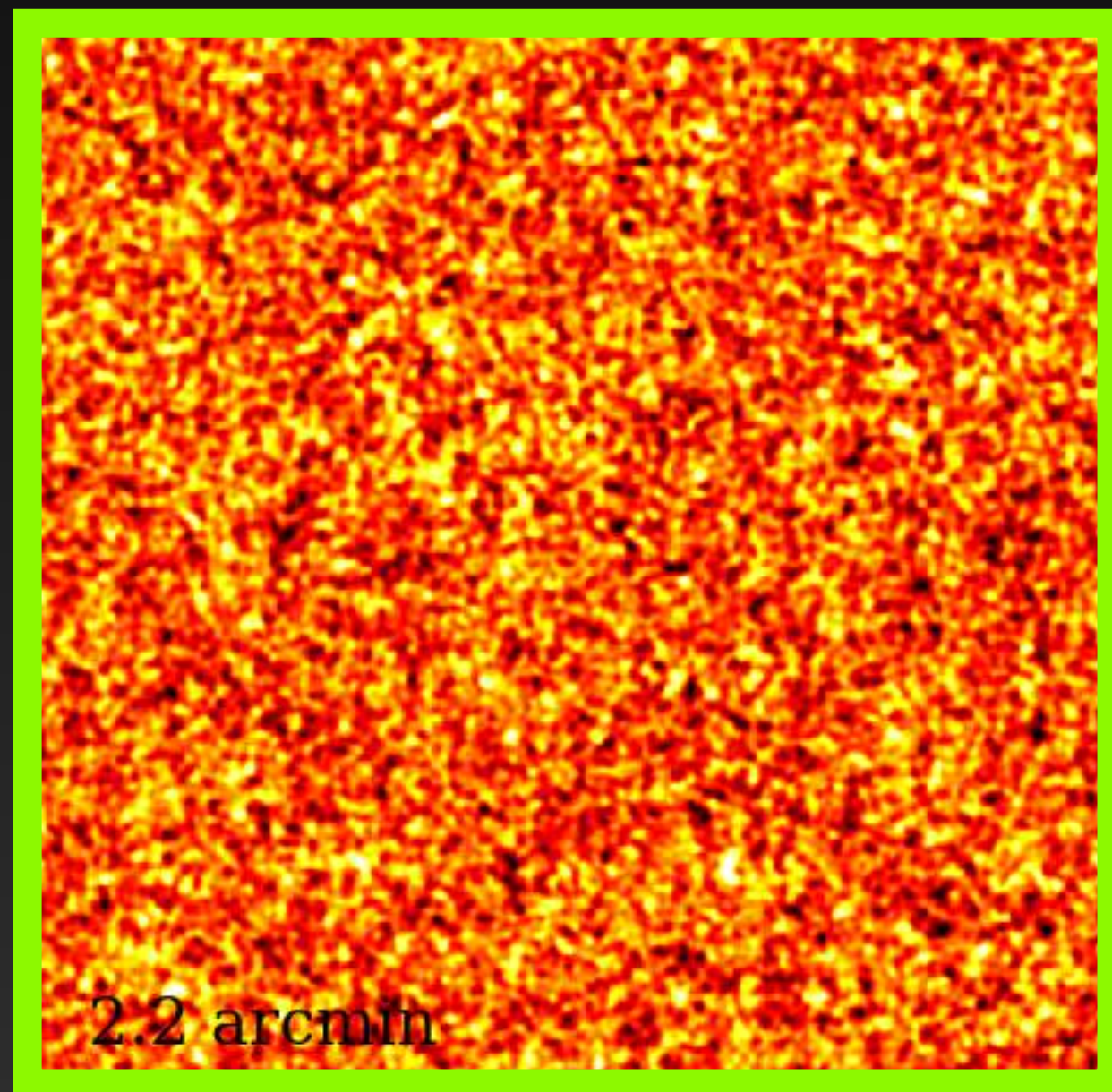
- Cosmological constraints

- A look to the future

Weak lensing:
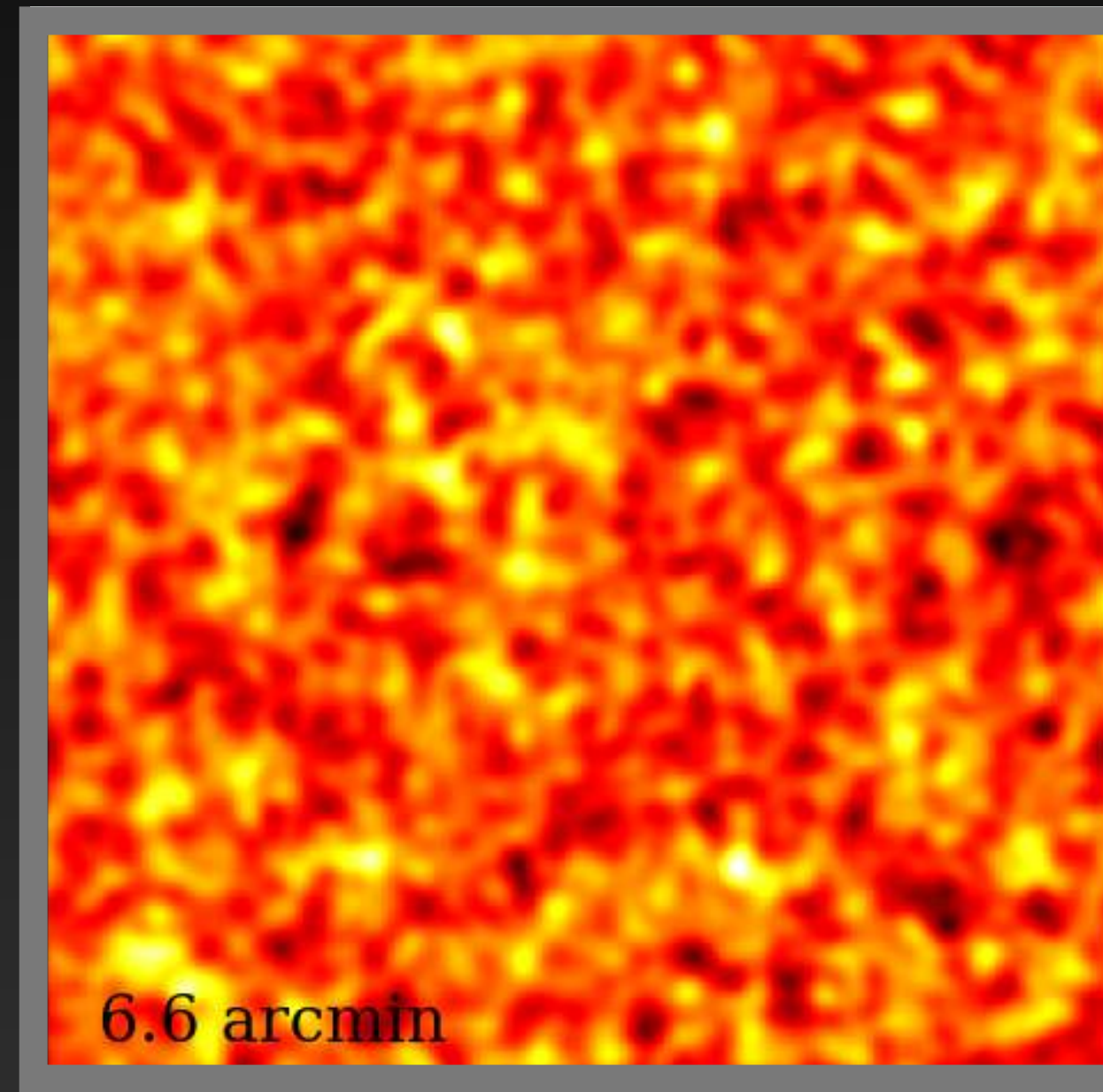## A powerful cosmological probe

θ

Credit: Stonebreaker, APS

Weak lensing:
A powerful cosmological probe

COSEBIs
Band Powers
2PCFs
Planck

Latest from the
Kilo-Degree Survey (KiDS)
(Asgari et al. 2021)

