NORDITA
The Nordic Institute for Theoretical Physics

Illuminating the Dark Universe:
Precision cosmology from weak lensing and galaxy clustering

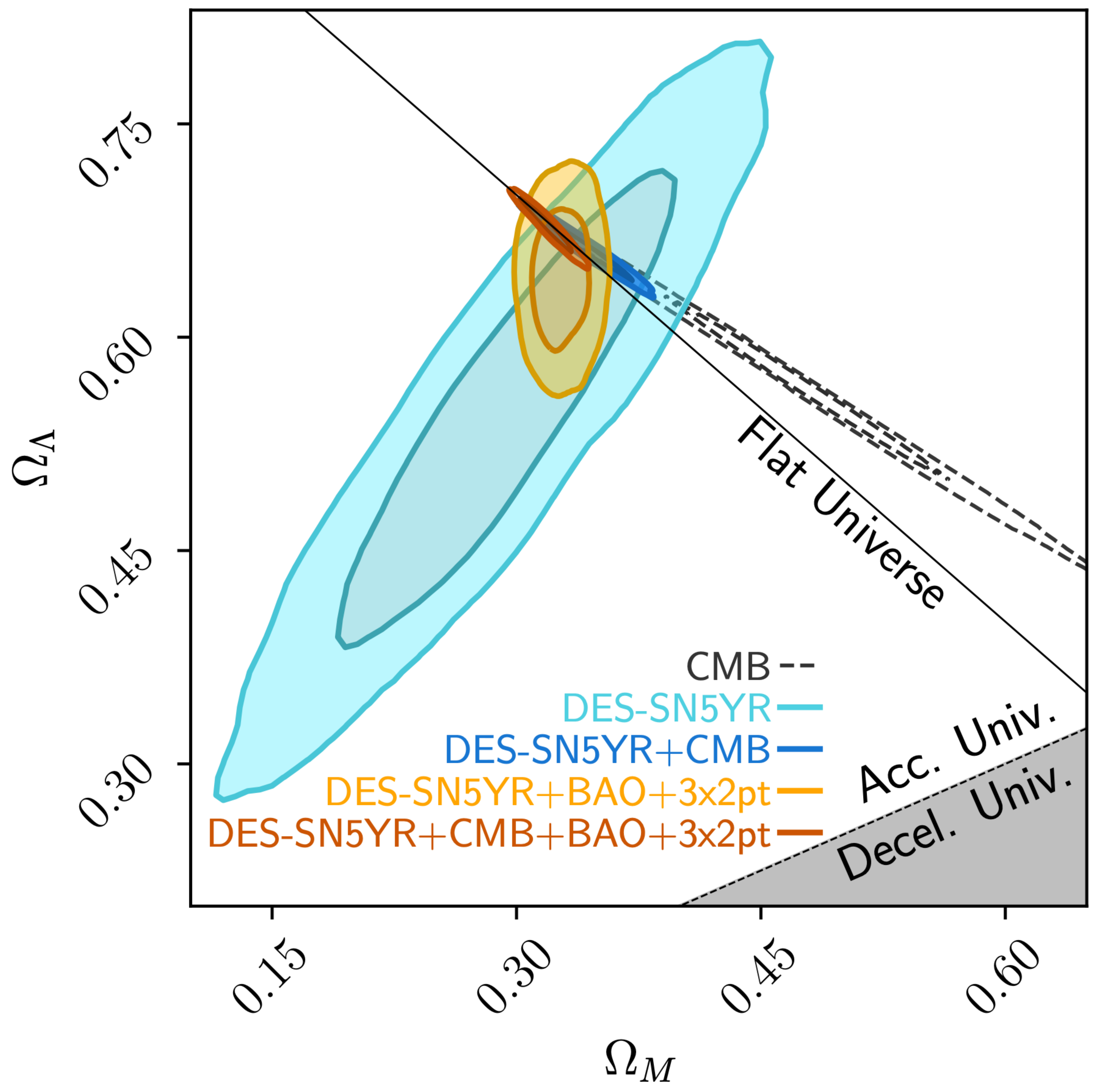
Judit Prat Marti
Nordita fellow at Stockholm University and KTH. March 2025.
Seminar at University of Iceland.

A flat and accelerating Universe

- We have known for some time that the Universe is pretty flat from the combination of CMB, SN Type Ia & Large-Scale Structure measurements.

- Supernovae measurements discovered the acceleration of the expansion Universe three decades ago —> There is a missing piece in our understanding driving this accelerated expansion, usually referred to as dark energy.

DES Collaboration: arXiv 2401.02929

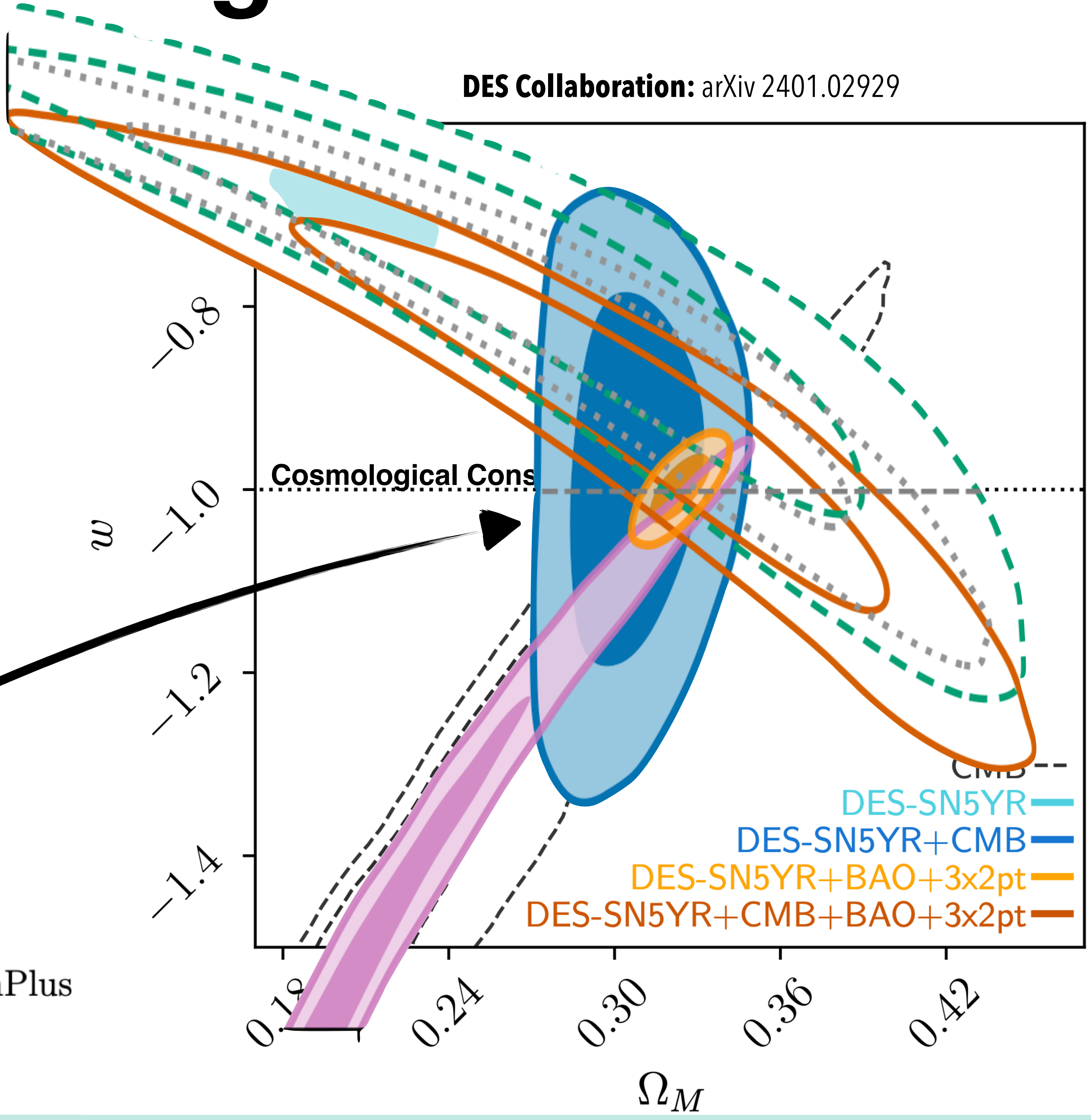


Is Dark Energy a cosmological constant?

- Dark Energy seems to be compatible with a **cosmological constant** with the most recent observations —> w, the parameter describing the evolution of dark energy with time is compatible with -1 given the current uncertainties.

$$w \equiv \frac{P}{\rho}$$

DES Collaboration: arXiv 2401.02929



DESI Collaboration: arXiv: 2404.03002

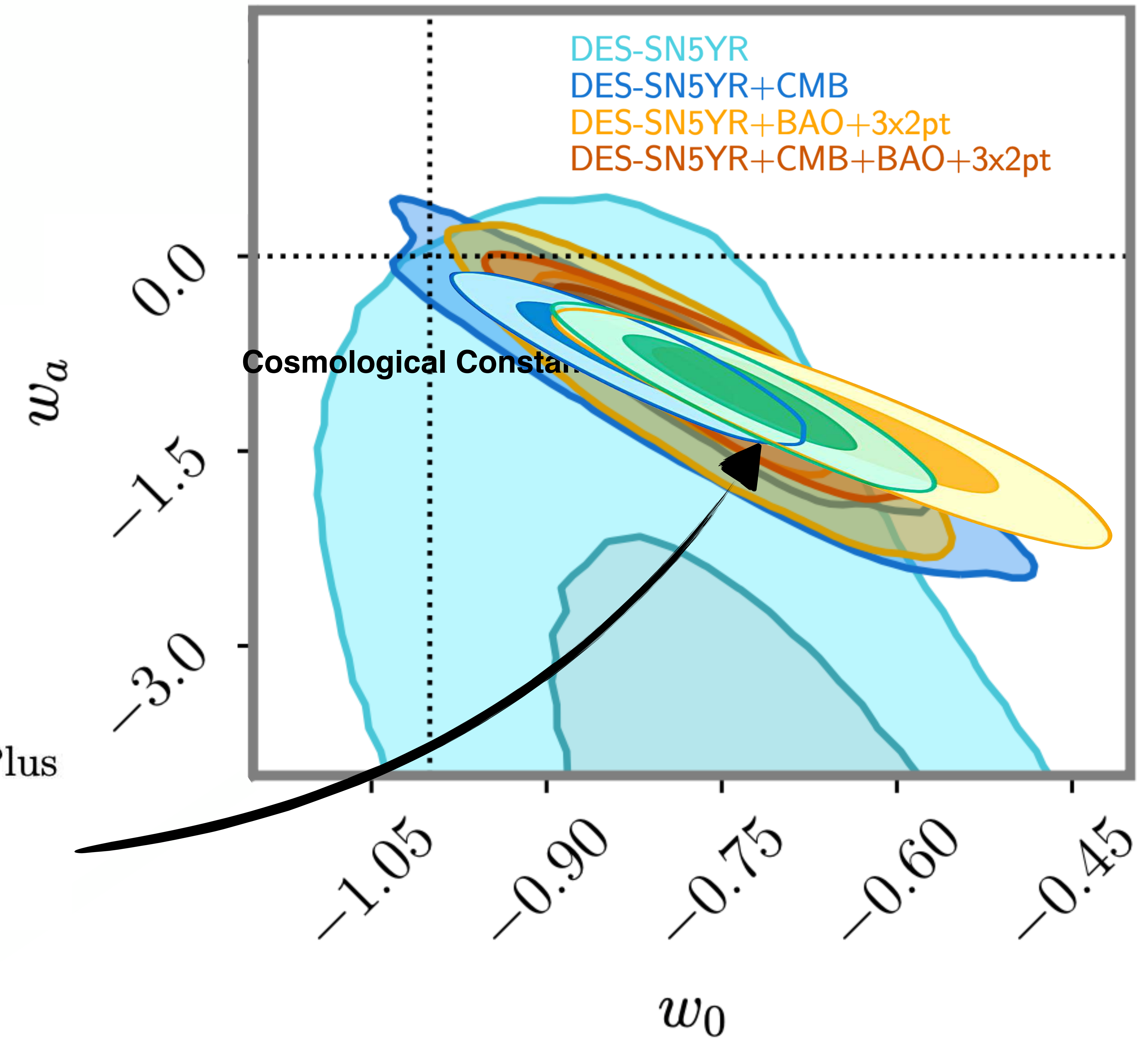
Is Dark Energy a cosmological constant?

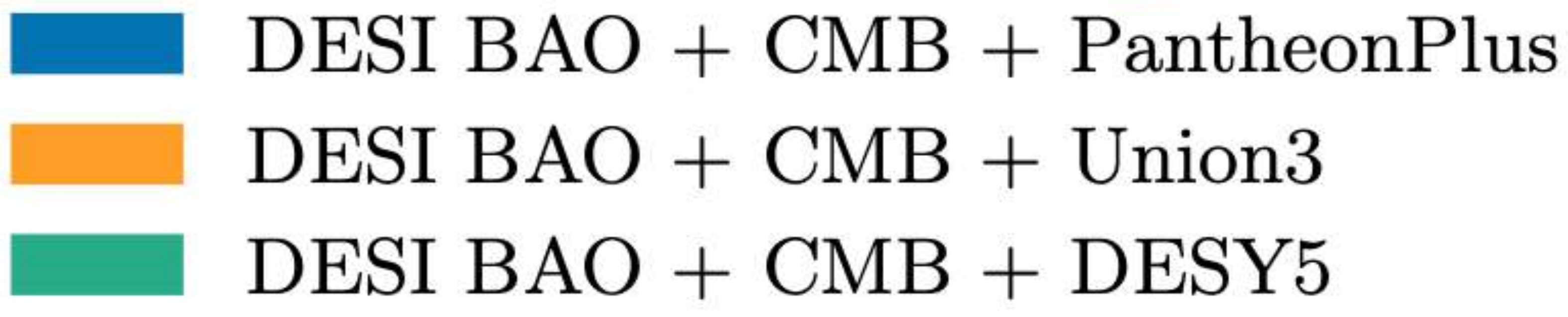
- In w_0w_aCDM model there are hints of evolving dark energy at the ~2σ level.

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

- When including DESI BAO, significance is at 2.5-3.9σ level, depending on the supernovae sample.

DES Collaboration: arXiv 2401.02929





DESI Collaboration: arXiv: 2404.03002


Where does that leave us?

The Standard Cosmological model is still standing: ΛCDM

Flat Universe with Dark Energy in the form of a cosmological constant Λ + Cold Dark Matter, assuming general Relativity.

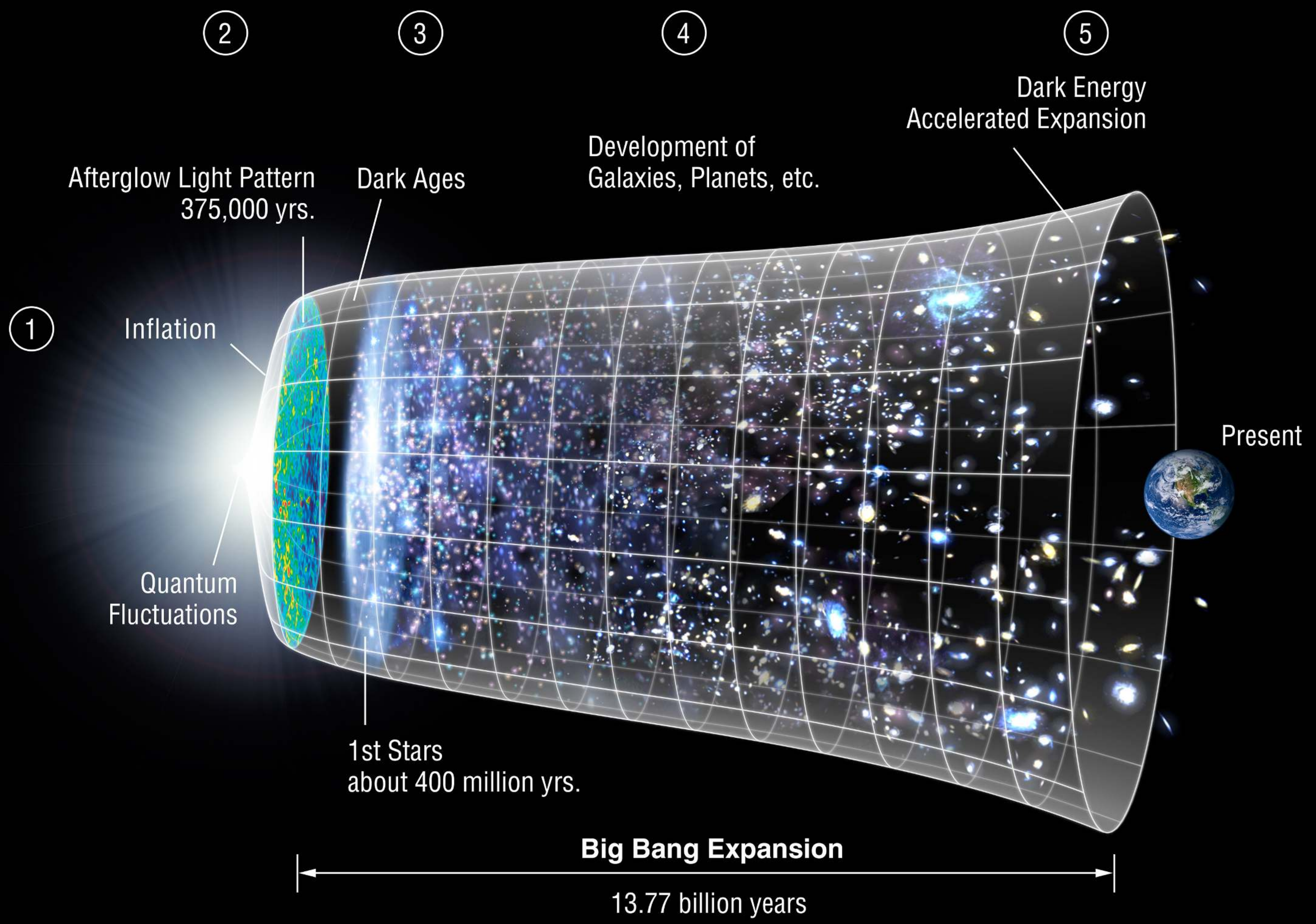


Image Credit: NASA / LAMBDA Archive / WMAP Science Team

However there are a few open questions

ΛCDM model under discussion

ΛCDM adds **2 new components** to the Standard Model of physics, neither of which have been observed in a laboratory.

The cosmological constant interpreted as the vacuum energy is ~**120 orders of magnitude lower** than the naive prediction coming from particle physics.

Is **dark energy evolving with time?**

Dark Energy or modified gravity?

Some paths forward

ΛCDM model under discussion

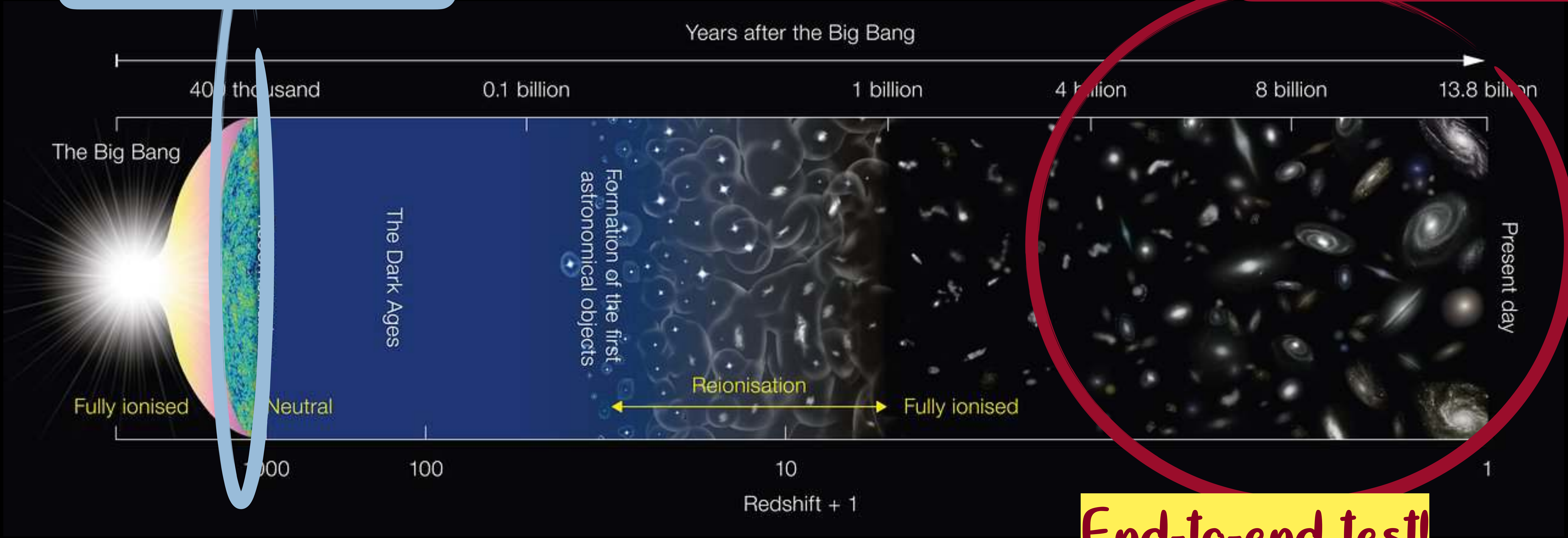
- Stress-testing ΛCDM.
- Testing if extensions of ΛCDM are preferred. Model comparison.

Stress-testing ΛCDM

Is the late time Universe compatible with the ΛCDM prediction assuming initial conditions from the CMB?

CMB experiments observe the early Universe

Galaxy surveys observe the late Universe

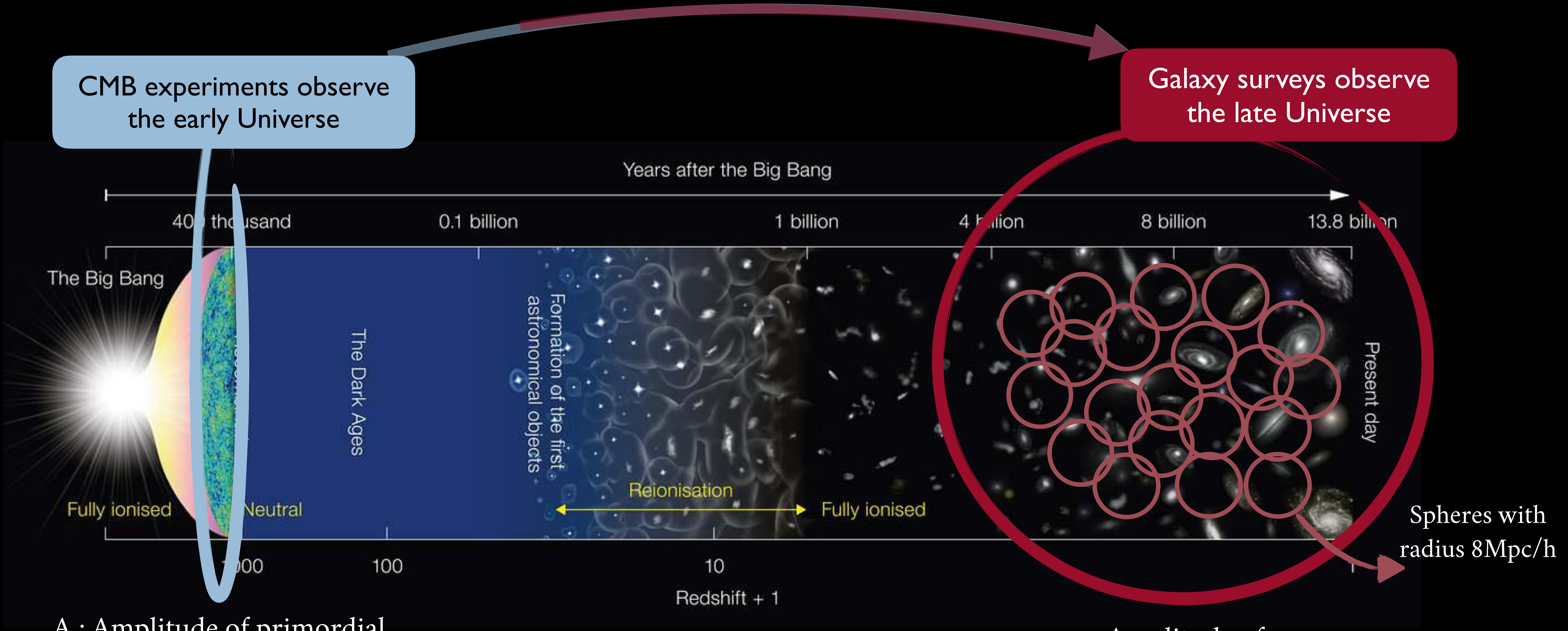


End-to-end test!

Image credit: NAOJ

Stress-testing ΛCDM

Is the late time clustering compatible with the ΛCDM prediction assuming initial conditions from the CMB?



A_s: Amplitude of primordial scalar density fluctuations.

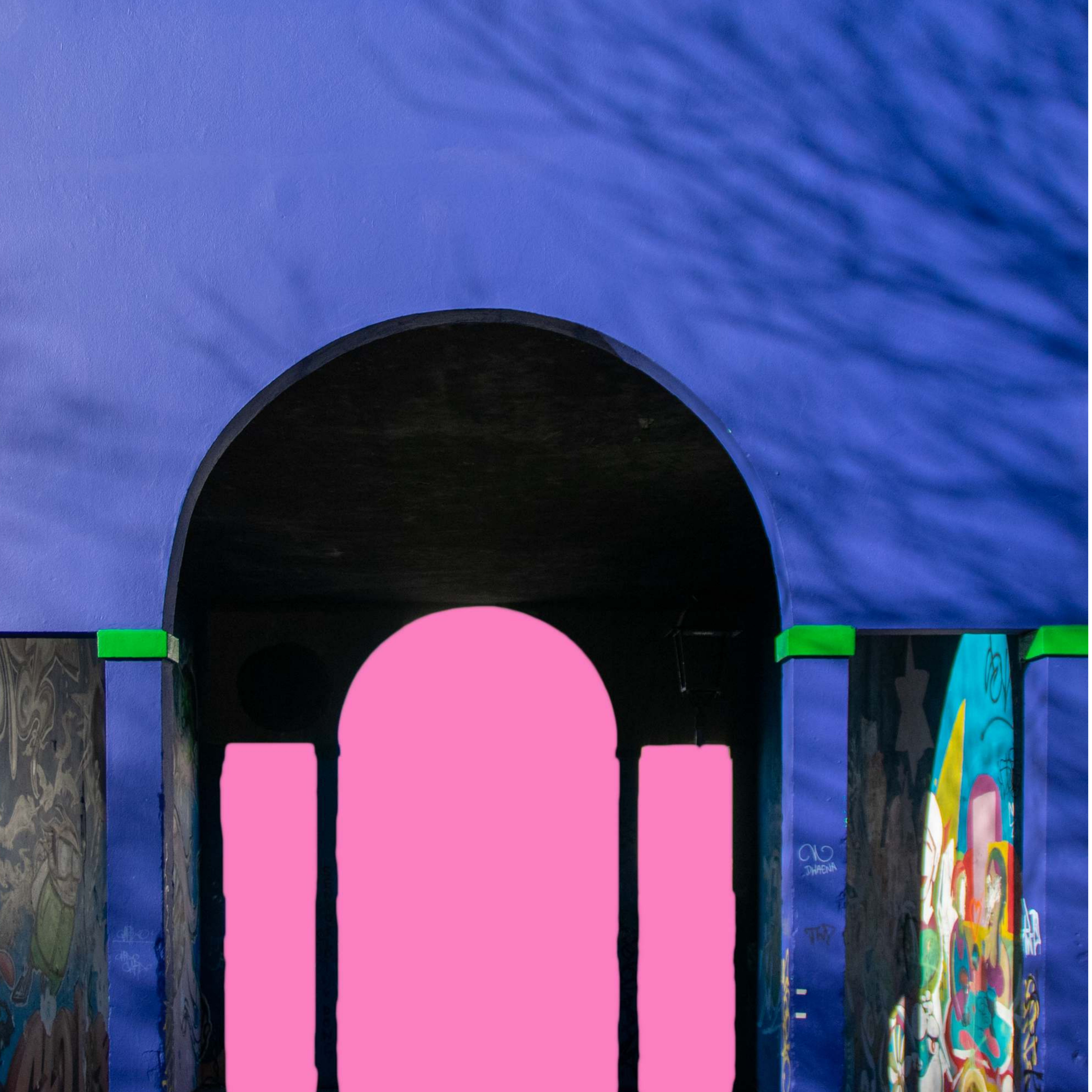
Image credit: NAOJ

σ_8: Amplitude of mass fluctuations today.

Some paths forward

ΛCDM model under discussion

- Stress-testing ΛCDM.
- Then, ***if measurements with different experiments and epochs agree***, combinations can be used to test if extensions of ΛCDM are preferred. Model comparison.



How can we probe cosmological information?

How can we probe cosmology information?

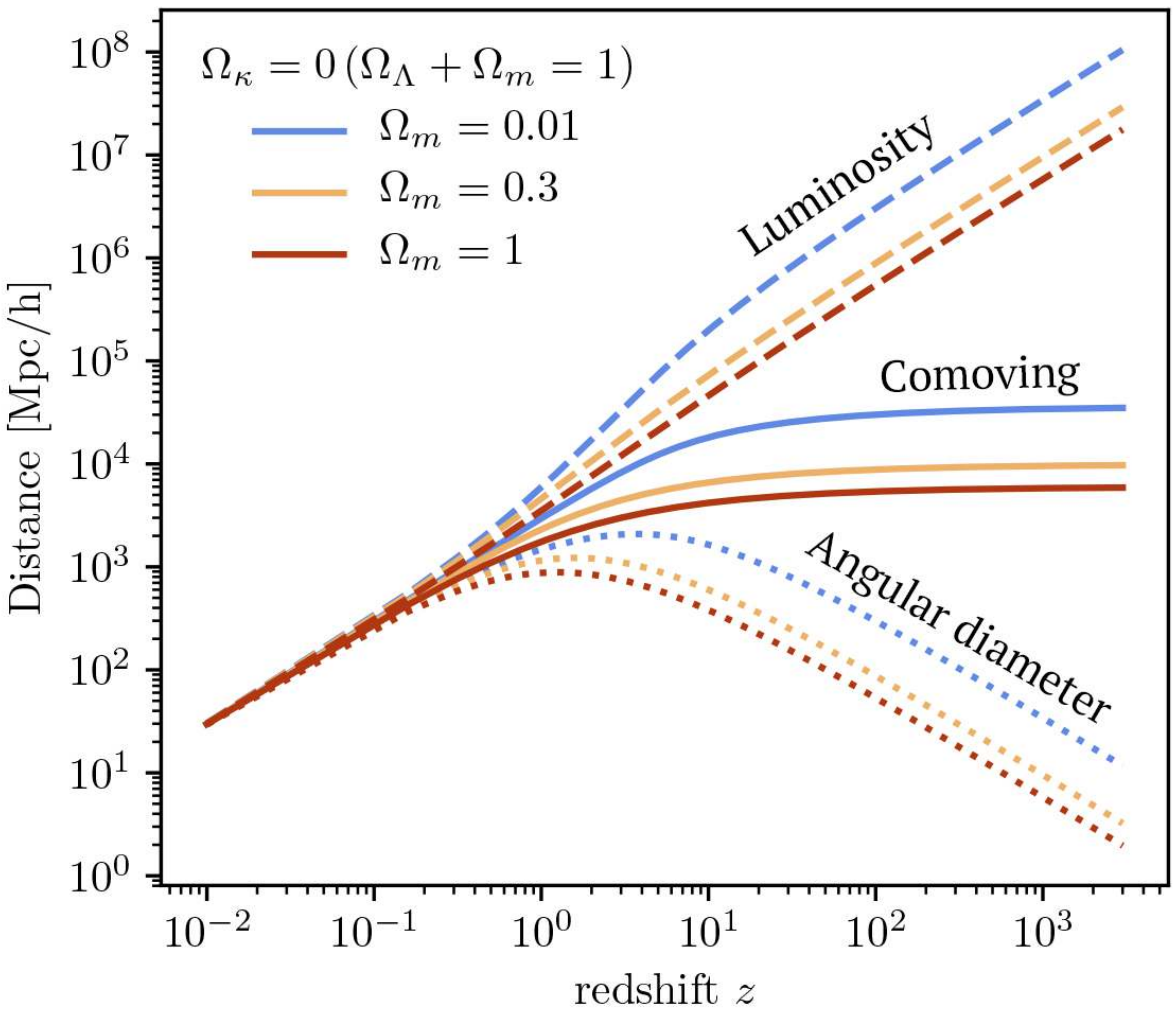
We can probe a cosmological model by studying:

(i) The history of **expansion** of the Universe (kinematics probe).

$$\chi(z) = c\int_0^{z_e} \frac{dz}{H(z)}$$

Via the first Friedmann equation:

$$H^2(z) = H_0^2\left[\Omega_m(1+z)^3 + \Omega_r(1+z)^4 + \Omega_k(1+z)^2 + \Omega_{de}(1+z)^{3(1+w)}\right]$$



How can we probe cosmology information?

