Slicing through tension: Enhanced precision from cosmological weak lensing

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(arXiv: 2211.05708)

Cosmoverse, Lisbon
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RSE The Royal Society of Edinburgh KNOWLEDGE MADE USEFUL
UNIVERSITAT DE BARCELONA
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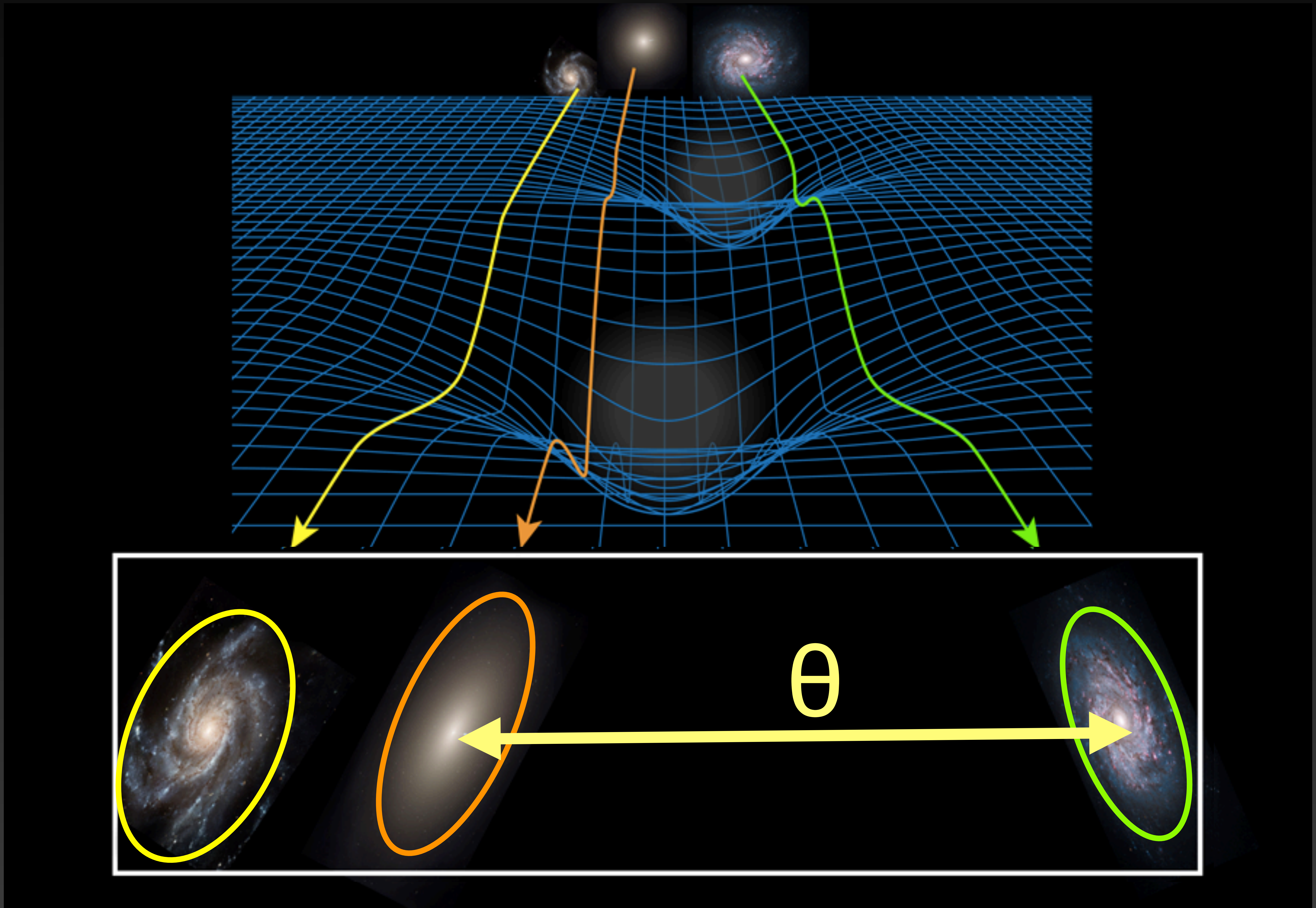
Coming up...

- 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



Credit: Stonebreaker, APS

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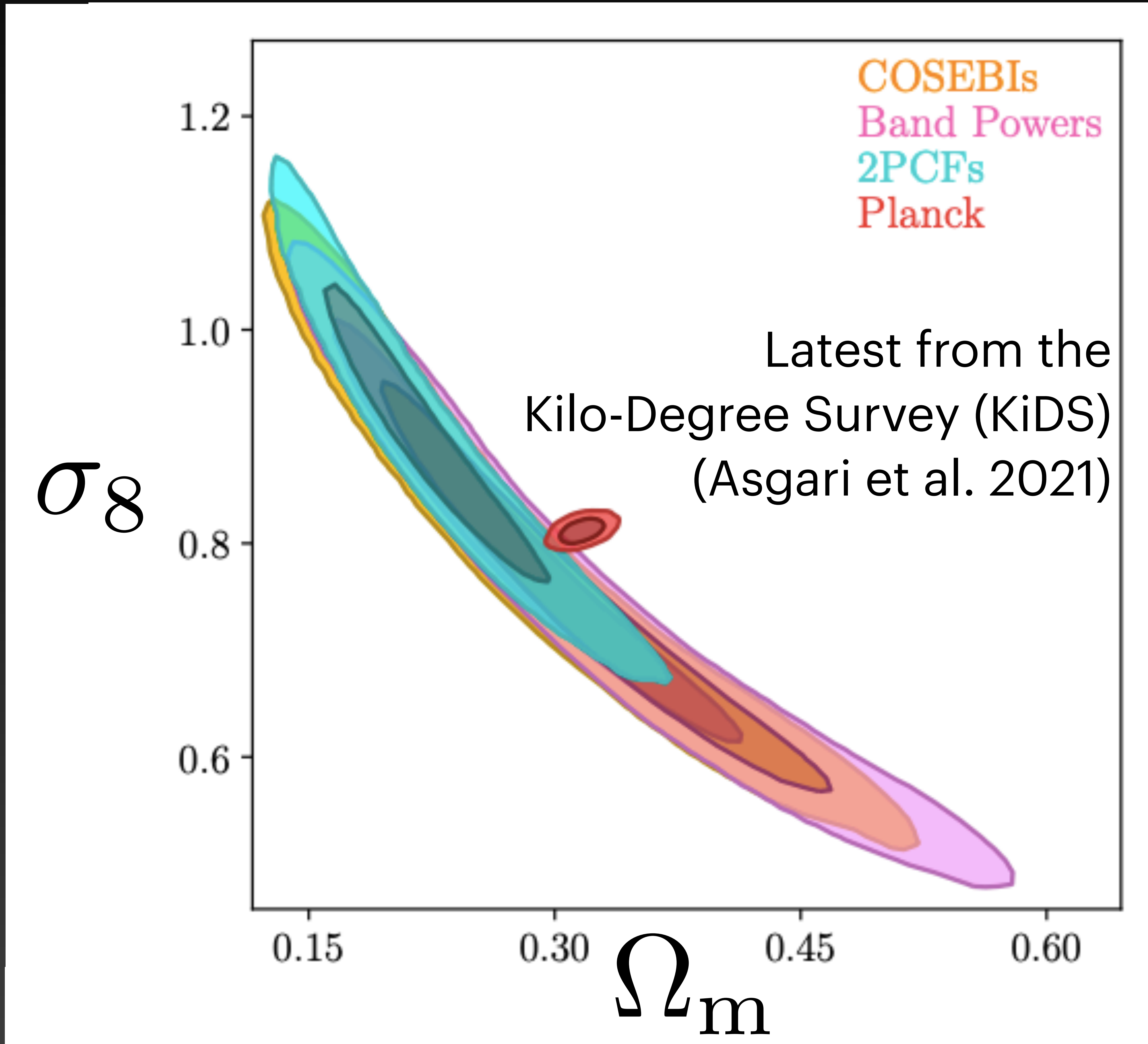
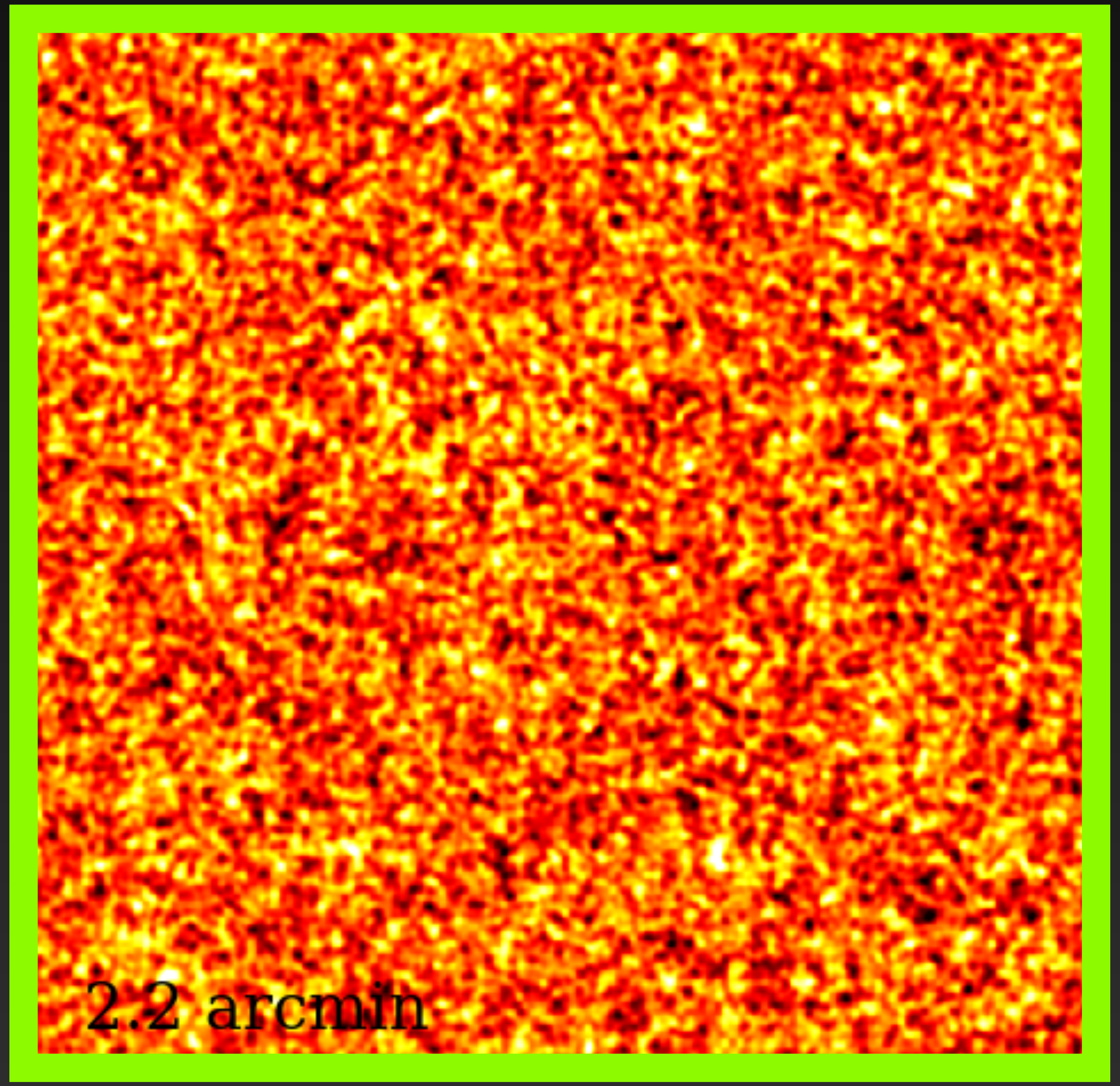
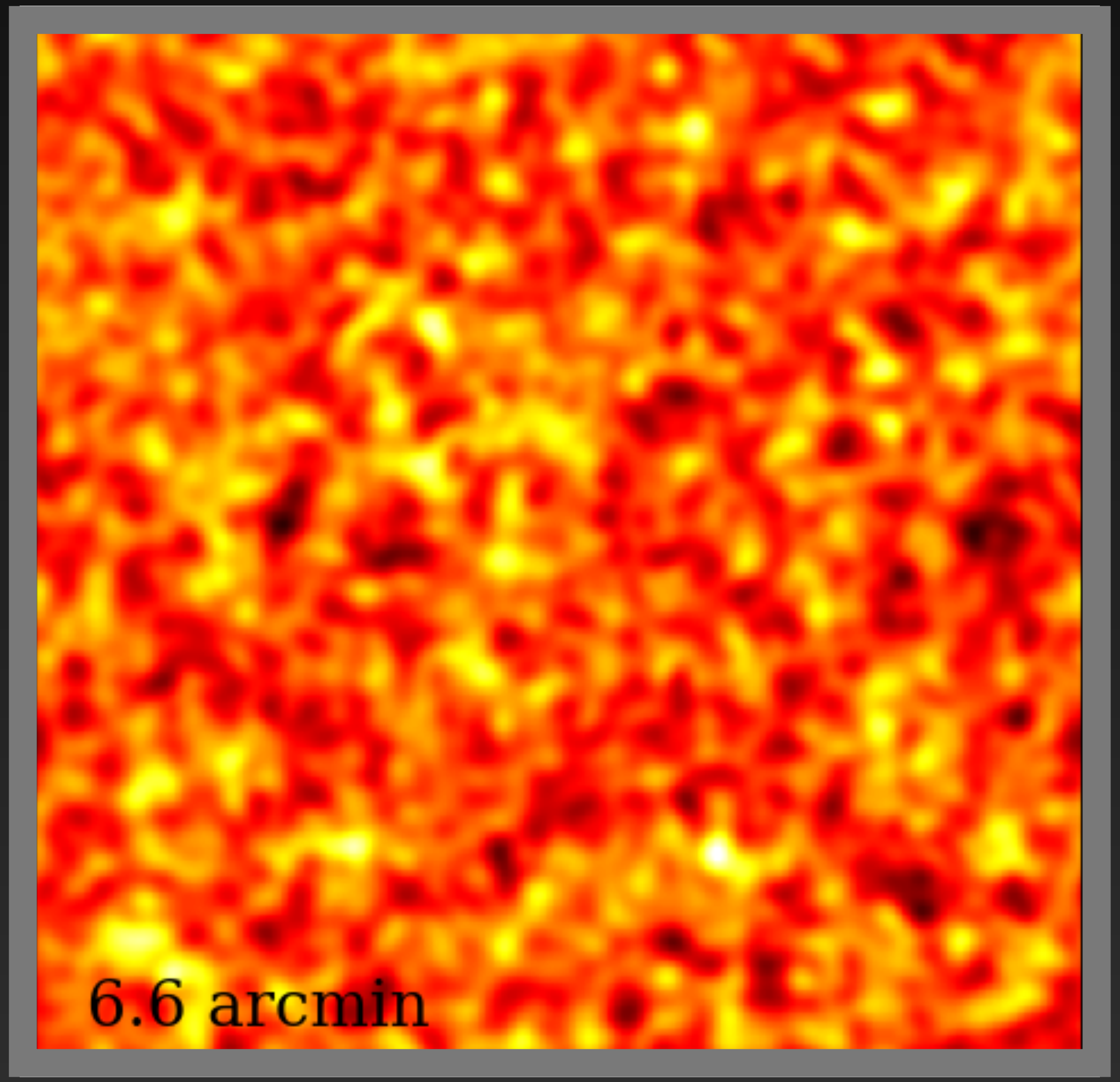