Projected density from weak lensing

2.2 arcmin

Low smoothing

6.6 arcmin

Medium smoothing

60 arcmin
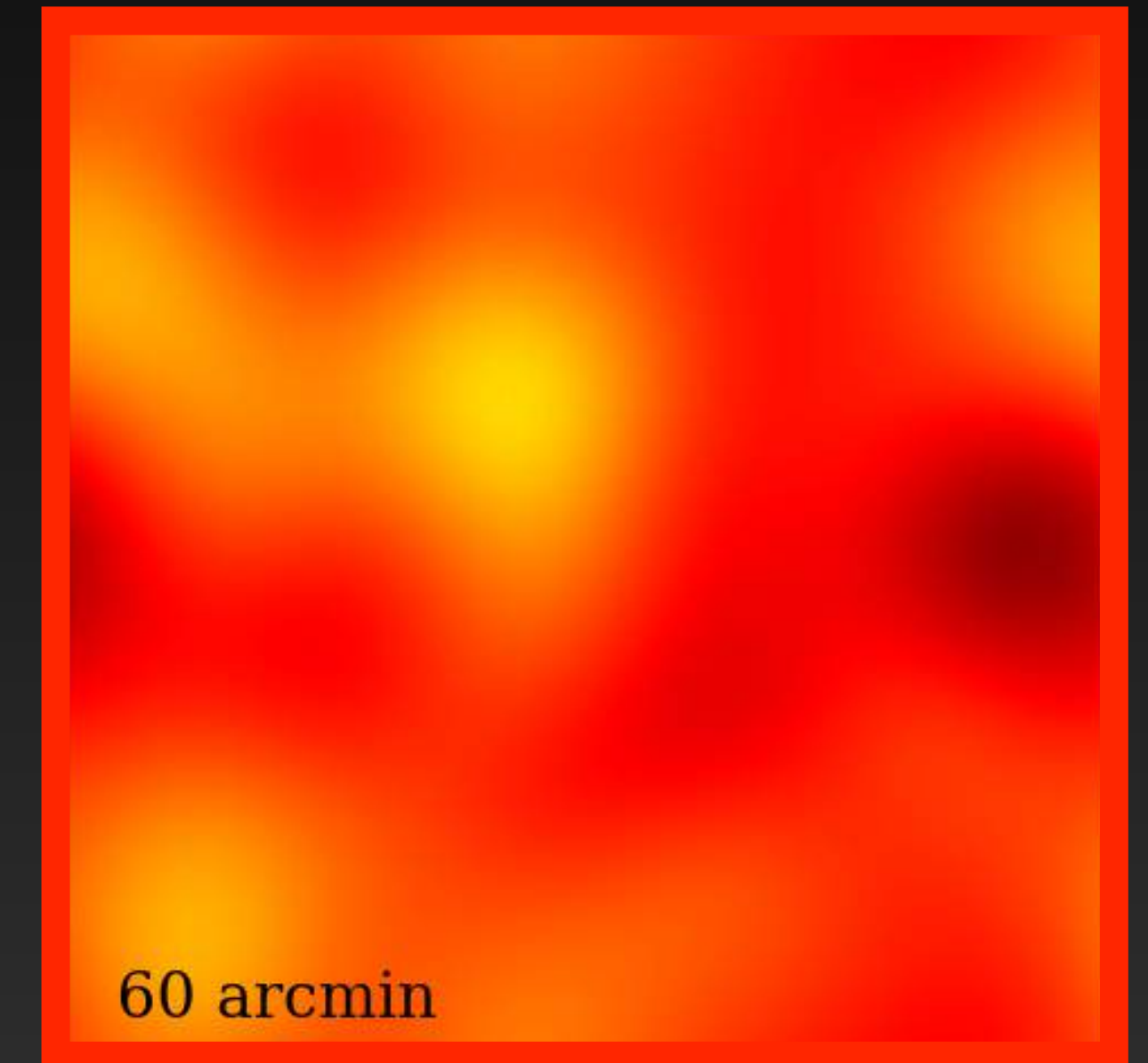
High smoothing

Constraining cosmology with the weak lensing density
"The lensing PDF"
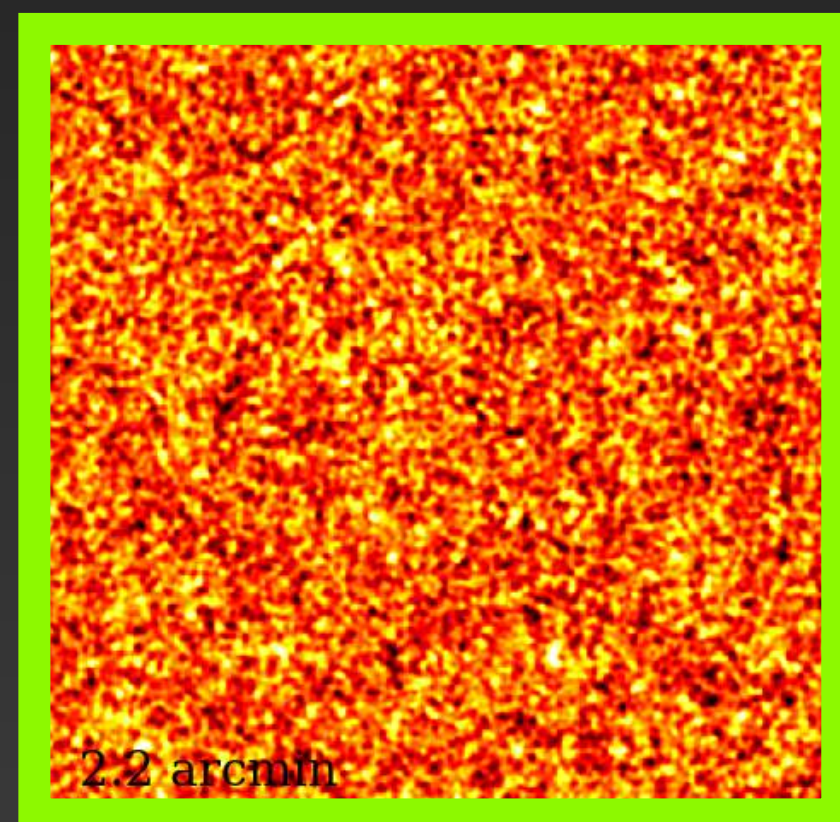
Beyond two-point statistics:
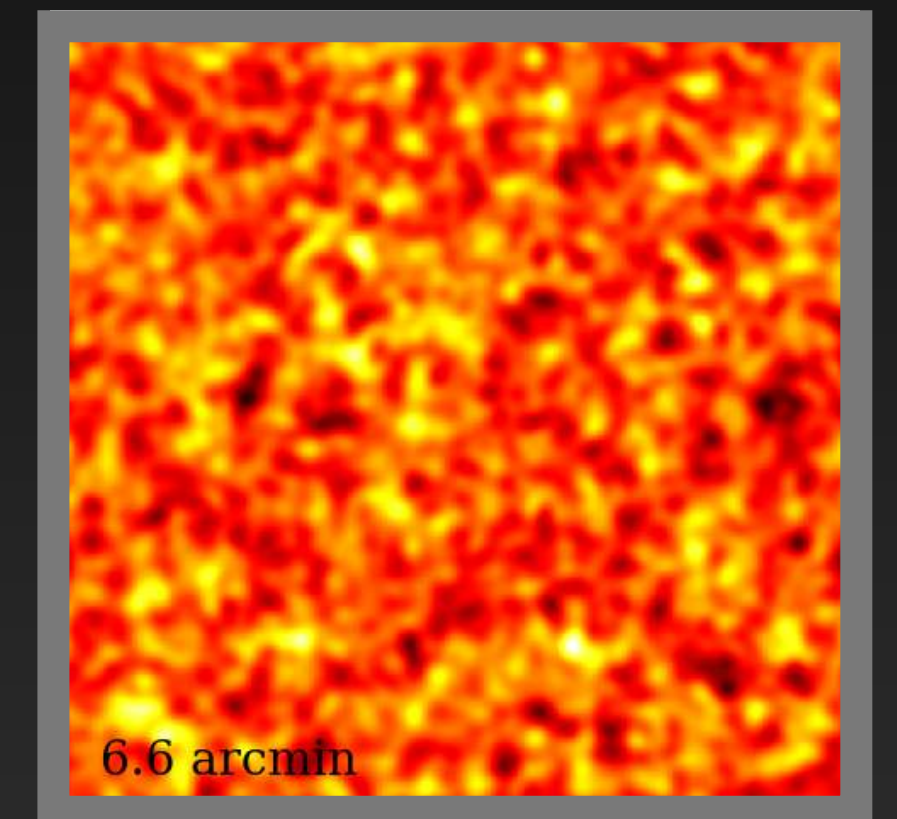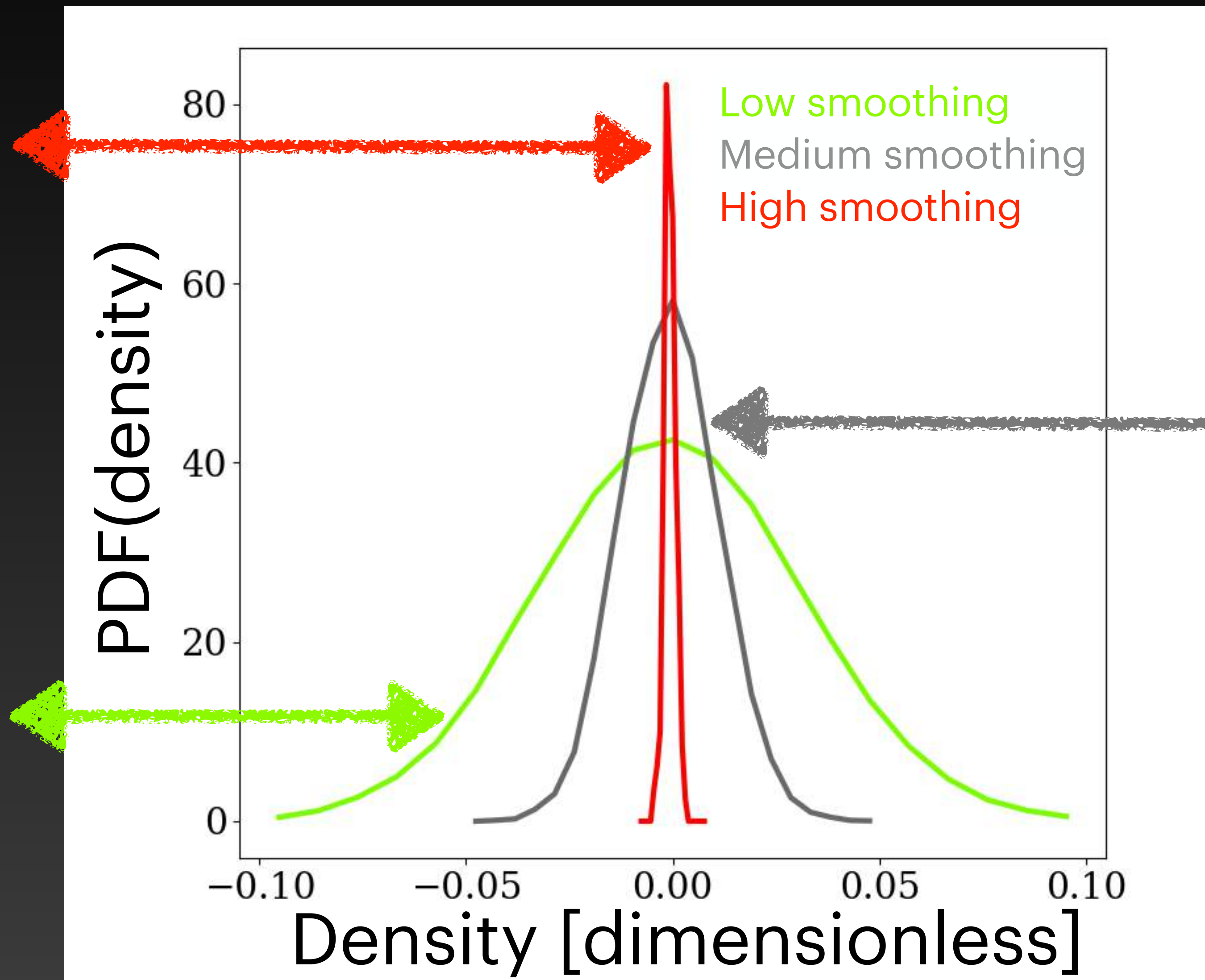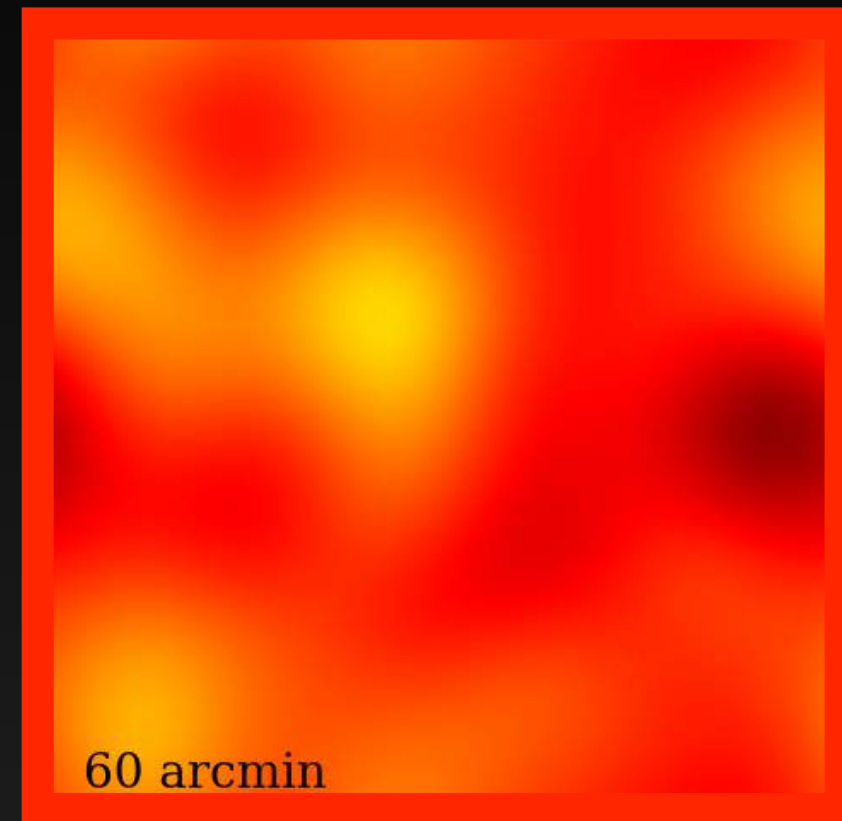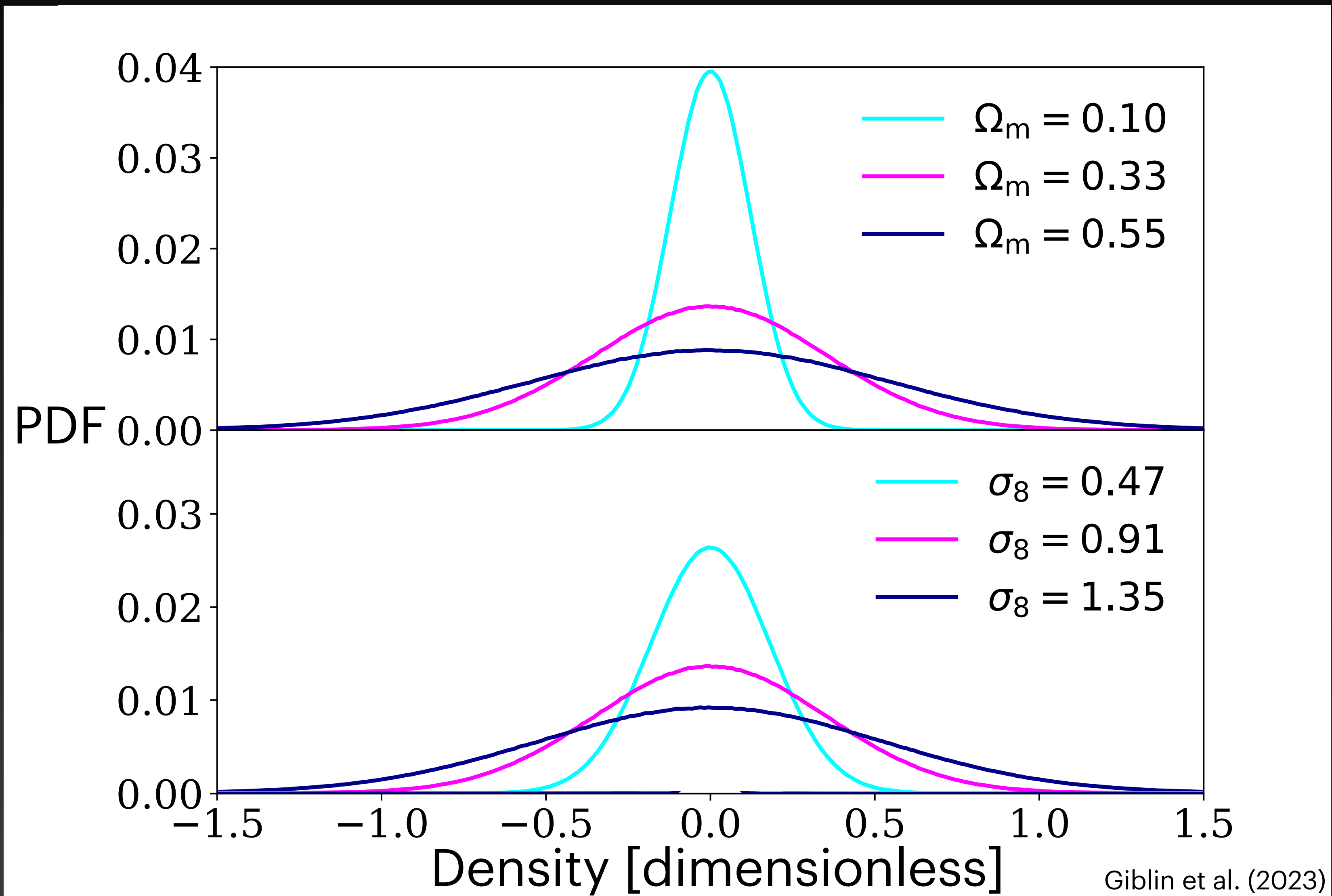## *"The lensing PDF"*