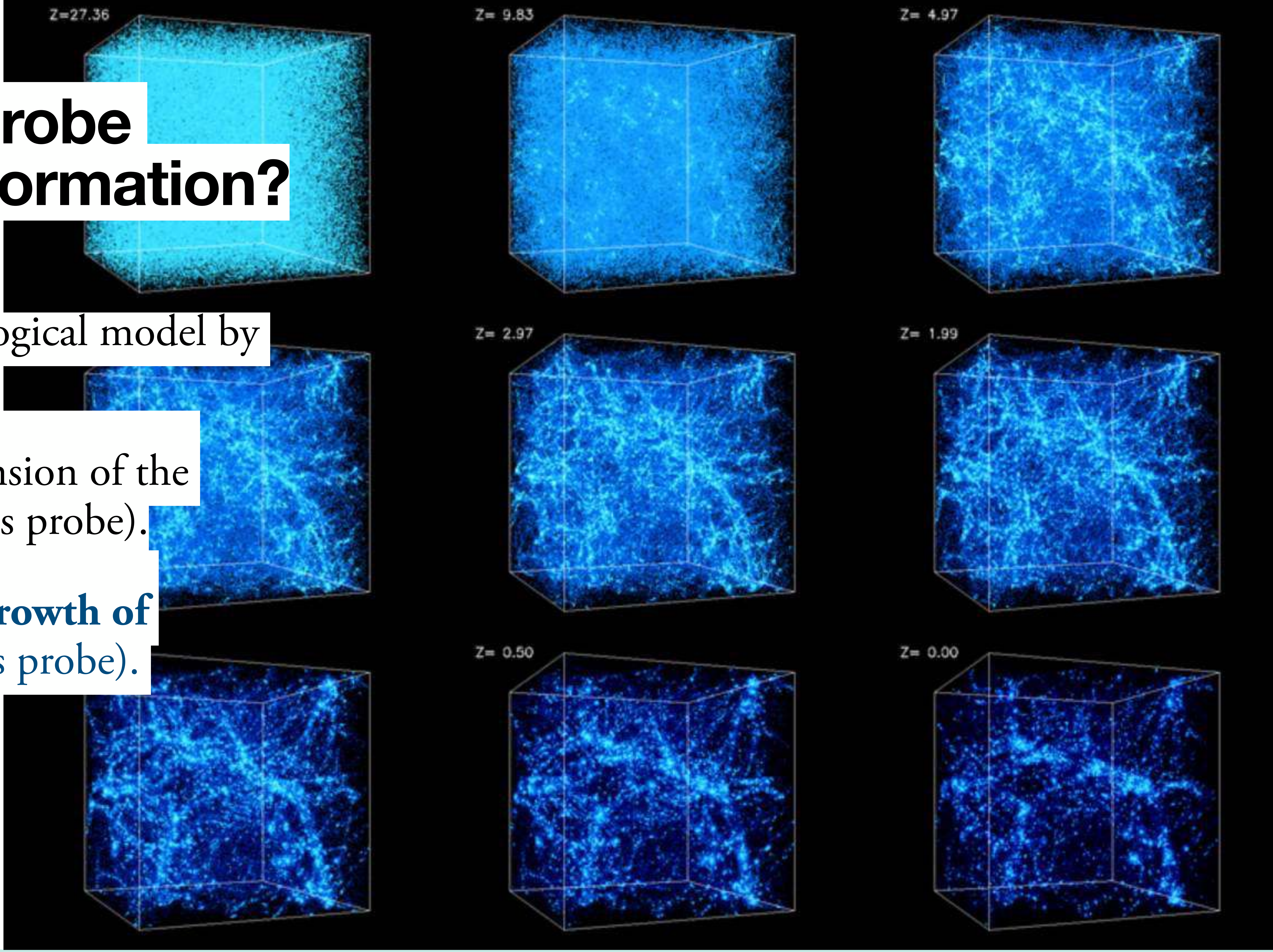
We can probe a cosmological model by studying:

(i) The history of expansion of the Universe (kinematics probe).

(ii) The history of the **growth of structure** (dynamics probe).

Via the Poisson equation:

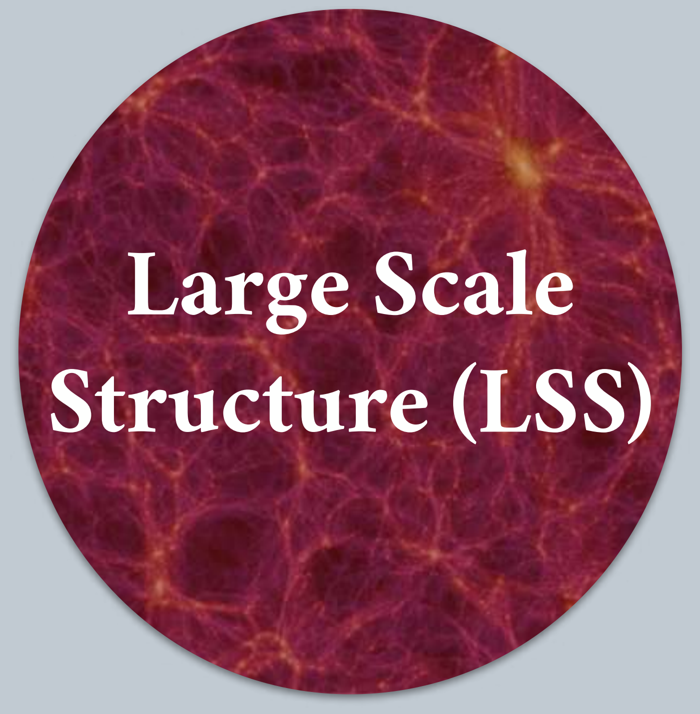
$$\nabla_r^2 \Phi(t, \boldsymbol{r}) = \frac{3\Omega_{\rm m} H_0^2}{2a(t)} \delta(t, \boldsymbol{r})$$



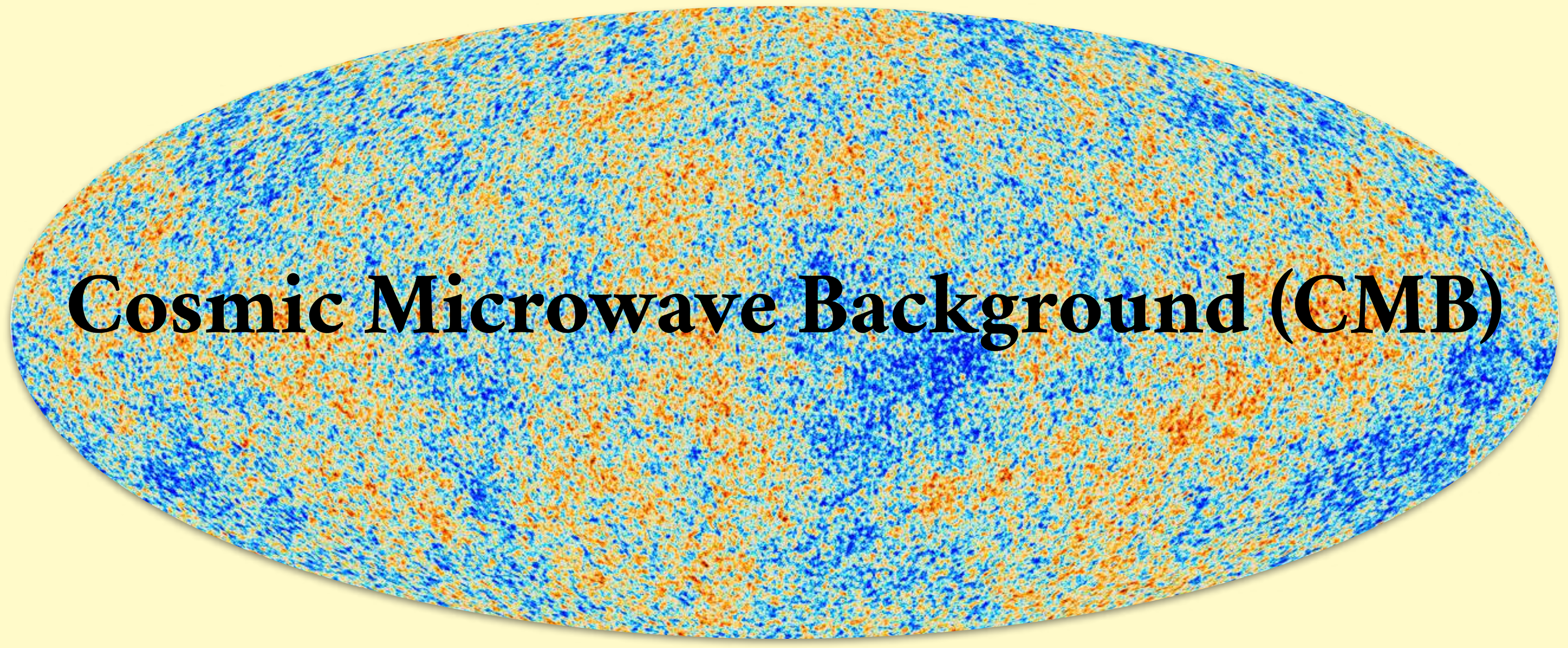
Probes to measure cosmological parameters

History of Expansion

More Growth, but also a bit of expansion

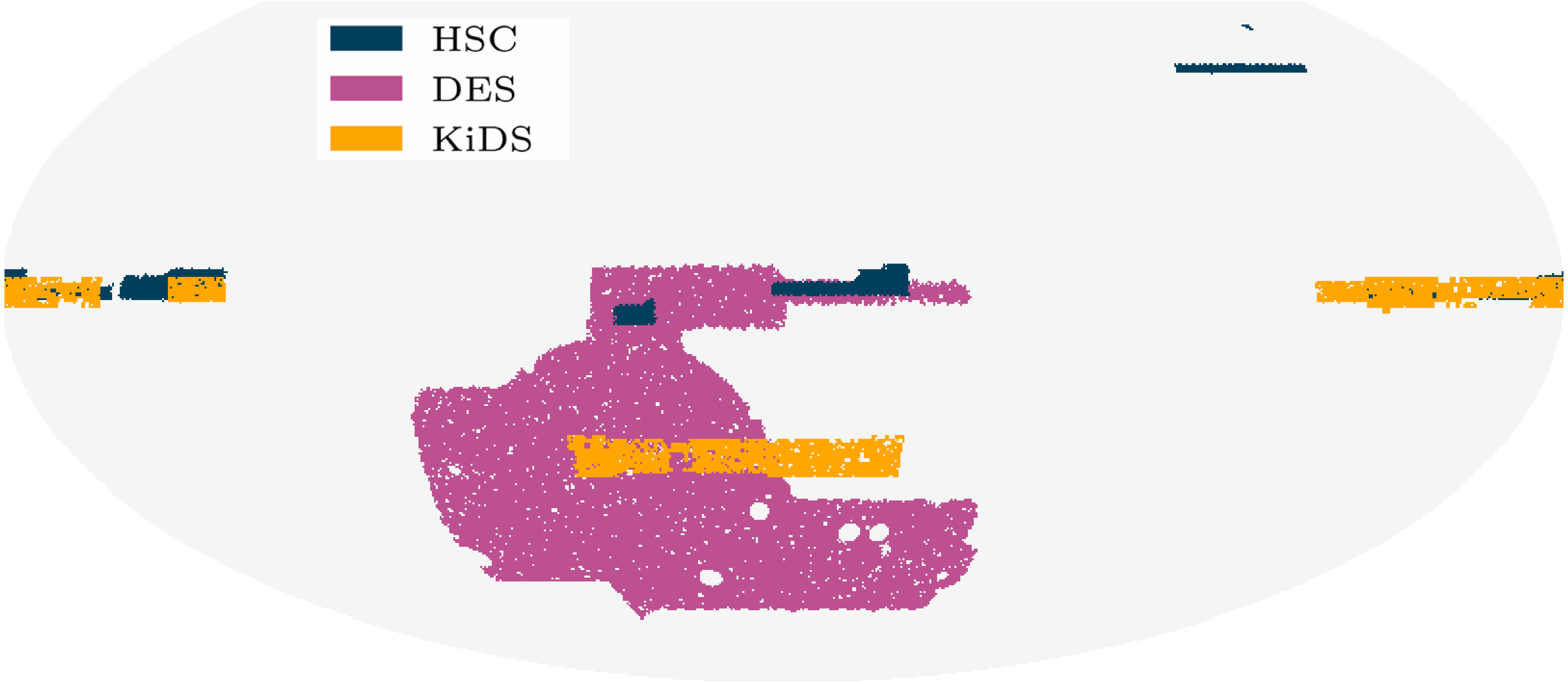


Growth and Expansion

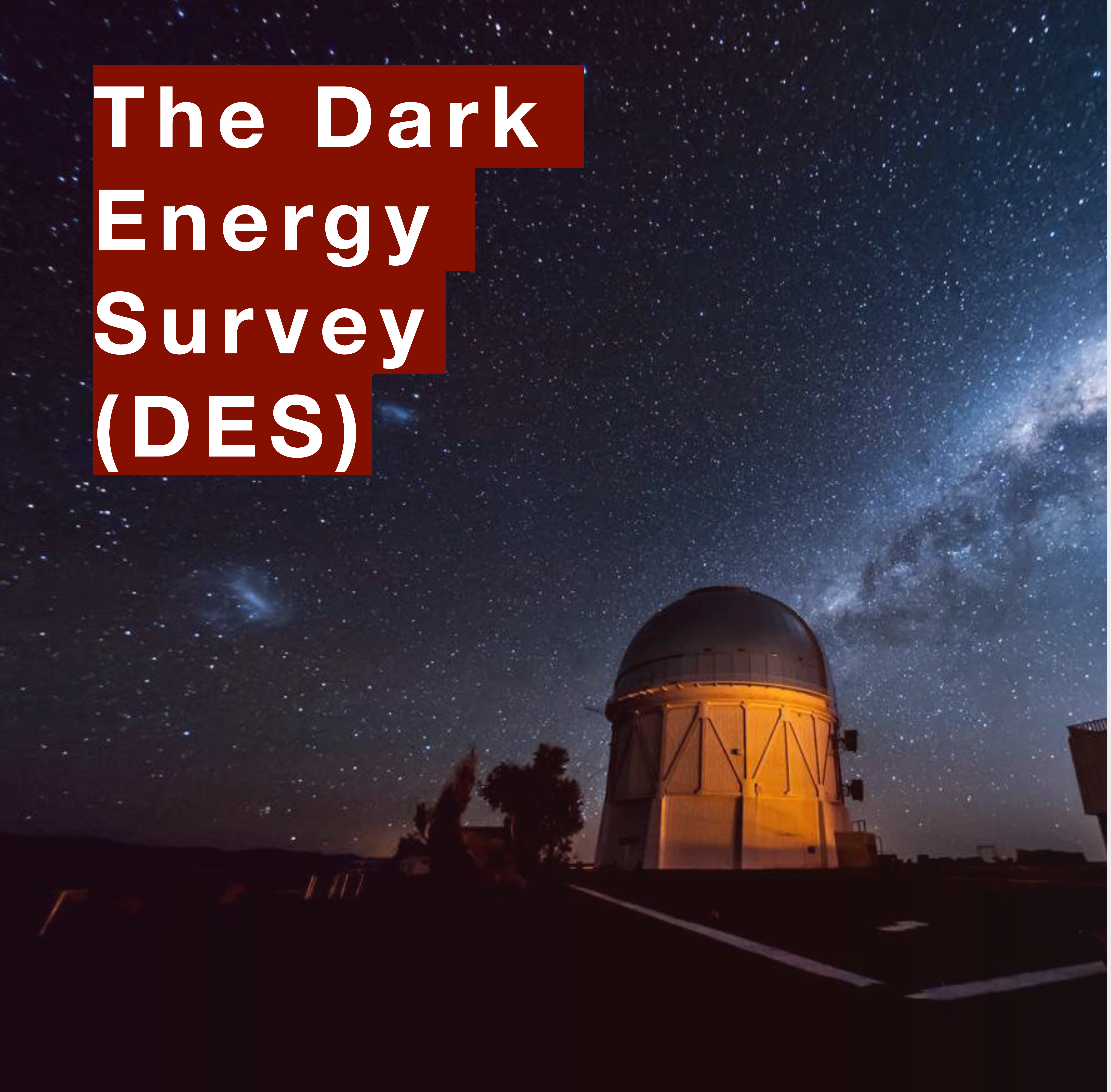


Photometric surveys for weak lensing: Stage III Surveys

	Survey	Area (deg^2)	Source density [arcmin^{-2}]	Redshift range	Observing Status
Stage III	DES Y3	4,143	5.59	0.2 - 1.3	Completed
	KiDS-1000	773	6.17	0.1 - 1.2	Completed
	HSC Y3	416	15	0.3 - 1.5	Ongoing



The Dark Energy Survey (DES)

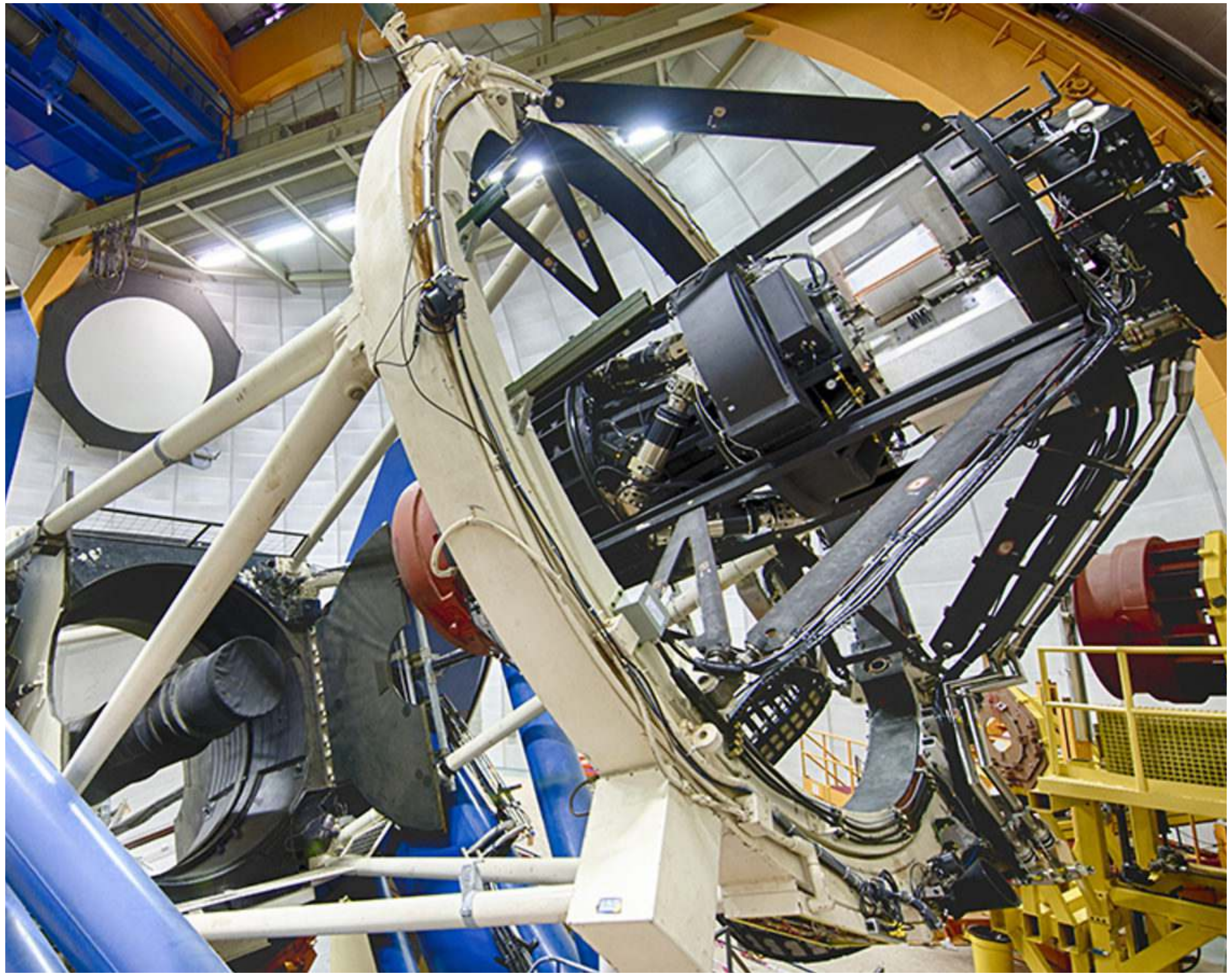


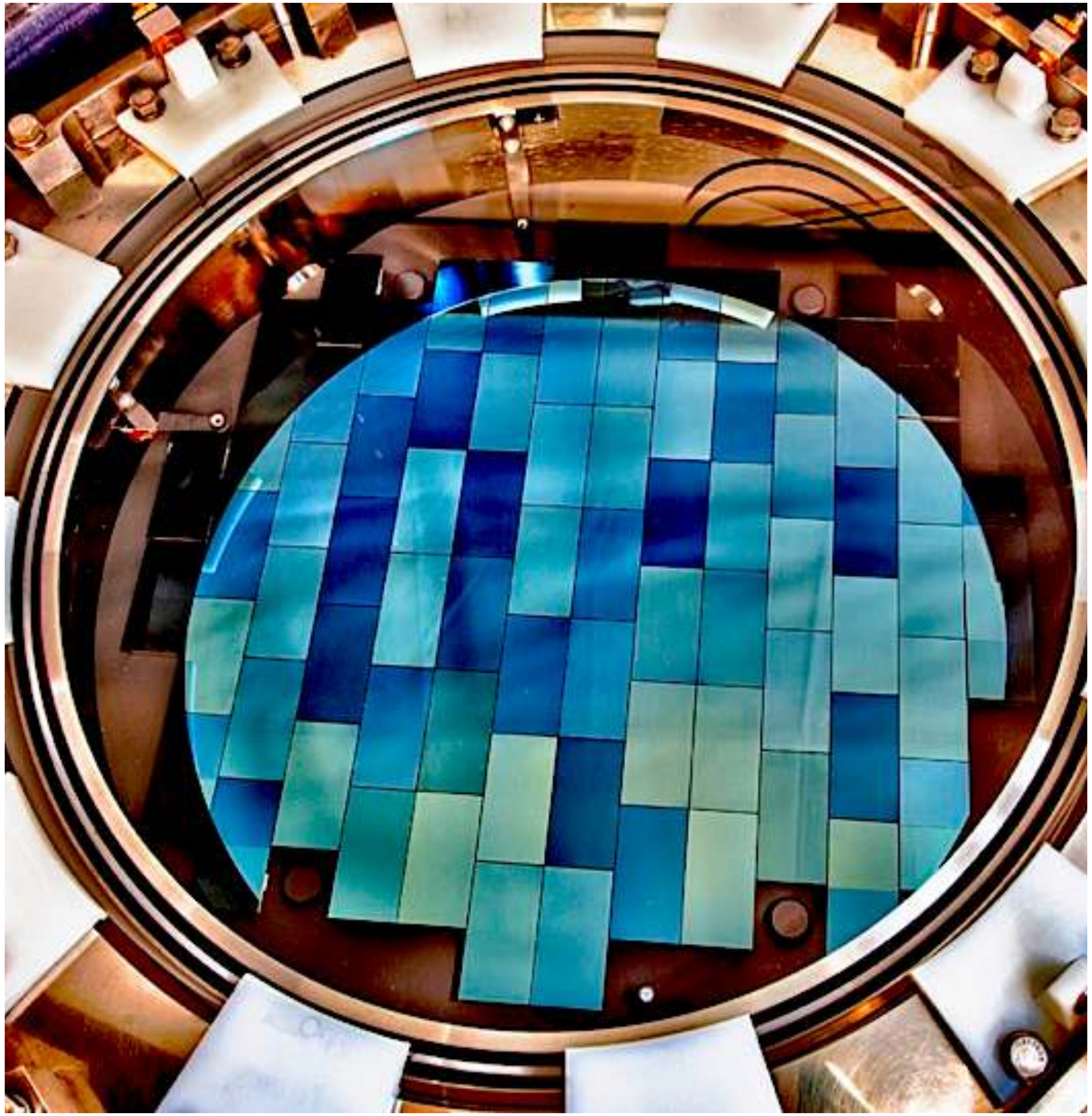
- Imaging galaxy survey.
- 5000 sq. deg. after 6 years (2013-2019)
- 570-Megapixel digital camera, DECam, mounted on the Blanco 4-meter telescope at Cerro Tololo Inter-American Observatory (Chile).
- Five filters are used (grizY) with a nominal limiting magnitude $i_{AB} \simeq 24$ and with a typical exposure time of 90 sec for griz and 45 sec for Y.