Latest from the
Kilo-Degree Survey (KiDS)
(Asgari et al. 2021)

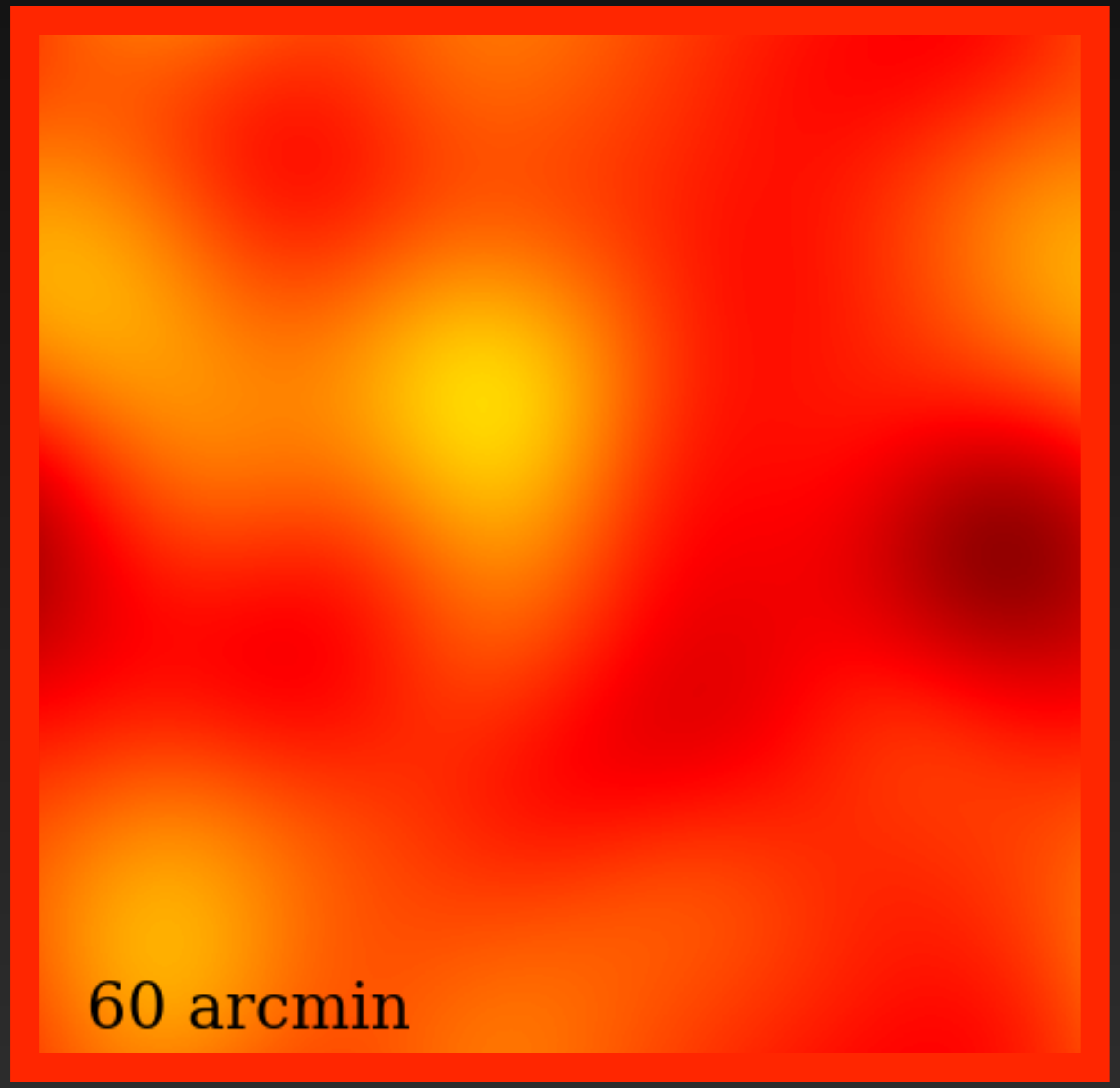
Projected density from weak lensing



Low smoothing



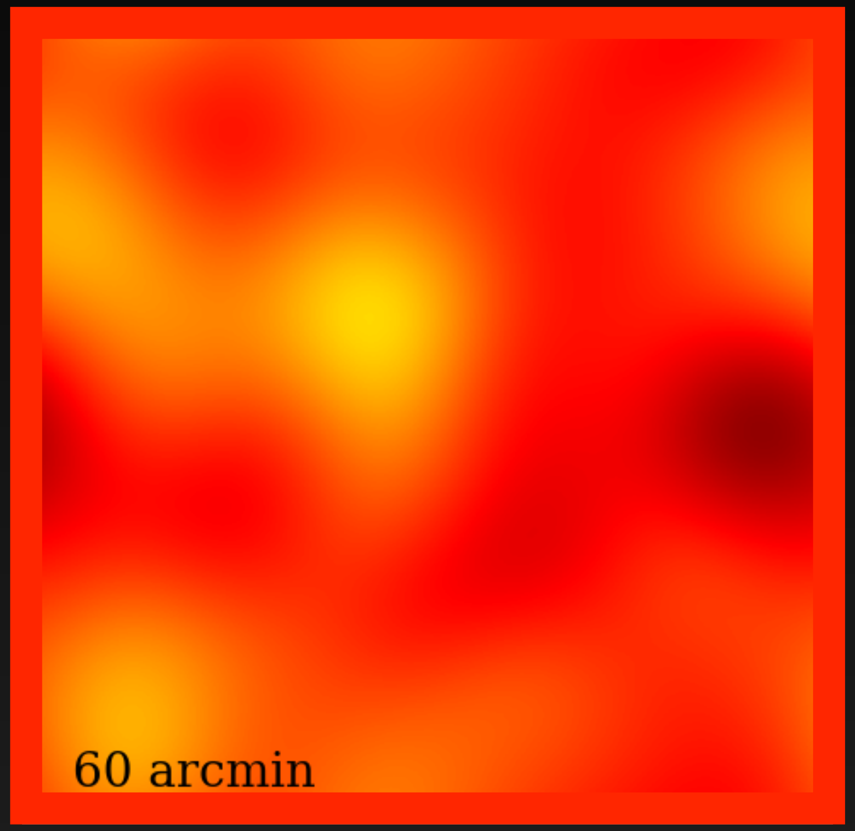
Medium smoothing

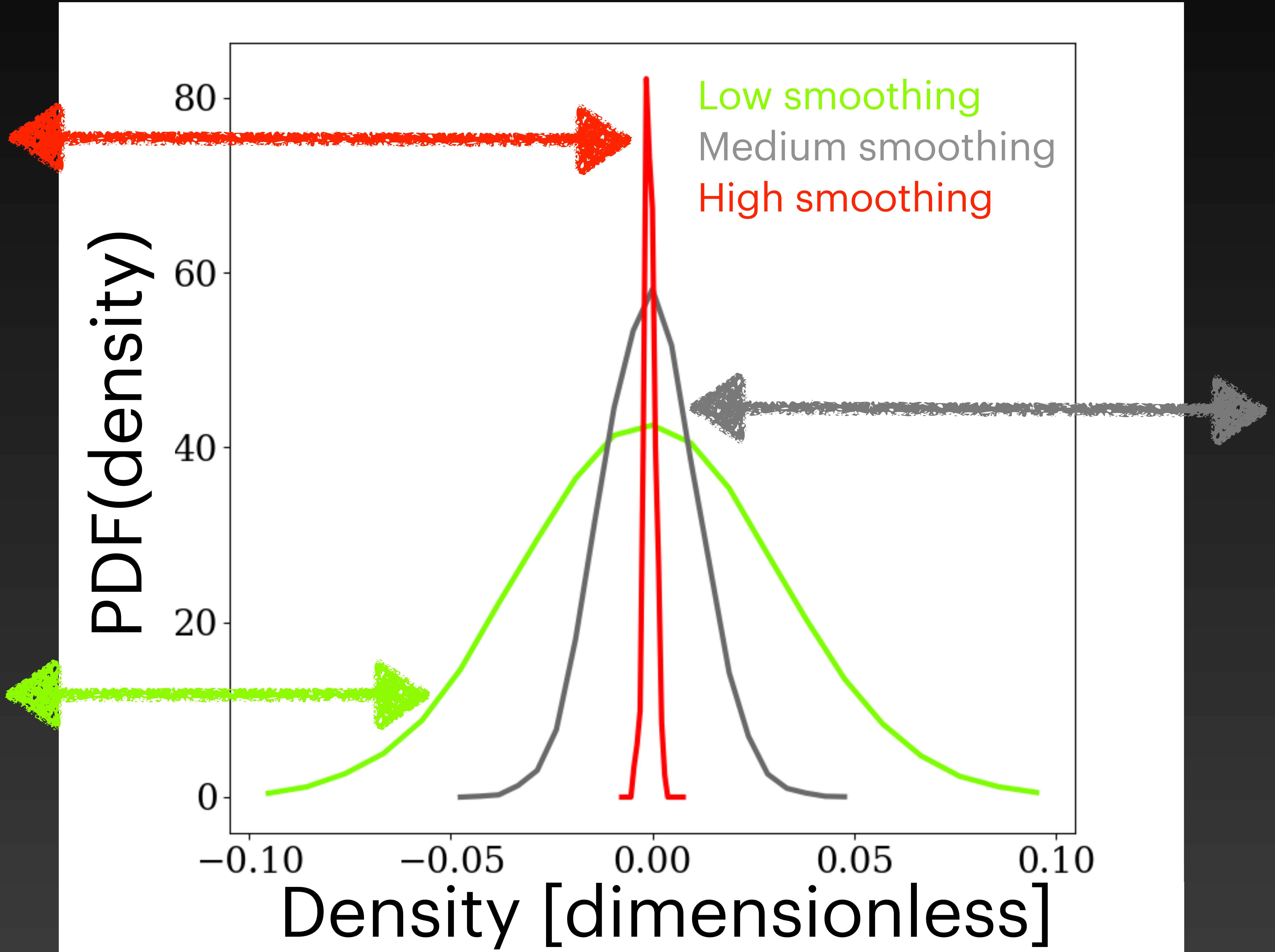


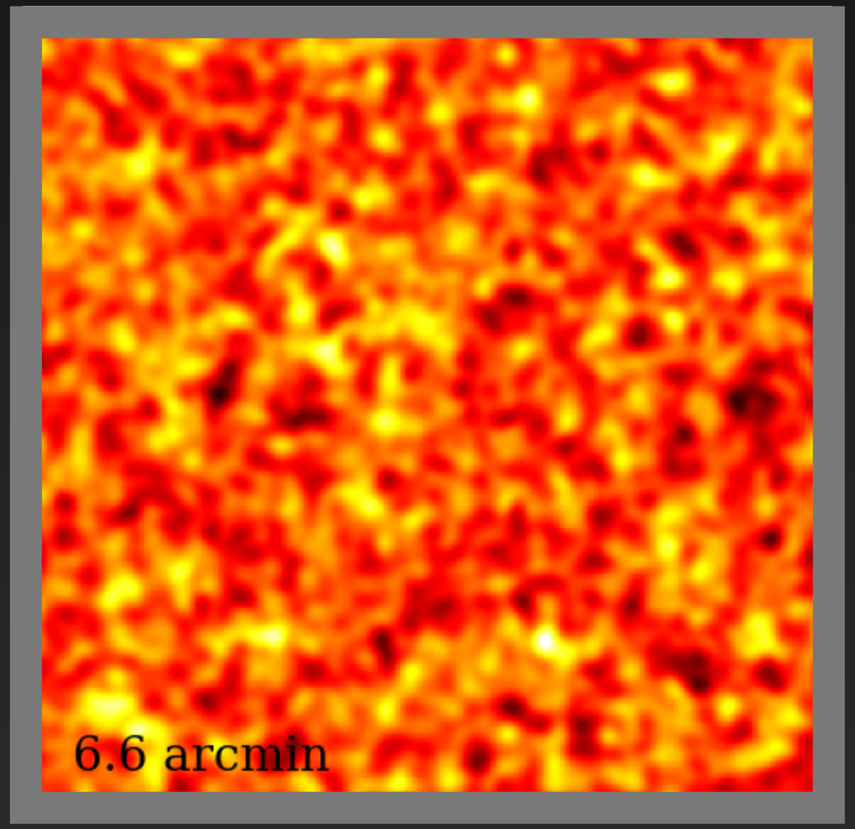