Giblin et al. (2023)

PDF vs 2pt Stats
The sanity test: a Gaussian field

Giblin et al. (2023)
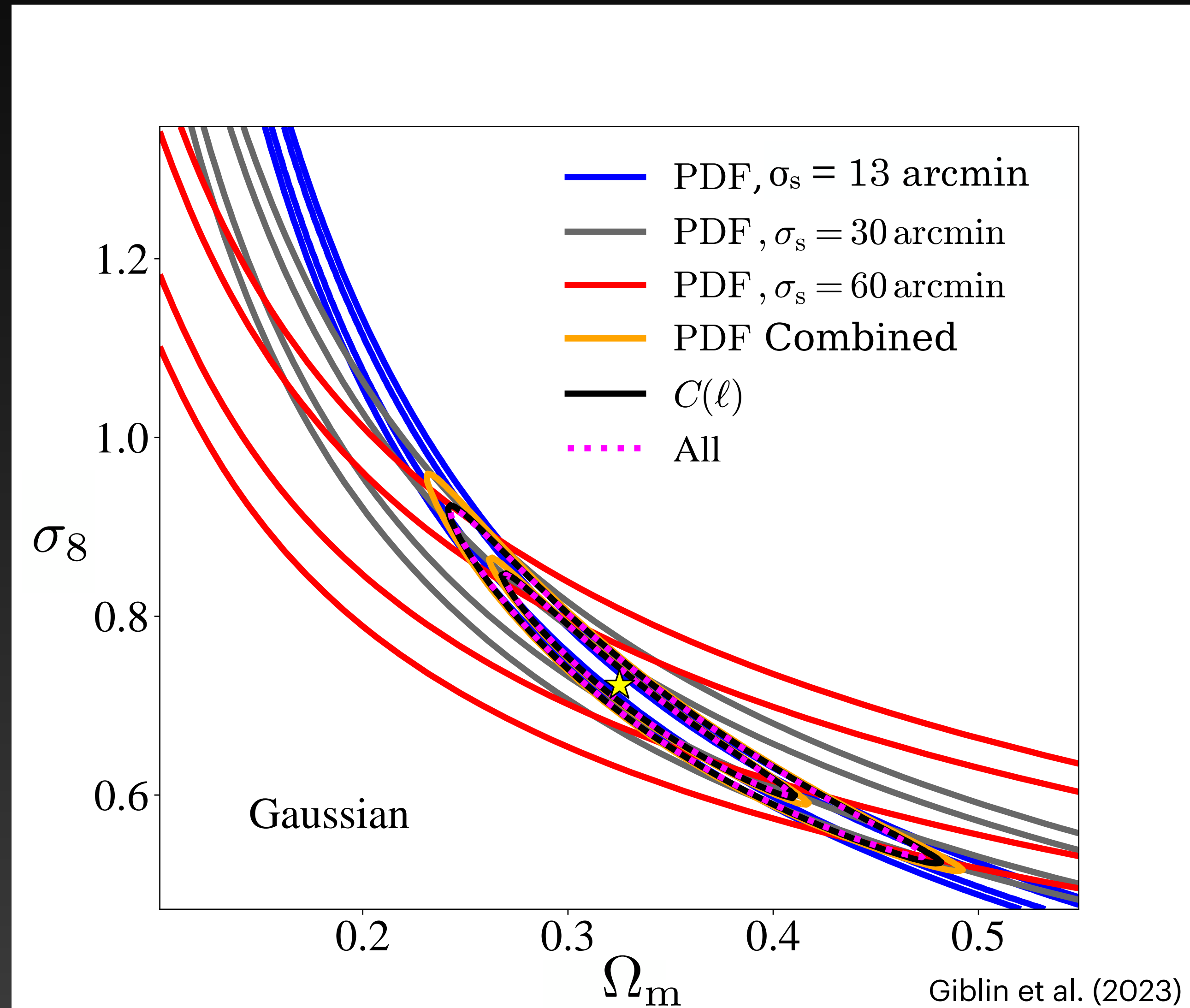
PDF vs 2pt Stats
The test case: a lognormal field
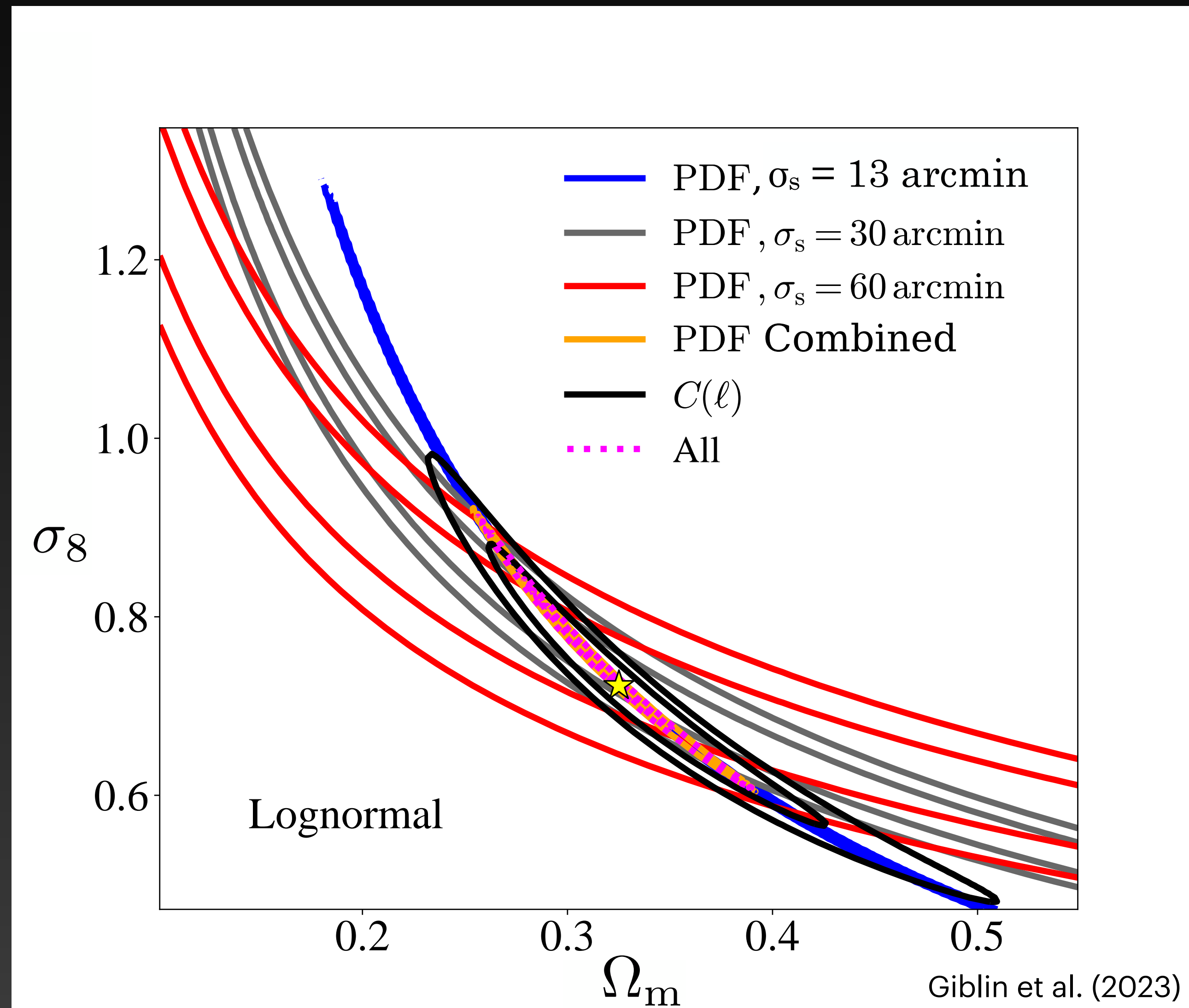
Giblin et al. (2023)

Moving towards real cosmological fields:
how do we model the cosmological dependence?

$$\mathcal{L}(\boldsymbol{d}|\boldsymbol{\pi}) \propto \exp\left(-\frac{1}{2} \left[\boldsymbol{d} - \boldsymbol{m}(\boldsymbol{\pi}) \right]^{\mathsf{T}} \Sigma^{-1} \left[\boldsymbol{d} - \boldsymbol{m}(\boldsymbol{\pi}) \right] \right)$$

Moving towards real cosmological fields:
how do we model the cosmological dependence?

$$\mathcal{L}(\boldsymbol{d}|\boldsymbol{\pi}) \propto \exp\left(-\frac{1}{2}\left[\boldsymbol{d} - \boldsymbol{m}(\boldsymbol{\pi})\right]^{\mathsf{T}} \Sigma^{-1}\left[\boldsymbol{d} - \boldsymbol{m}(\boldsymbol{\pi})\right]\right)$$