The Dark Energy Telescope

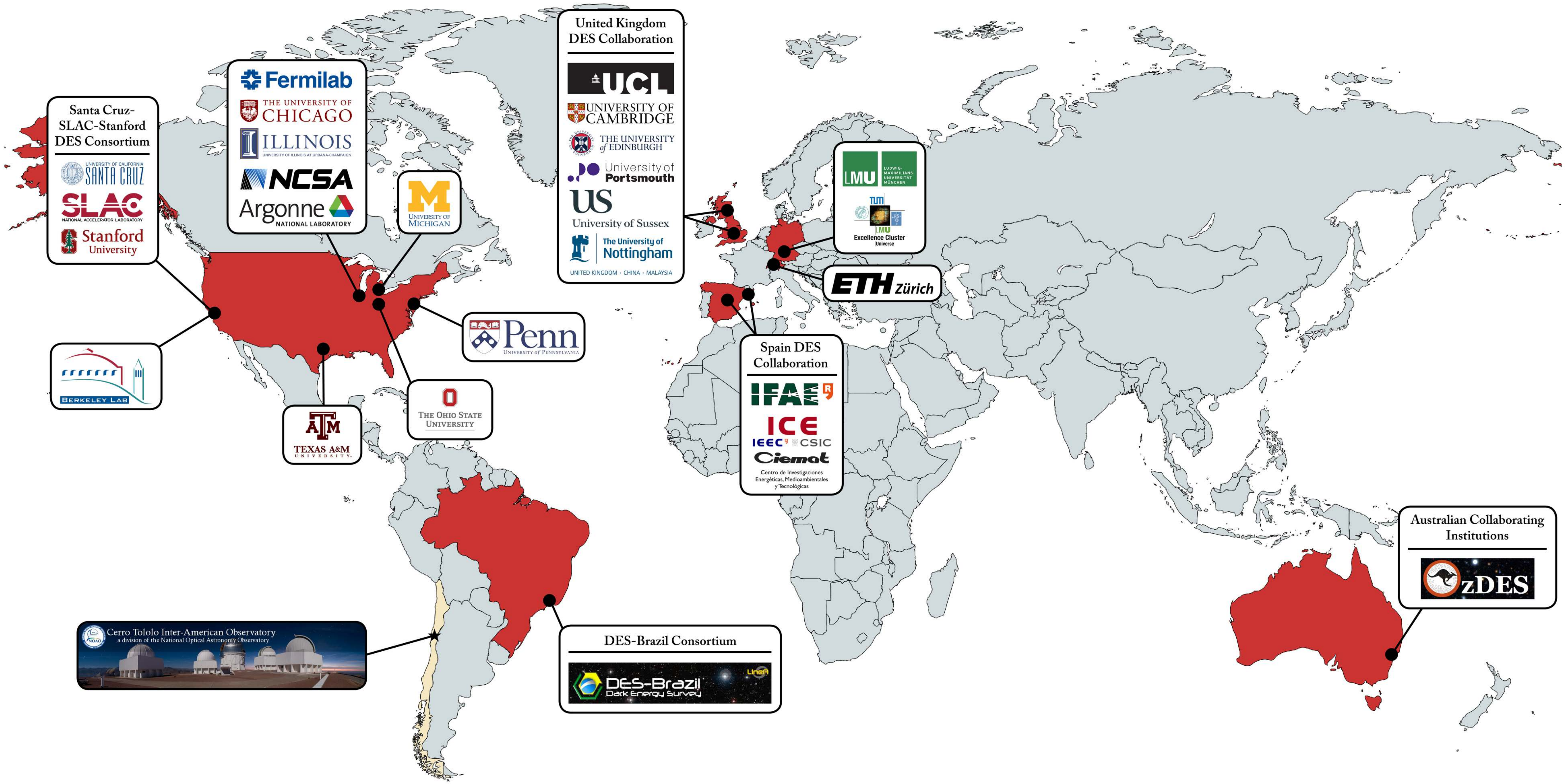
Blanco & DECam

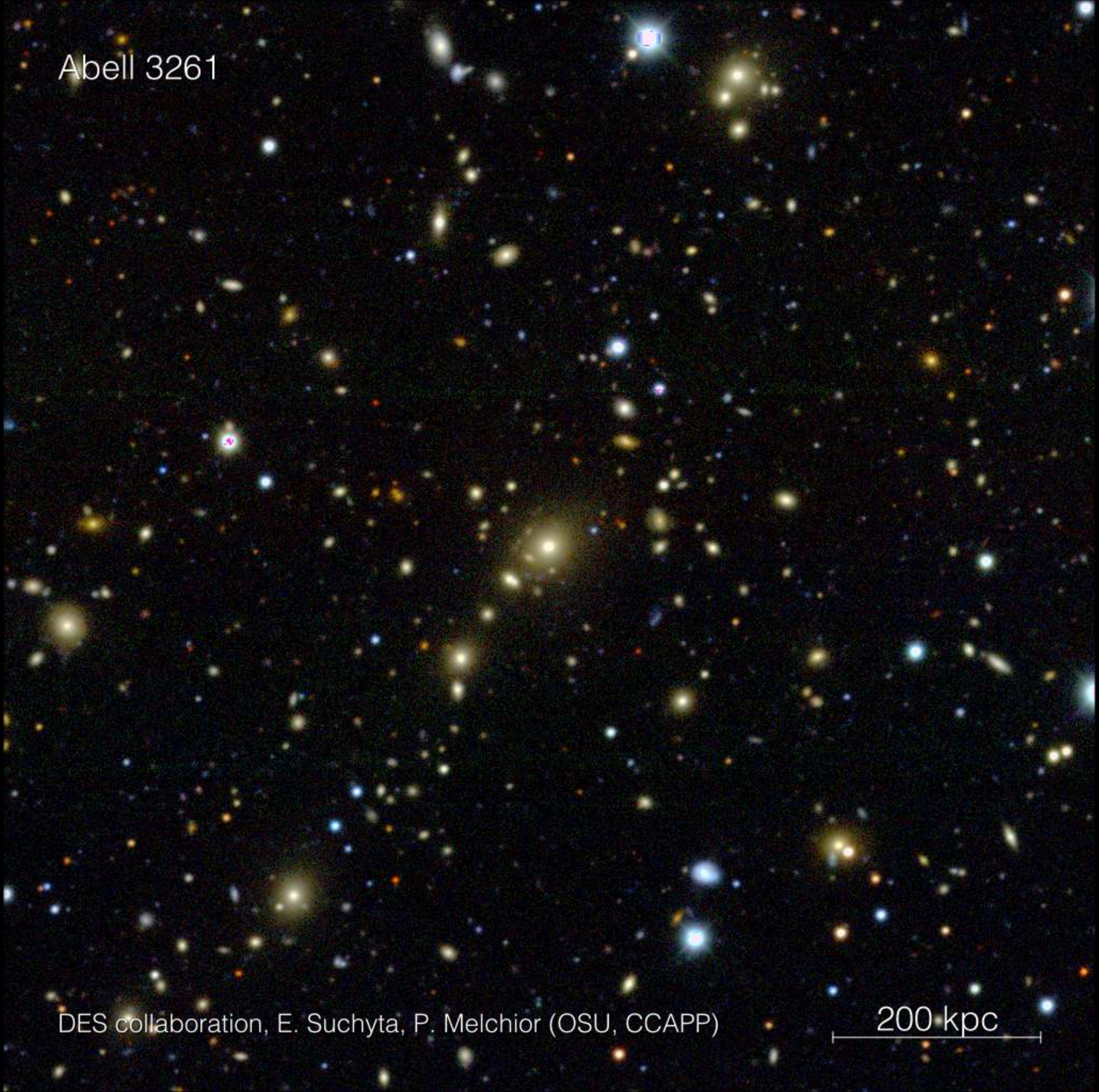
Telescope & Camera



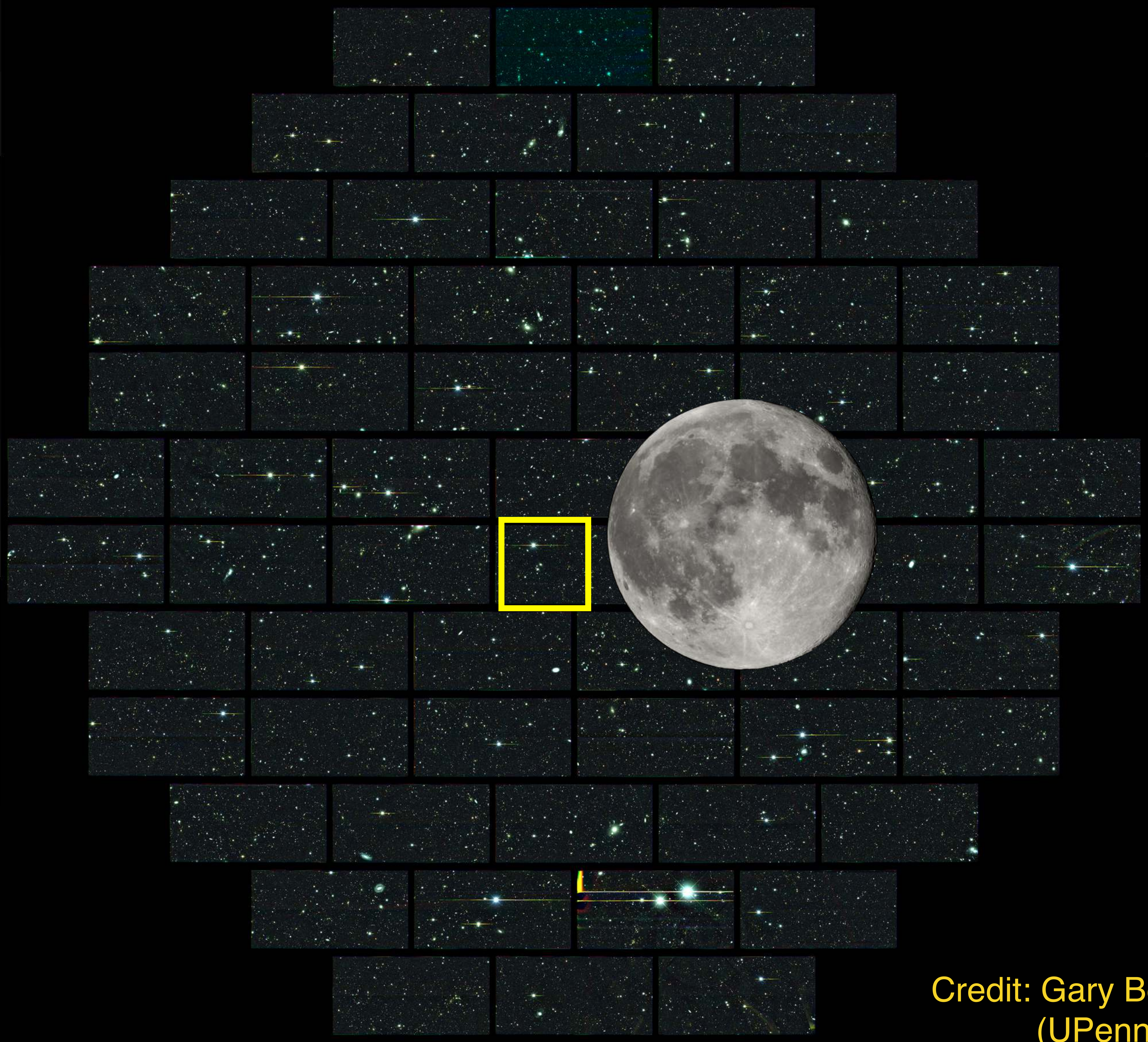


Dark Energy Survey Collaboration




Abell 3261
DES collaboration, E. Suchyta, P. Melchior (OSU, CCAPP)
200 kpc


Credit: Gary Bernstein
(UPenn)



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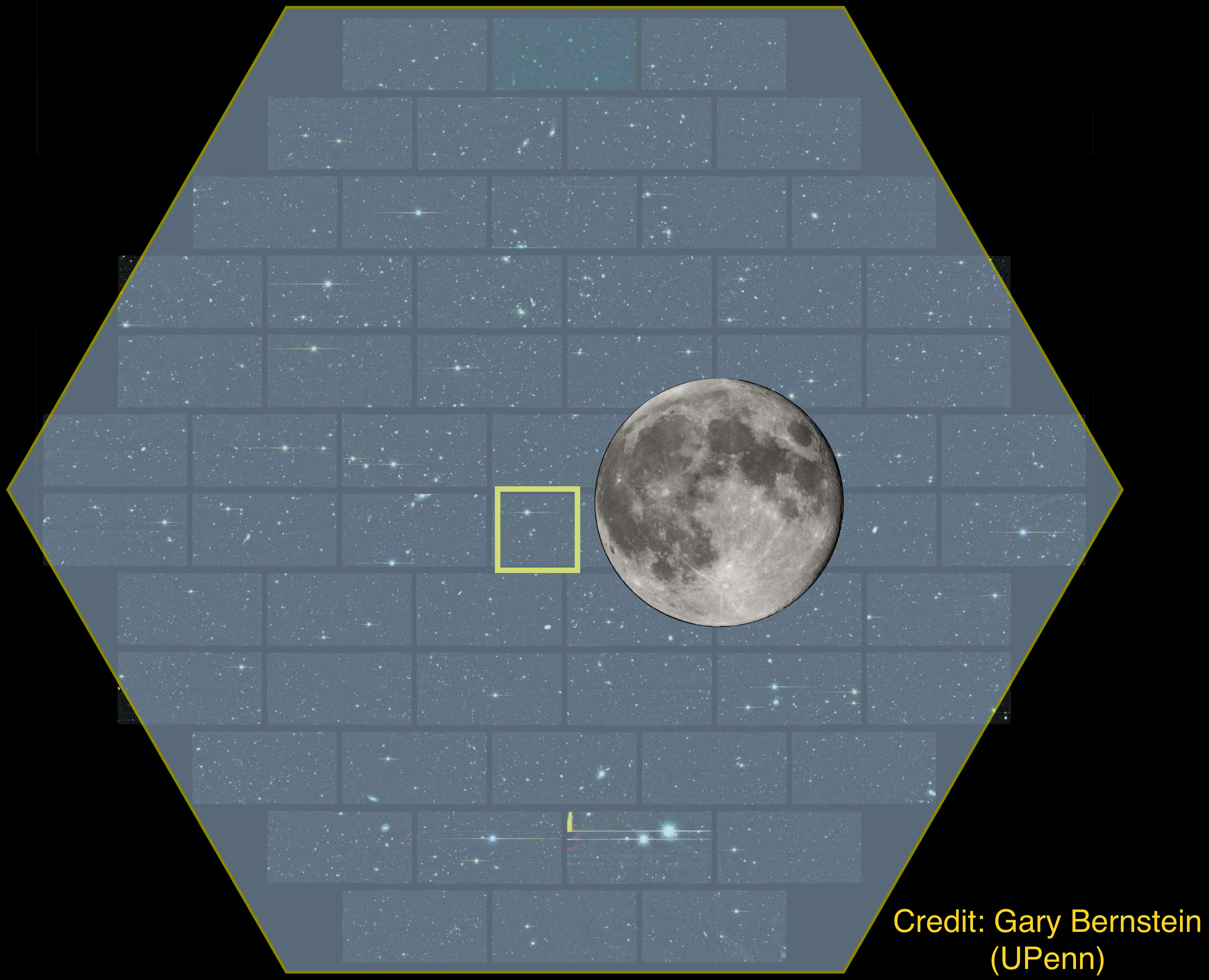
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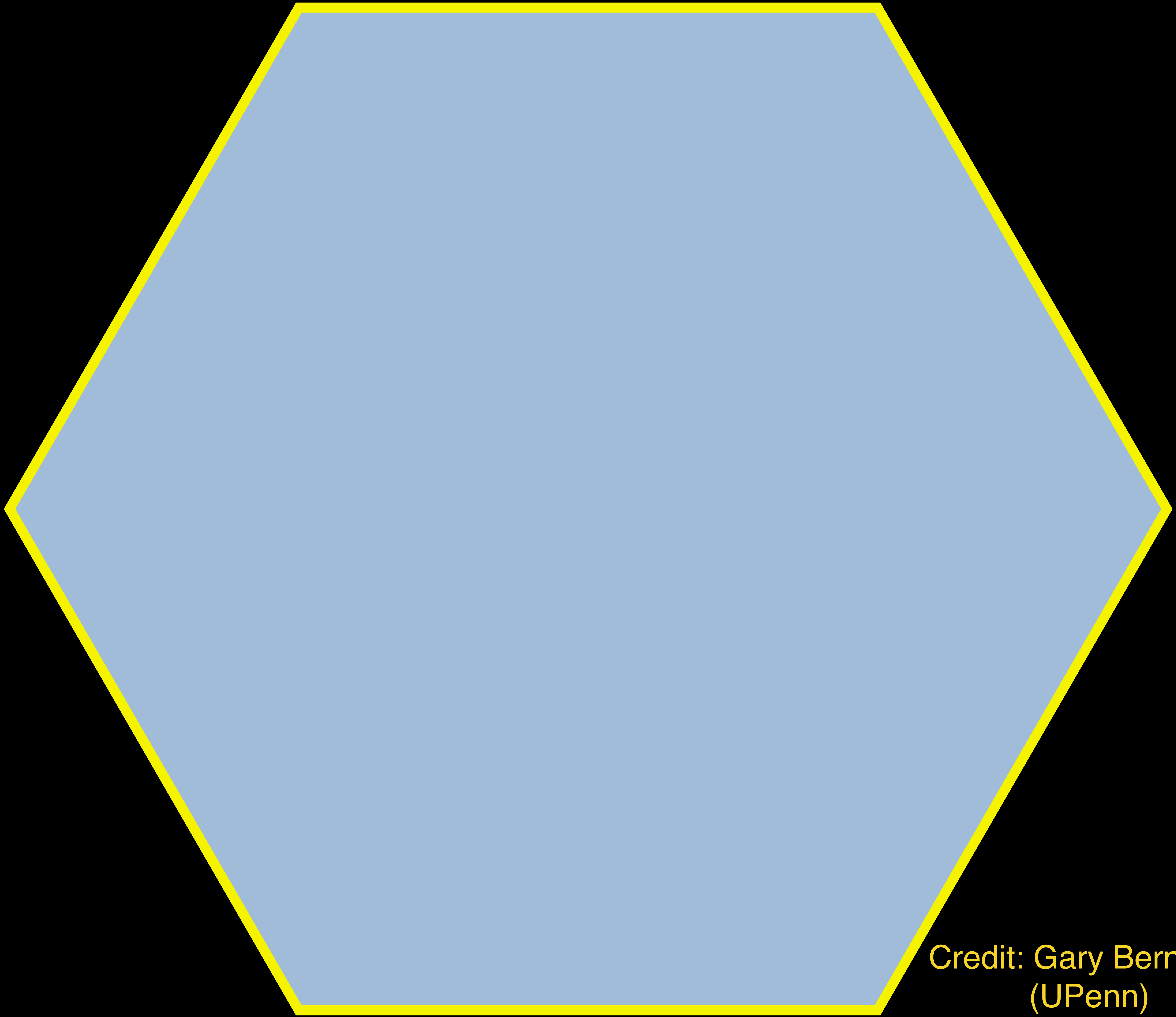

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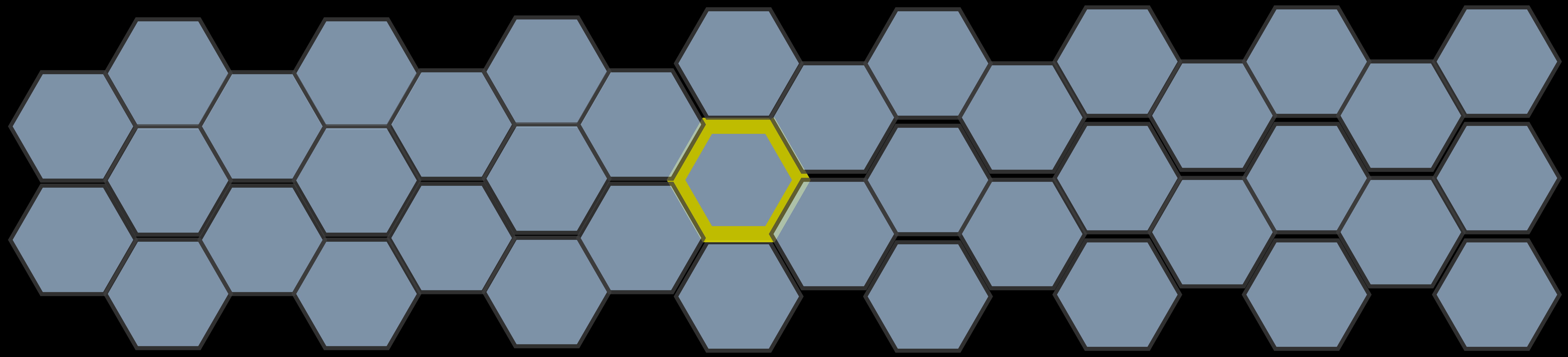

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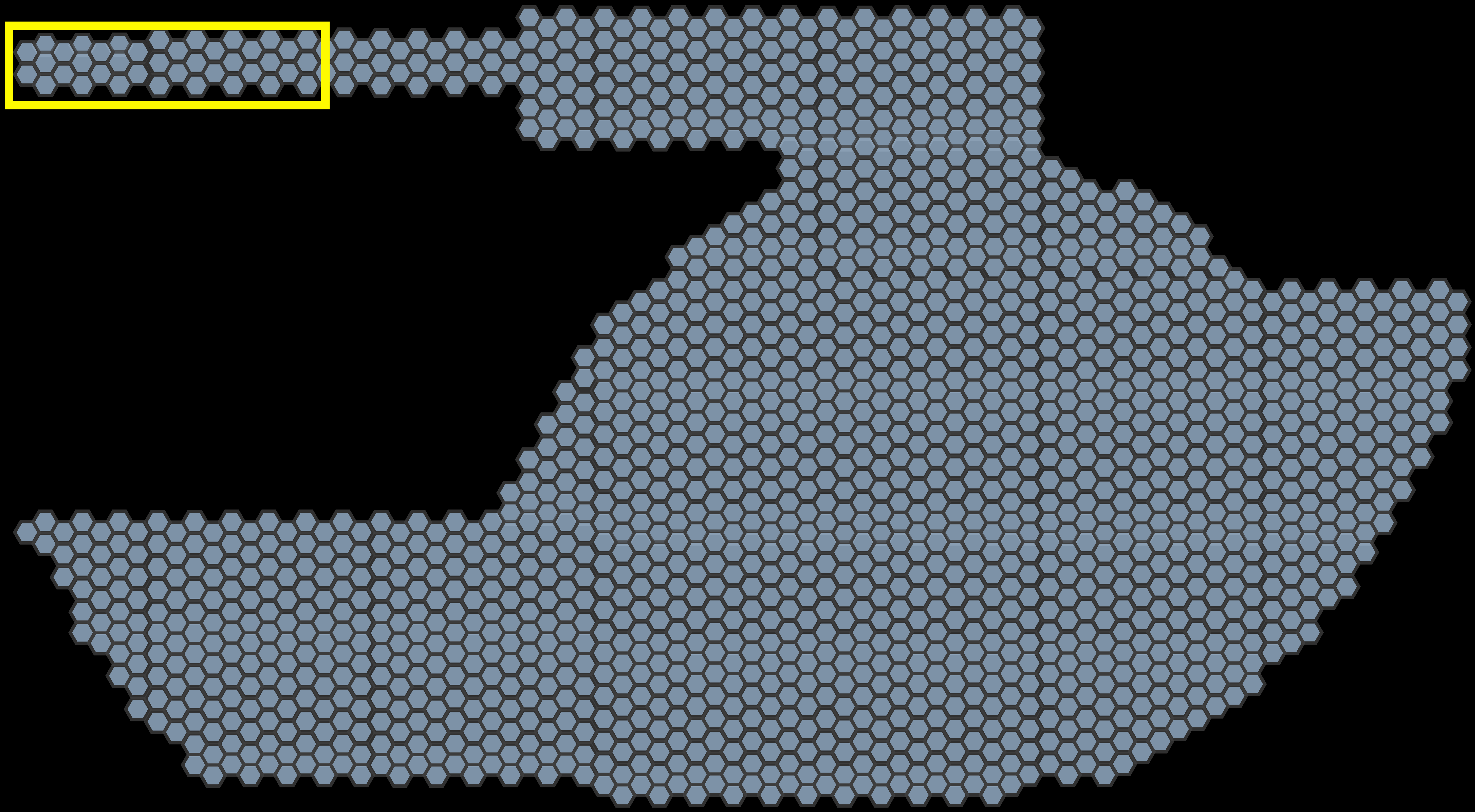

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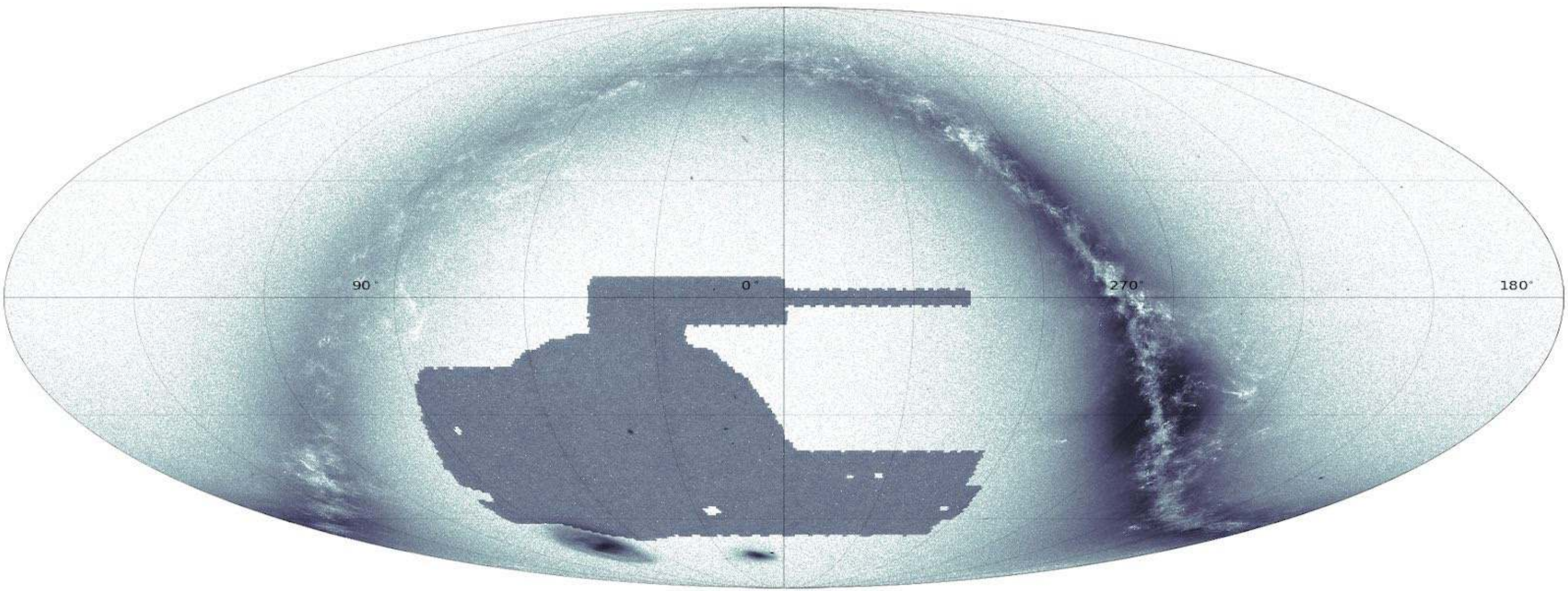
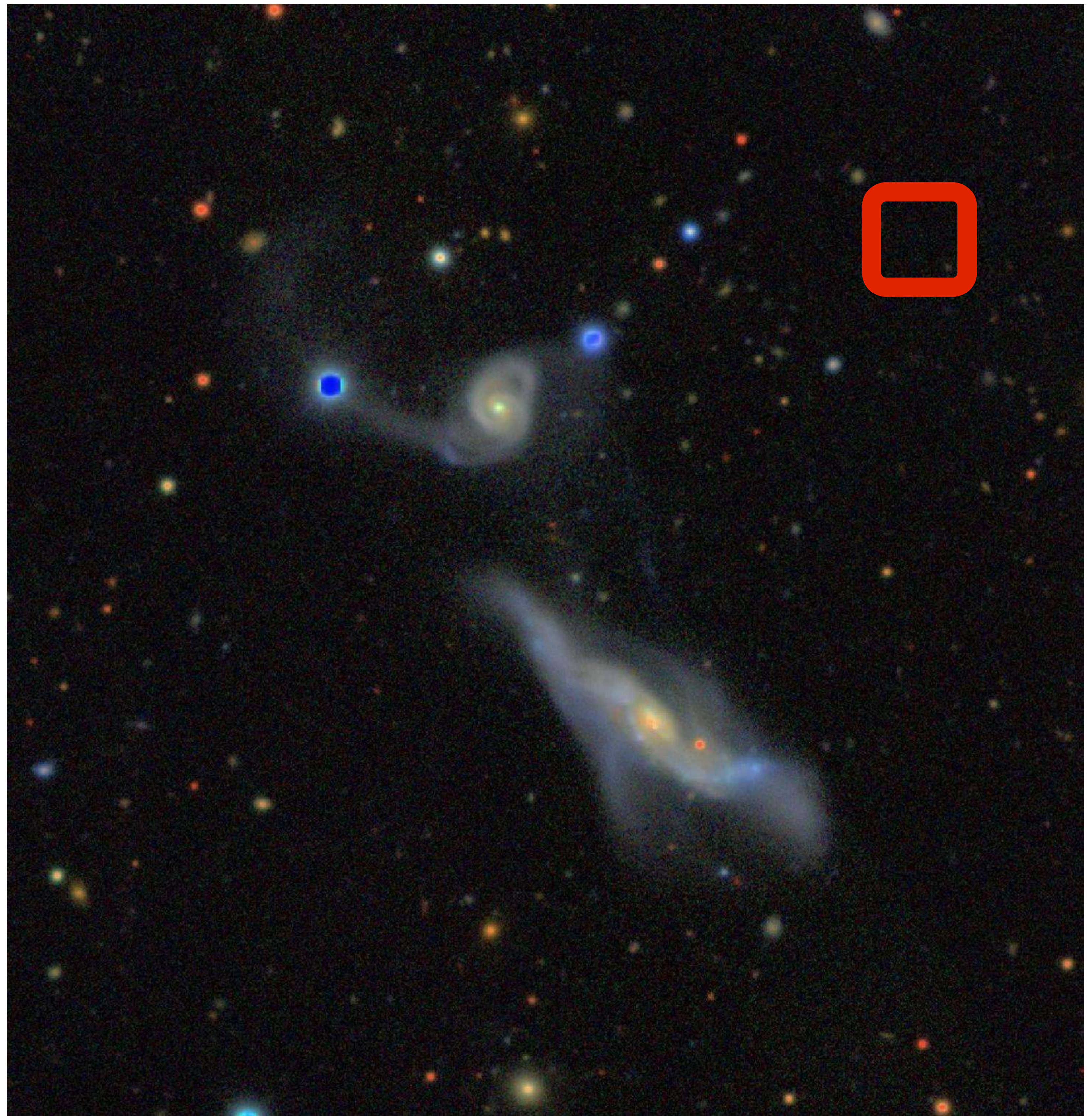


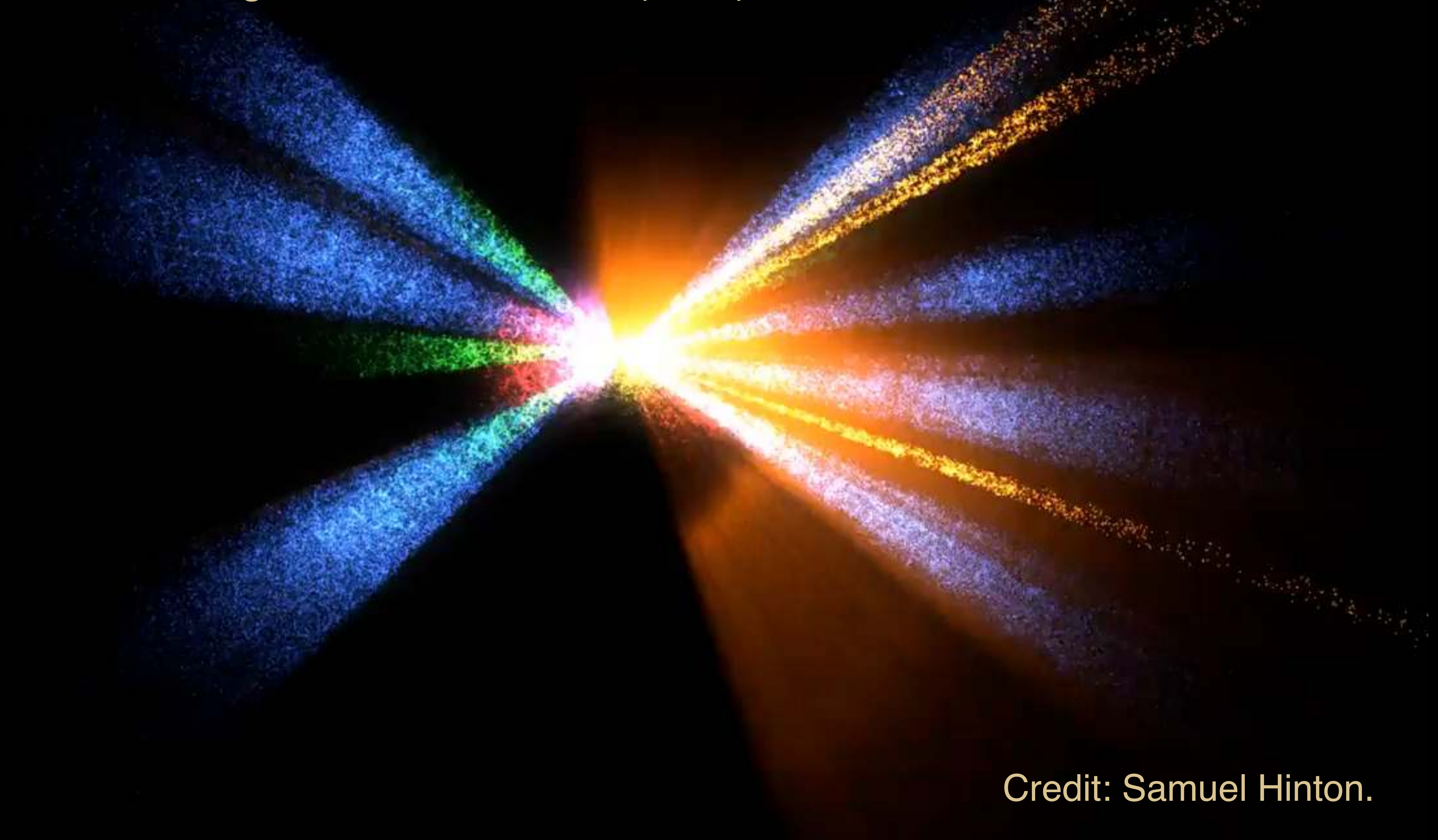
Detecting galaxies



Detecting galaxies

Large Scale Structure (LSS)

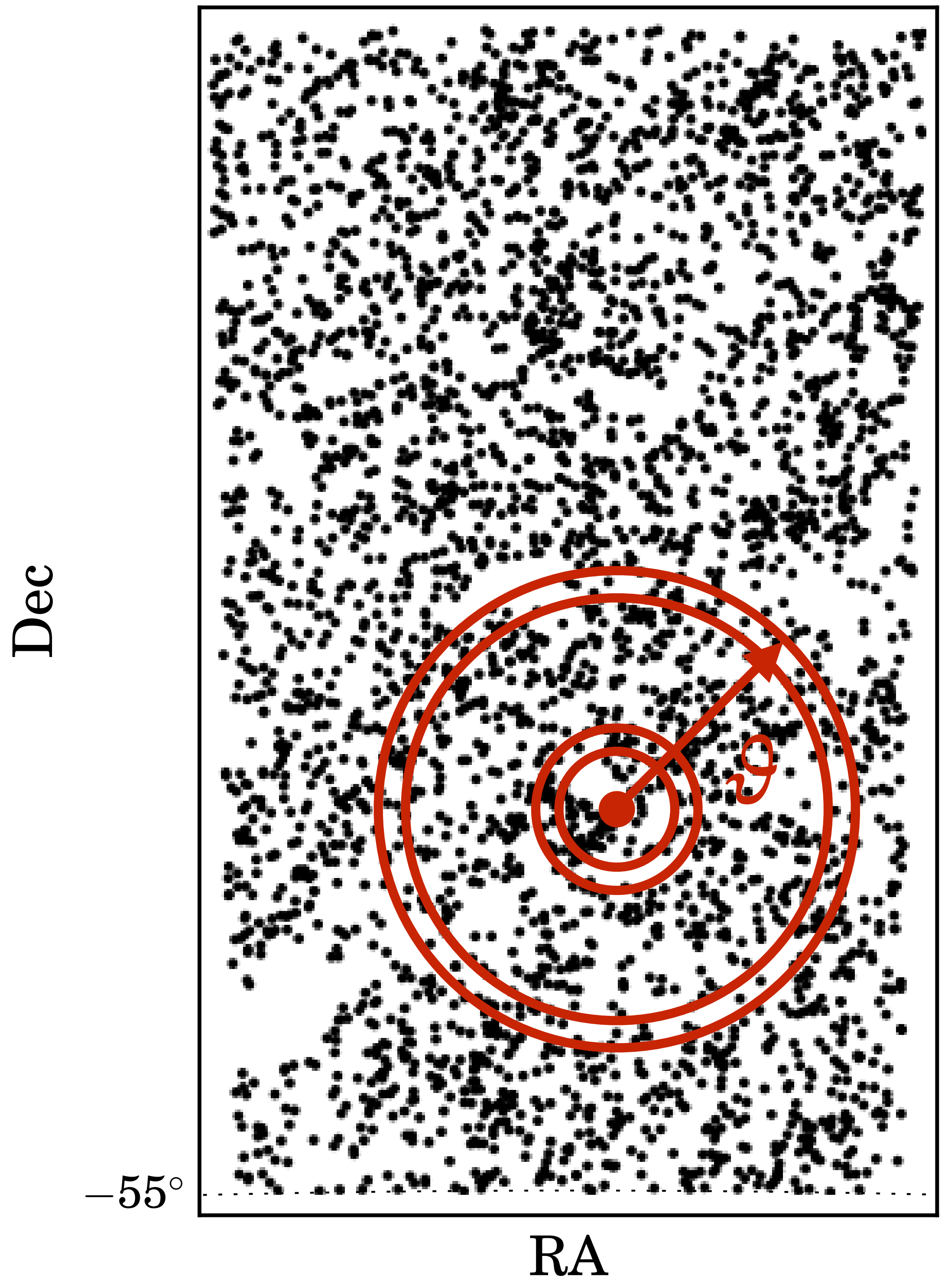
By the effect of gravity, matter (mostly dark) forms a complicated filamentary network, known as the Large Scale Structure (LSS) of the Universe.