High smoothing

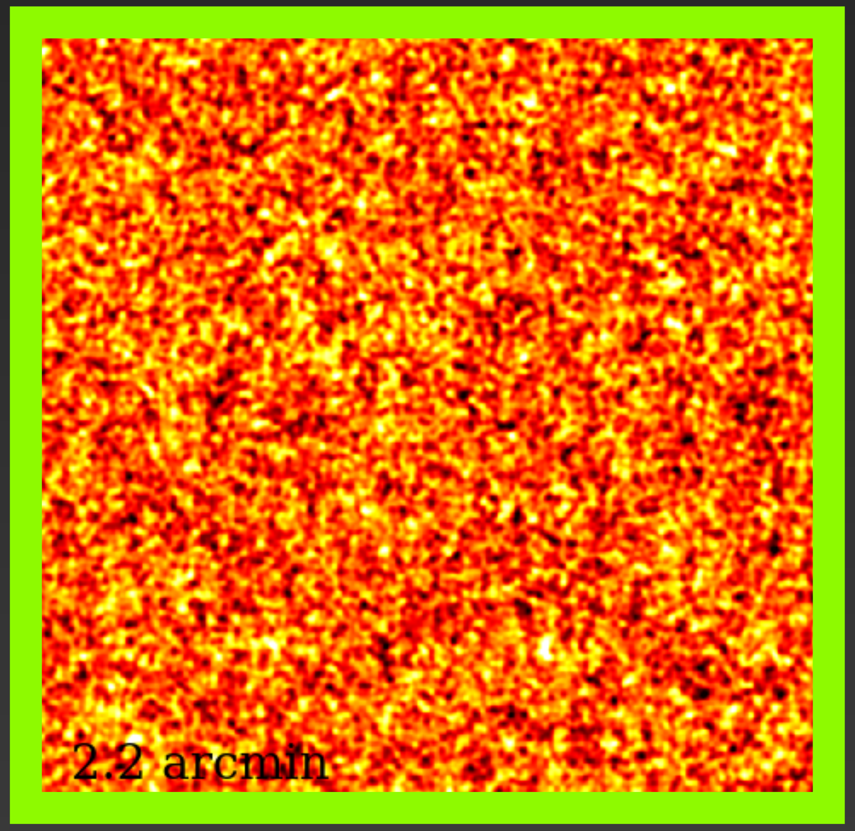
Constraining cosmology with the weak lensing density

"The lensing PDF"



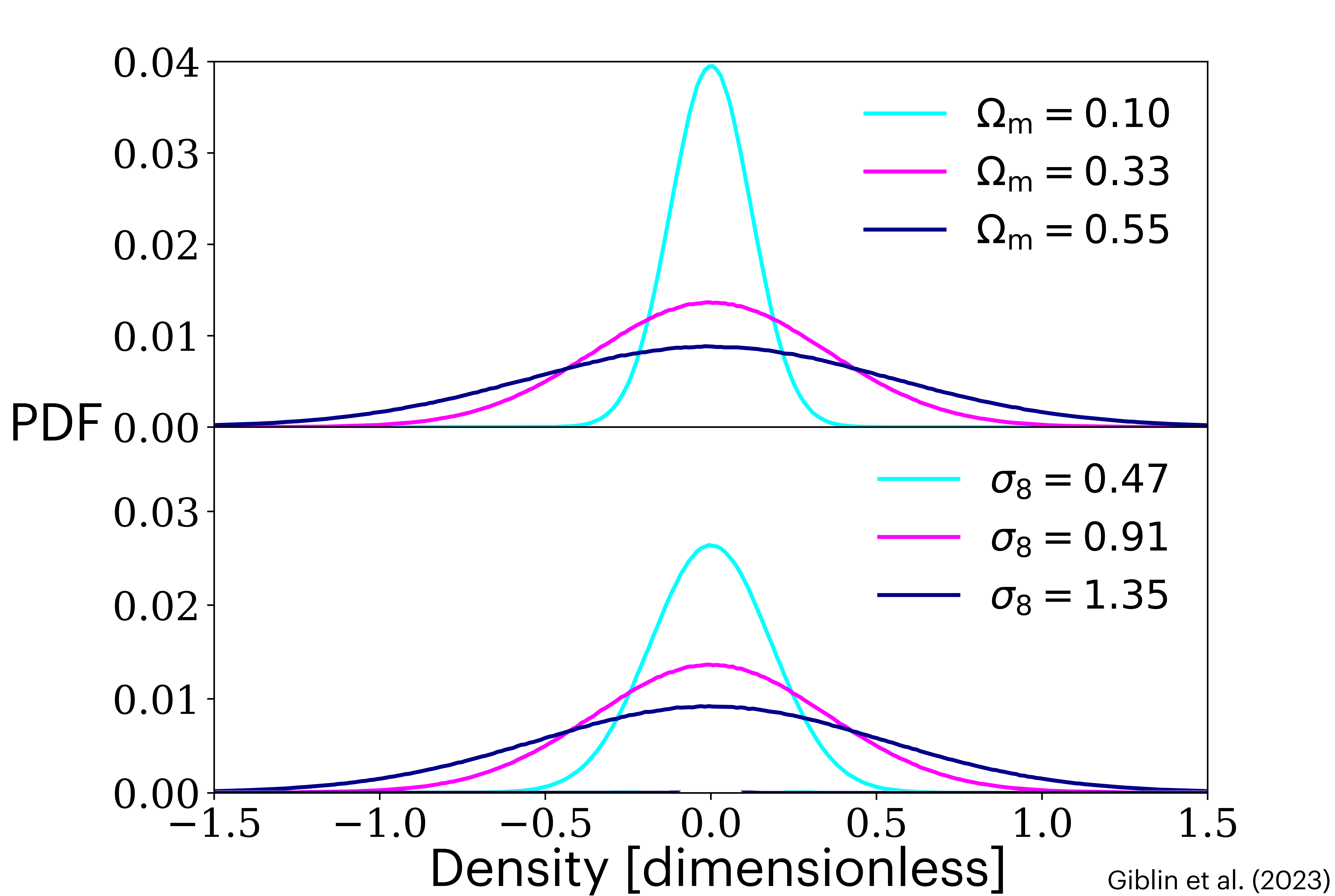






Beyond two-point statistics:

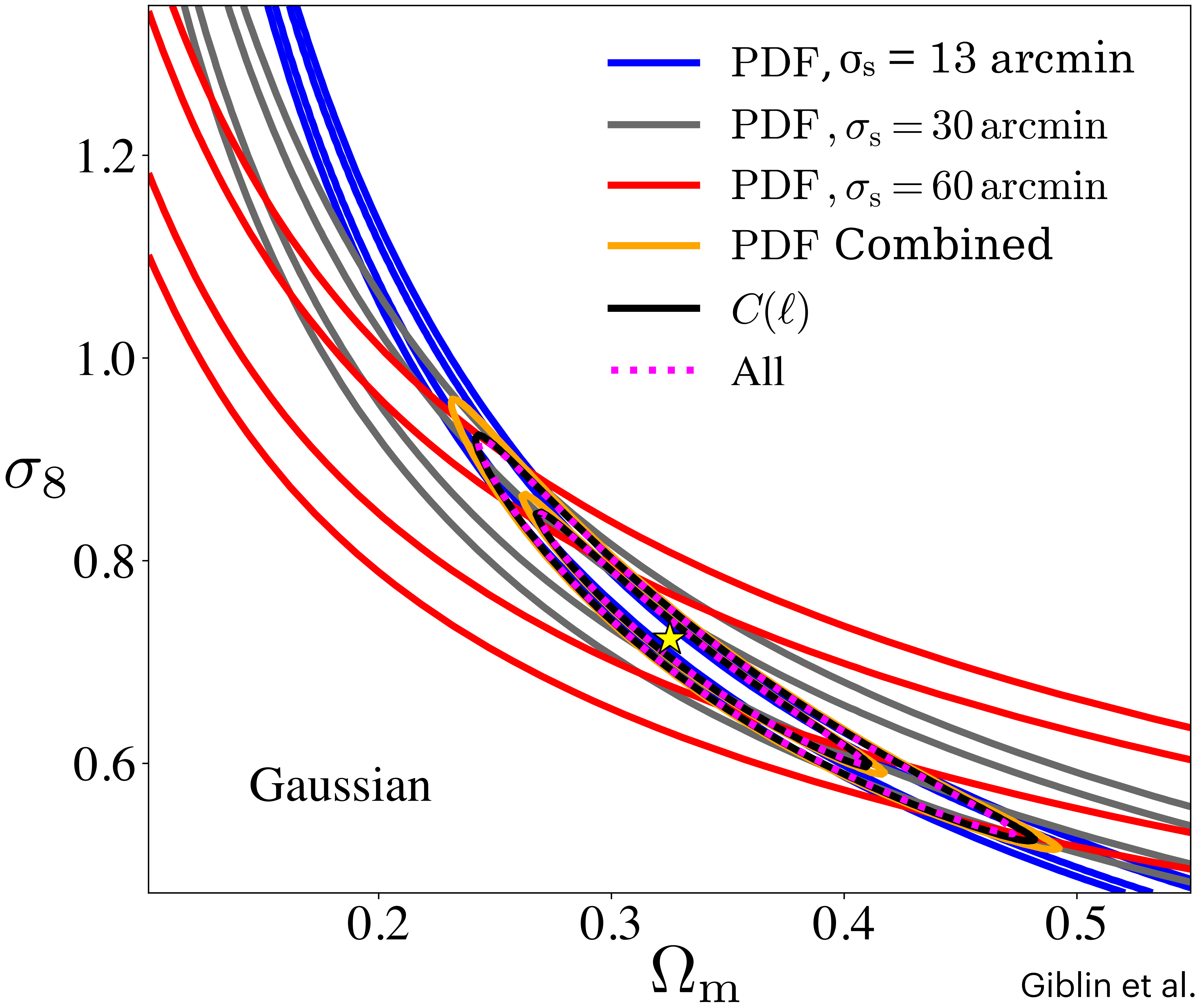
"The lensing PDF"



Giblin et al. (2023)