Require a model for
our statistics as a function of
cosmological parameters **π**
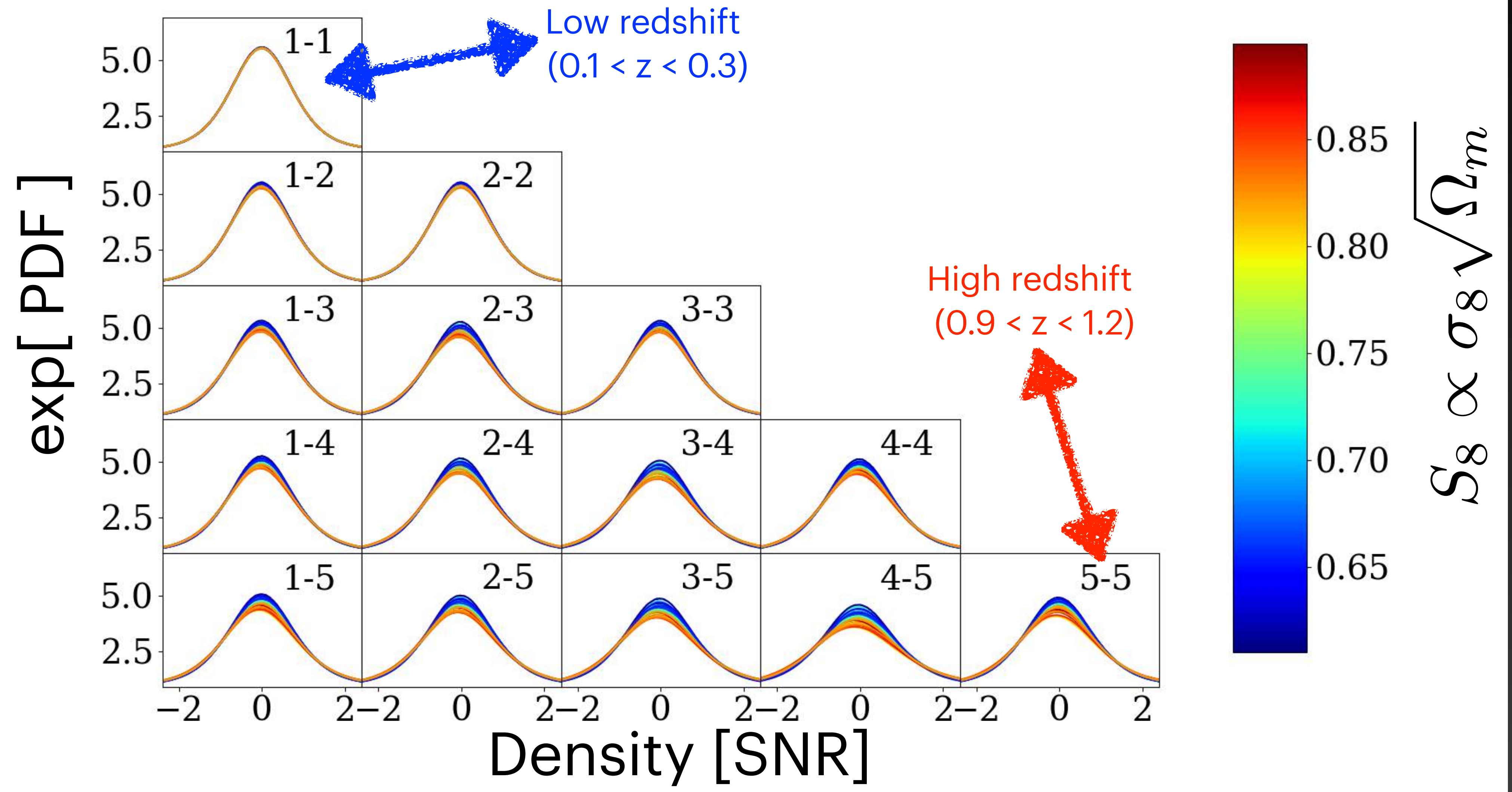
....with numerical simulations!

cosmoSLICS
(Harnois-Déraps, Giblin and Joachimi, 2019)

....with numerical simulations!

Cosmological constraints

Simulated "data" tailored to match
the Kilo-Degree Survey (KiDS)

— 2.2 arcmin
— 6.6 arcmin
— 13.2 arcmin
— Combined

Giblin et al. (in 2023)

Cosmological constraints

Simulated "data" tailored to match
the Kilo-Degree Survey (KiDS)

CF
PDF
PDF & CF

Giblin et al. (in 2023)

Cosmological constraints

Simulated "data" tailored to match
the Kilo-Degree Survey (KiDS)

CF
PDF
PDF & CF
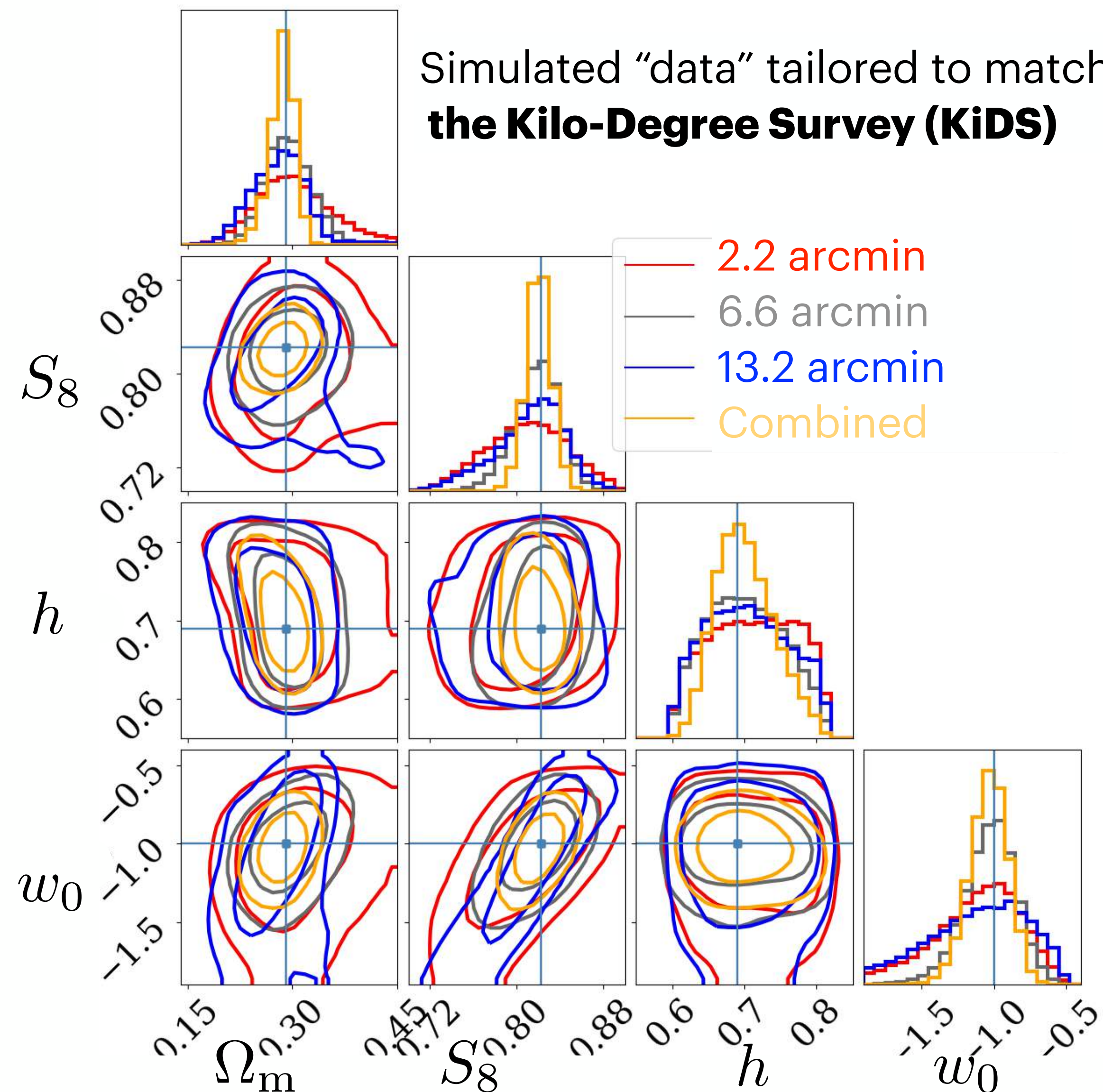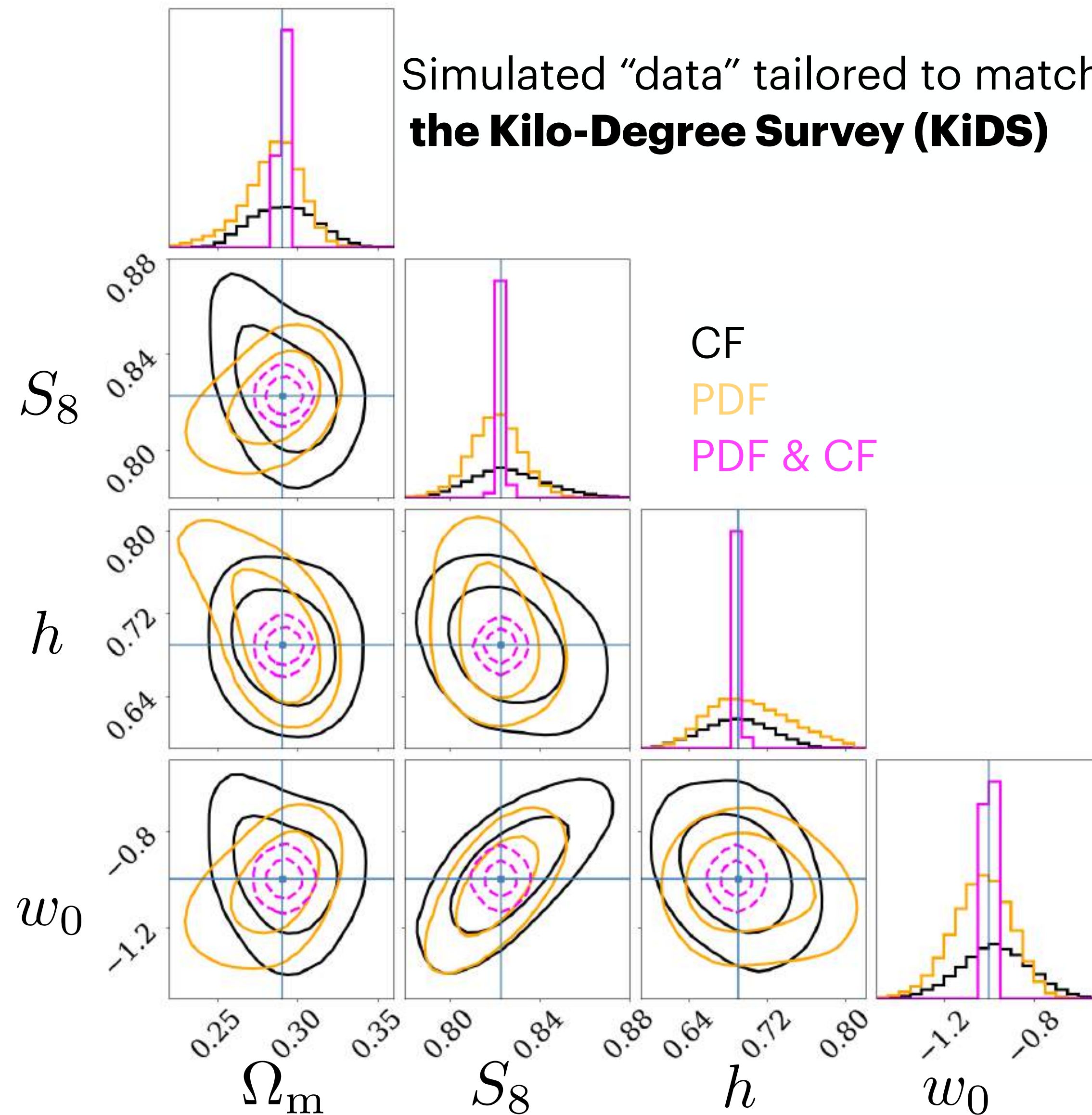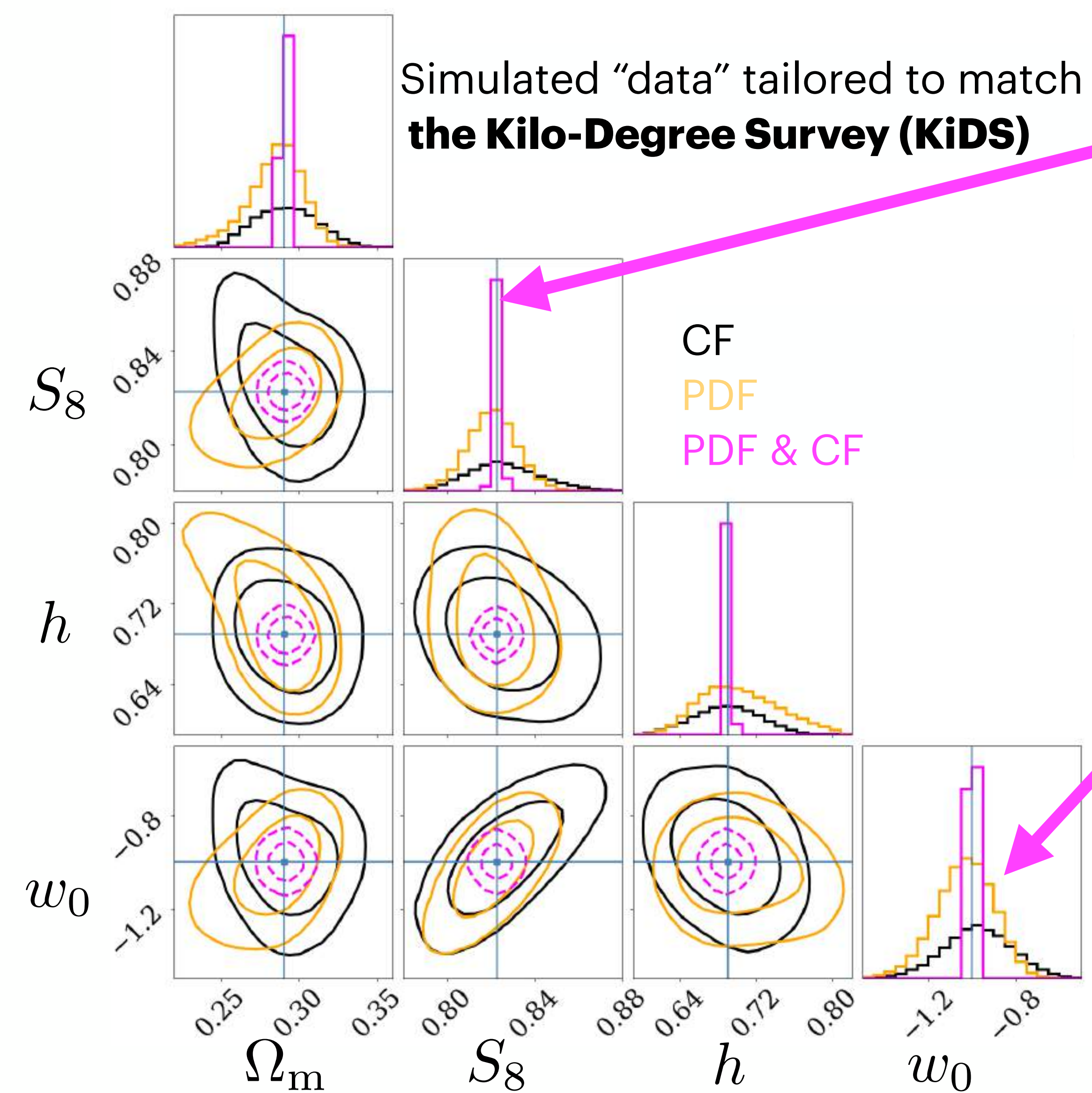
~50% improvement on S_8 constraint