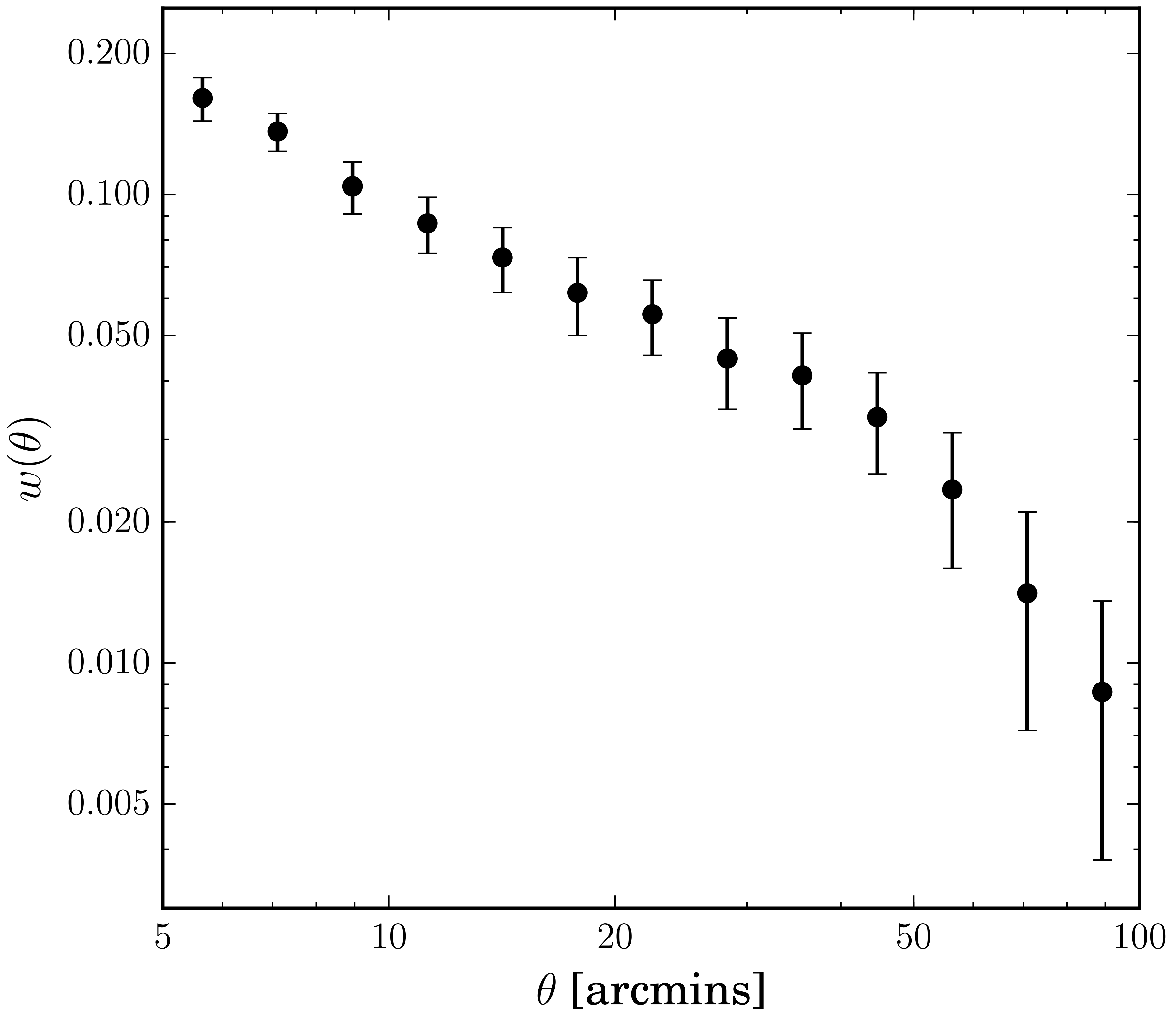


Credit: Samuel Hinton.

Galaxy clustering: two-point correlation function (2PCF)

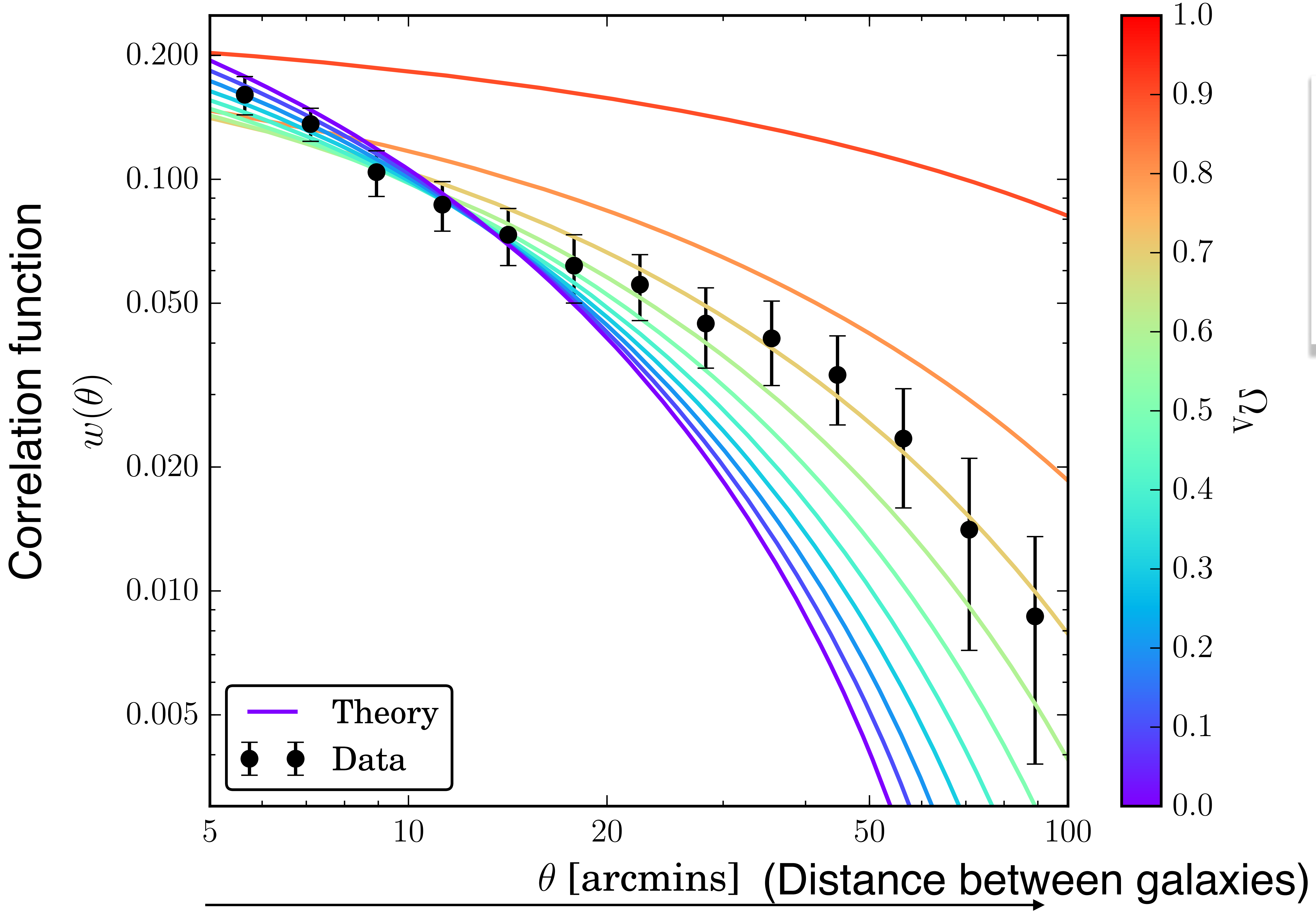
- Given a random galaxy in a location, the correlation function describes the probability that another galaxy will be found within a given distance.
- It can be thought of as a lumpiness factor - the higher the value for some distance scale, the more lumpy the Universe is at that distance scale.





Modeling two-point correlation functions…

Figure Credit: Carles Sánchez



$$w^i(\theta) = \int \frac{d\ell\,\ell}{2\pi} J_0(\ell\theta) \int d\chi \frac{q^i_{\delta_g}\left(\frac{\ell+1/2}{\chi},\chi\right) q^j_{\delta_g}\left(\frac{\ell+1/2}{\chi},\chi\right)}{\chi^2} \times P_{NL}\left(\frac{\ell+1/2}{\chi}, z(\chi)\right)$$

LSS kernel

$$q^i_{\delta_g}(k,\chi) = b^i(k, z(\chi)) \frac{n^i_g(z(\chi))}{\bar{n}^i_g} \frac{dz}{d\chi}$$

It is sensitive to the matter power spectrum (through the galaxy bias)

Modeling two-point correlation functions…

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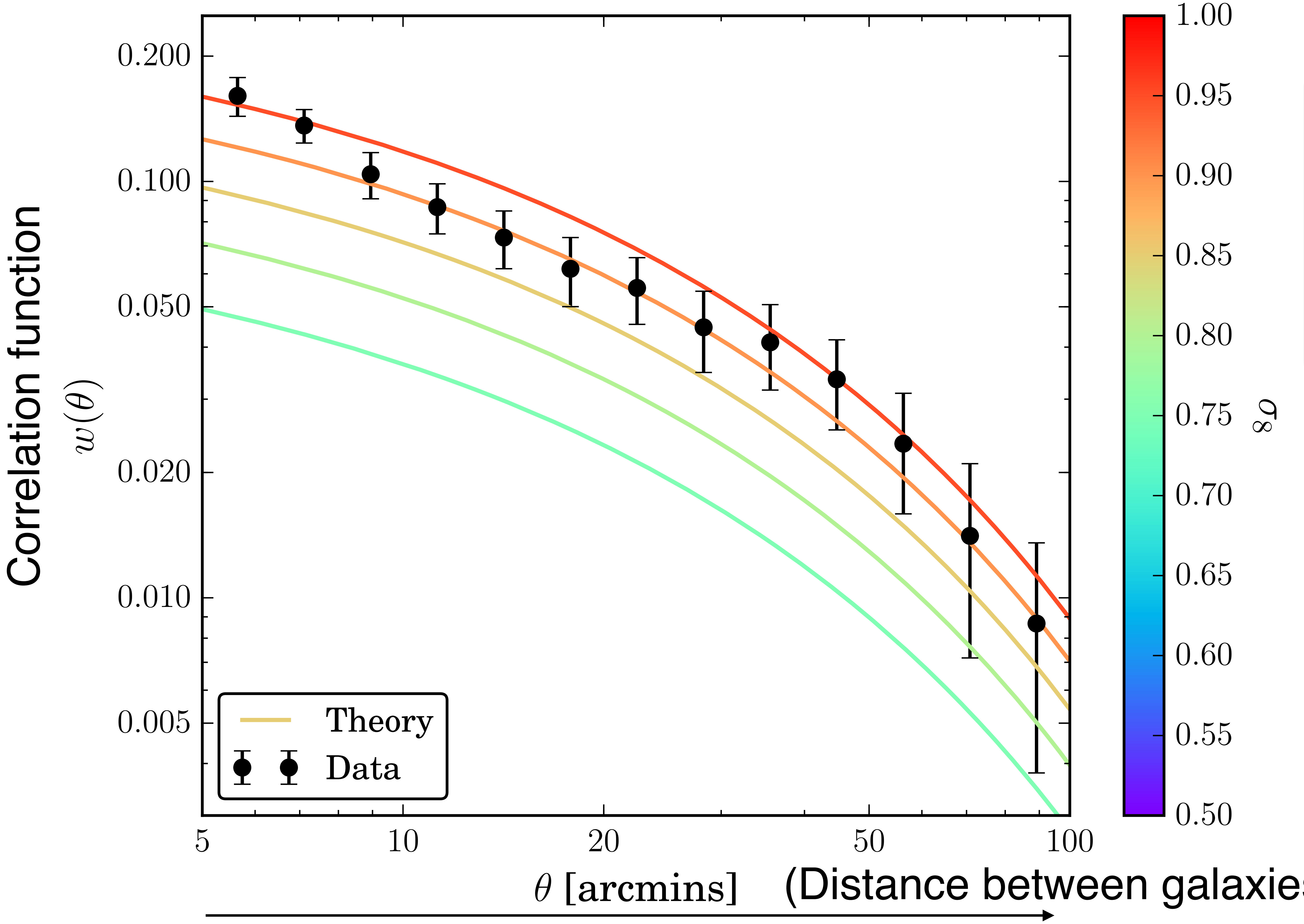

(Distance between galaxies)

$$w^i(\theta) = \int \frac{d\ell\,\ell}{2\pi} J_0(\ell\theta) \int d\chi \frac{q^i_{\delta_g}\left(\frac{\ell+1/2}{\chi},\chi\right) q^j_{\delta_g}\left(\frac{\ell+1/2}{\chi},\chi\right)}{\chi^2} \times P_{NL}\left(\frac{\ell+1/2}{\chi}, z(\chi)\right)$$

LSS kernel

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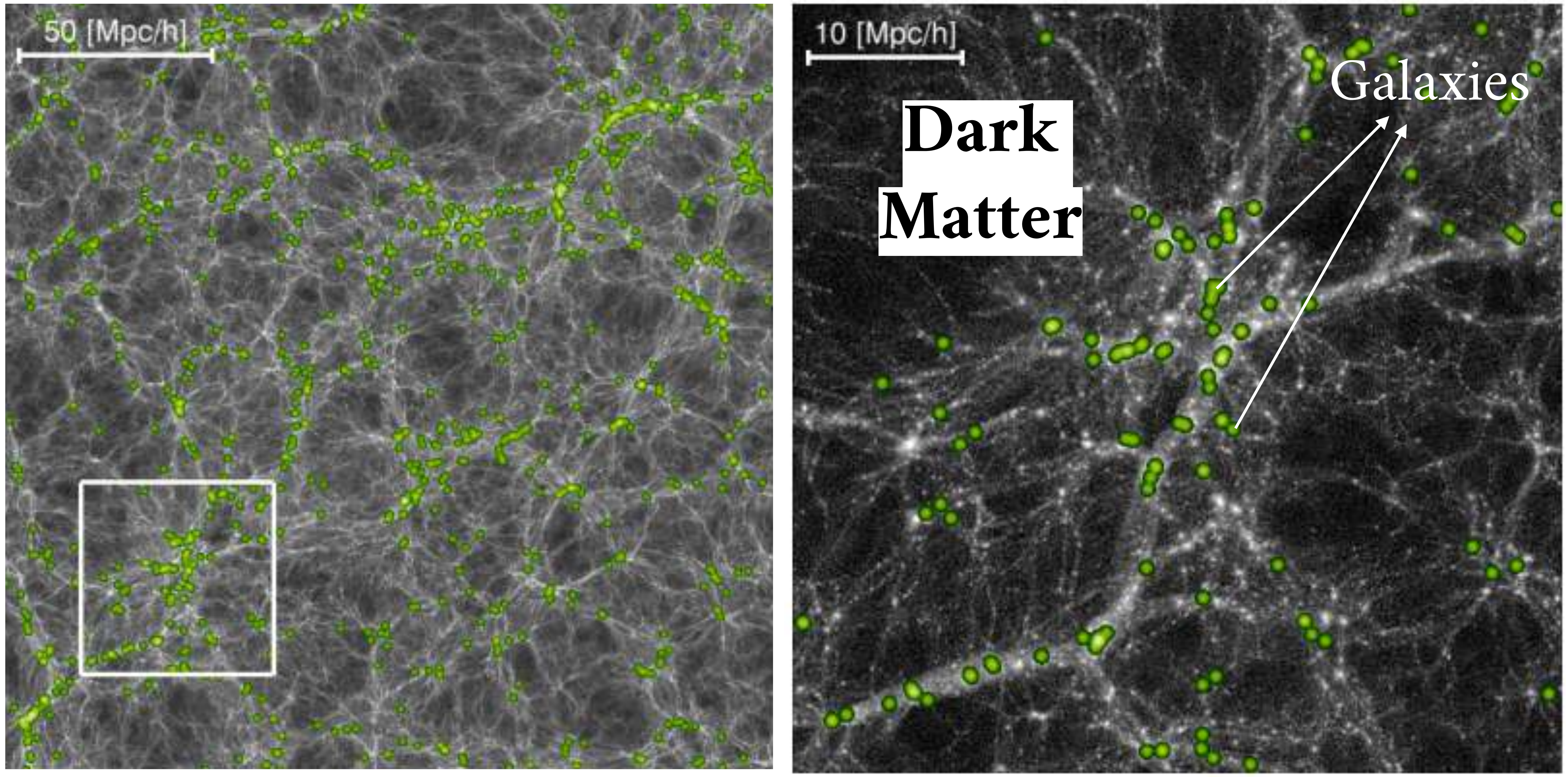
It is sensitive to the matter power spectrum (through the galaxy bias)

Galaxy bias

- Matter correlation function cannot be observed directly because most matter is in the form of dark matter. Galaxies populate dark matter haloes and thus trace dark matter, but not perfectly.
- **Galaxy bias:** The statistical difference between the clustering of galaxies and that of dark matter.

$$\xi_{gg}(r) = b^2(r)\,\xi_{\delta\delta}(r) \qquad P_{gg}(r) = b^2(r)\,P_{\delta\delta}(r)$$

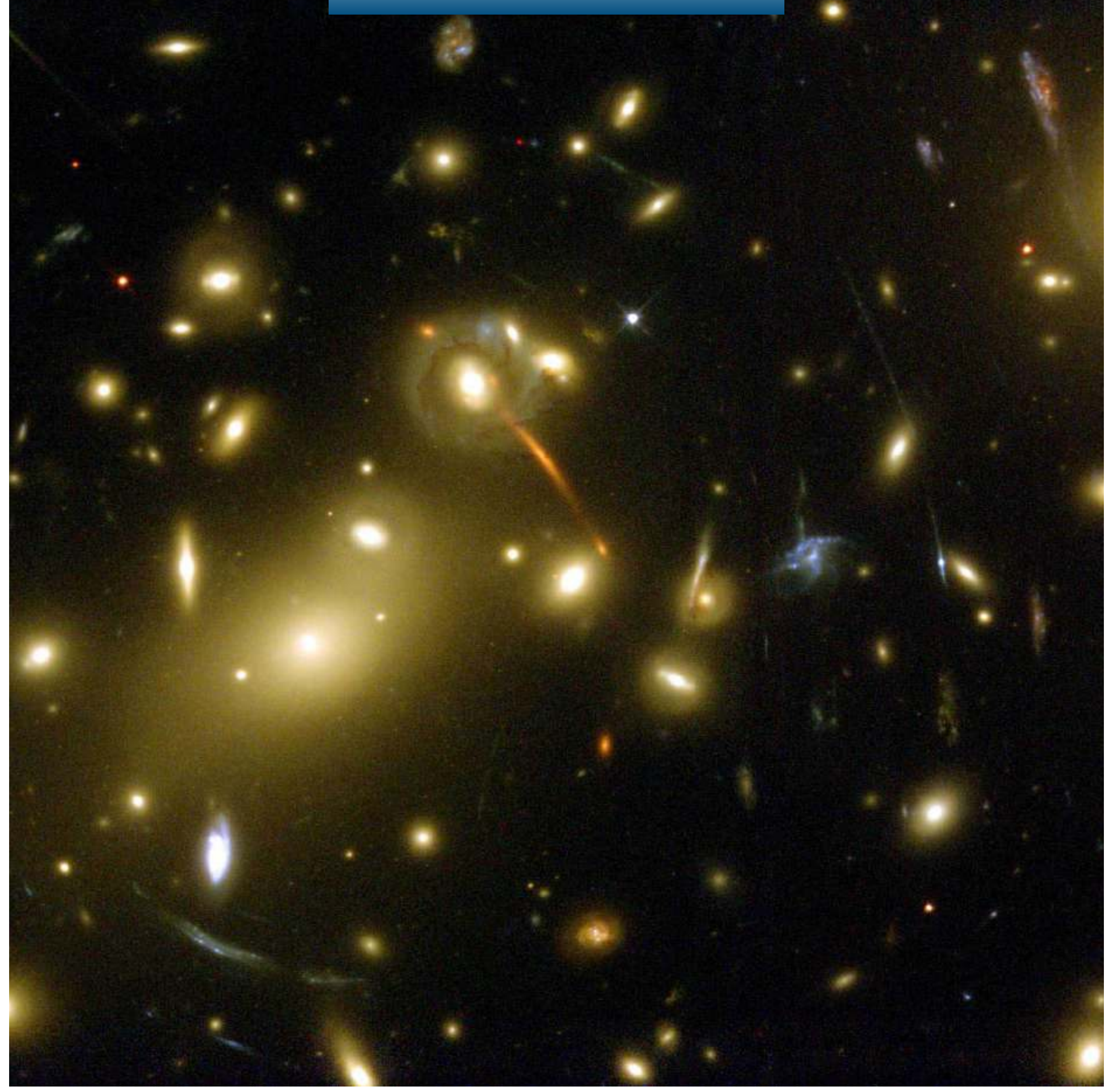


From Orsi et al. (2009)

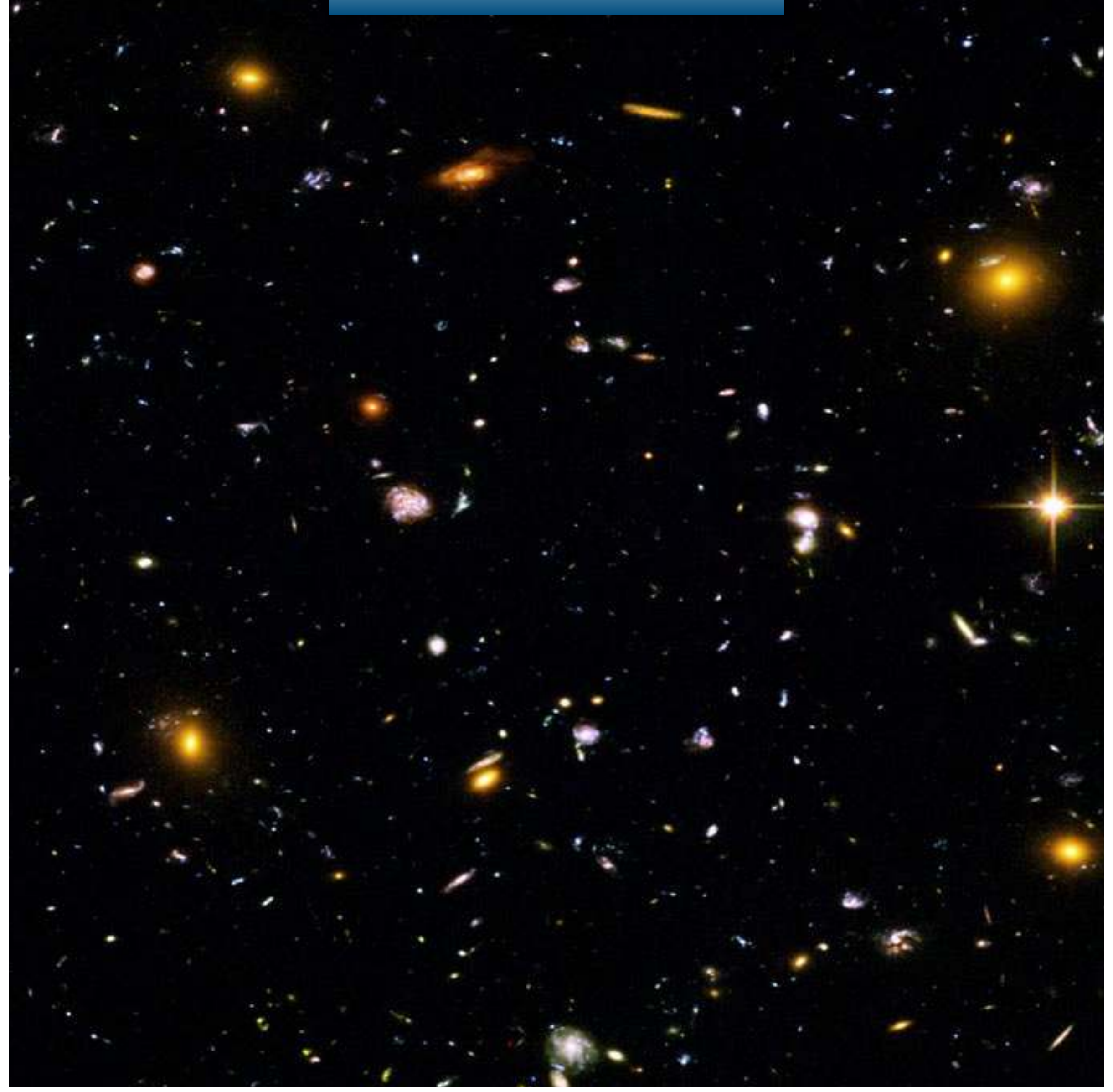
Gravitational lensing

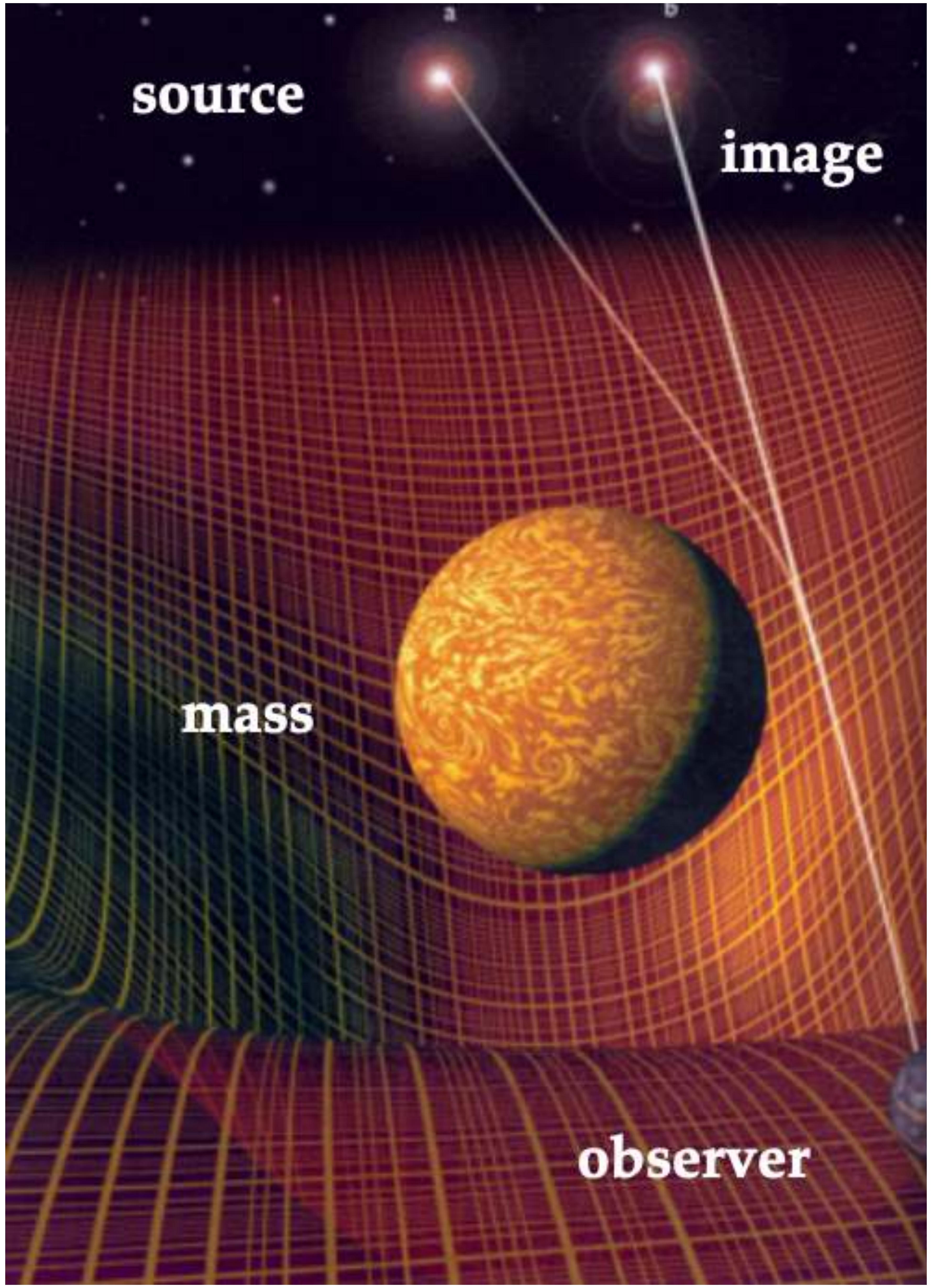
- **Strong gravitational lensing:** If the bending produces multiple images of the galaxy and/or arcs.
- **Weak gravitational lensing:** If the bending is small, the image of galaxies are distorted, stretched and magnified in small amounts. The distortion can be quantified with **shear** (shape) and **convergence** (size).