PDF vs 2pt Stats

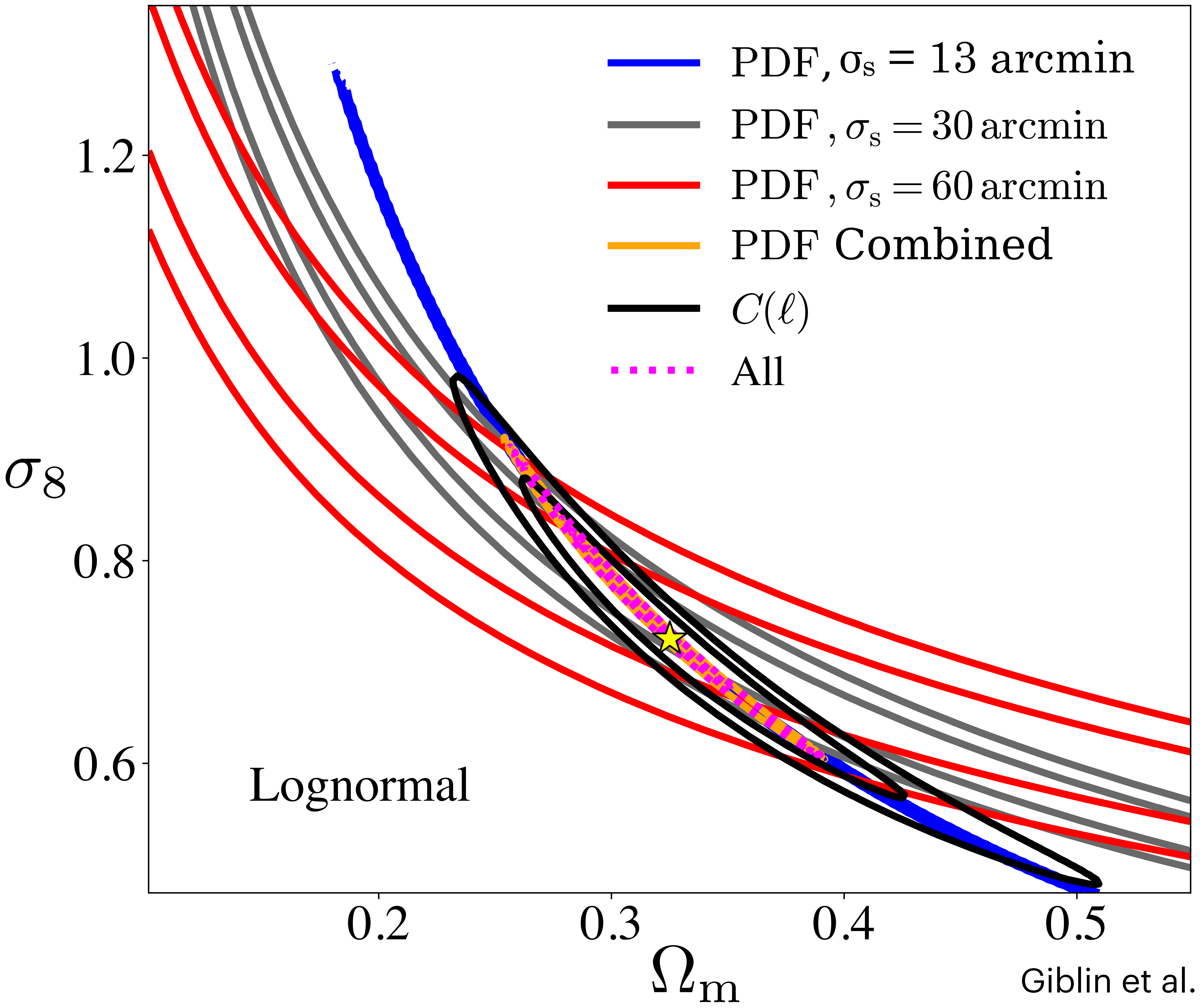
The sanity test: a Gaussian field



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?

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

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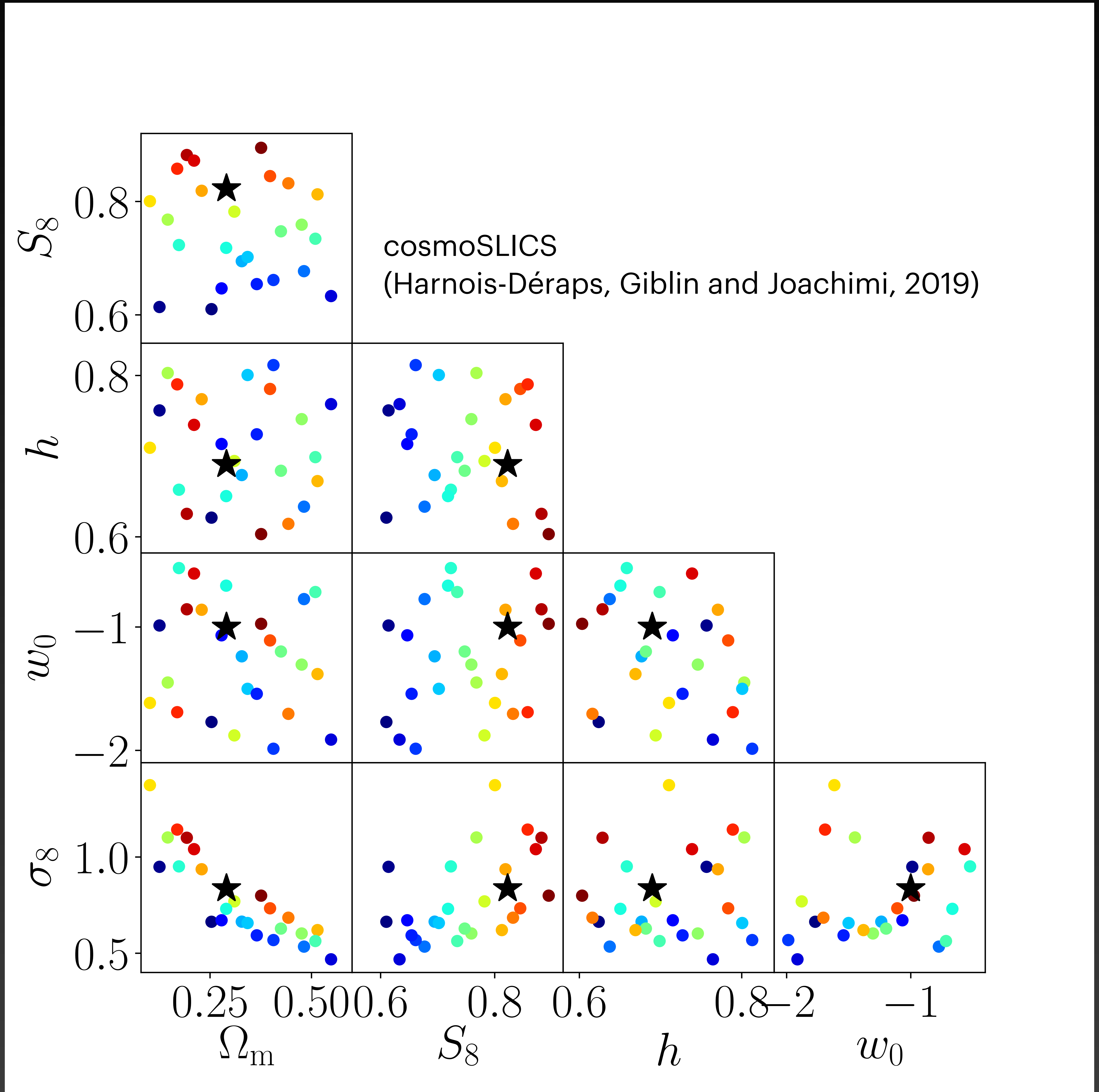
Require a model for our statistics as a function of cosmological parameters **π**

....with numerical simulations!



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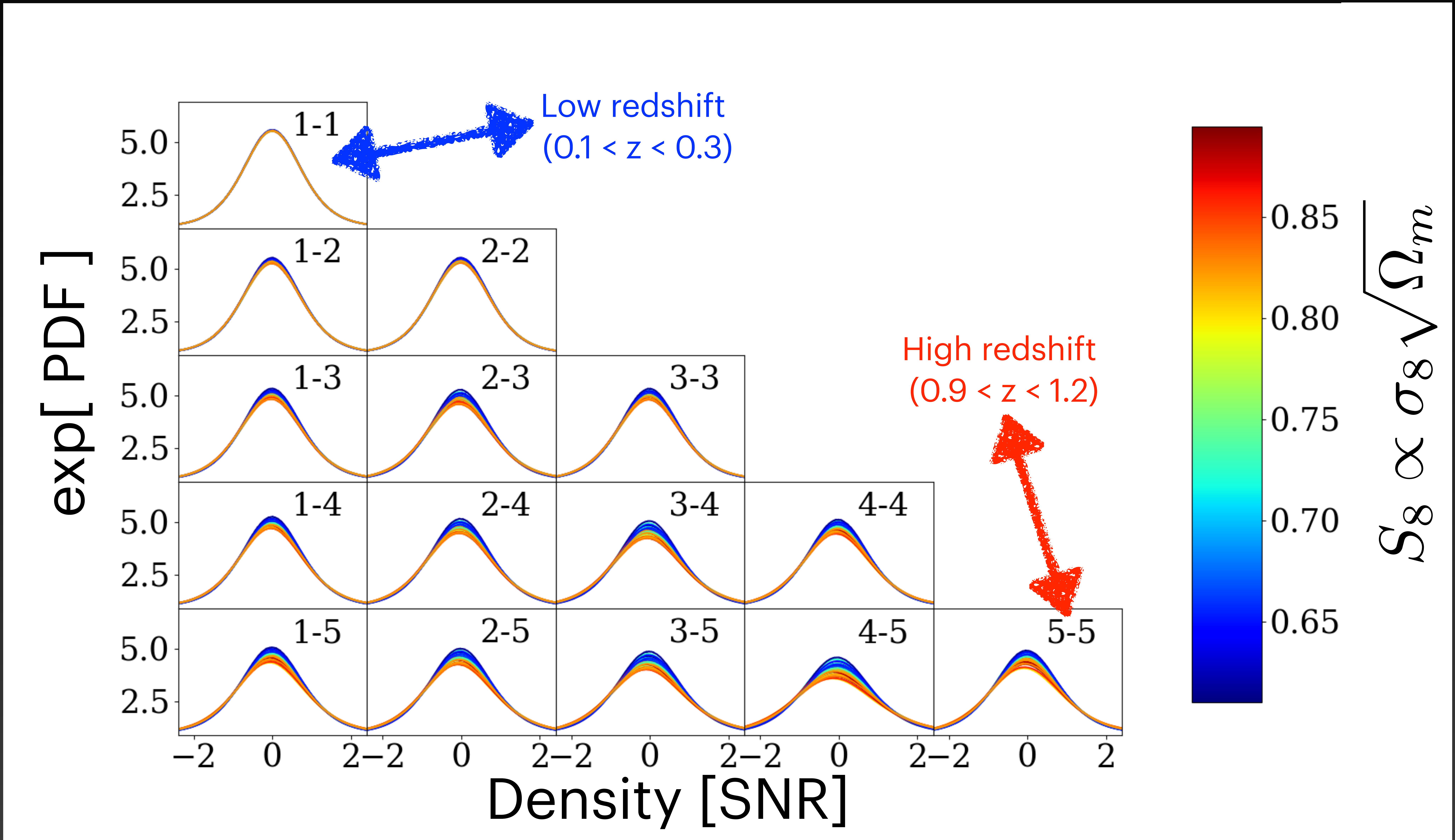
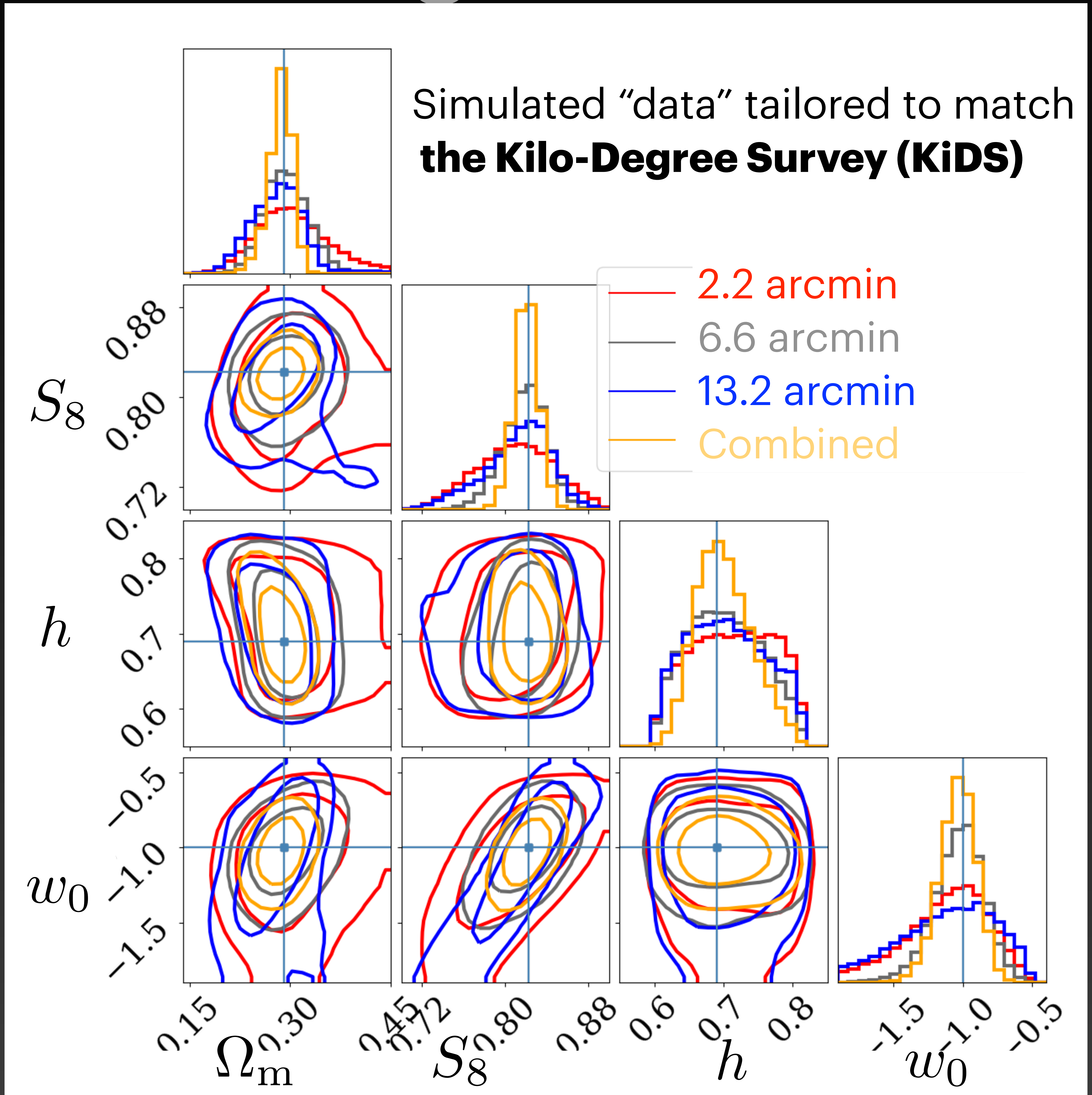
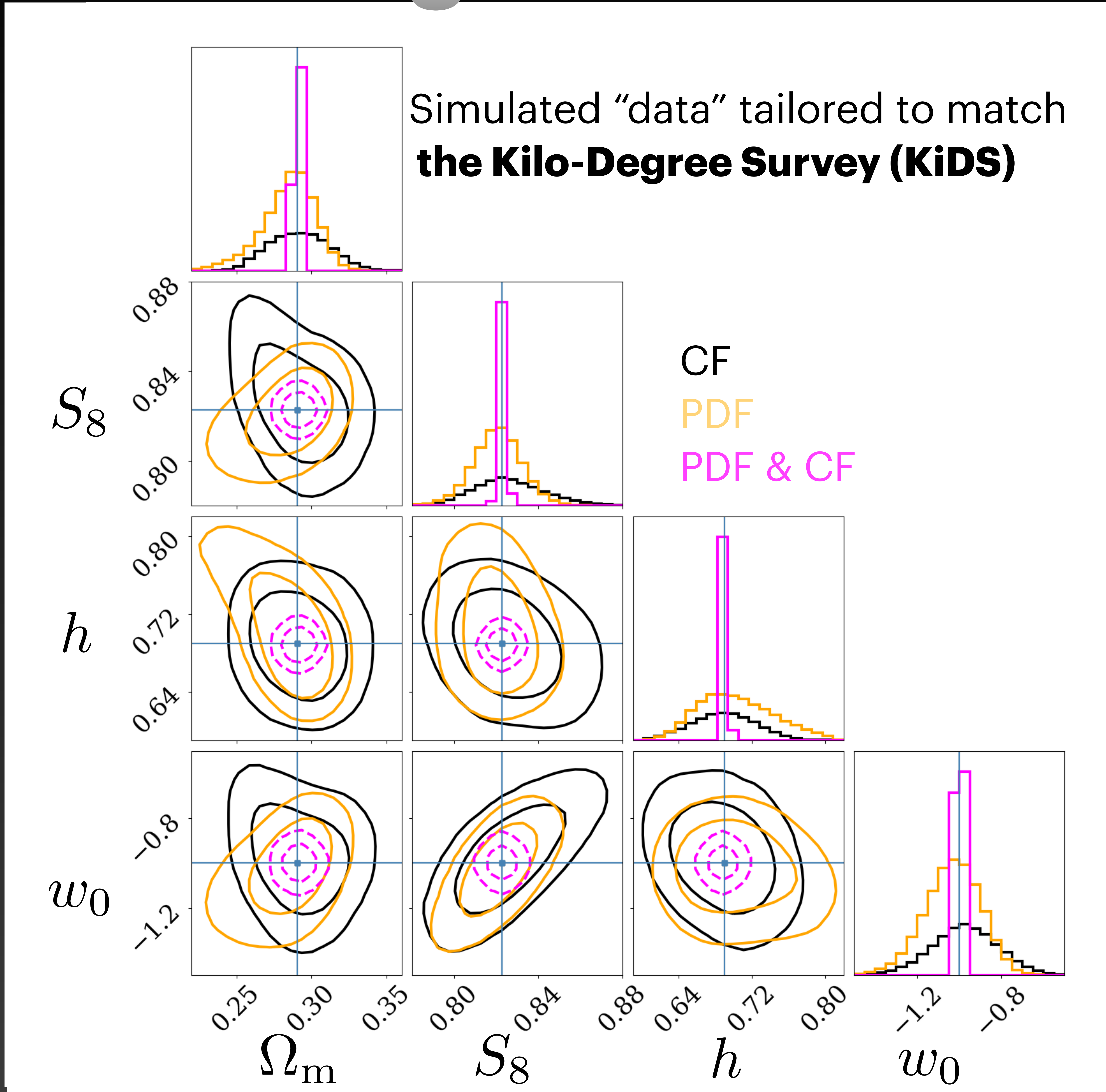