~45% improvement for w_0

Giblin et al. (in 2023)

Cosmological constraints

Simulated "data" tailored to match
LSST

CF
PDF
PDF & CF
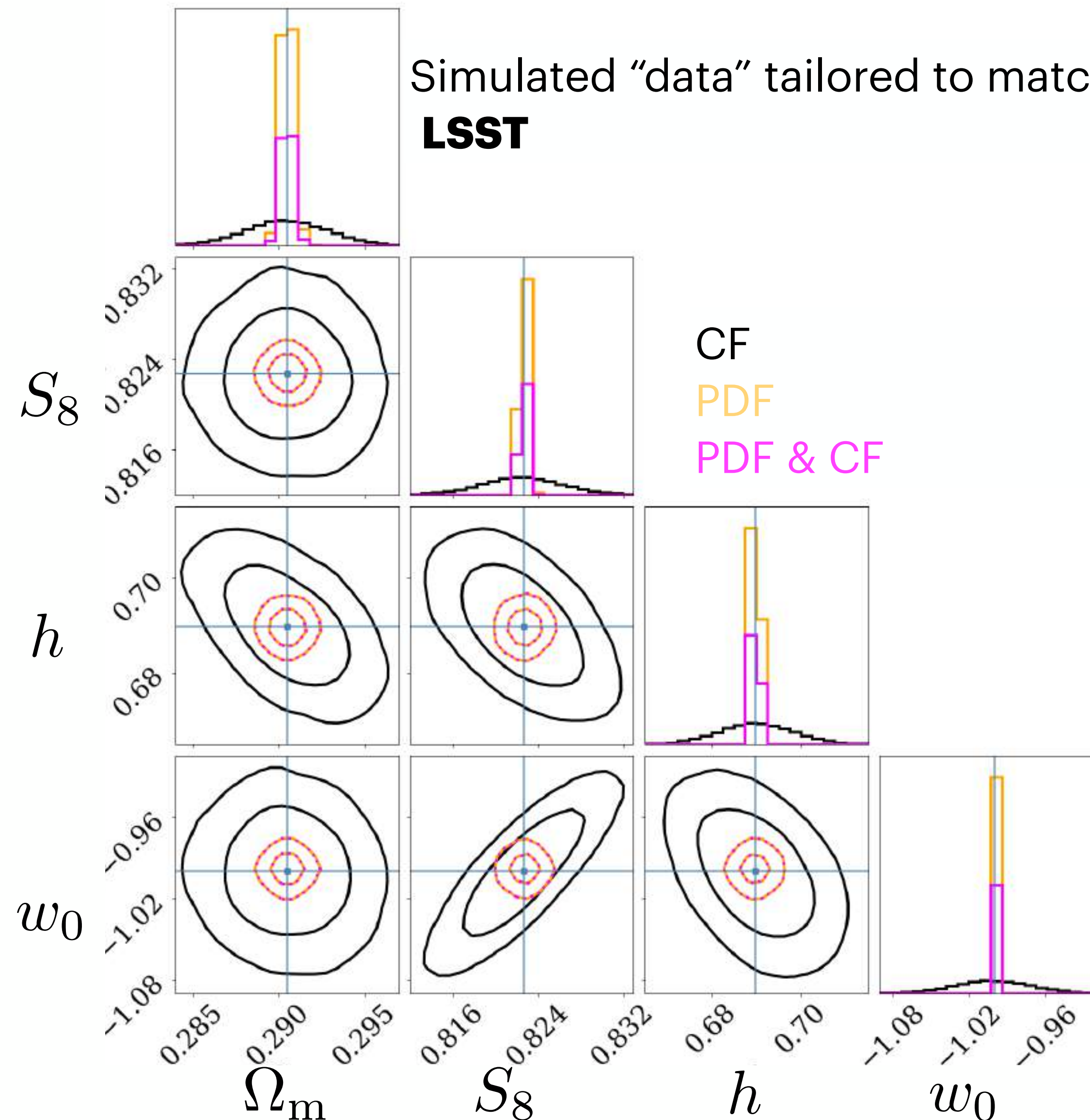
The combined-scale PDF captures **all** of the information in the 2PCF **and more**.

~86%-98% gains in precision

Giblin et al. (in 2023)

Summary

- There's information beyond 2nd order in our data!

- The lensing PDF is one way to get at it, by measuring the non-Gaussianity of the field directly.

- Measuring the lensing PDF on different scales is the key to optimising constraining power.

- For a Stage-III WL surveys, improvements over 2PCFs of ~30-50%.