Strong lensing



Weak lensing

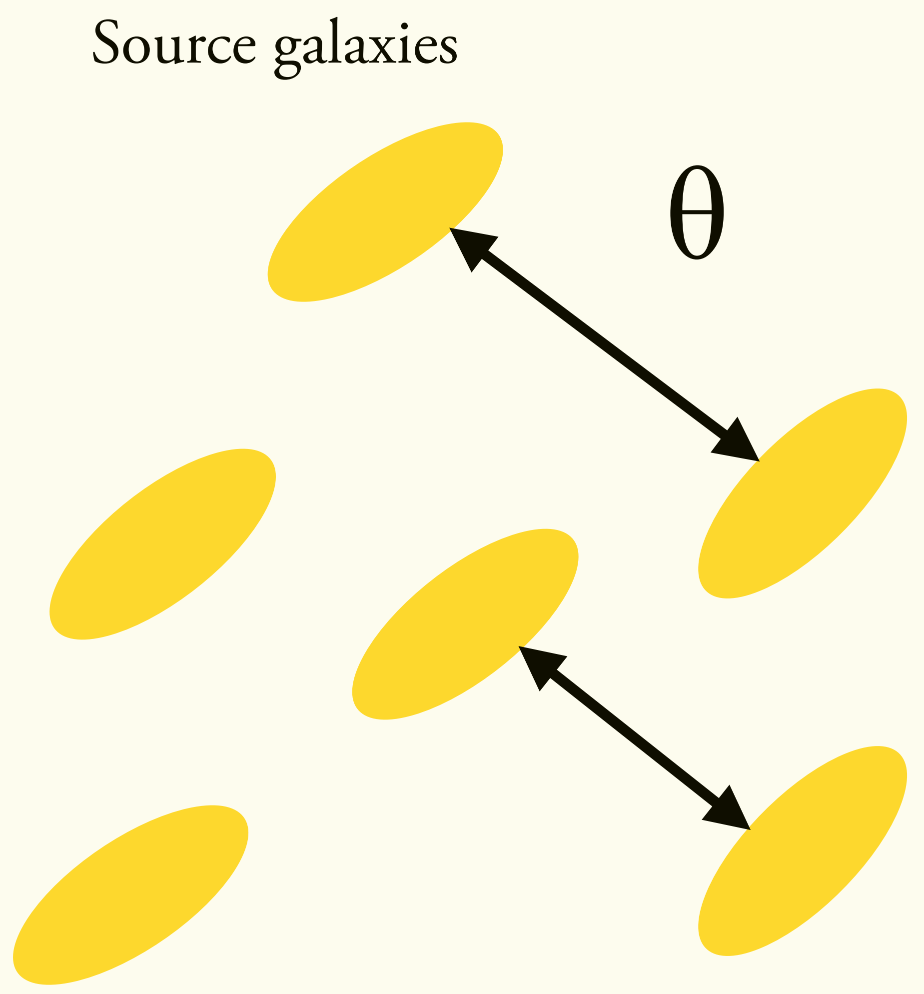




Weak gravitational lensing two-point correlation functions

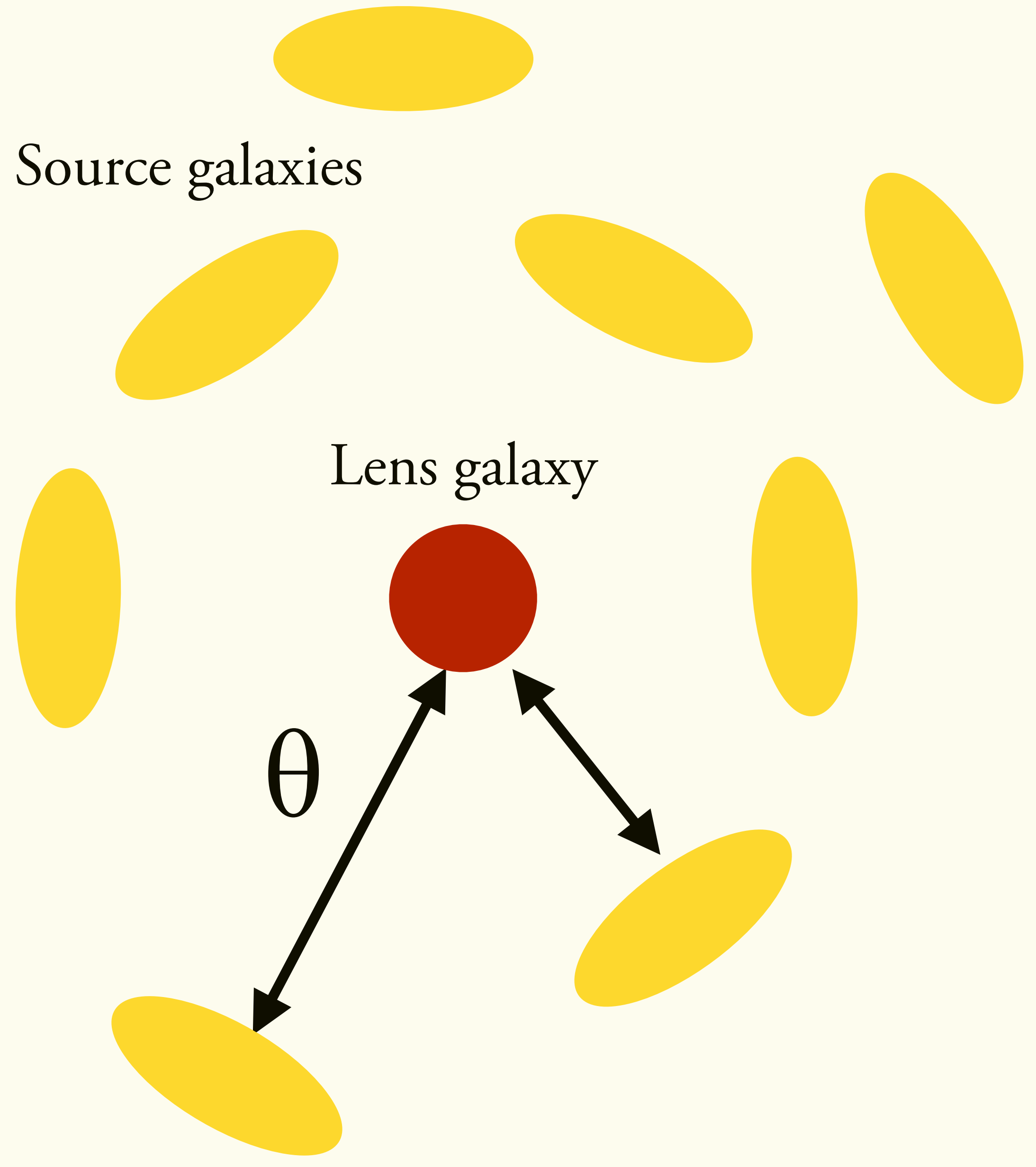
Cosmic shear: source-source correlation

Coherent distortion of galaxy shapes from large-scale structure.

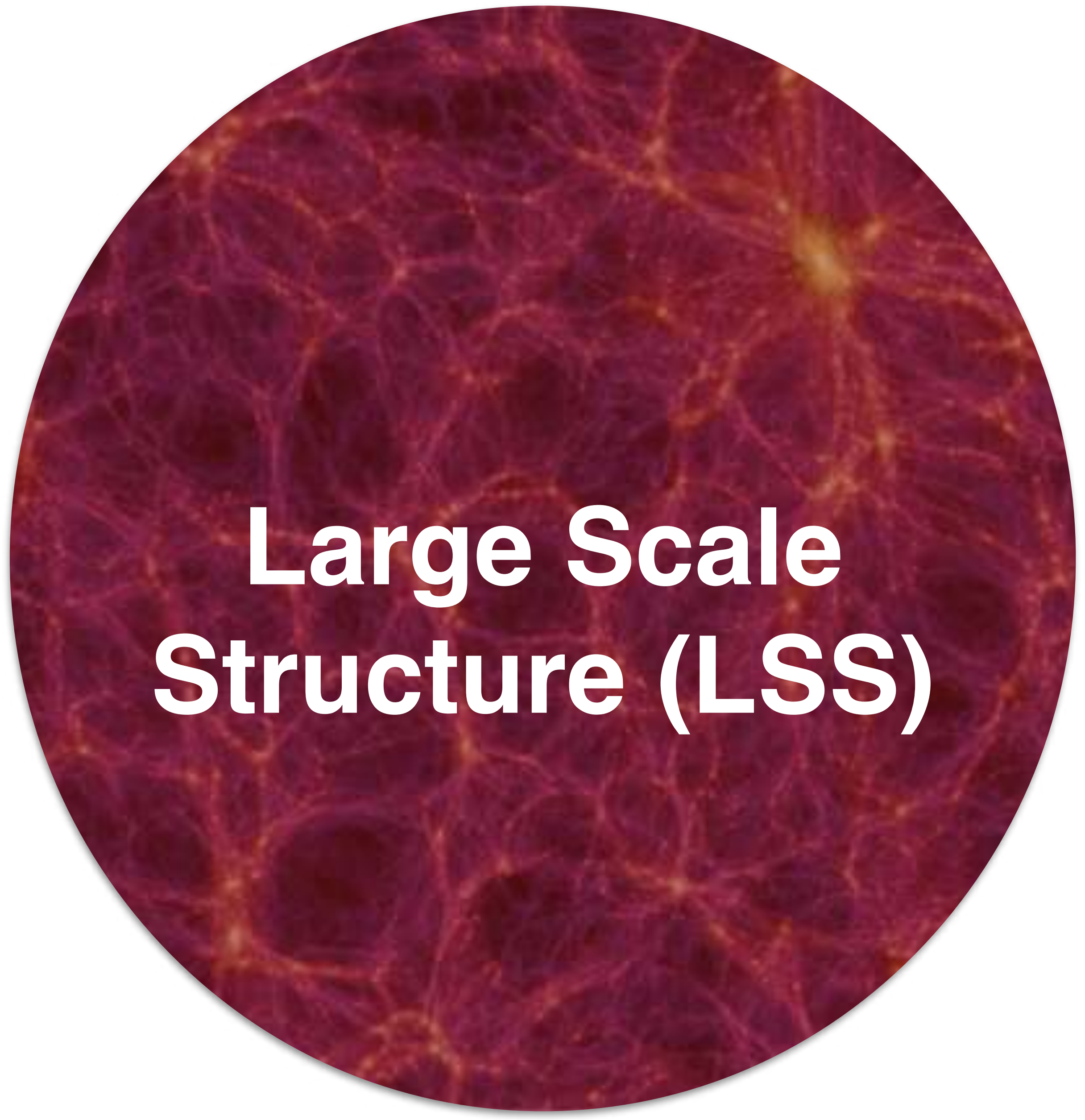


Galaxy-galaxy lensing: lens-source correlation

Tangential distortion of galaxy shapes around individual galaxies in the foreground.



LSS + WL: 3x2pt analysis

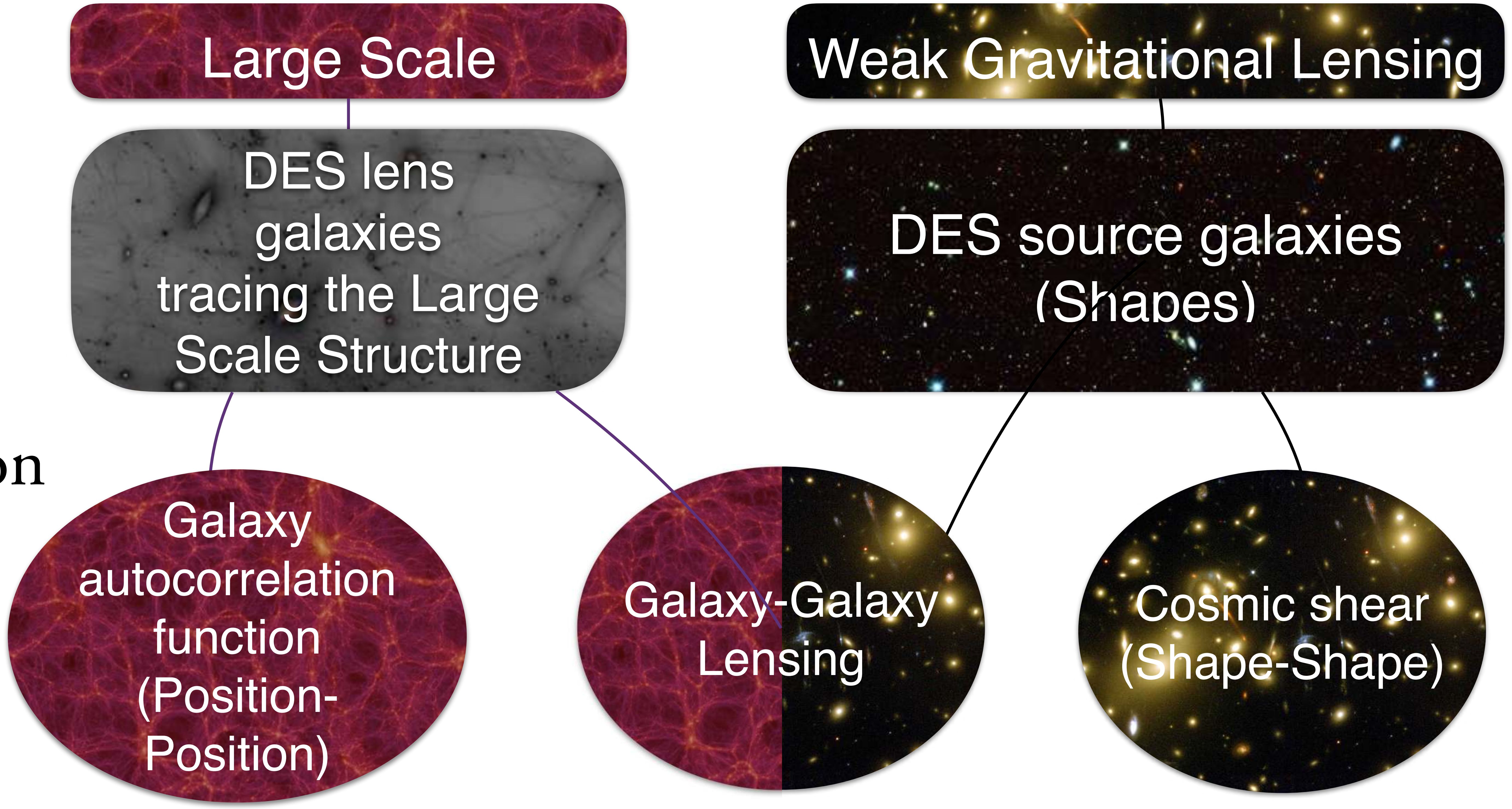


+

LSS + WL

3x2pt analysis

- Using two galaxy samples we can construct three 2-point correlation functions.
- The combination helps break degeneracies and self-calibrate nuisance parameters.
- This kind of analysis has been performed using DES, KiDS and HSC data.



$$\xi_{gg} = \langle \delta_g \, \delta_g \rangle \propto b^2 \, \langle \delta_m \, \delta_m \rangle$$

$$\xi_{gm} = \langle \delta_g \, \delta_m \rangle \propto b \, \langle \delta_m \delta_m \rangle$$

$$\xi_{mm} = \langle \delta_m \, \delta_m \rangle$$

LSS + WL

3x2pt analysis

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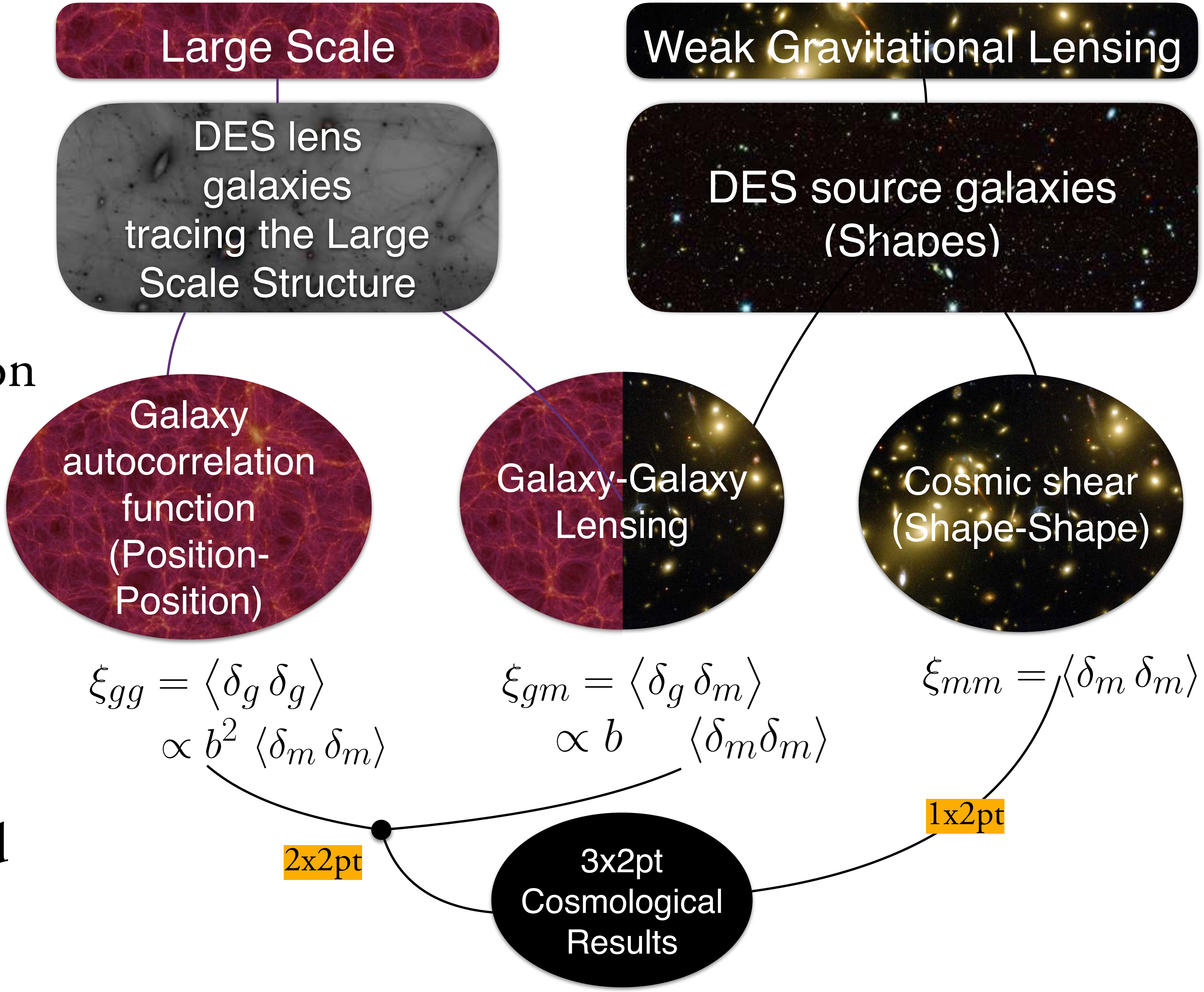
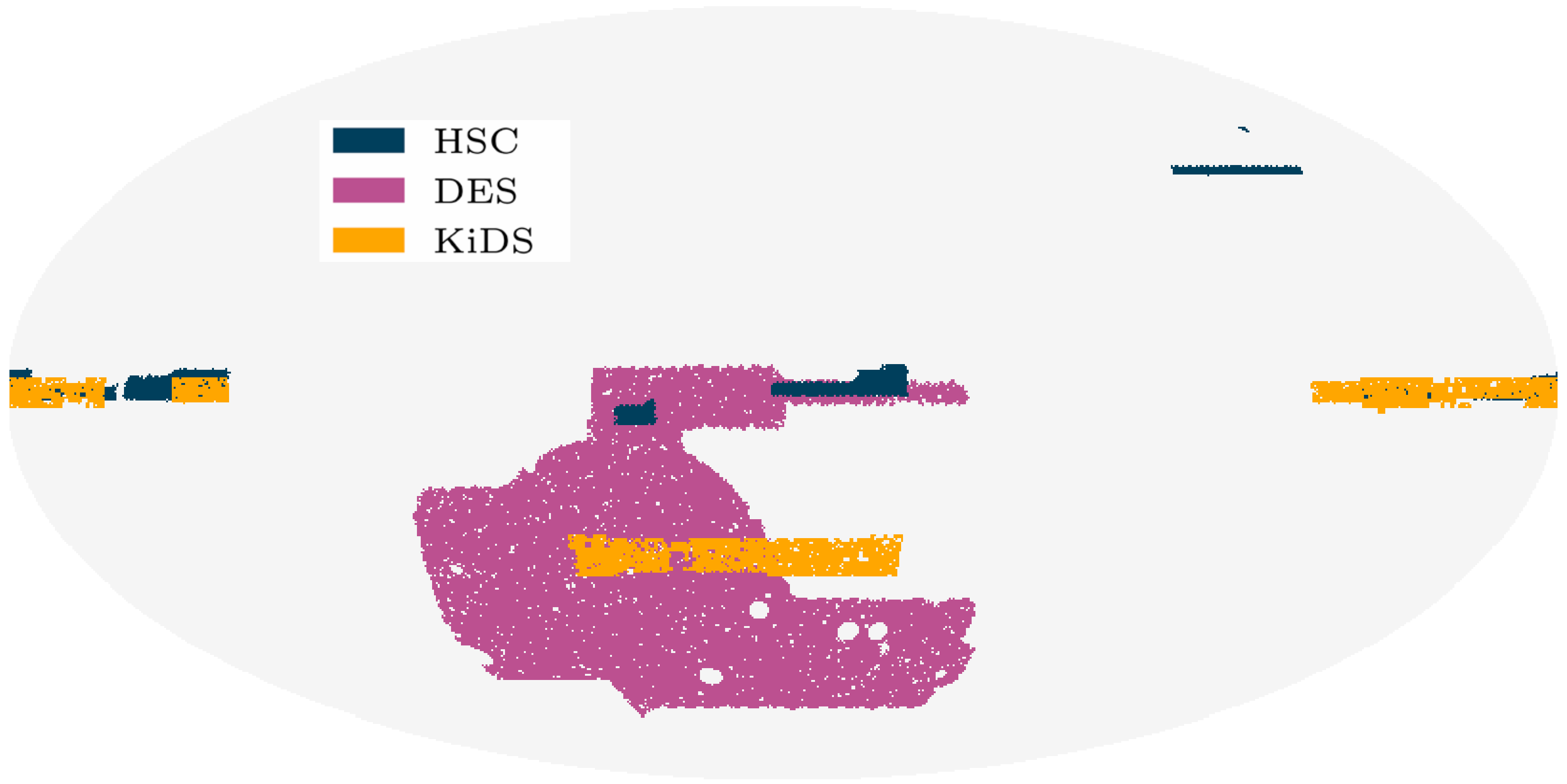


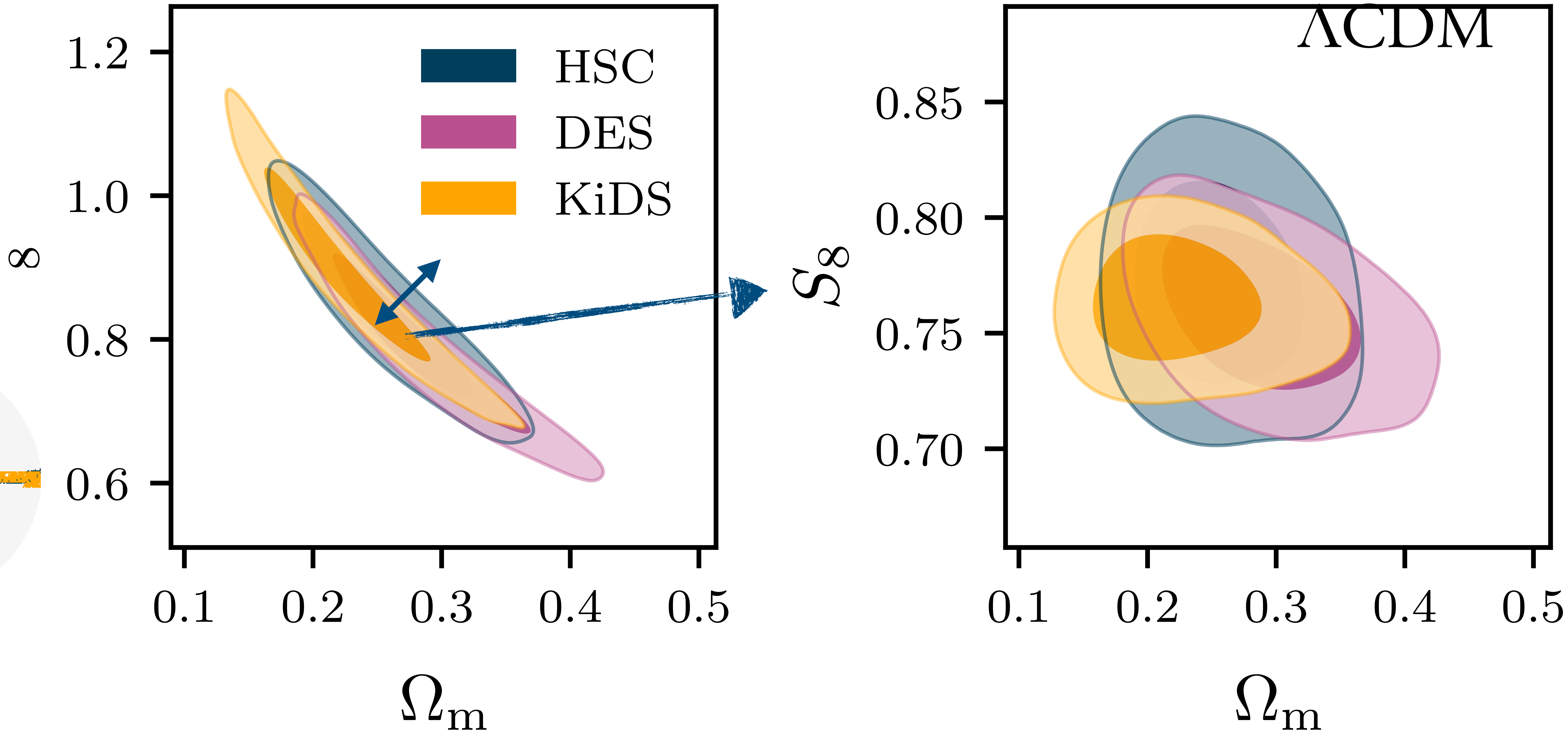
Agreement between surveys: *cosmic shear only*

$$\sigma_8^2 = \frac{1}{2\pi^2} \int k^2 P(k) \left[\frac{3\,j_1(kR)}{kR}\right]^2 dk$$

$$S_8 \equiv \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{0.5}$$

- All cosmic shear results from Stage III surveys are consistent.



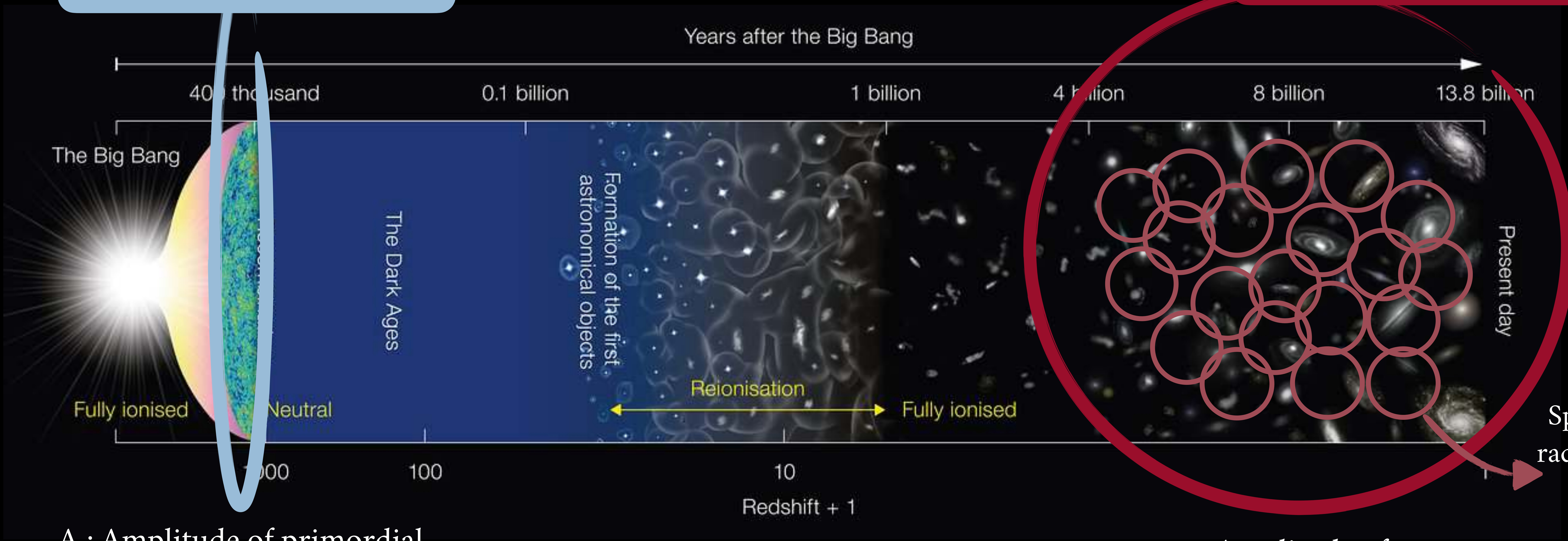


Testing ΛCDM

Is the late time clustering compatible with the ΛCDM prediction assuming initial conditions from the CMB?

CMB experiments observe the early Universe

Galaxy surveys observe the late Universe



Spheres with radius 8Mpc/h

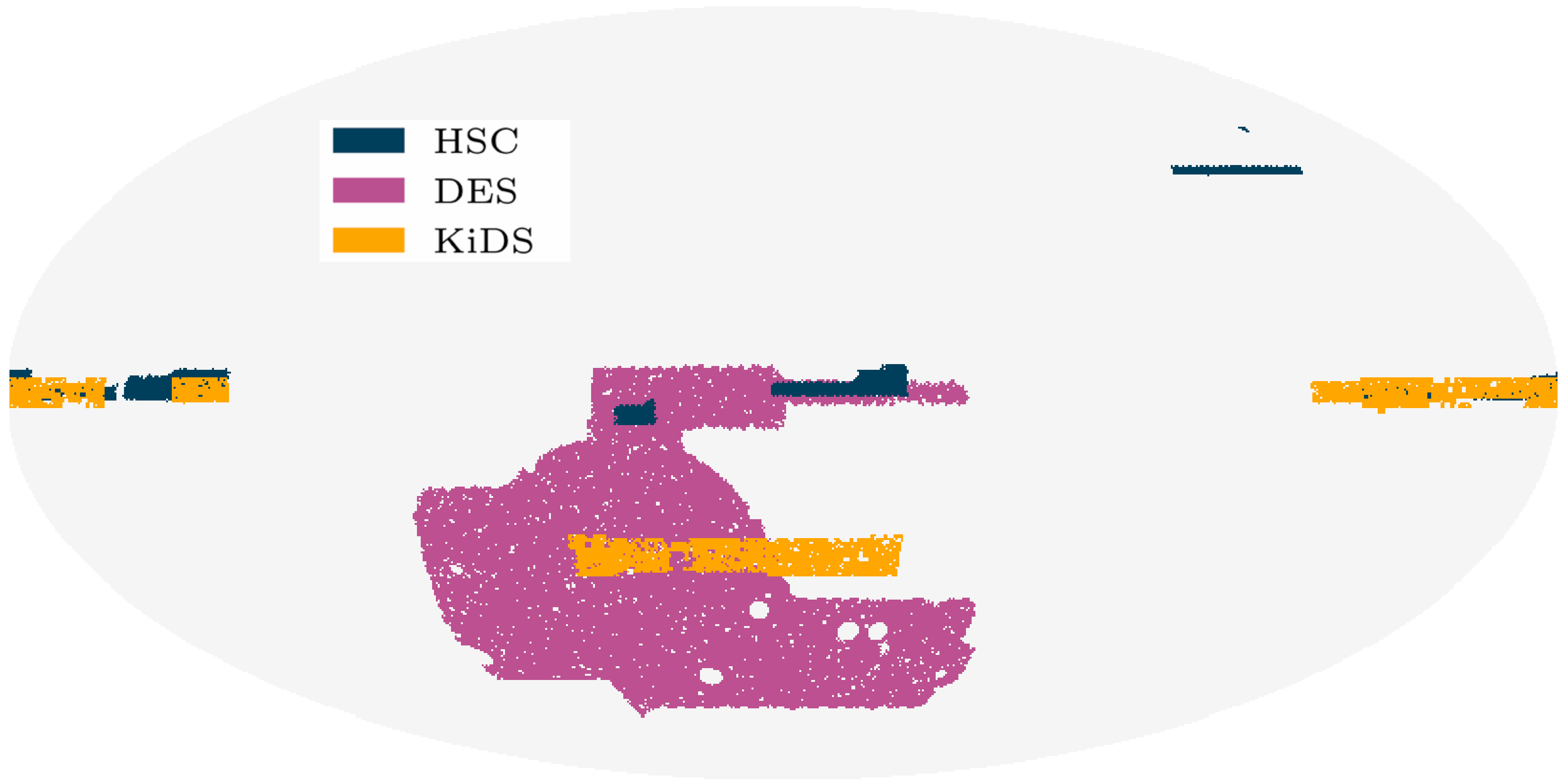
A_s: Amplitude of primordial scalar density fluctuations.