Cosmological constraints



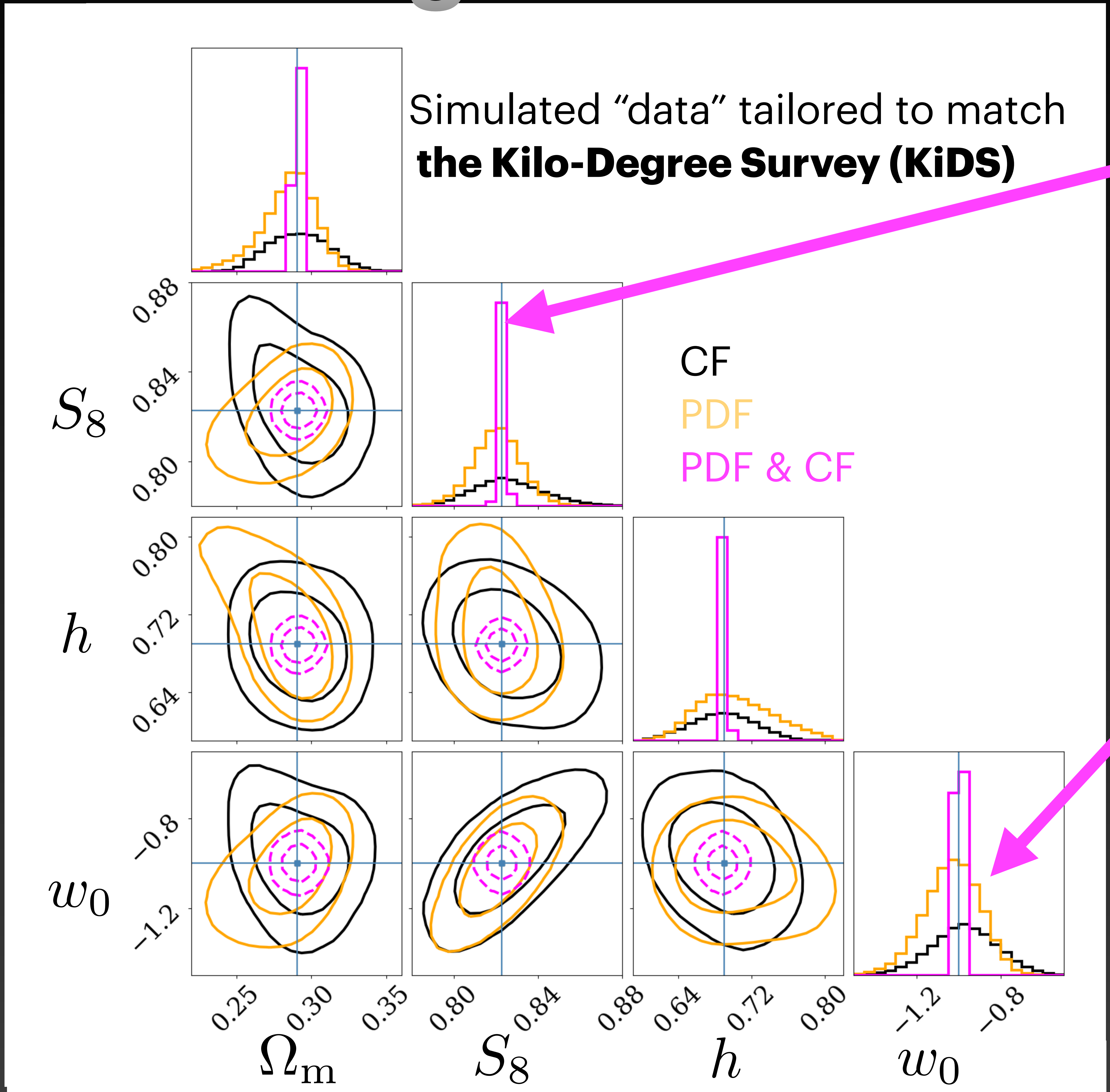
Giblin et al. (in 2023)

Cosmological constraints



Giblin et al. (in 2023)

Cosmological constraints

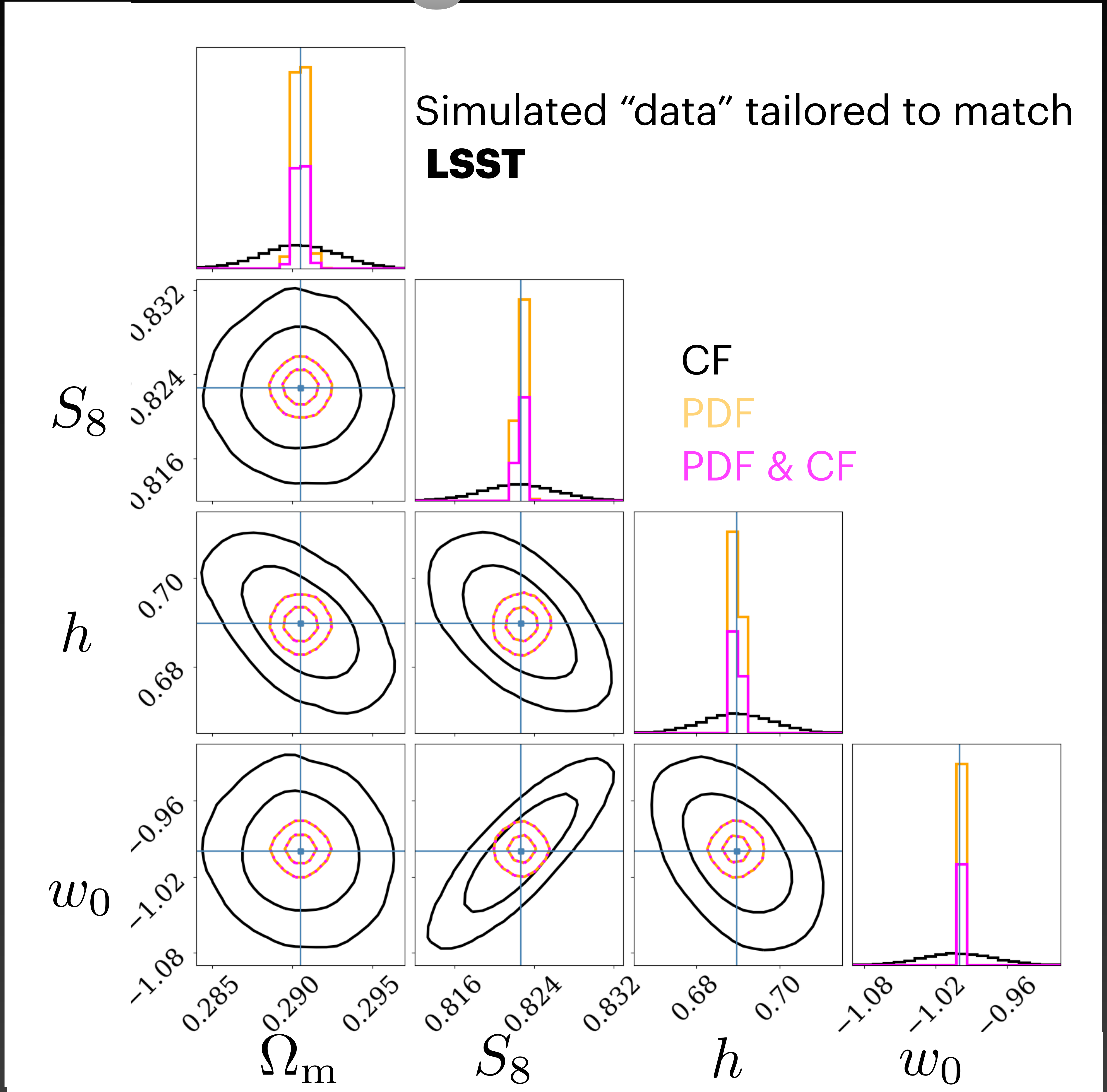


~50% improvement on S_8 constraint

~45% improvement for w_0

Giblin et al. (in 2023)