- The future is bright! With LSST this approach really starts to shine (~90% improvements in cosmic shear).
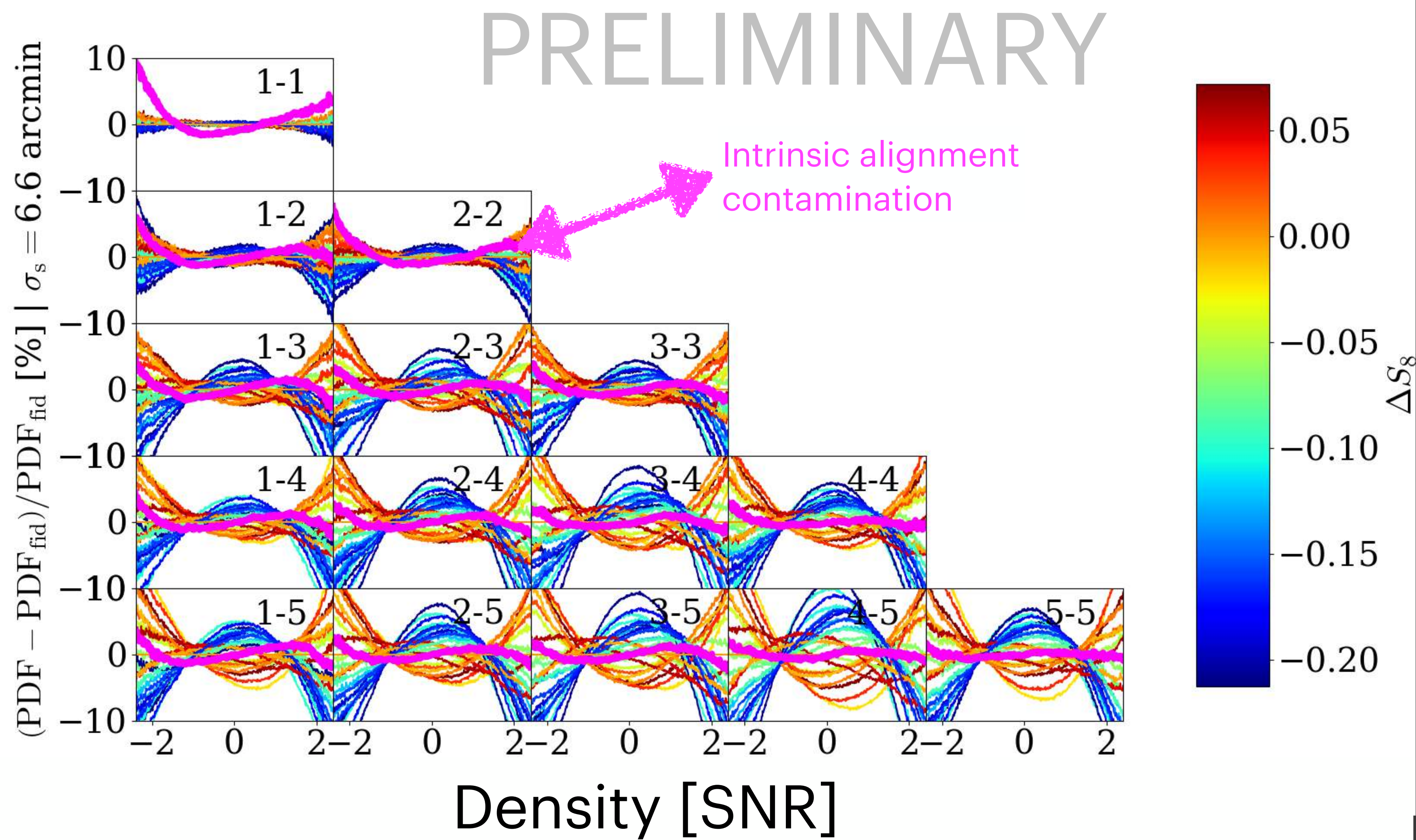
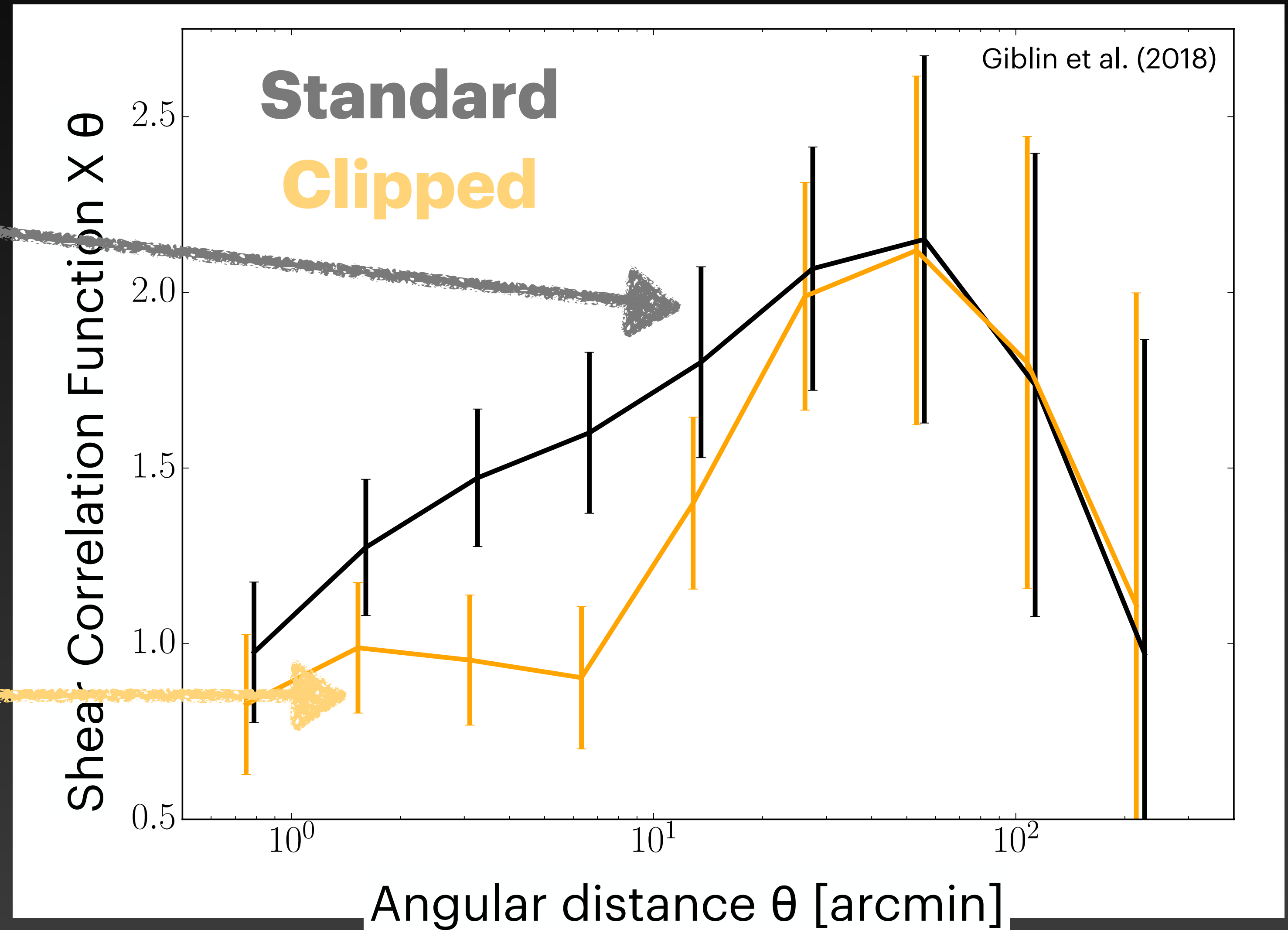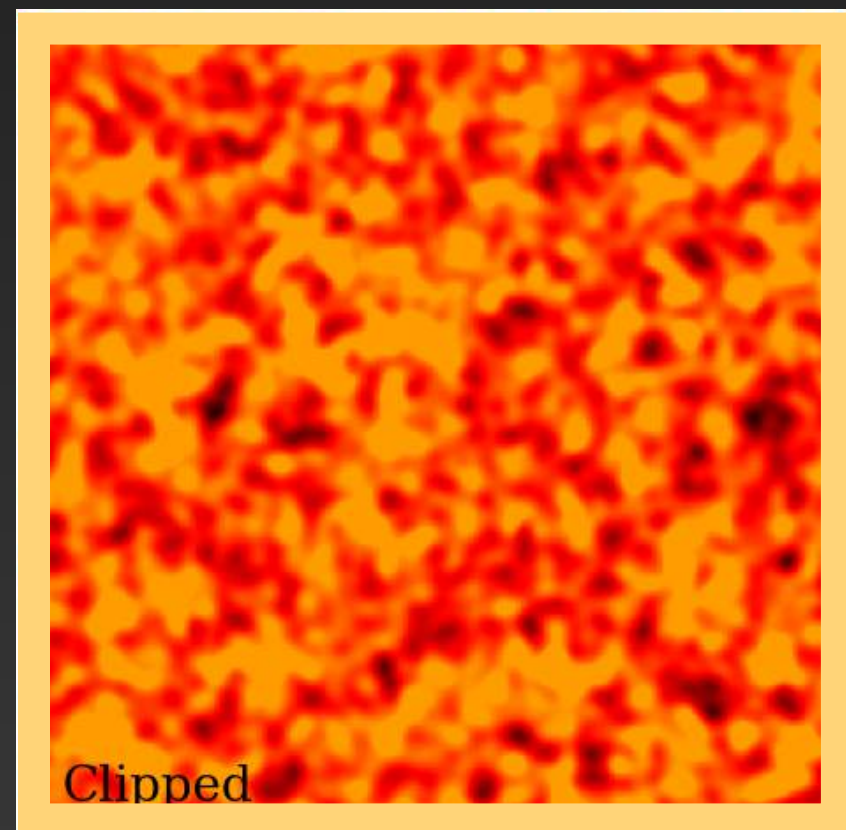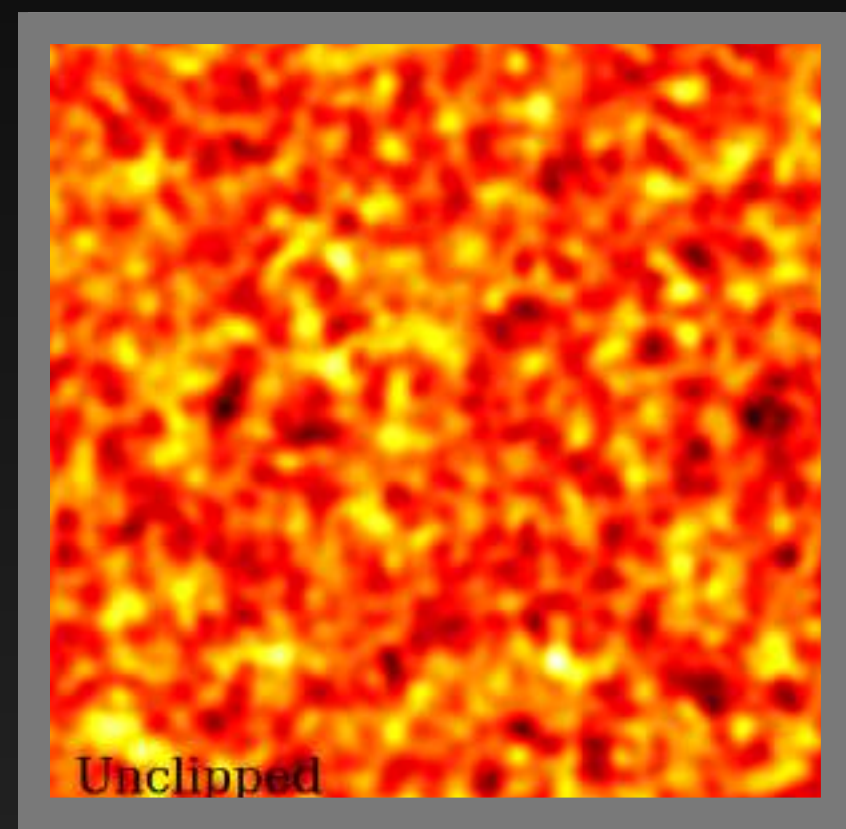(arXiv: 2211.05708)

EXTRA SLIDES

Q:
Is PDF cosmic shear worth it?

The impact of intrinsic alignments

Aside: Clipped Lensing

Standard
Clipped

Giblin et al. (2018)

Unclipped

Clipped

Results: Clipped Lensing

Credit: Louise Paquereau
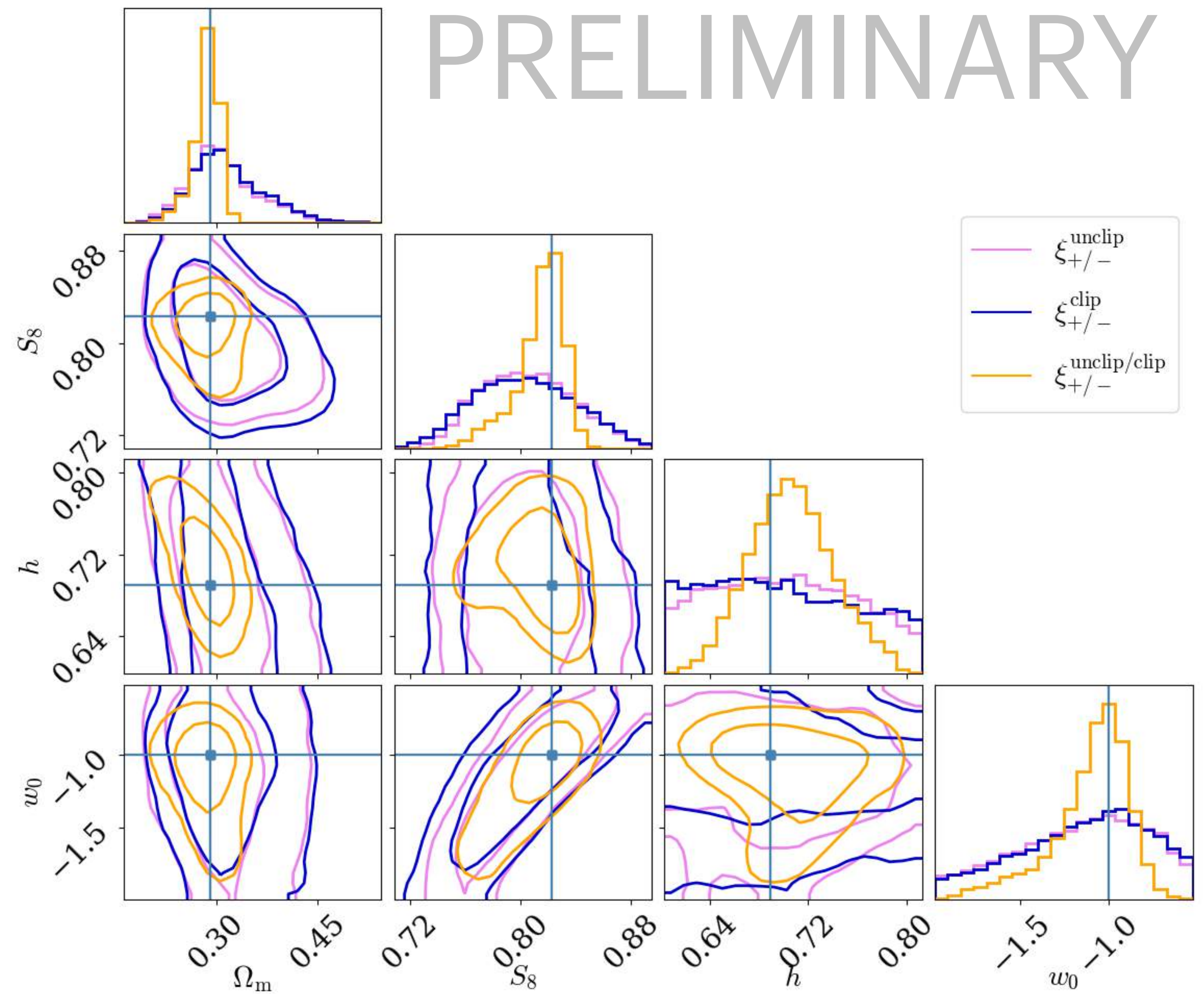
Going beyond the standard shear correlation function

Alternative statistics:

- The lensing probability density function (PDF)[1,2,3]
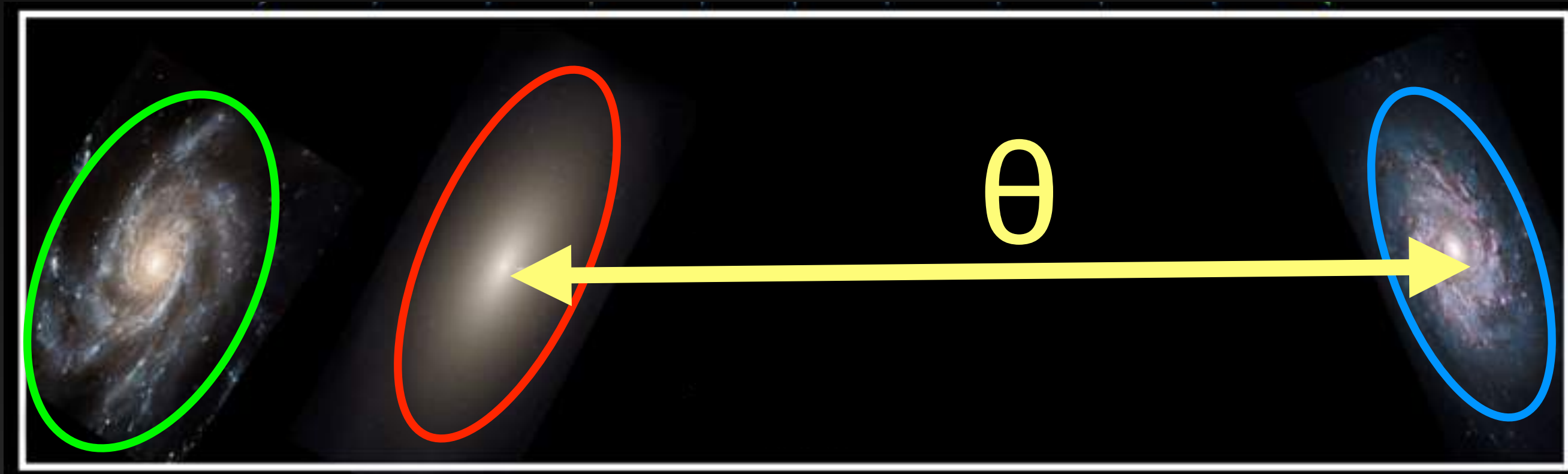
- "Clipped" shear correlation function[4]