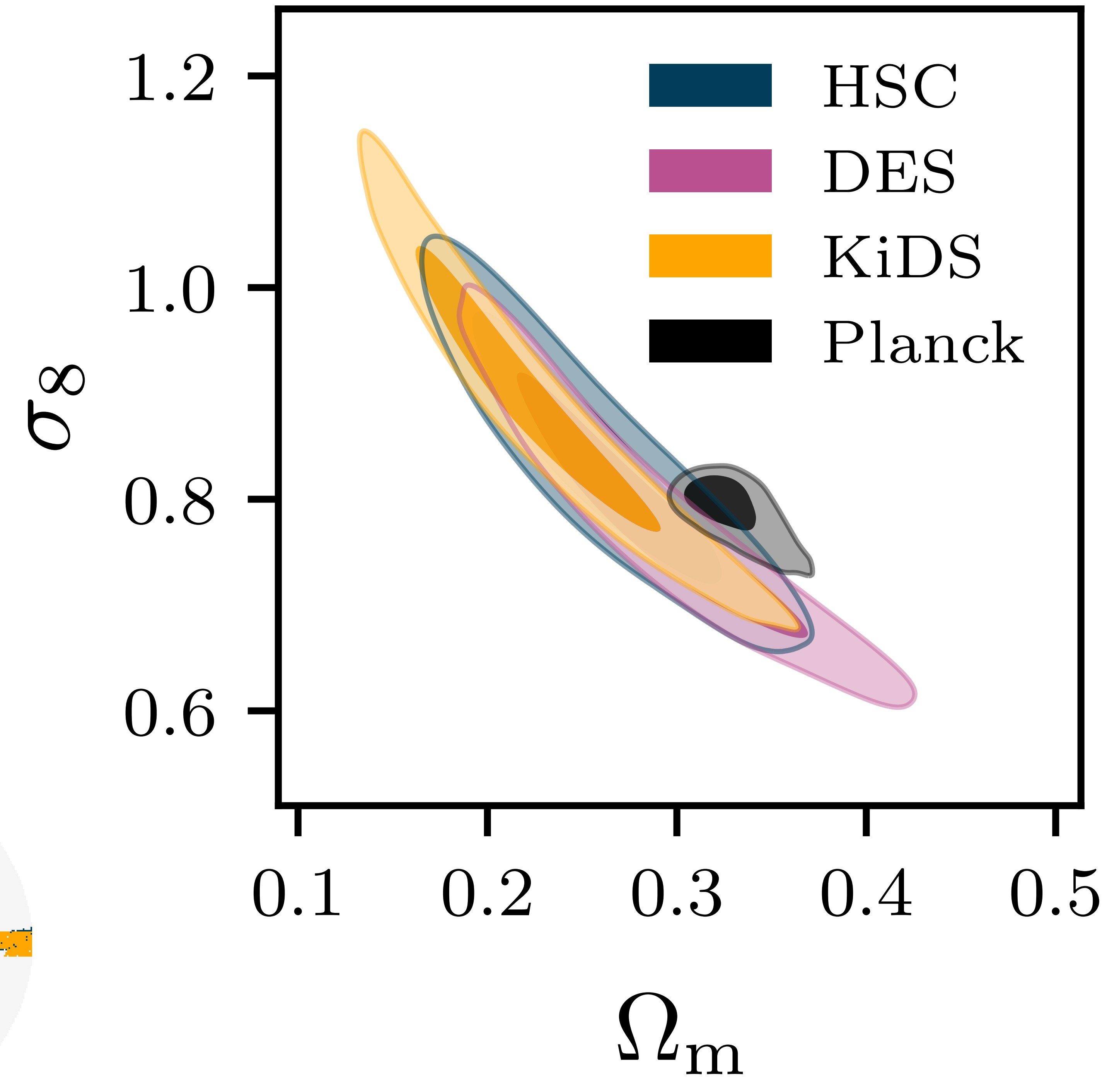
Image credit: NAOJ

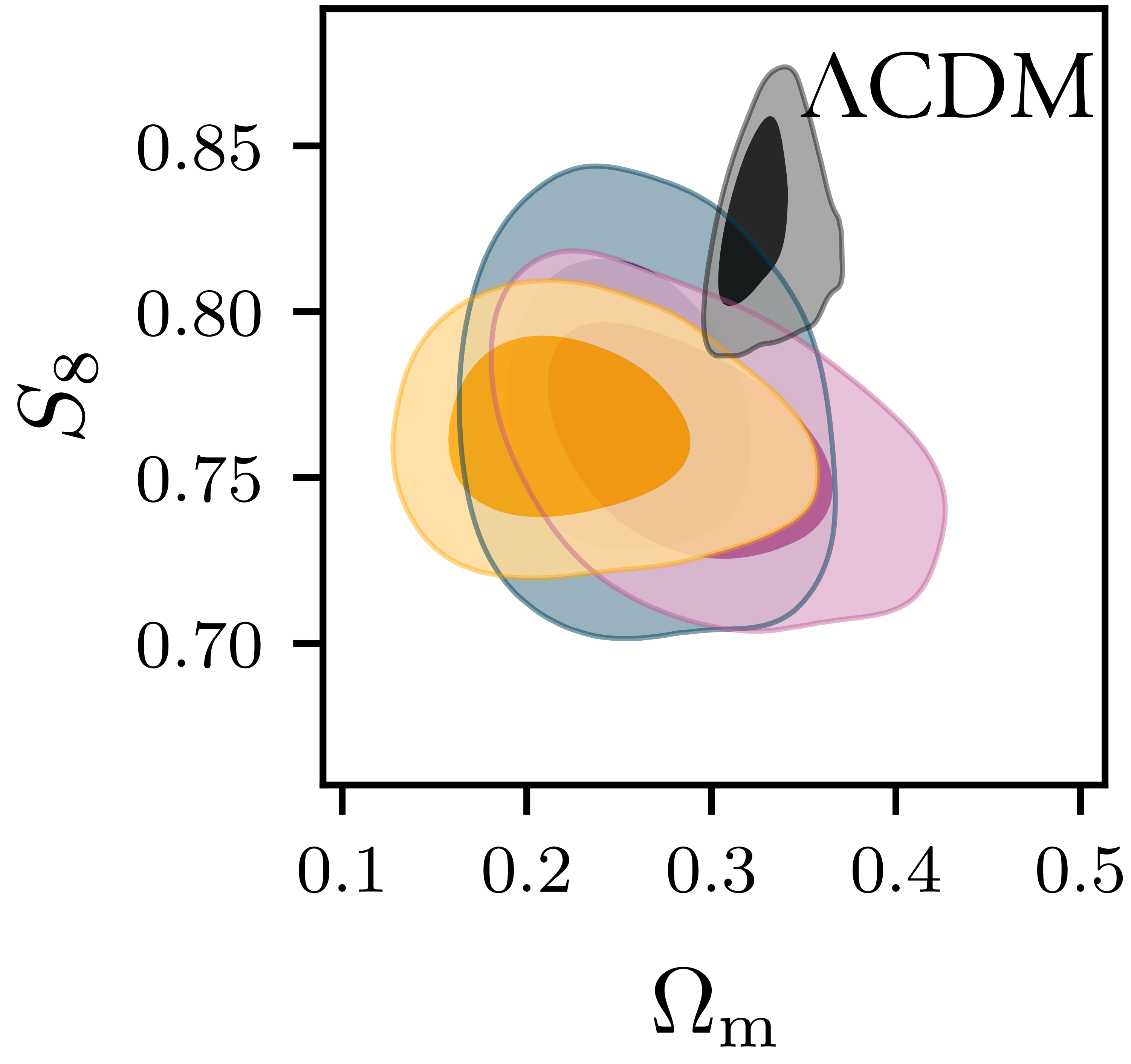
σ_8: Amplitude of mass fluctuations today.

Agreement between surveys: *cosmic shear only*

- All cosmic shear results from Stage III are about 2σ lower than the expected result assuming LCDM.





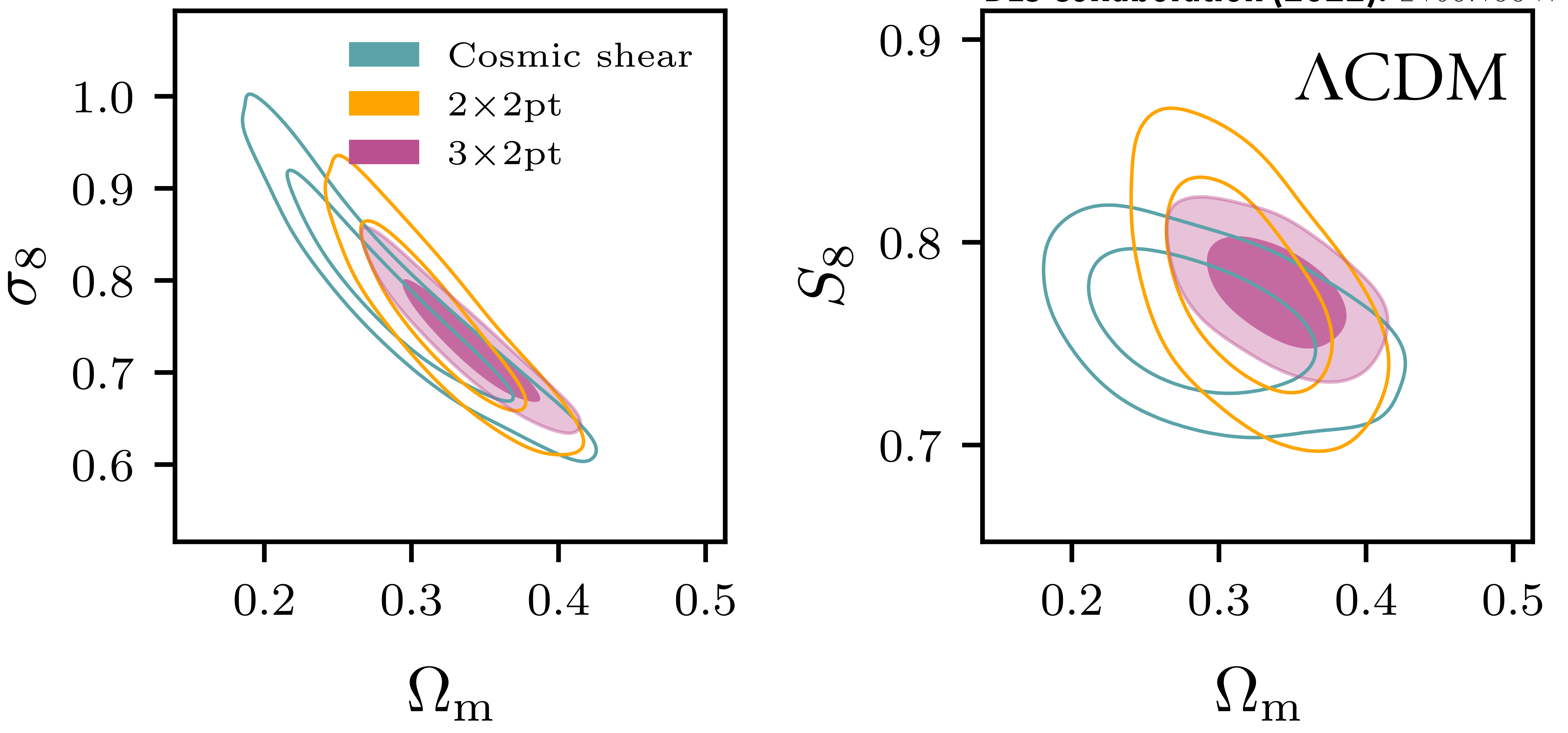


3x2pt combination: DES Y3 results

We find consistency between cosmic shear and 2x2pt.

- Cosmic shear more sensitive to clustering amplitude.
- Galaxy clustering and galaxy-galaxy lensing more sensitive to total matter density.

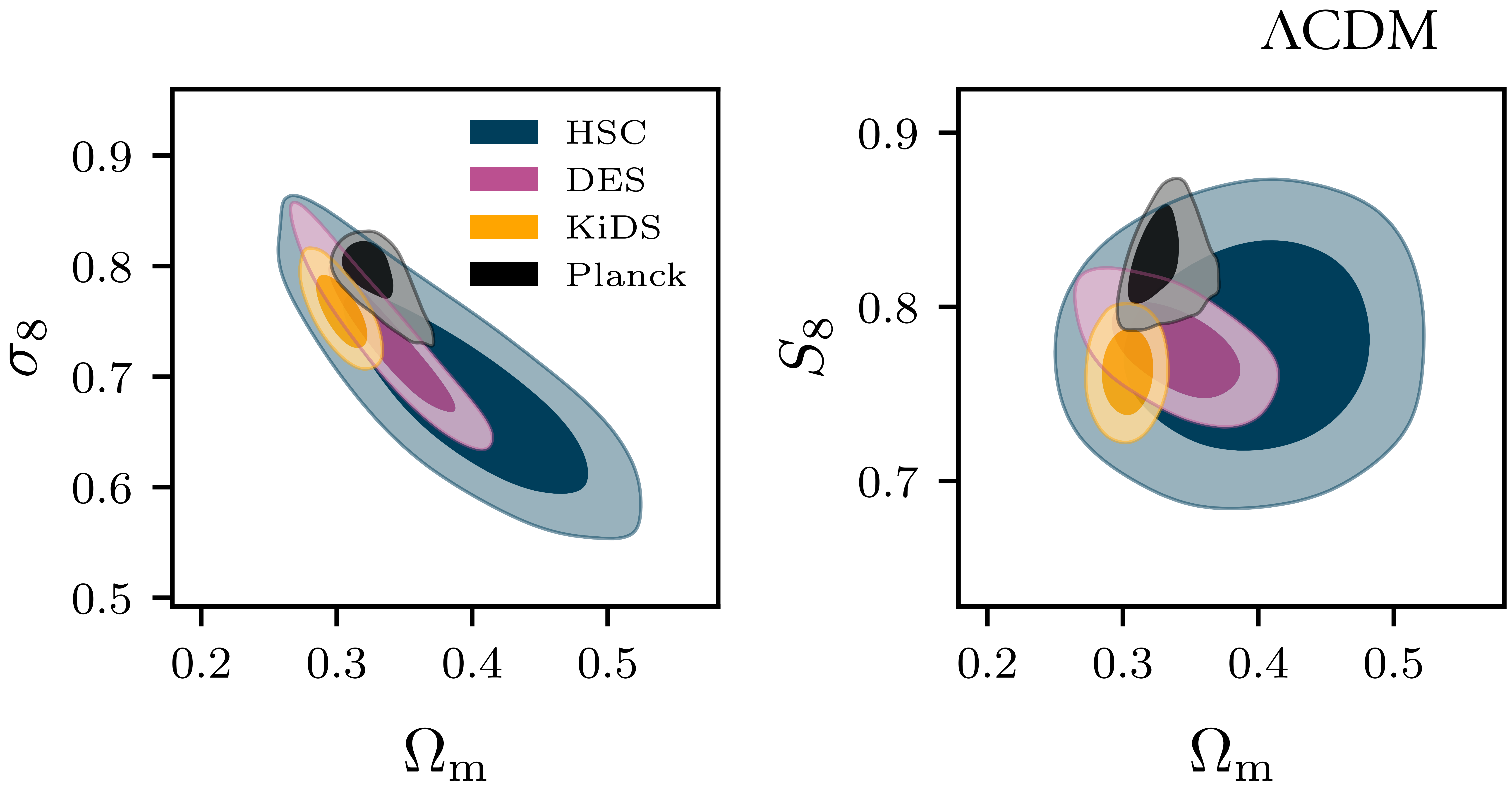
DES Collaboration (2022): 2105.13549



Late time vs early time comparison

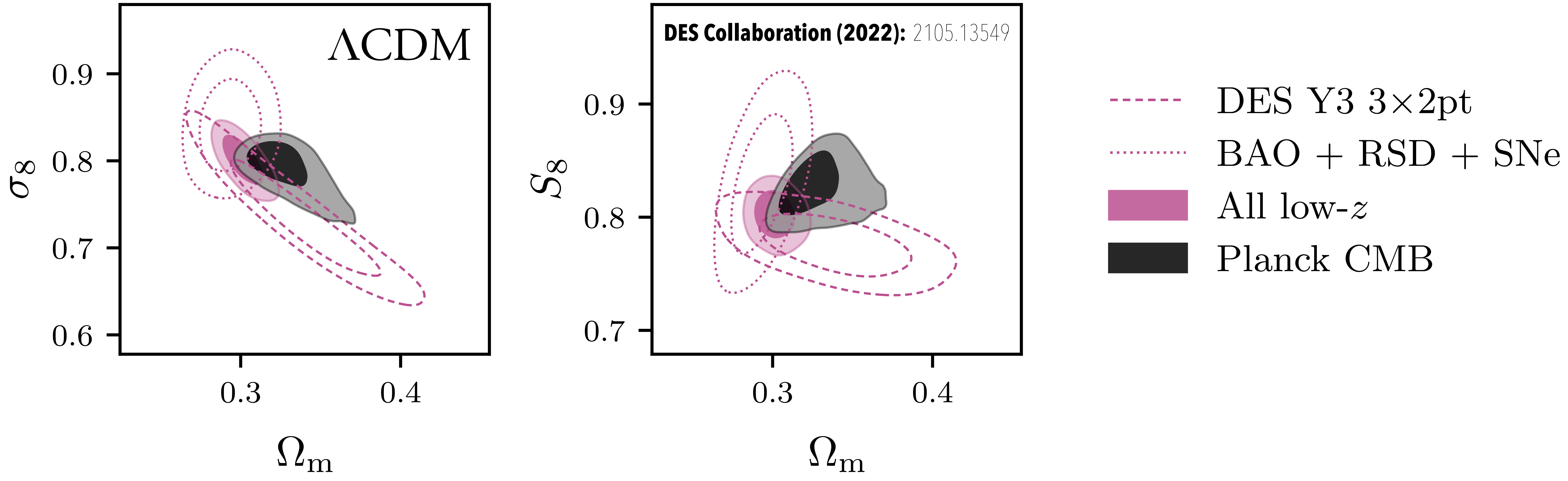
- Planck and DES Y3 are consistent assuming the ΛCDM model (1.5σ), although the clustering amplitude is lower for DES Y3 than Planck.

- KiDS is ~2σ below Planck.



3x2pt in context: *Low redshift Universe constraints*

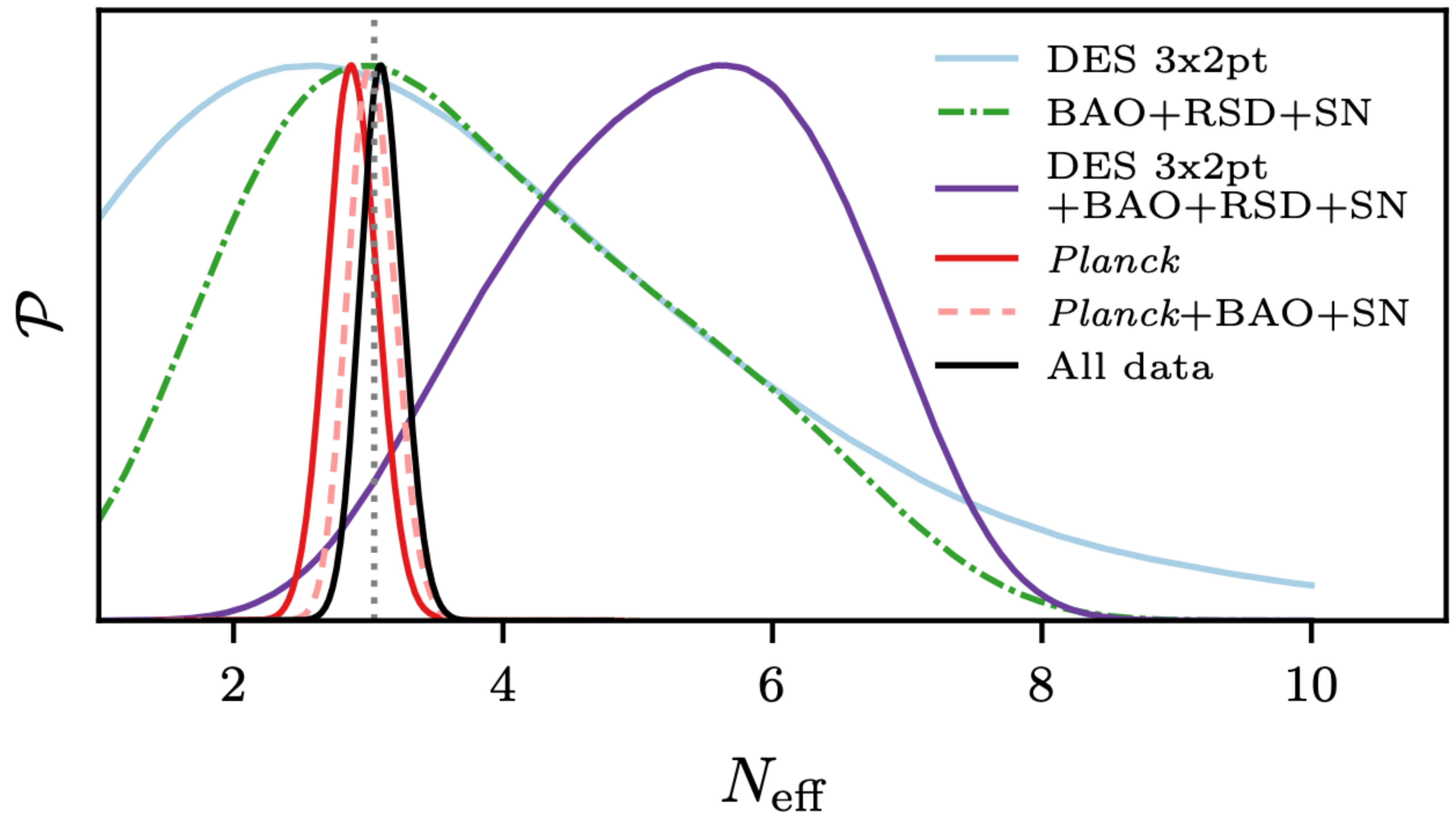
- In ΛCDM, 3x2pt mostly helps in the σ_8-Ω_m plane.
- When combined with other external redshift probes (*Pantheon SNe IA, BOSS BAO, BOSS RSD*), they are also consistent (0.9σ), with smaller uncertainties.



Work led by Jessie Muir and Agnes Ferte

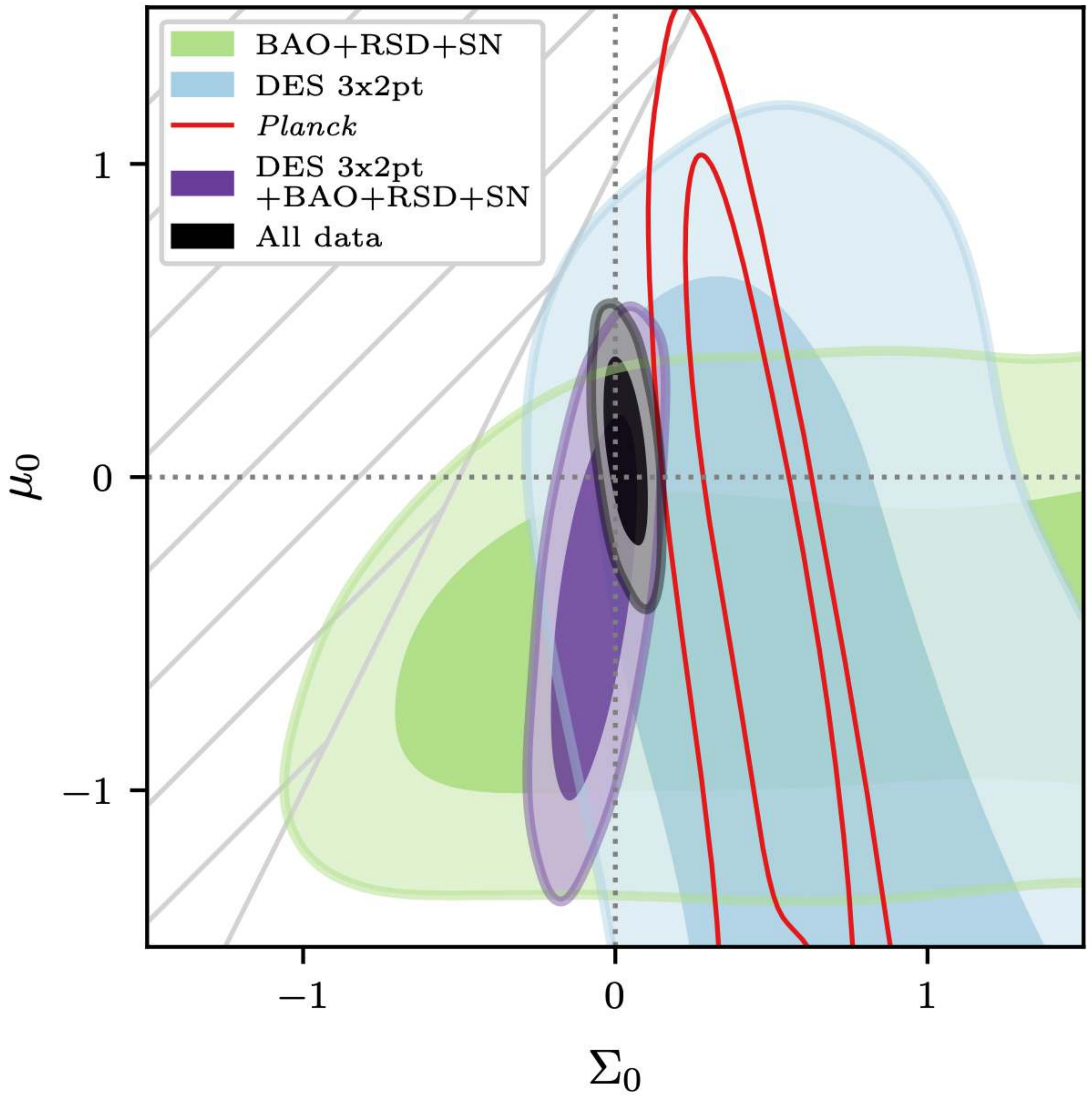
DES Y3 results:
Other extended models

Marginalized posterior on the number of relativistic species.



Modified gravity

DES Collaboration (2022): arXiV: 2207.05766



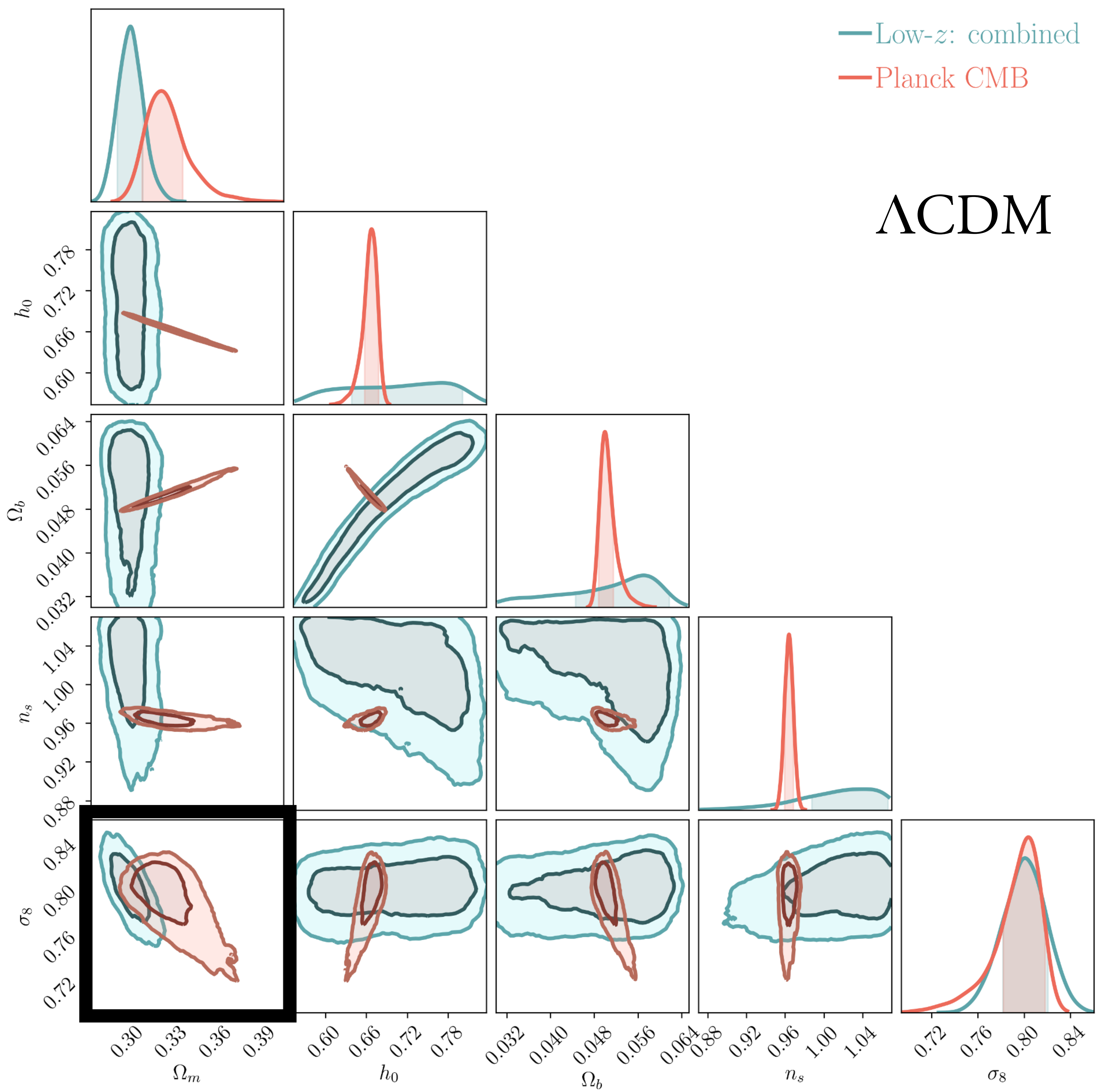
Stress testing ΛCDM:

Looking at the full parameter space

- When we look at the full parameter space we can see that only two parameters are constrained to a similar precision as Planck. —>We still have a long way to go to reach the same precision in the late time Universe.

- We have work to do to be able to do an even more compelling test.

DES Collaboration (2022) 2105.13549



Thoughts on current and future directions

3 ways to move forward:

What am I doing?

How can we get more precise constraints from the late-time Universe?

Combining more probes from the late-time Universe

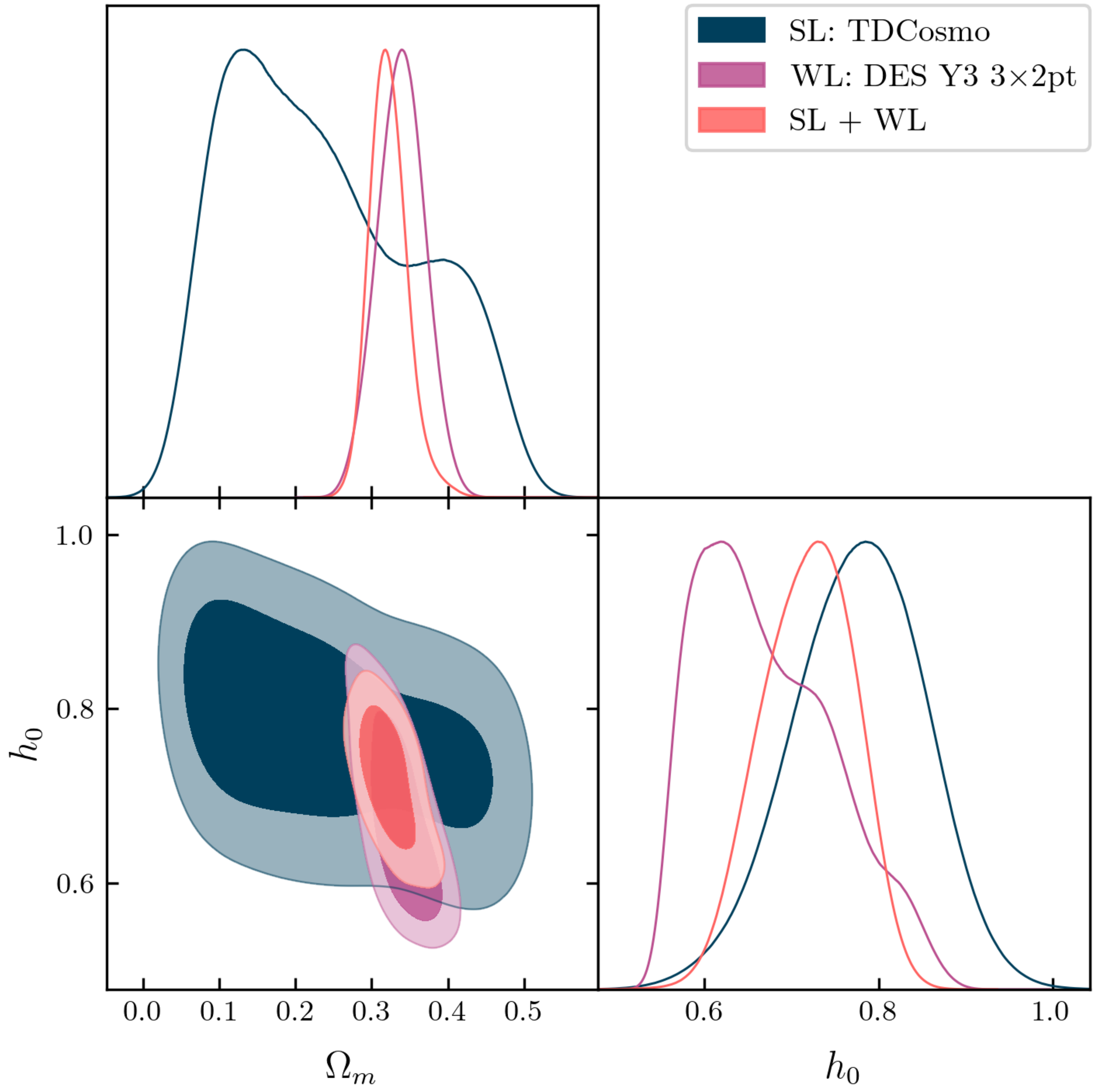
Exploring new combinations of data:
(i) Strong Lensing + Weak Lensing
(ii) Cosmological Constraints from Combining Galaxy Surveys and Gravitational Wave Observatories

Gagnon, Anbajagane, Prat et al. (2023): *2312.16289*

Strong Lensing + Weak Lensing

- Strong Lensing (SL) + Weak Lensing (WL) is an example of how we can do better by combing emerging synergetic probes.
- SL is sensitive to H_0, and WL is sensitive to $\Omega_m + \sigma_8$.