Cosmological constraints



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

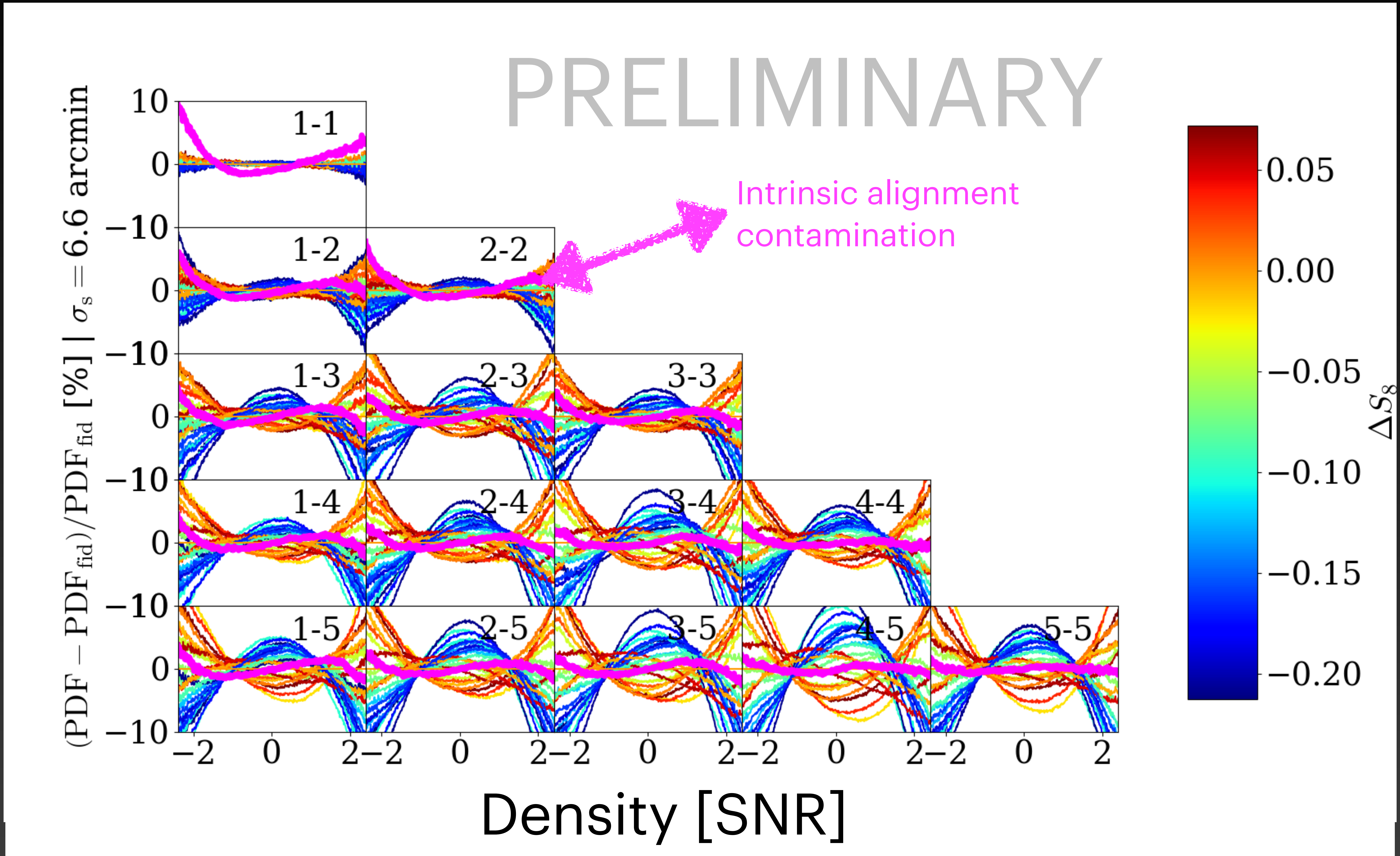
- There's information beyond 2nd order in our data!
- The lensing PDF is one way to get at it, by measuring the non-Gaussianity of the field directly.
- Measuring the lensing PDF on different scales is the key to optimising constraining power.
- For a Stage-III WL surveys, improvements over 2PCFs of ~30-50%.
- The future is bright! With LSST this approach really starts to shine (~90% improvements in cosmic shear).

(arXiv: 2211.05708)

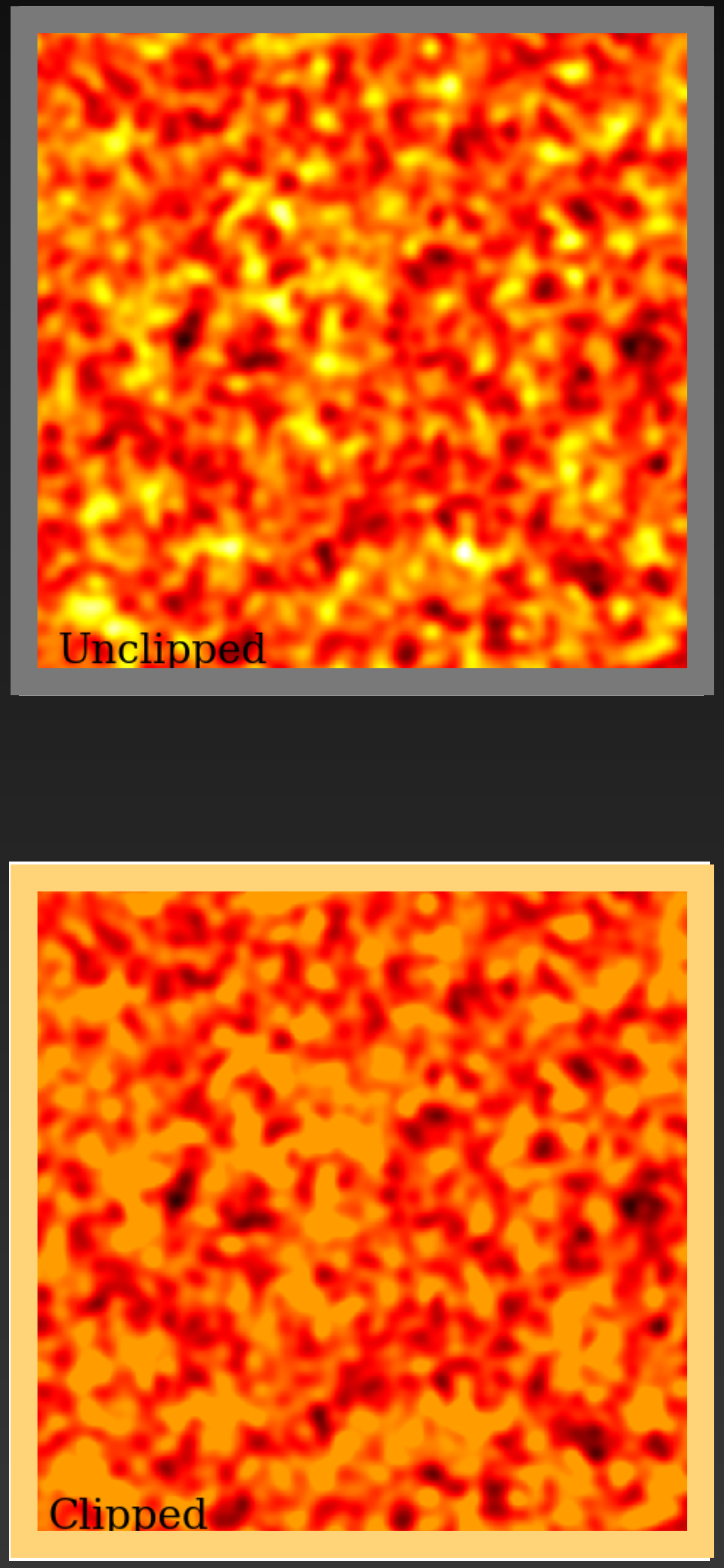
EXTRA SLIDES

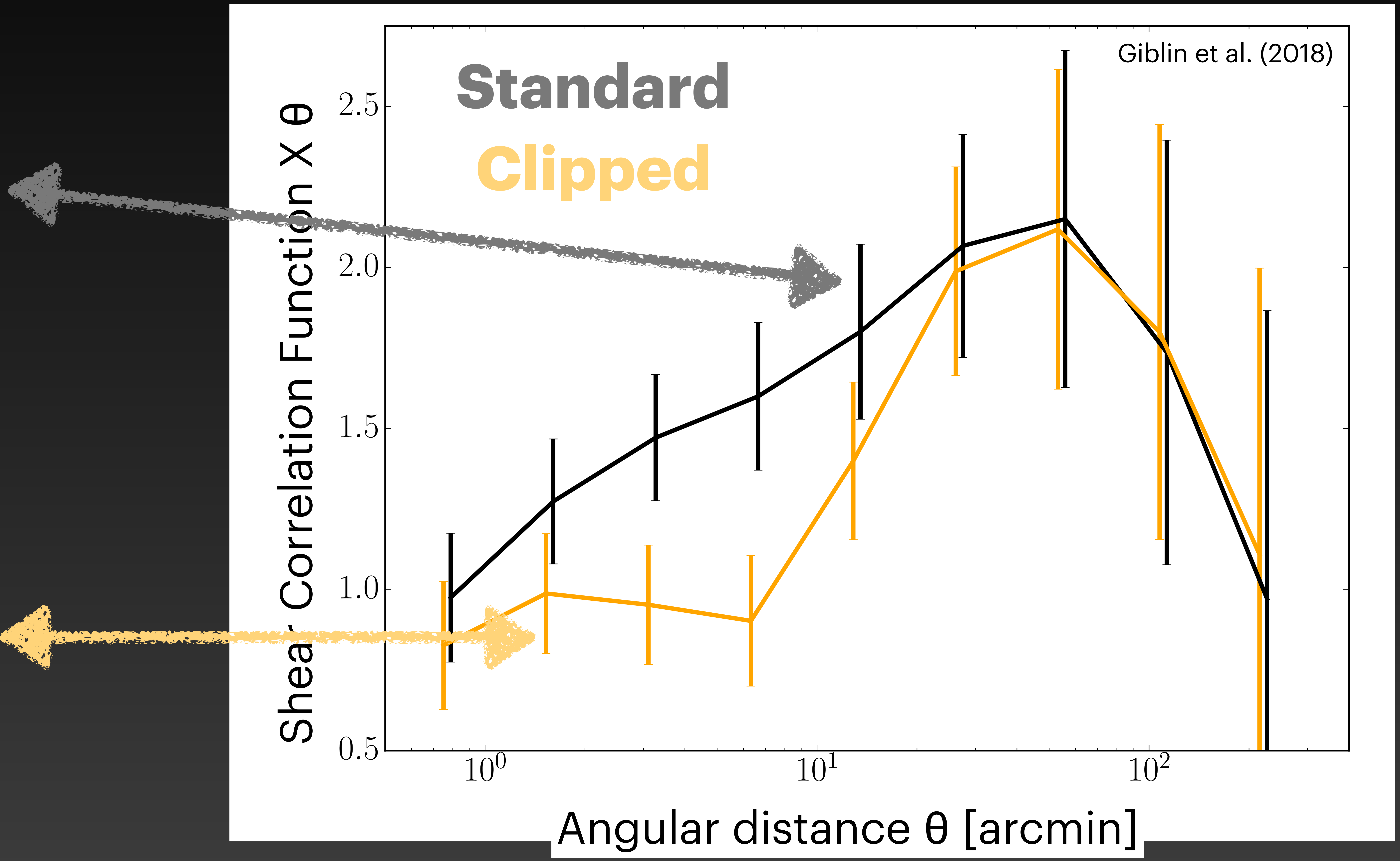
Q:
Is PDF cosmic shear worth it?