[1] Petri et al. (2015)
[2] Clerkin et al. (2016)
[3] Uhlemann et al. (2019)
[4] Giblin et al. (2018)

Credit: Kilo-Degree Survey Collaboration

Cosmic shear:
Constraining cosmological parameters with weak lensing

The shear correlation function (2PCF) measured from data

The measurement from the data is compared to a theoretical prediction which depends on cosmological parameters (e.g. Ω_m & σ_8)

Cosmic shear:
Constraining cosmological parameters with weak lensing

The shear correlation function (2PCF) measured from data

θ

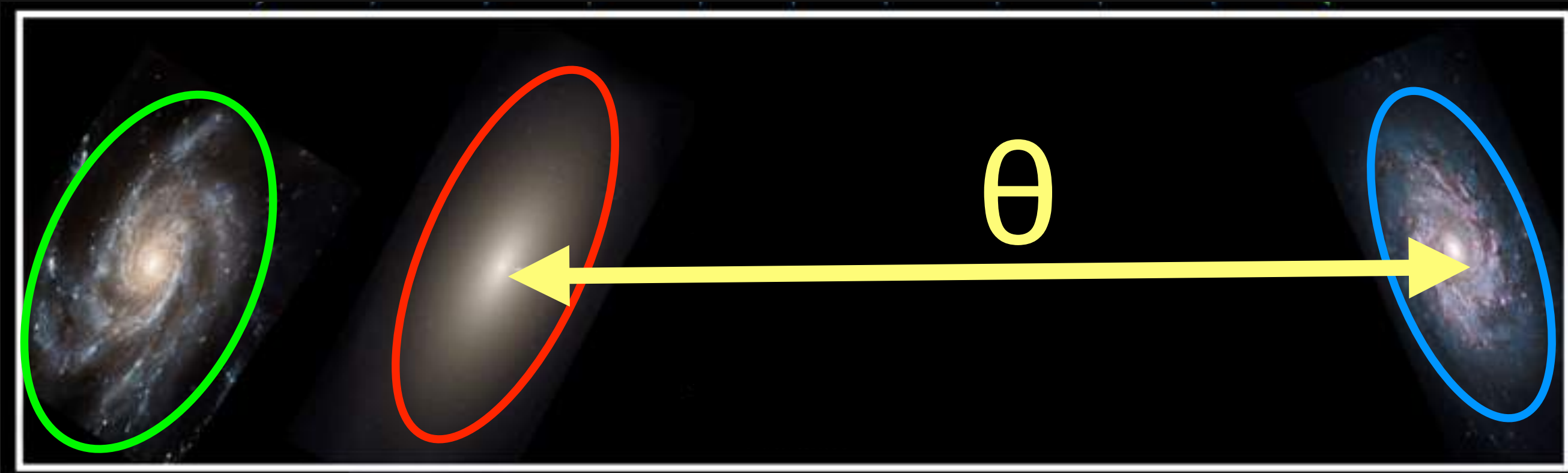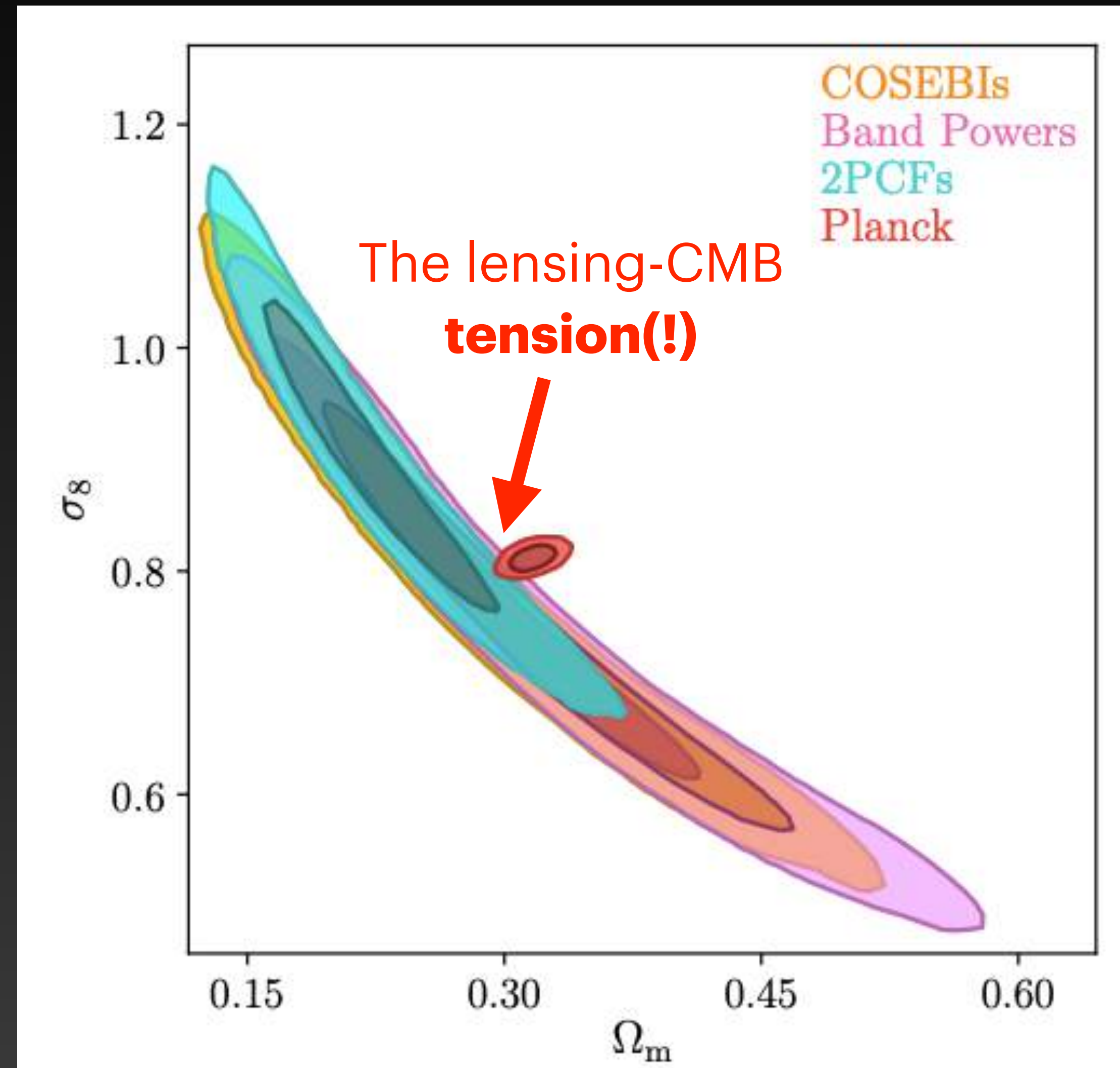**The measurement from the data is compared to a theoretical prediction which depends on cosmological parameters (e.g. Ω_m & σ_8)**

COSEBIs
Band Powers
2PCFs
Planck

The lensing-CMB
tension(!)

σ_8

Ω_m

Asgari et al. (2020)

Results: Both

PRELIMINARY

Standard 2pt CF
Clipped + Standard 2pt CF
PDF

Giblin et al. (in prep.)

The Kilo-Degree Survey (KiDS)