TDCOSMO likelihood publicly available in CosmoSIS now thanks to work with Martin Millon (KIPAC) & Simon Birrer (Stony Brook)



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    Gagnon, Anbajagane, Prat et al. (2023): *2312.16289*

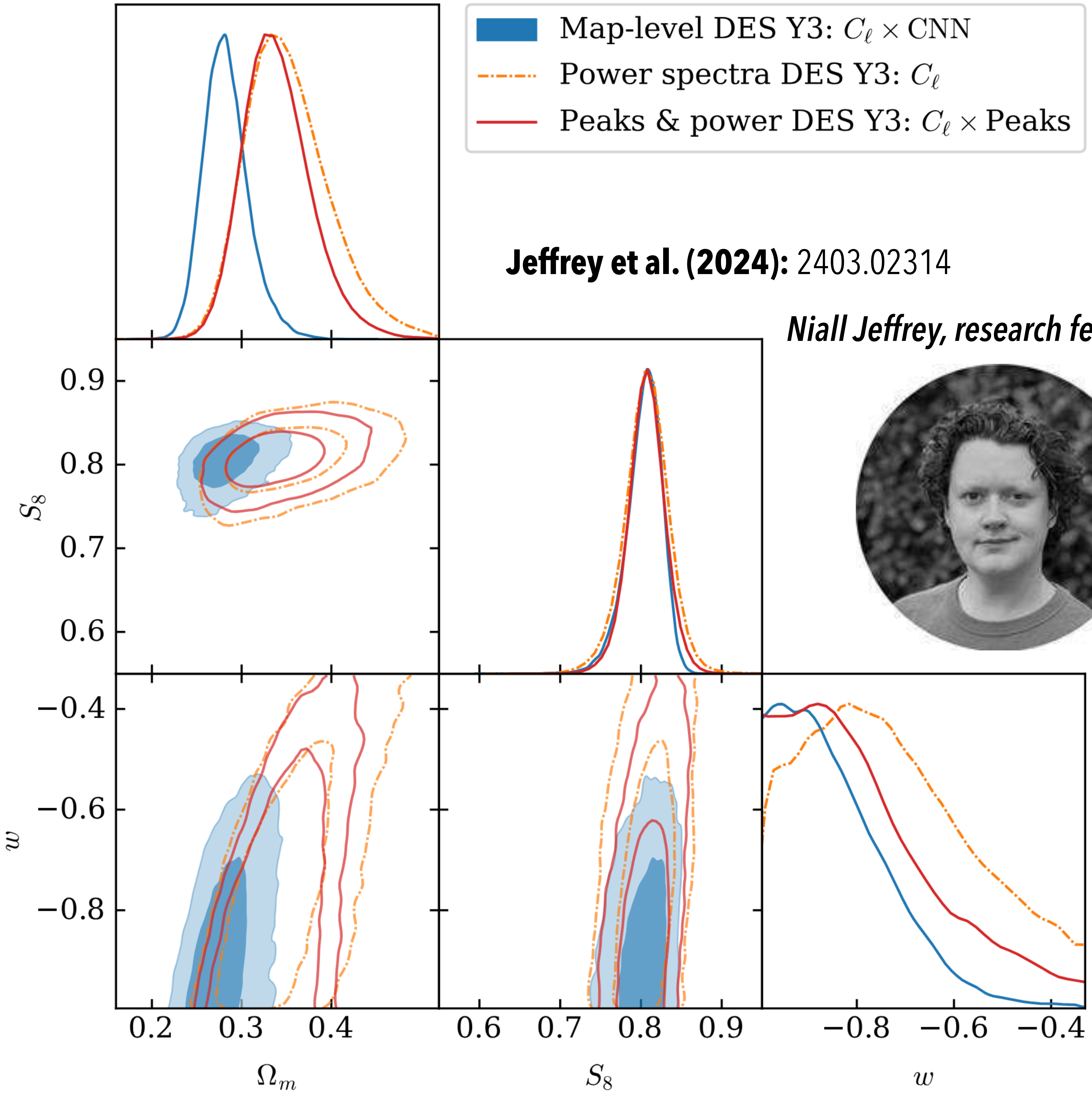
- **Extracting more information from the same data**
  - **Capture non-gaussian information from the late-time Universe with higher-order statistics:**
    (i) Persistent homology applied to DES Y3 WL mass maps
    (ii) Contrastive learning applied to DES Y3 WL mass maps

    (i) *Prat et al. (in prep)*
    (ii) Ongoing

- **With more data**

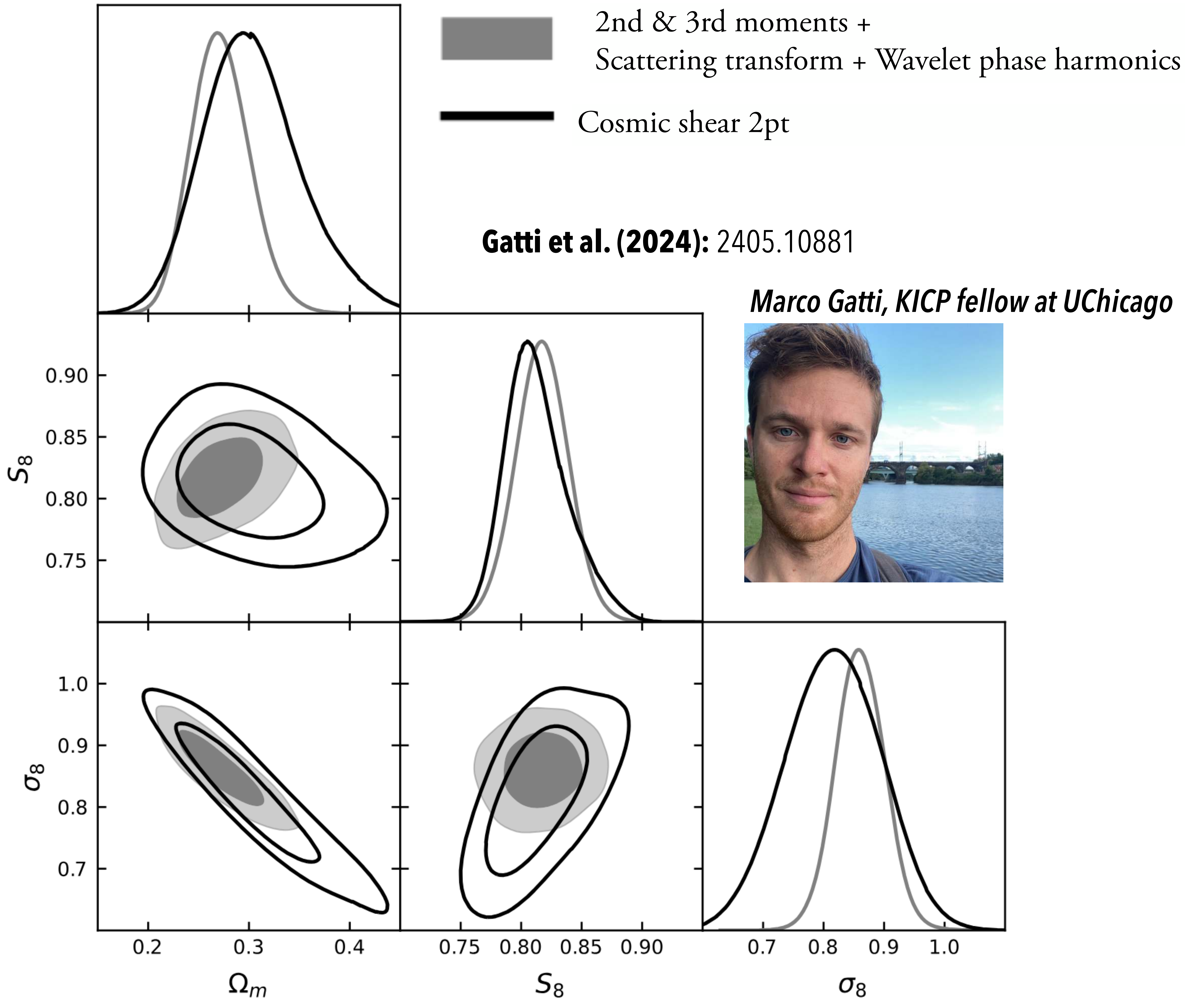
Where is the gain?

Improvement is on the 2D plane, S_8 is not a good metric to compare methods anymore



Jeffrey et al. (2024): 2403.02314

Niall Jeffrey, research fellow at UCL



Gatti et al. (2024): 2405.10881

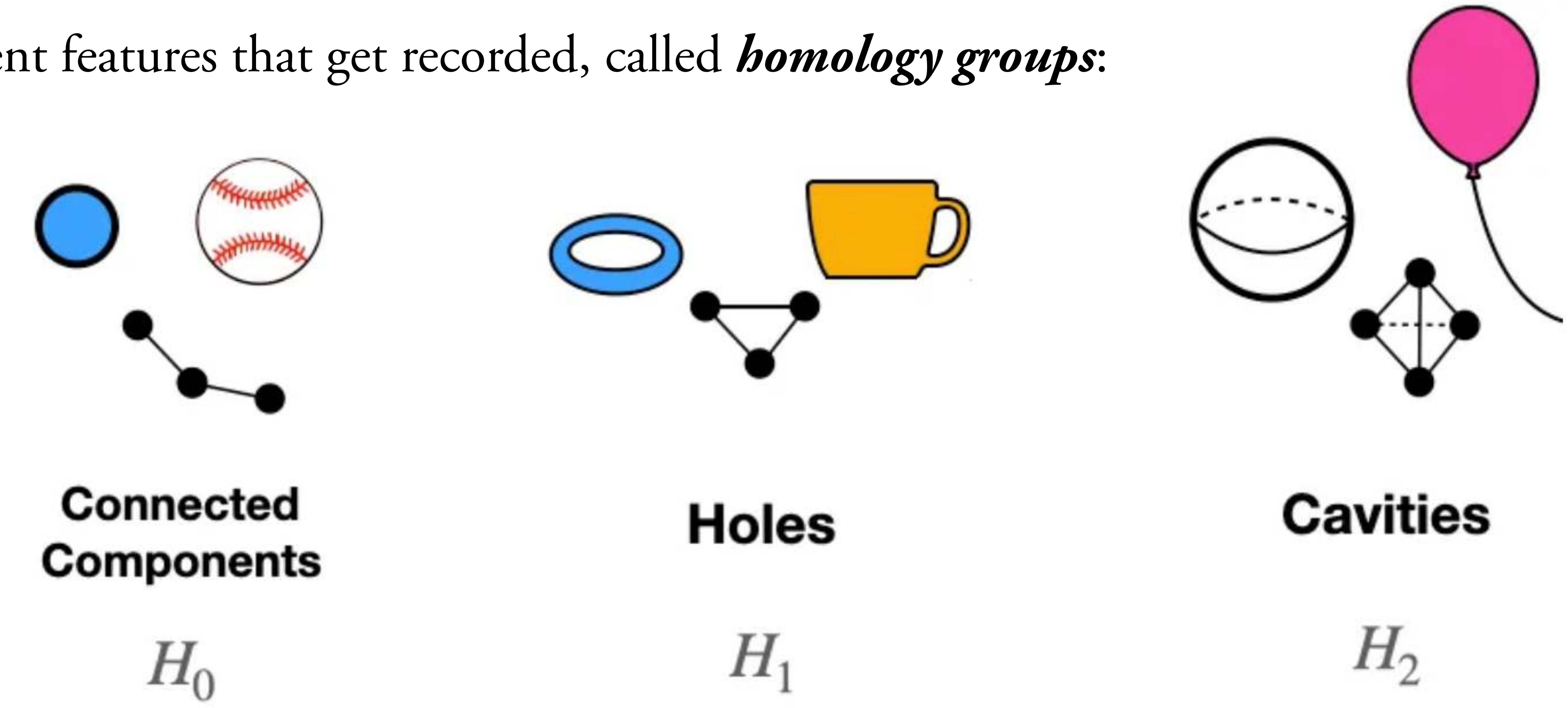
Marco Gatti, KICP fellow at UChicago

Persistent homology

What is it?

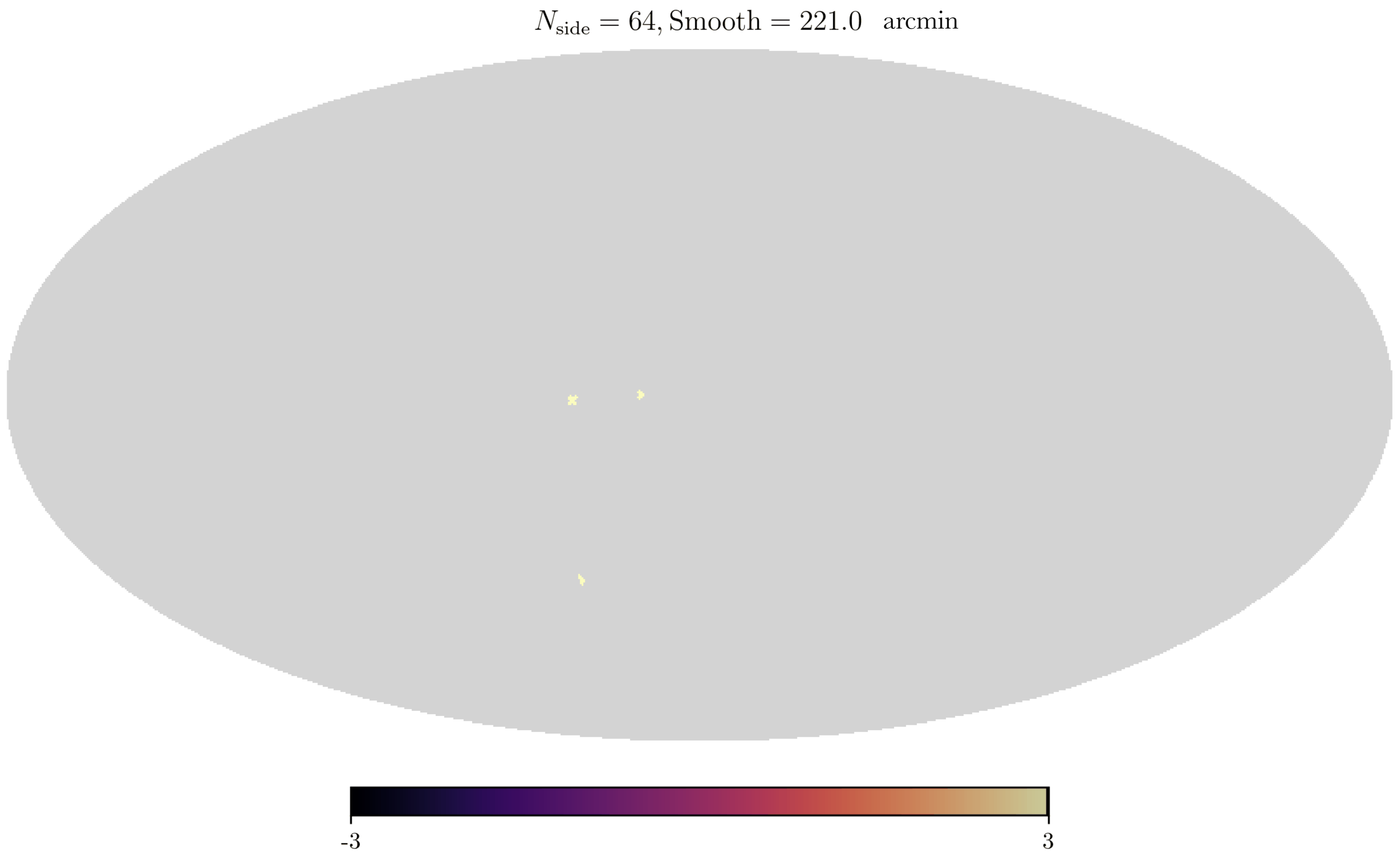
Persistent homology is a method for computing topological features of a space. More persistent features are detected over a wide range of spatial scales and are deemed more likely to represent true features of the underlying space rather than artifacts of sampling, noise, or particular choice of parameters.

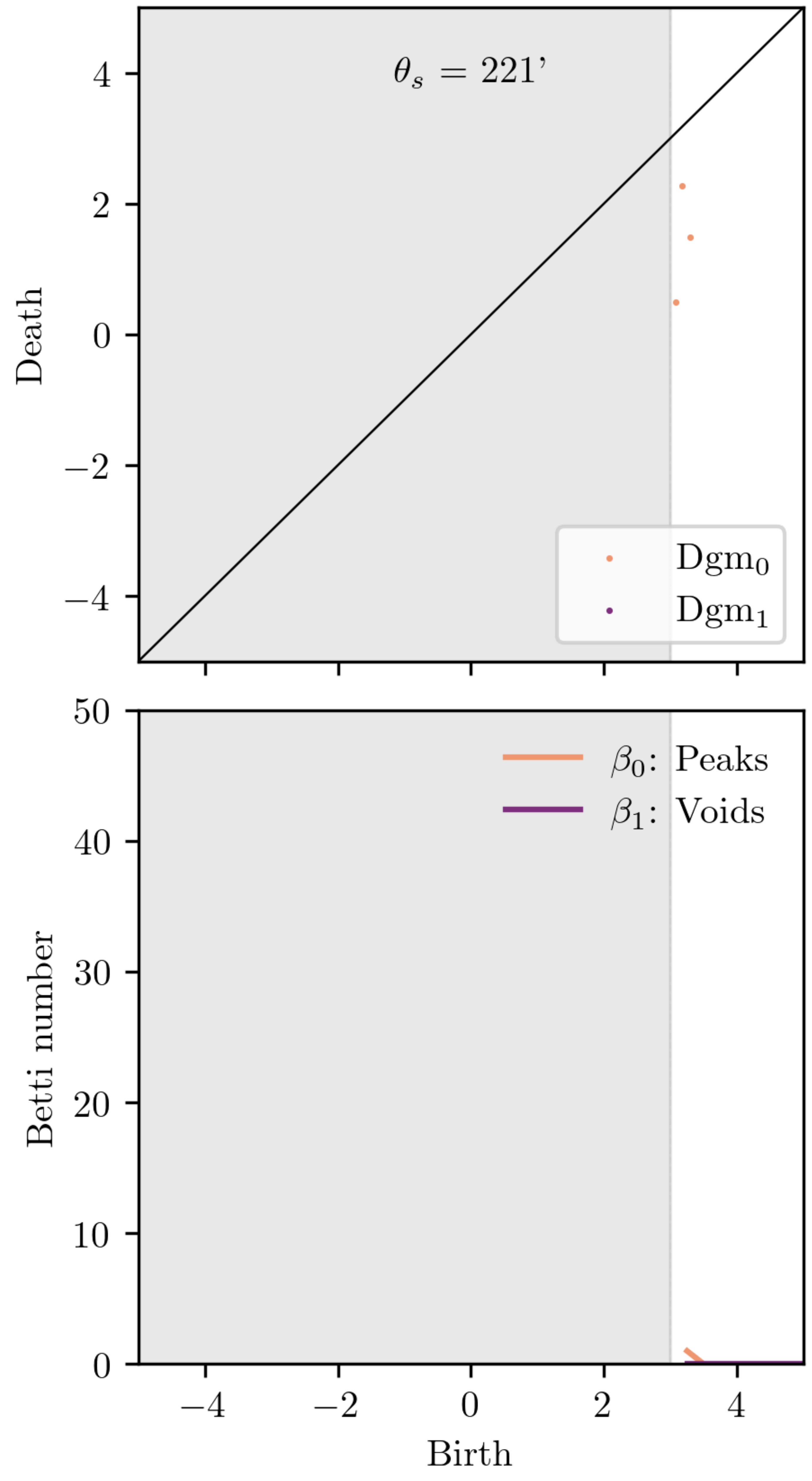
There are different features that get recorded, called ***homology groups***:



Persistent homology

Persistent diagram and Betti numbers

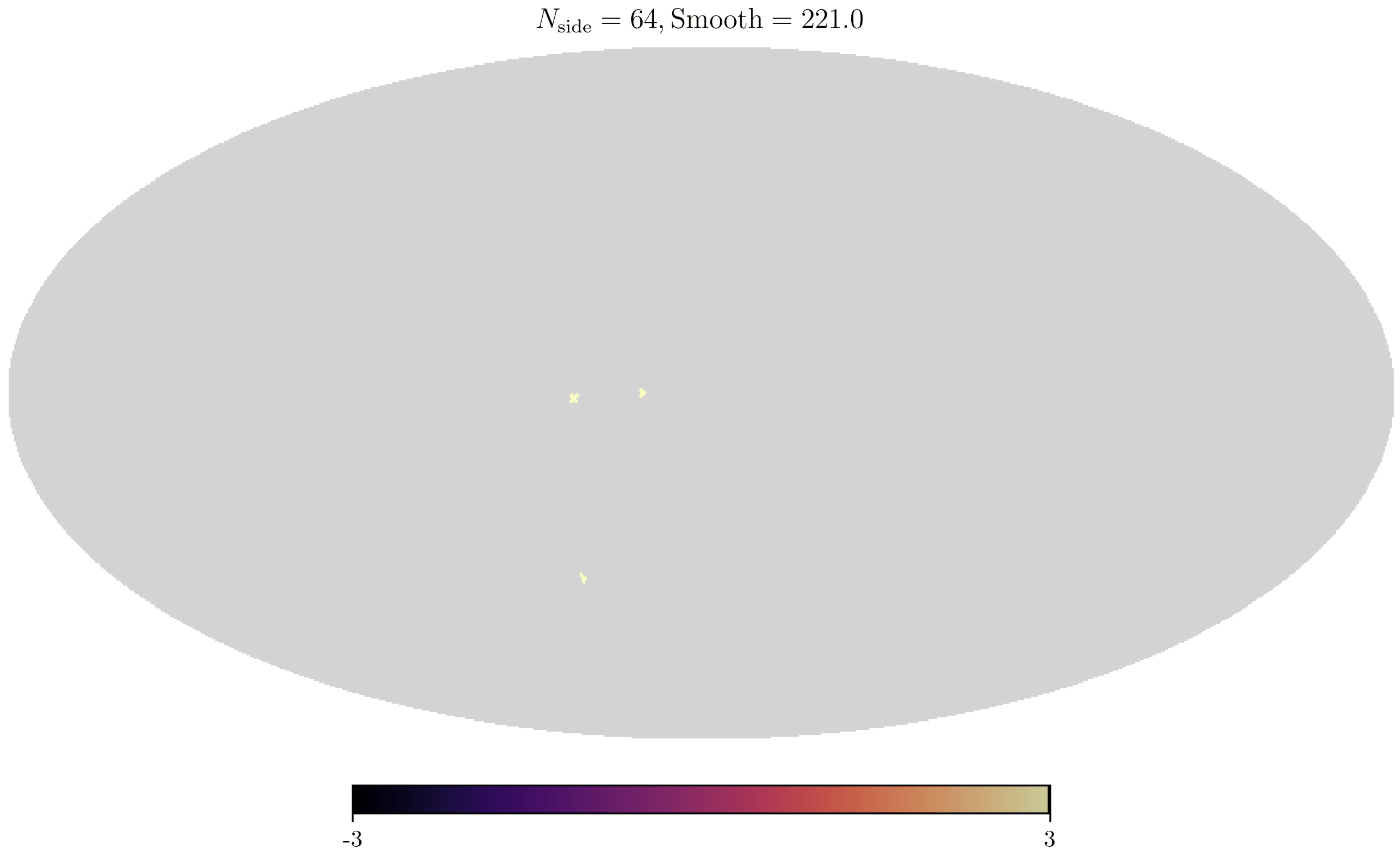


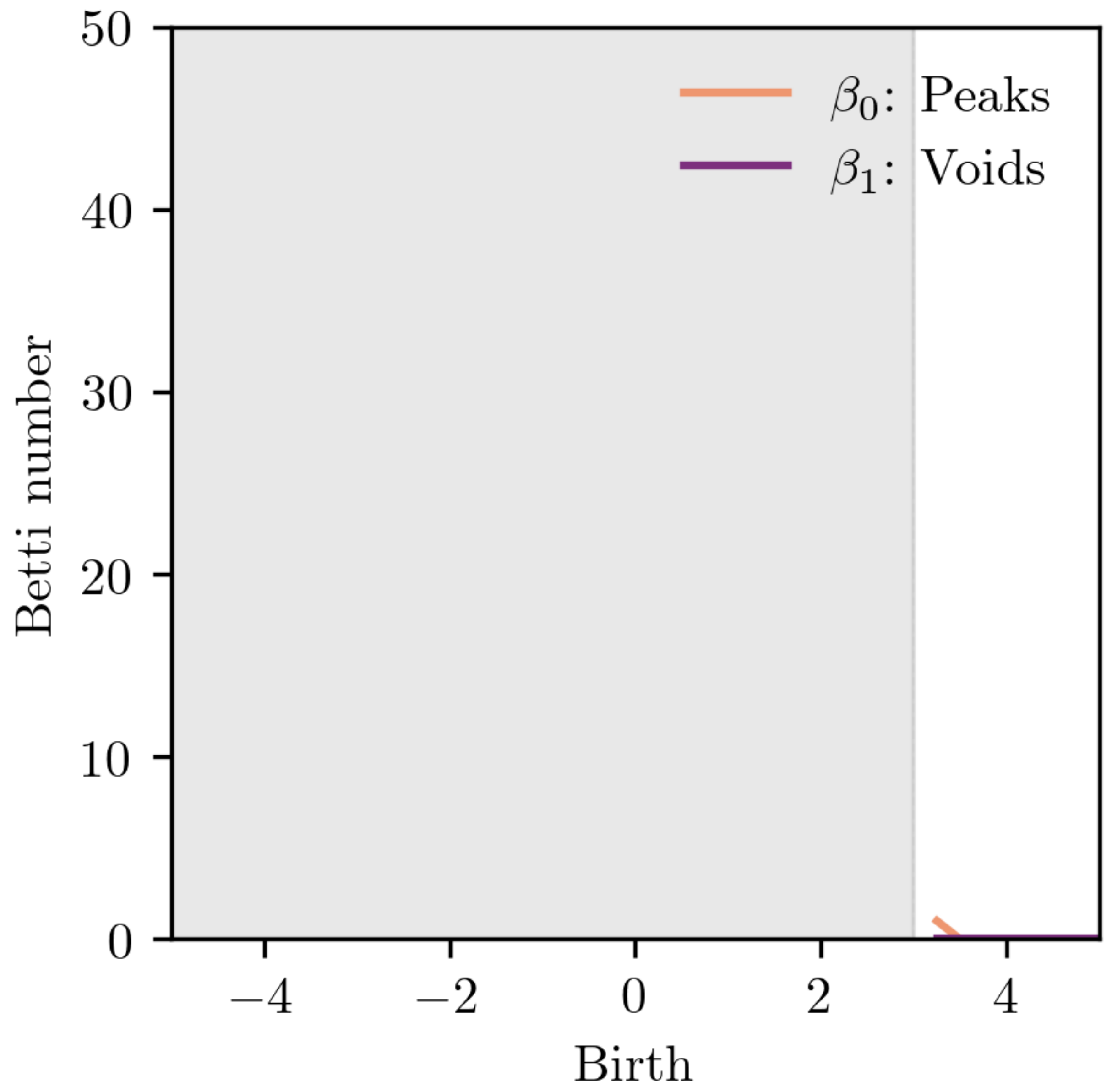


With Marco Gatti (UChicago), Niall Jeffrey (UCL), Pratyush Pranav (Bennett University), Chihway Chang (UChicago), Cyrille Doux (CNRS) ++

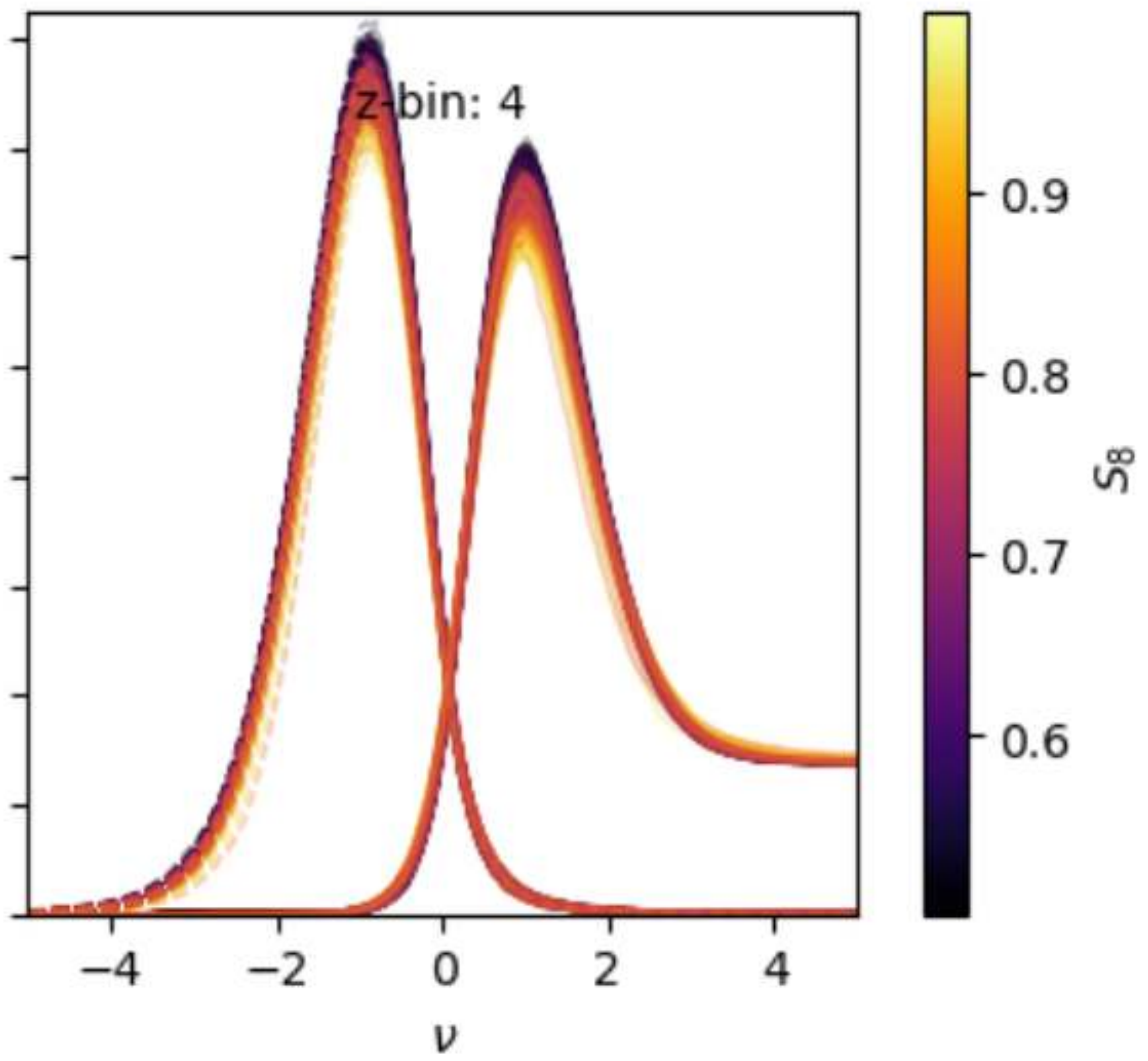
Persistent homology

Filtration





Betti numbers count the number of **connected components** and **holes** that are present above a given threshold ν_0. These are called the 'Betti numbers' β_0 (for connected components) and β_1 (for holes).