The impact of intrinsic alignments

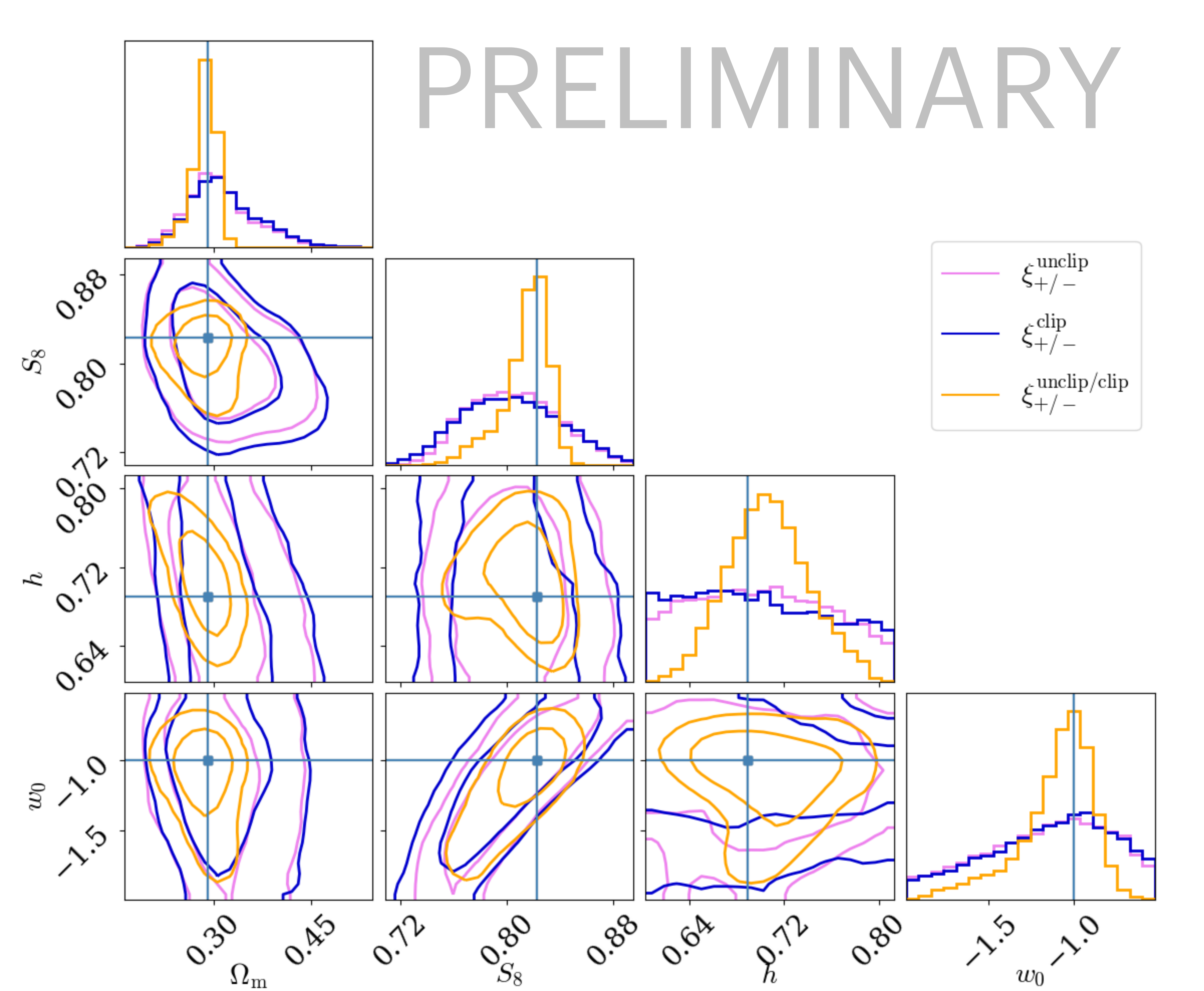


Aside: Clipped Lensing





Results: Clipped Lensing

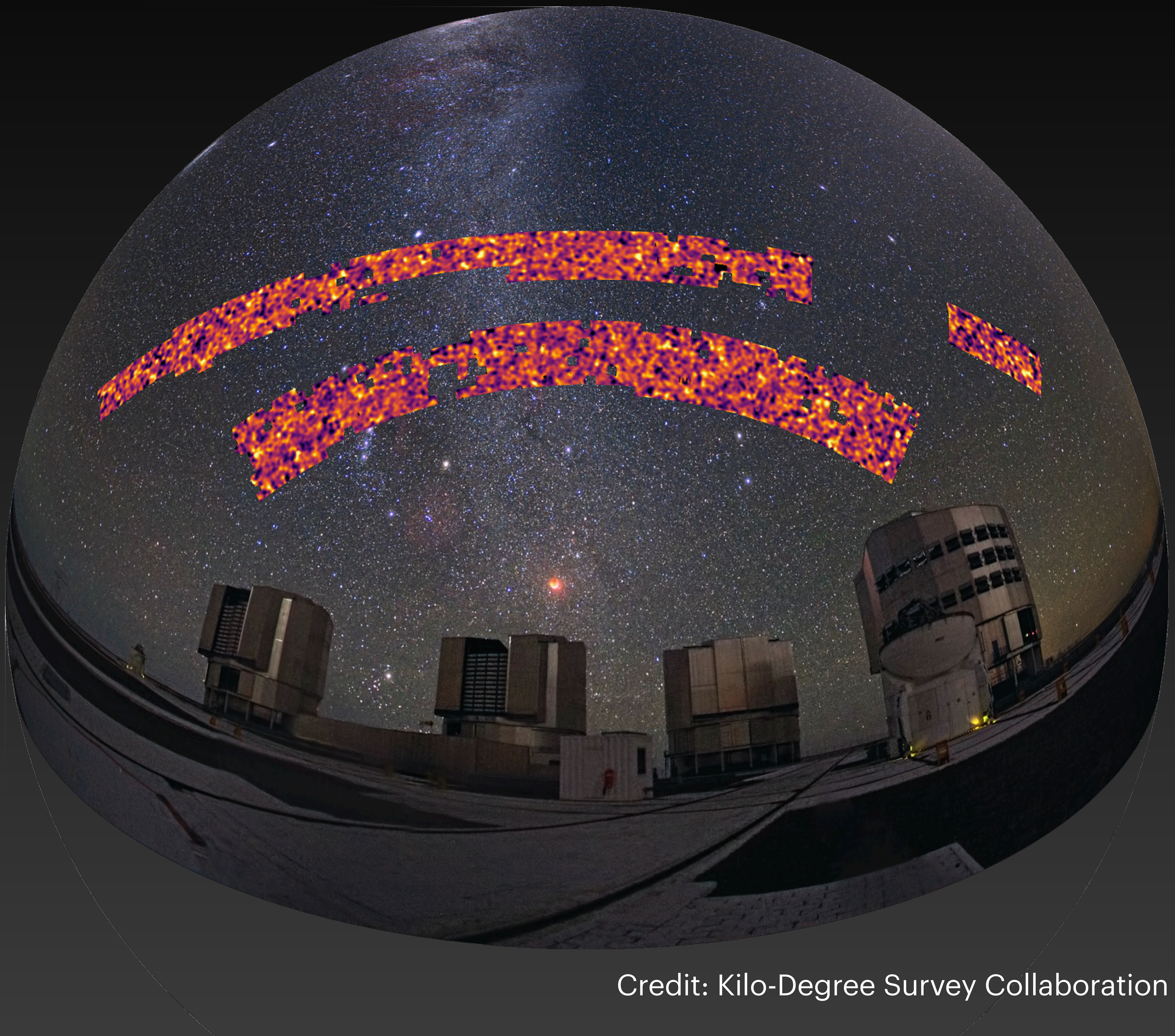


Credit: Louise Paquereau

Going beyond the standard shear correlation function

Alternative statistics:

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



Credit: Kilo-Degree Survey Collaboration

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

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)

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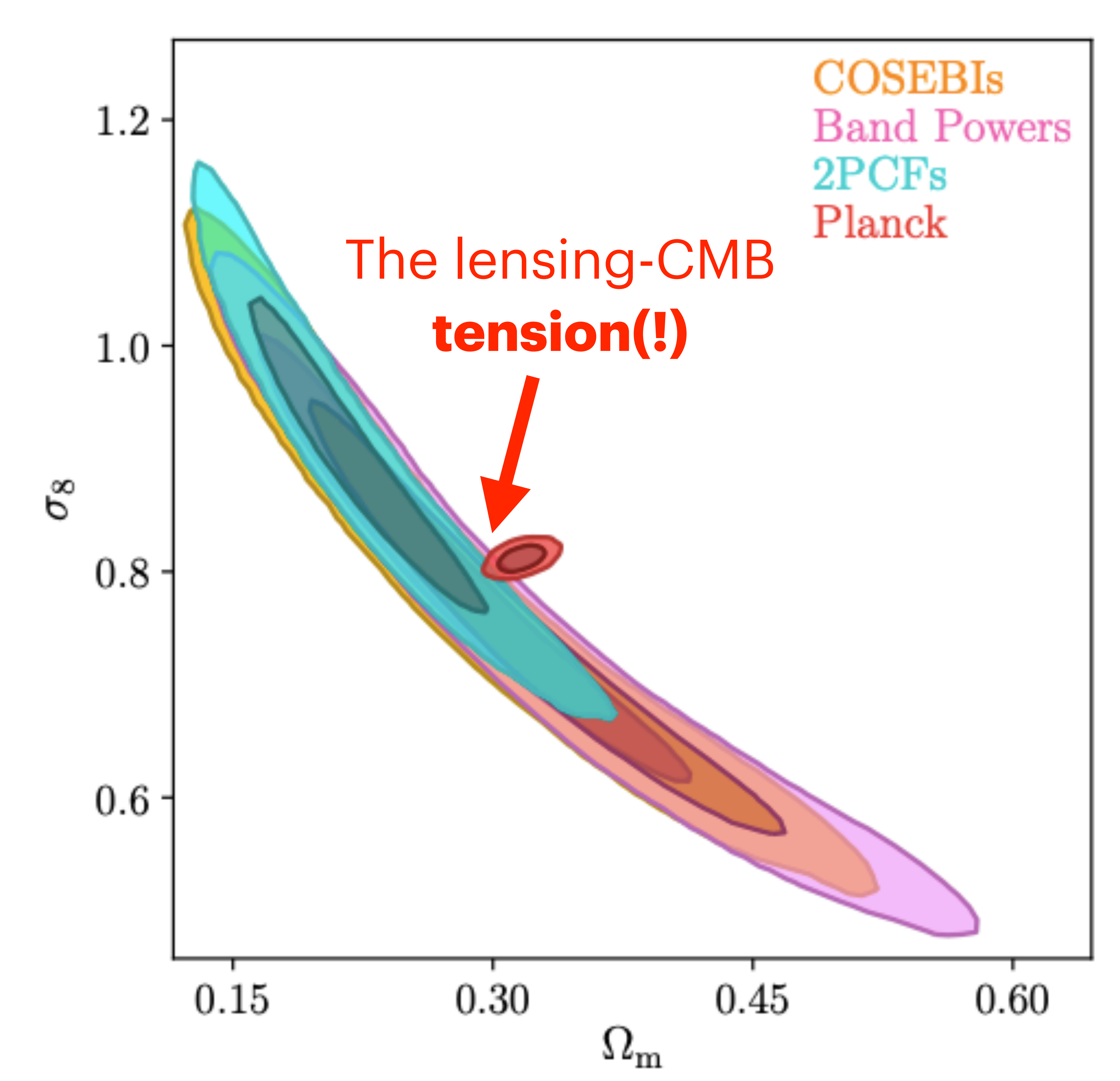
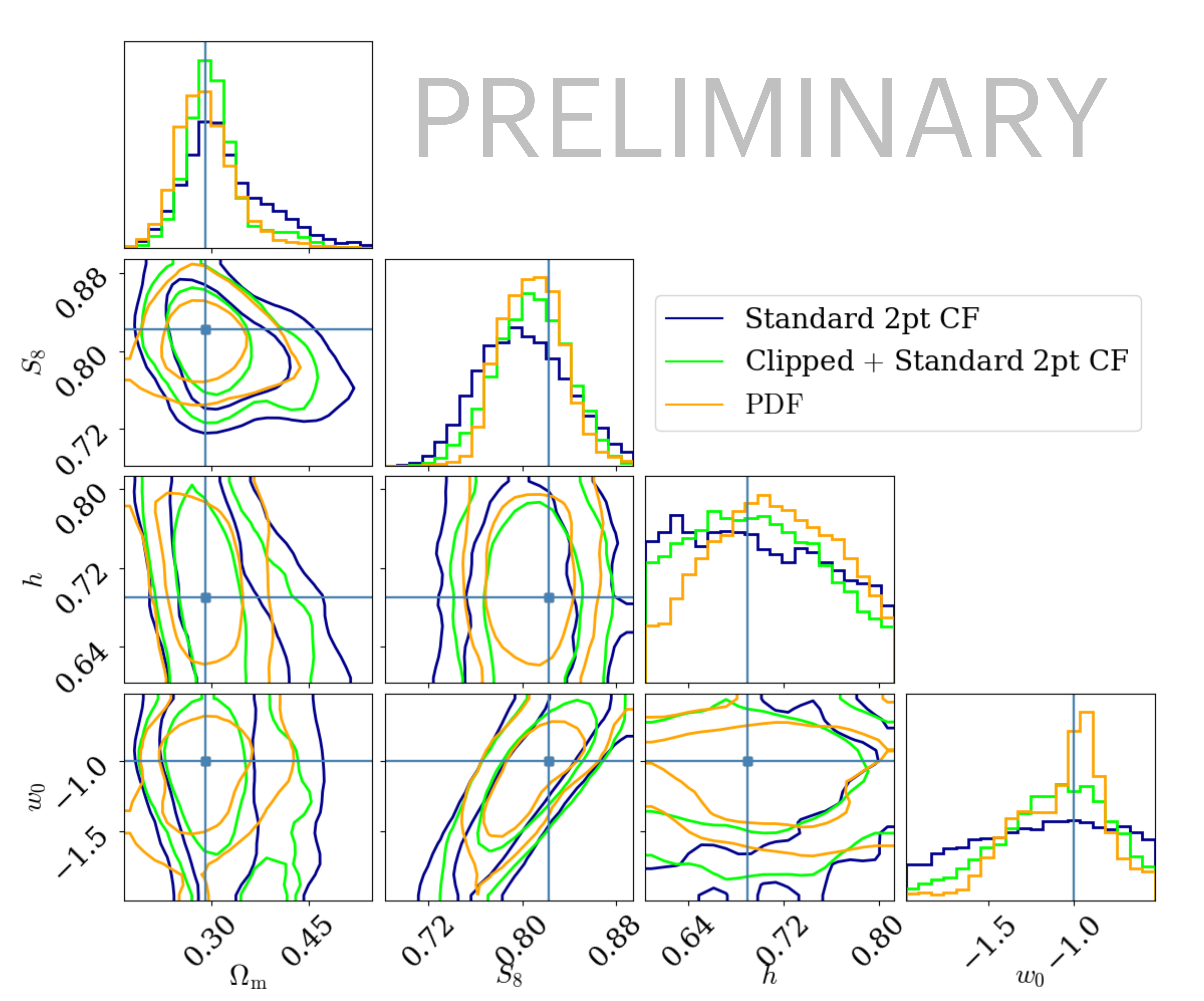