Credit: KiDS Collaboration
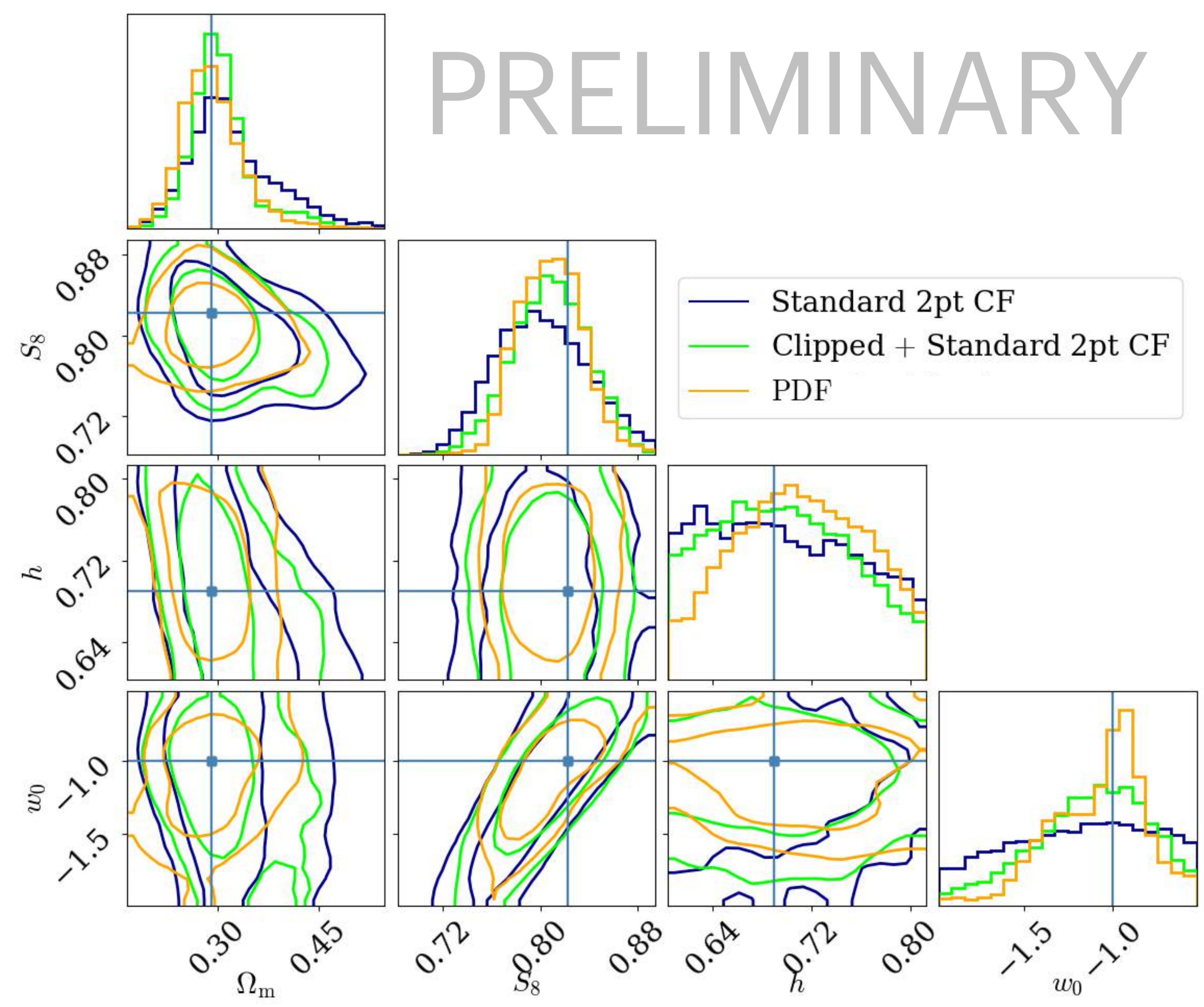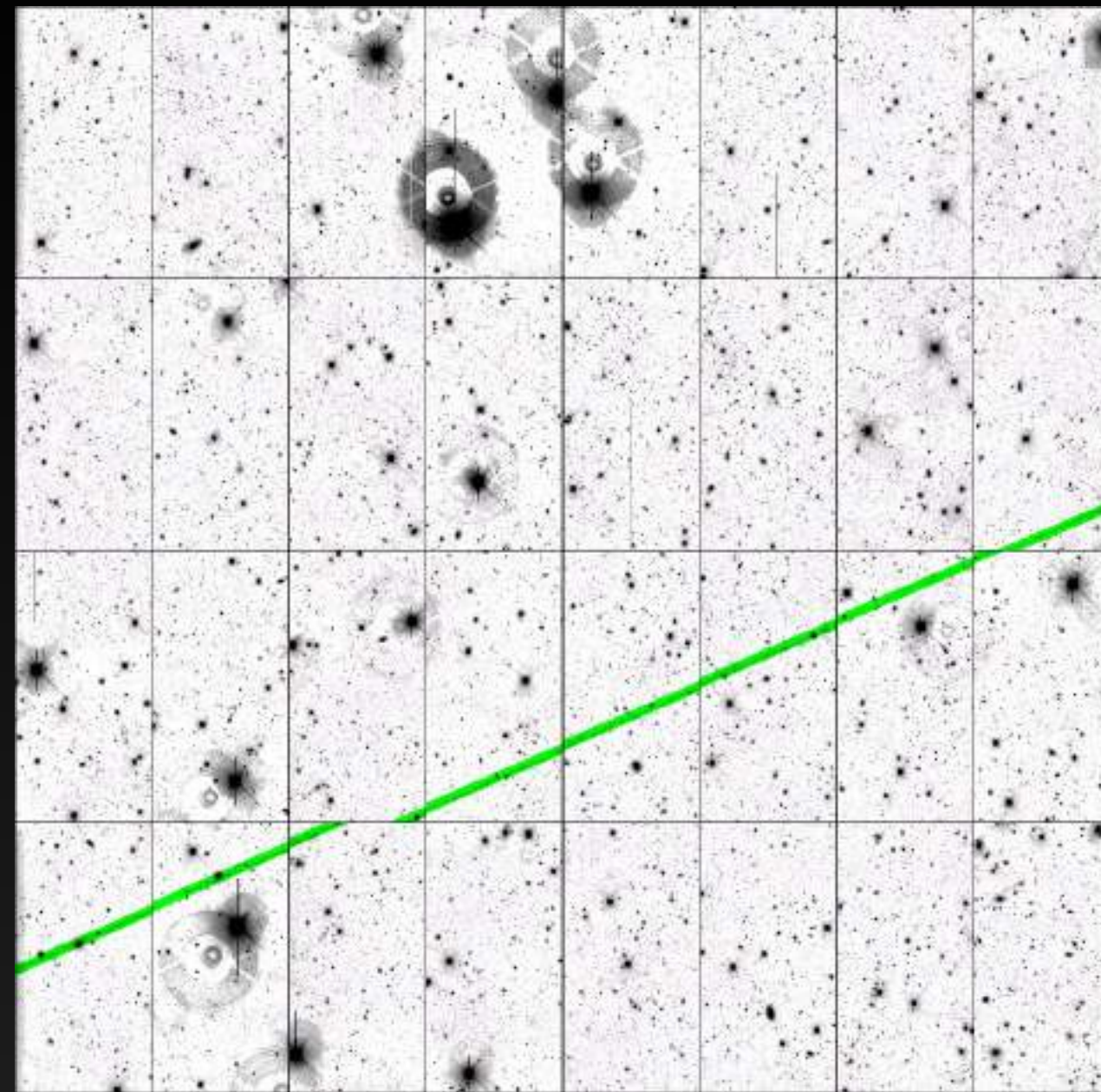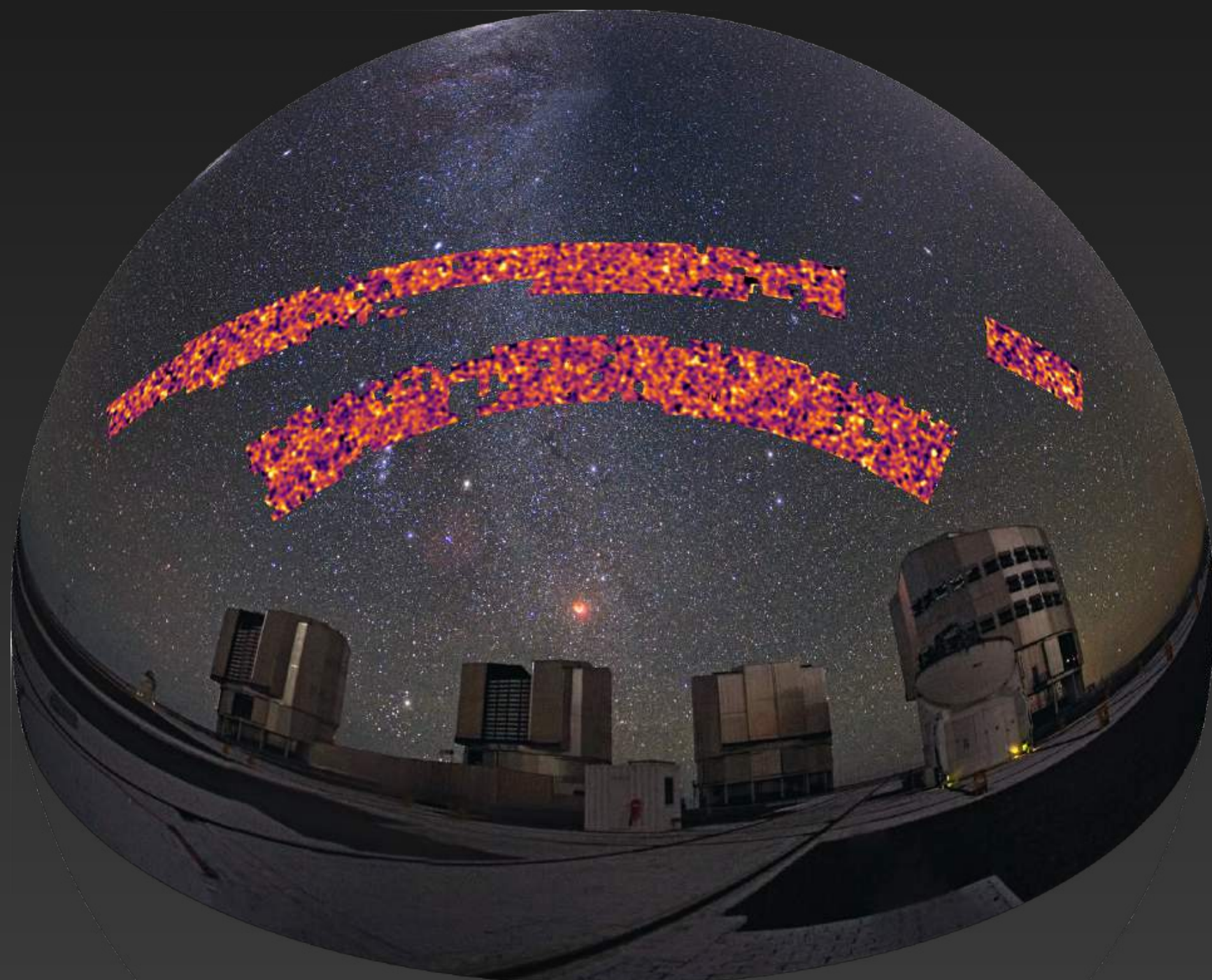
KiDS-1000

- 1000deg^2 of sky coverage.

- Images collected at the VLT Survey Telescope (VST).

- 5 dithered exposures in 4 optical bands, *ugri*, each 1deg^2 in size.

- Galaxies also imaged in 5 near-infrared bands with VIKING.

- Shape measurements & redshifts for 21 million galaxies.

Cosmic shear
Probing the standard model with weak lensing

The shear correlation function (2PCF) measured from data

$$\hat{\xi}_{\pm}^{ij}(\theta) = \frac{\sum_{ab} w_a w_b \left[\epsilon_t^i(\vec{x}_a)\epsilon_t^j(\vec{x}_b) \pm \epsilon_\times^i(\vec{x}_a)\epsilon_\times^j(\vec{x}_b)\right]}{\sum_{ab} w_a w_b}$$

Galaxy ellipticities
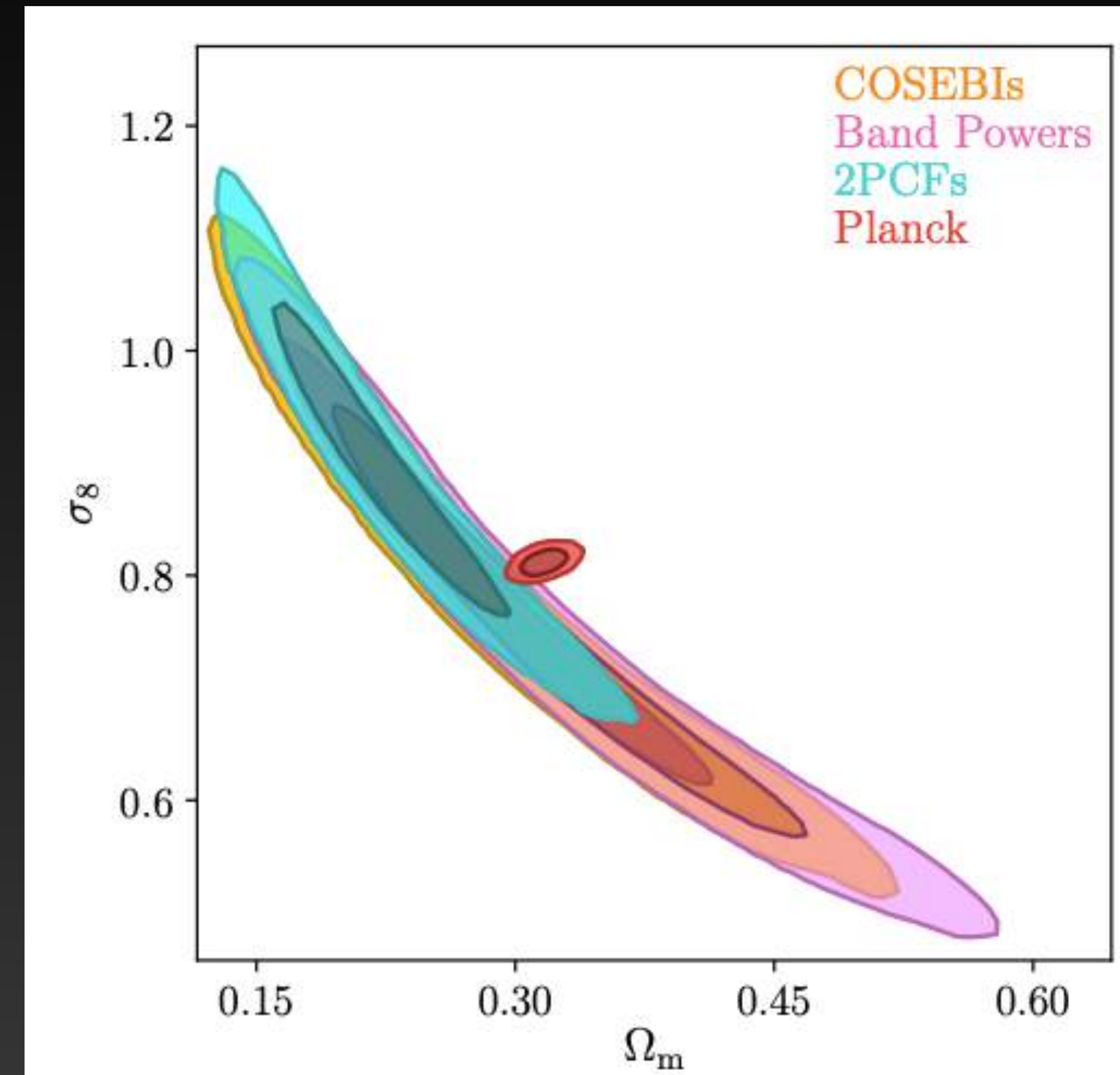measured in your data

The theoretical prediction you compare to

$$\xi_{\pm}^{ij}(\theta) = \frac{1}{2\pi} \int d\ell\, \ell\, P_\kappa^{ij}(\ell)\, J_{0,4}(\ell\theta),$$

$$P_\kappa^{ij}(\ell) = \int_0^{\chi_H} d\chi \frac{q_i(\chi)q_j(\chi)}{[f_K(\chi)]^2} P_\delta\left(\frac{\ell}{f_K(\chi)}, \chi\right),$$

Matter power spectrum
(depends on Ω_m, S8 etc.)

$$q_i(\chi) = \frac{3H_0^2\Omega_m}{2c^2}\frac{f_K(\chi)}{a(\chi)}\int_\chi^{\chi_H} d\chi'\, n_i(\chi)\frac{f_K(\chi'-\chi)}{f_K(\chi')},$$

Redshift distribution
of the lensed galaxies

Asgari et al. (2020)