Asgari et al. (2020)

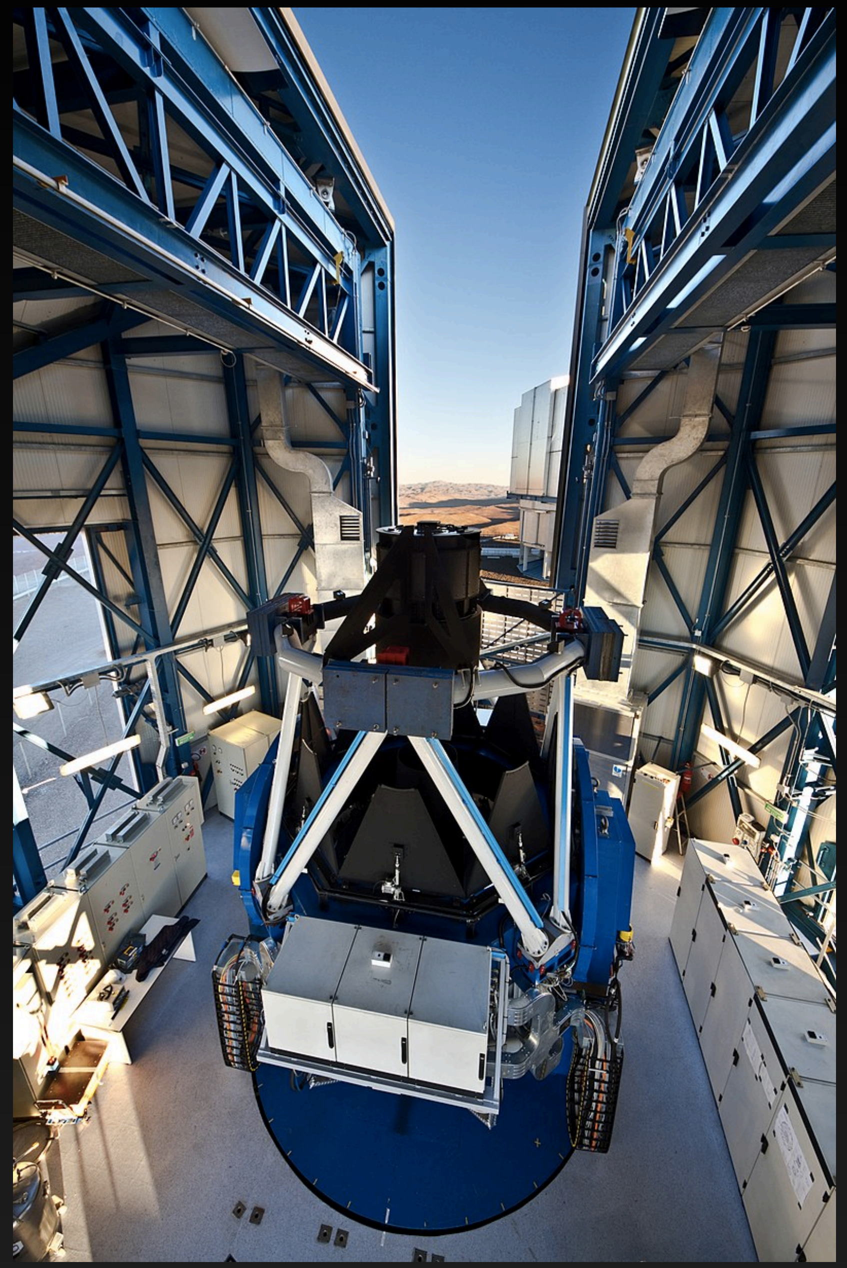
Results: Both

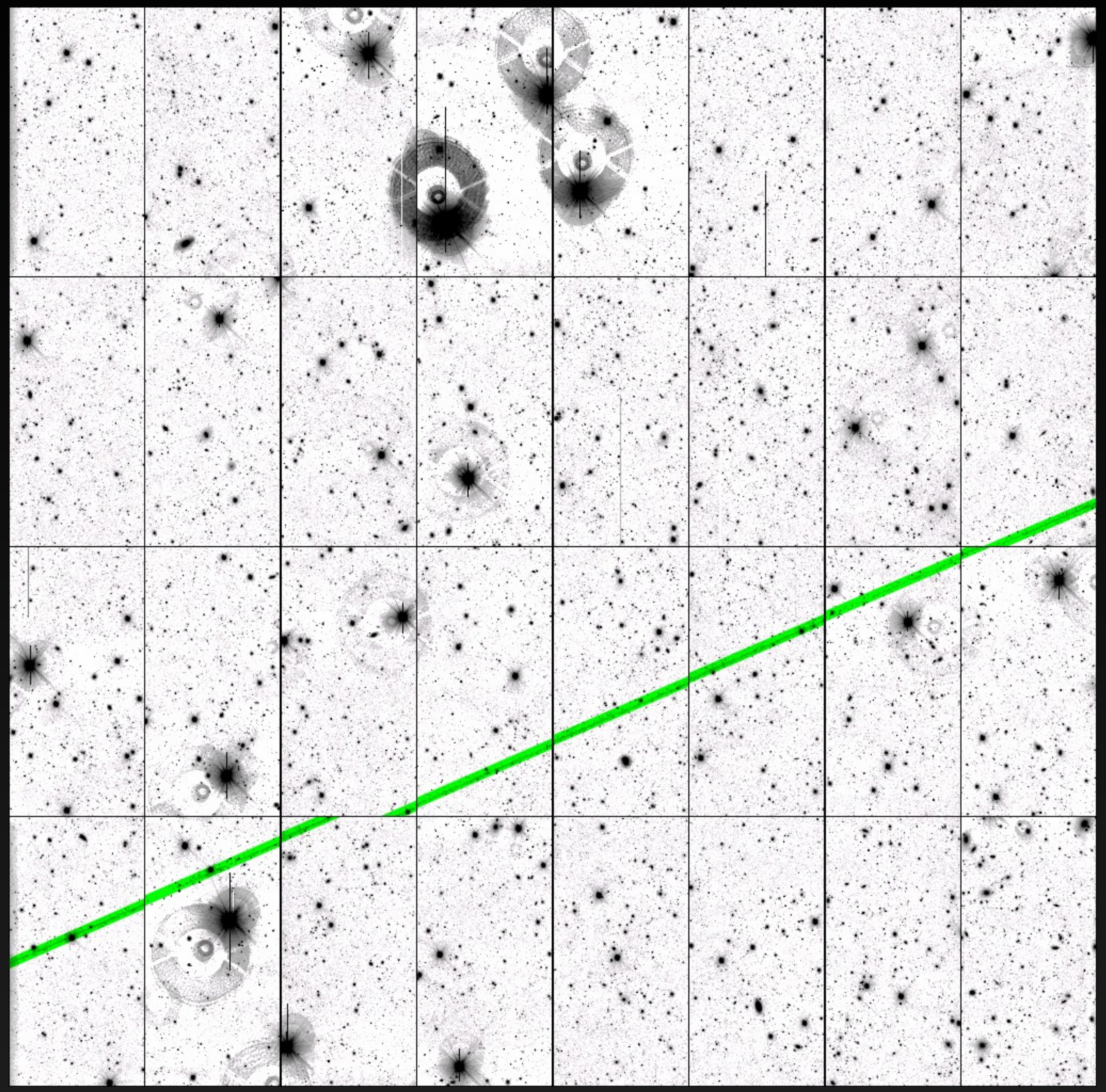


Giblin et al. (in prep.)

The Kilo-Degree Survey (KiDS)

Credit: KiDS Collaboration





KiDS-1000

- 1000deg² of sky coverage.
- Images collected at the VLT Survey Telescope (VST).
- 5 dithered exposures in 4 optical bands, *ugri*, each 1deg² 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

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

Galaxy ellipticities measured in your data

The theoretical prediction you compare to

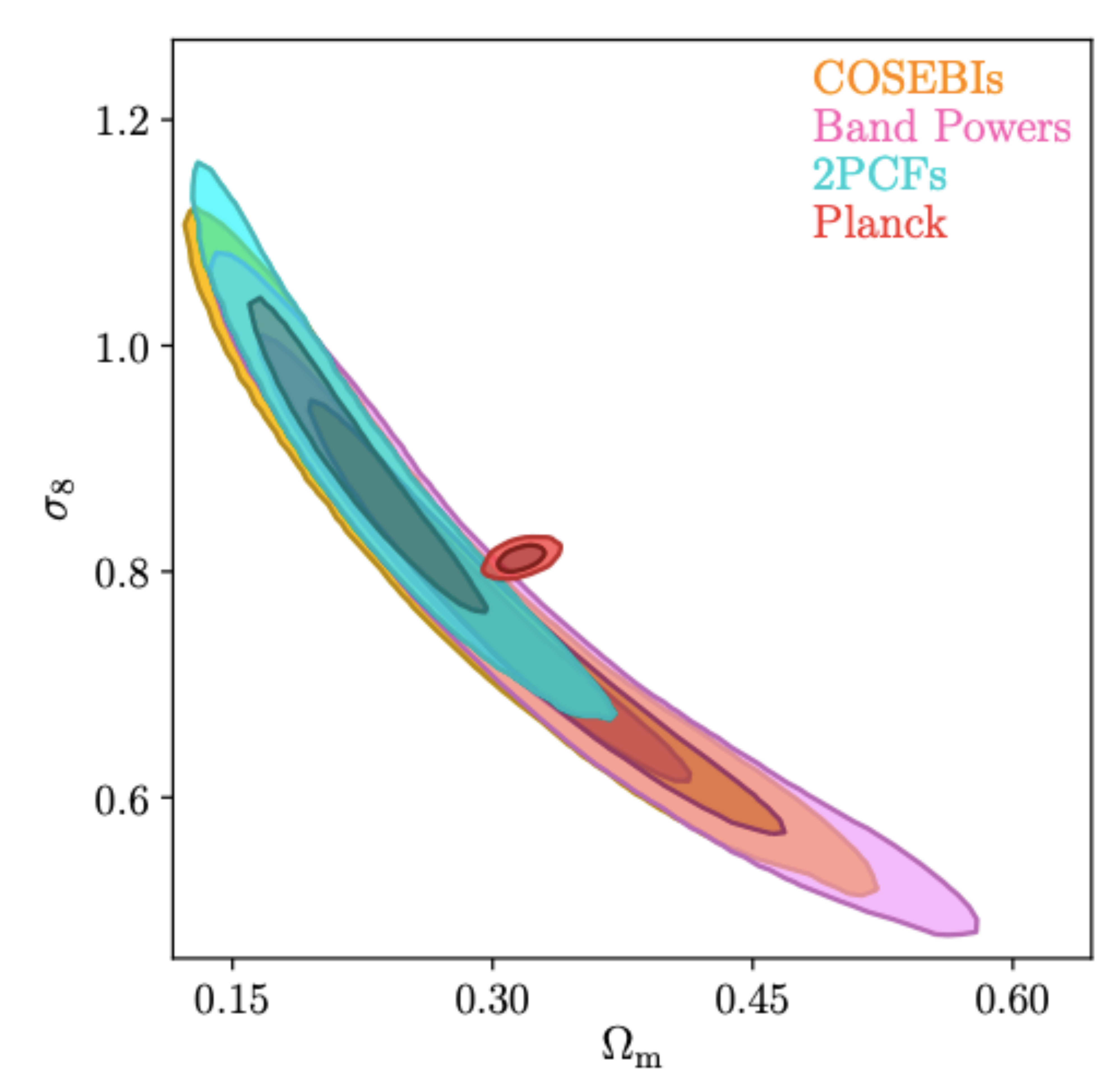
$$\xi_{\pm}^{ij}(\theta) = \frac{1}{2\pi}\int \mathrm{d}\ell\, \ell\, P_{\kappa}^{ij}(\ell)\, J_{0,4}(\ell\theta)\,,$$

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

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

$$q_i(\chi) = \frac{3H_0^2\Omega_{\rm m}}{2c^2}\frac{f_K(\chi)}{a(\chi)}\int_\chi^{\chi_{\rm H}} \mathrm{d}\chi'\, n_i(\chi')\frac{f_K(\chi'-\chi)}{f_K(\chi')},$$

Redshift distribution of the lensed galaxies



Asgari et al. (2020)