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(i) Galaxy-halo connection from galaxy-galaxy lensing
(ii) Weak Gravitational Lensing around Low Surface Brightness Galaxies
(iii) Cosmic filaments on DES Y3 data

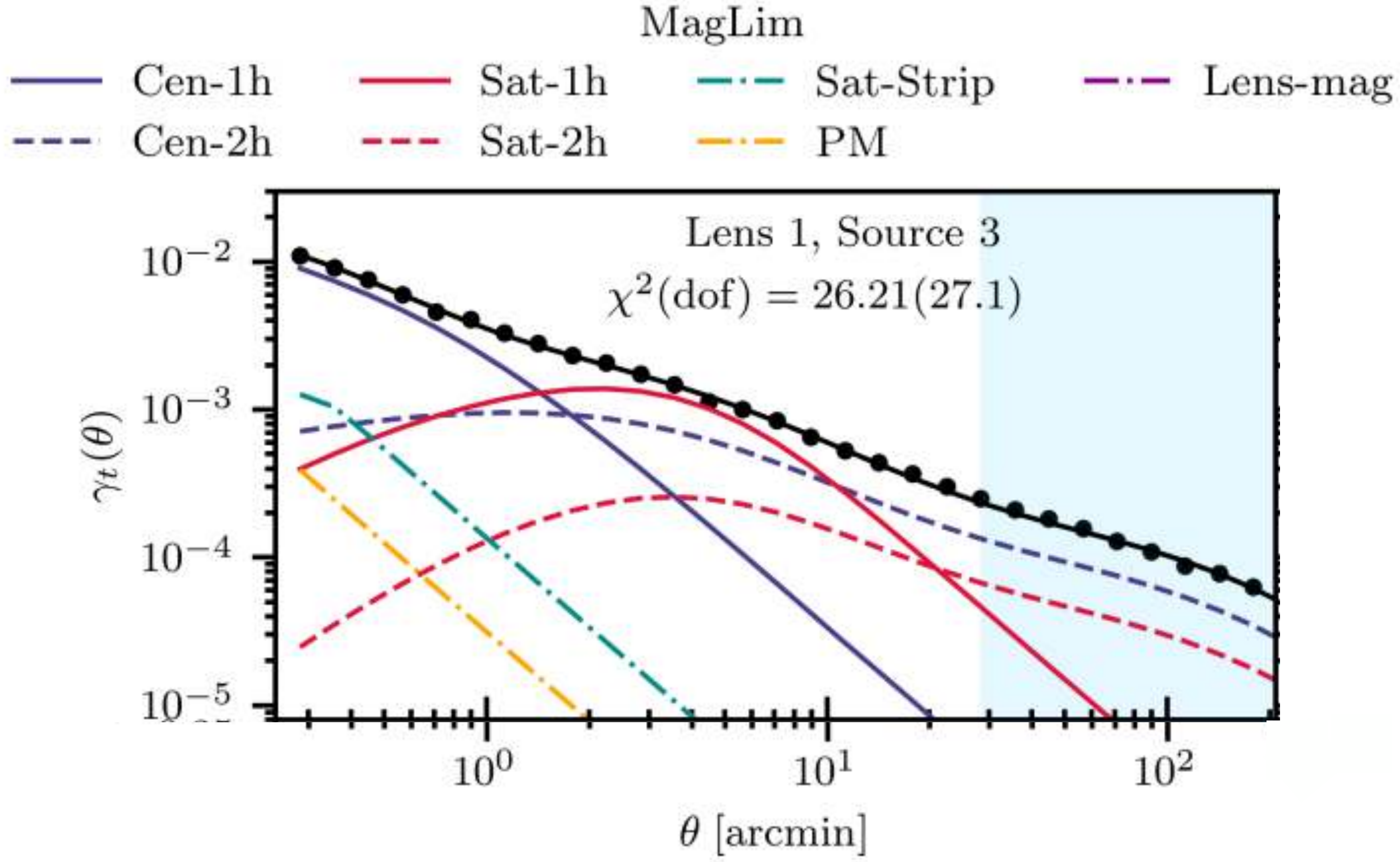
(i) *Zacharegkas, Chang, Prat et al (2022)* + in prep.
(ii) *Chicoine, Prat et al. (2024)*
(iii) Ongoing

The galaxy-matter connection

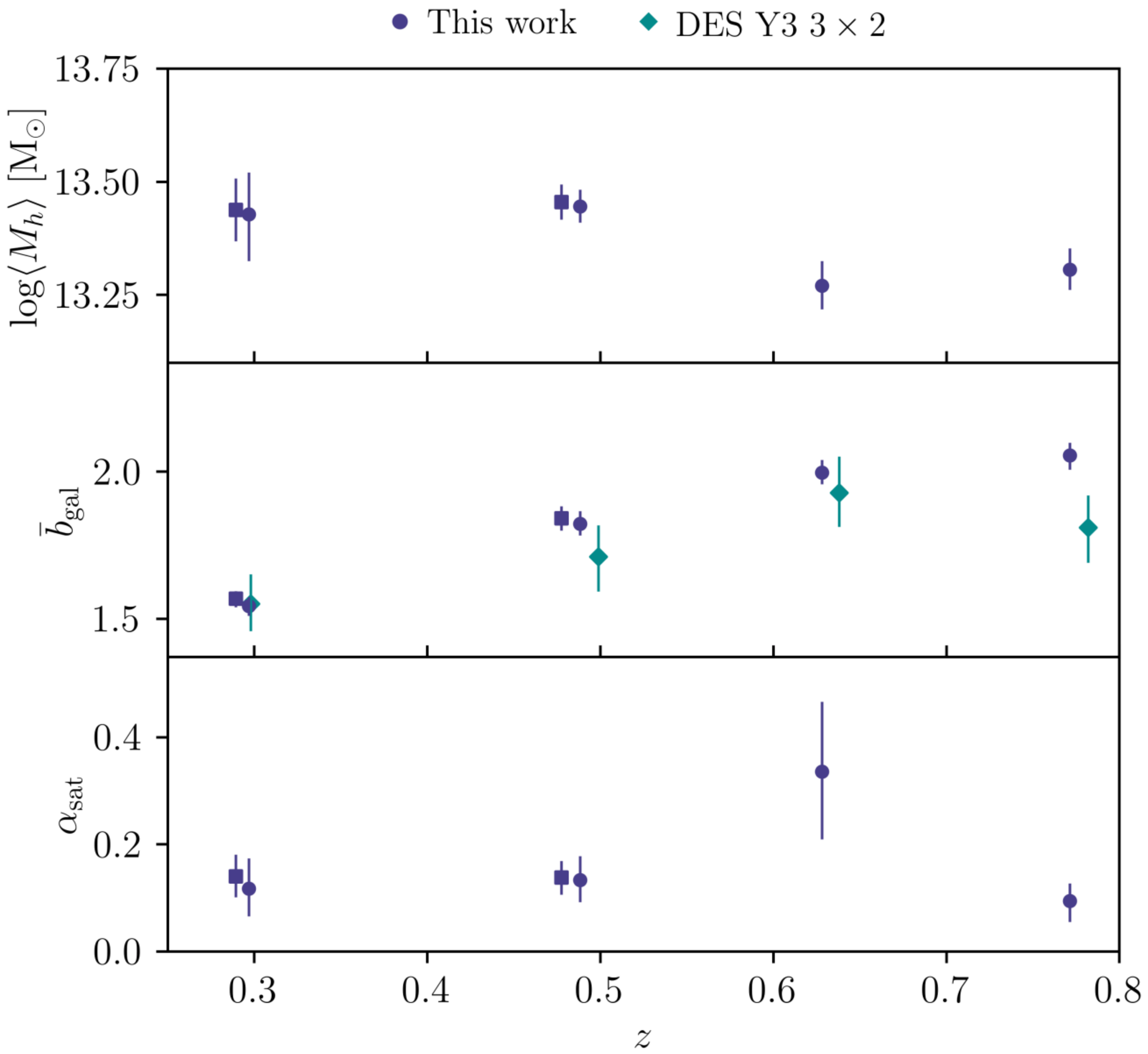
Halo Occupation Model (HOD)

Georgios Zacharegkas, Postdoc at Argonne National Laboratory, previous graduate student at UChicago

- Improving the modeling at small scales is key to extract the full constraining power of our data.
- HOD models allow us to also model the one-halo regime.



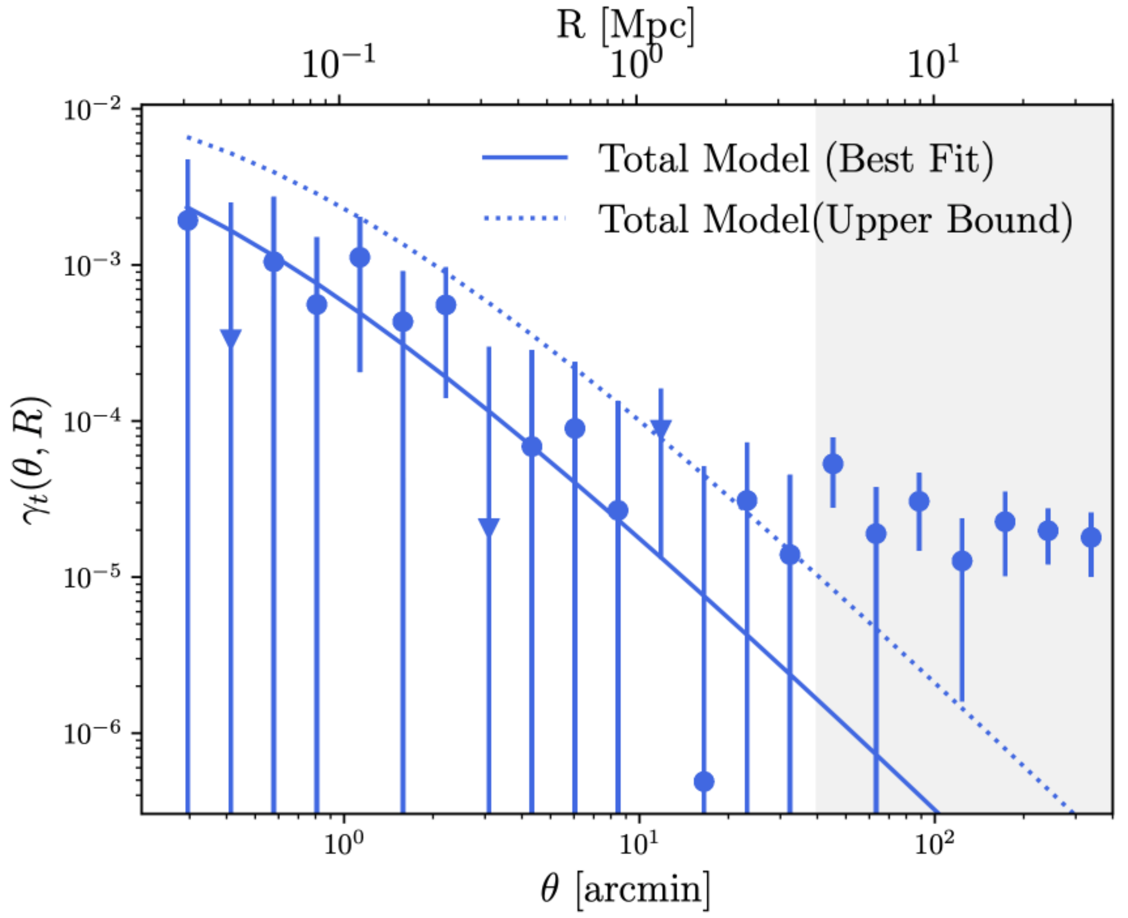
Zacharegkas, Chang, Prat et al. (2021): *arXiv: 2106.08438*

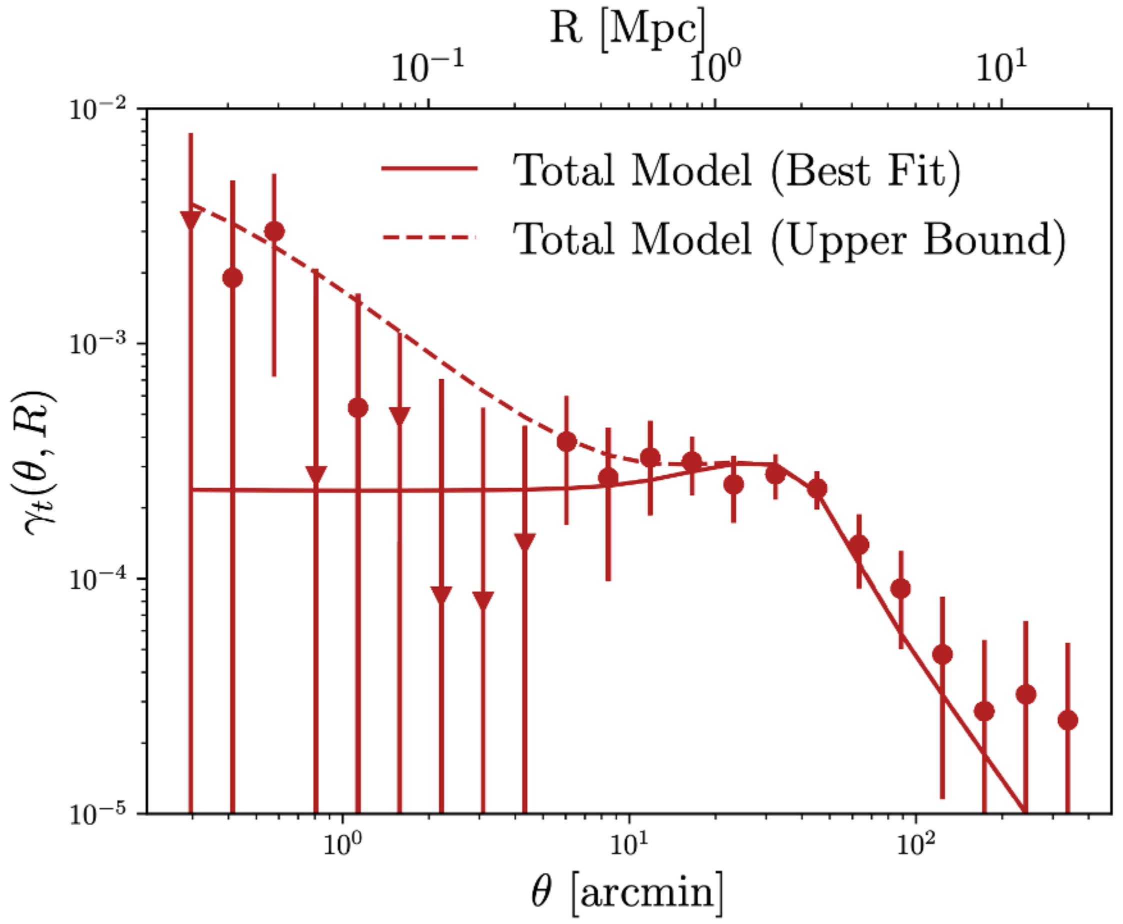


Galaxy-matter with low-surface brightness galaxies (LSBGs)

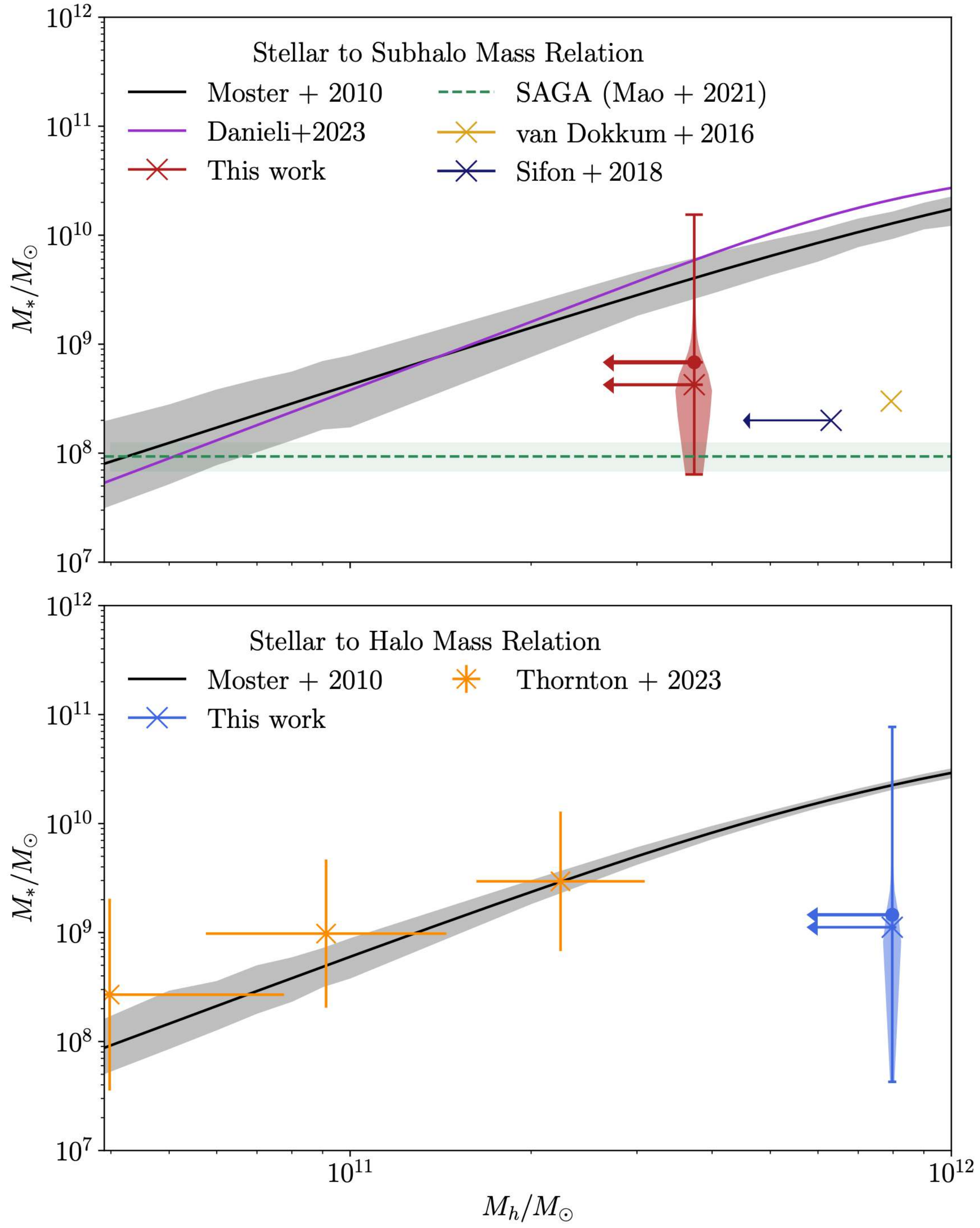
- We performed a weak lensing study around ~24000 LSBGs galaxies using DES Y3 data and measured the halo mass of such galaxies for the first time.

- Stellar-to-halo mass relation at small masses and for satellite galaxies.





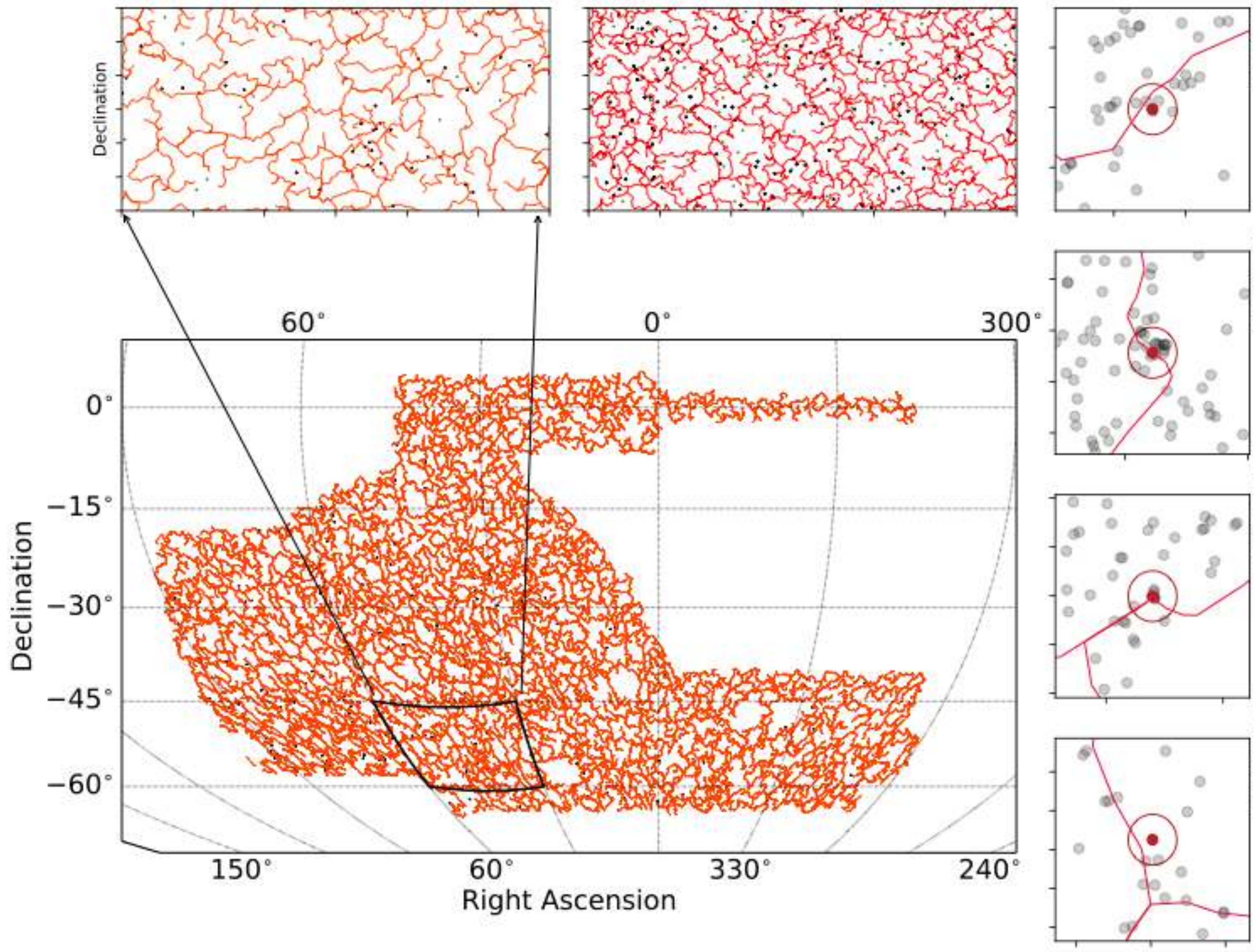
Chicoine, Prat et al. (2024): 2407.19081



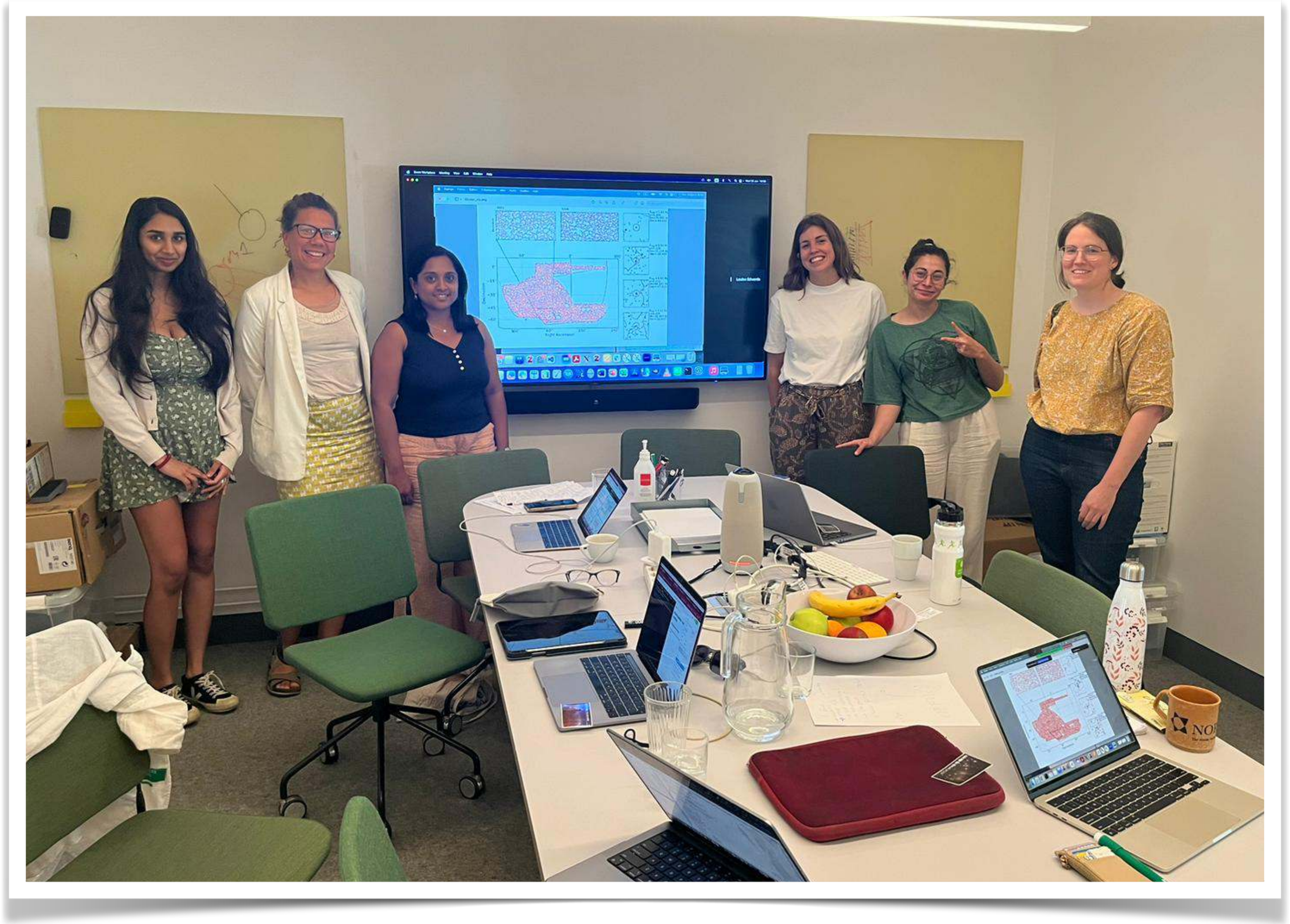
Nathalie Chicoine, PhD student at University of Pittsburg, previous undergraduate at UChicago

Cosmic filaments and connectivity from DES Y3 data

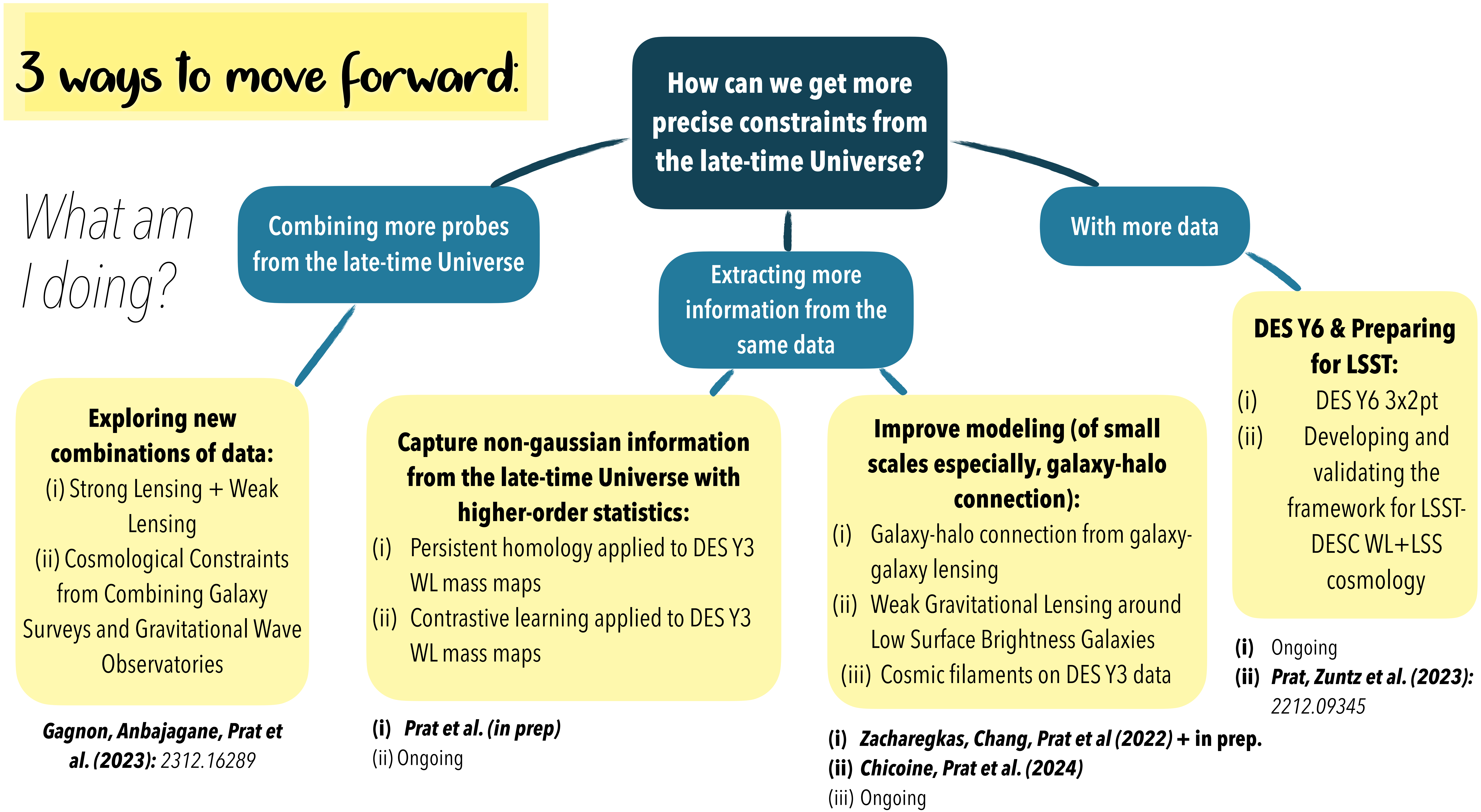
- The study of the cosmic web offers insights into galaxy formation and evolution.



Preliminary – to be submitted soon



- Geetika Gopidas — Undergraduate Student, California Polytechnic State University, San Luis Obispo.
- Punyakoti Ganeshaiah Veena — Postdoc at University of Genoa, Italy.
- Daniela Galárraga-Espinosa — Fellow at MPA, Germany.
- Louise Olivia Violet Edwards — Associate Professor, California Polytechnic State University, San Luis Obispo.
- Celine Gouin — Permanent researcher at Institut d'Astrophysique de Paris.
- Clotilde Laigle — Astronomer at Institut d'Astrophysique de Paris.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(ii) Chicoine, Prat et al. (2024)
(iii) Ongoing
DES Y6 & Preparing for LSST:
(i) DES Y6 3x2pt
(ii) Developing and validating the framework for LSST-DESC WL+LSS cosmology
(i) Ongoing
(ii) Prat, Zuntz et al. (2023): 2212.09345

The DESC pipeline from catalogs to summary statistics: *TXPipe*

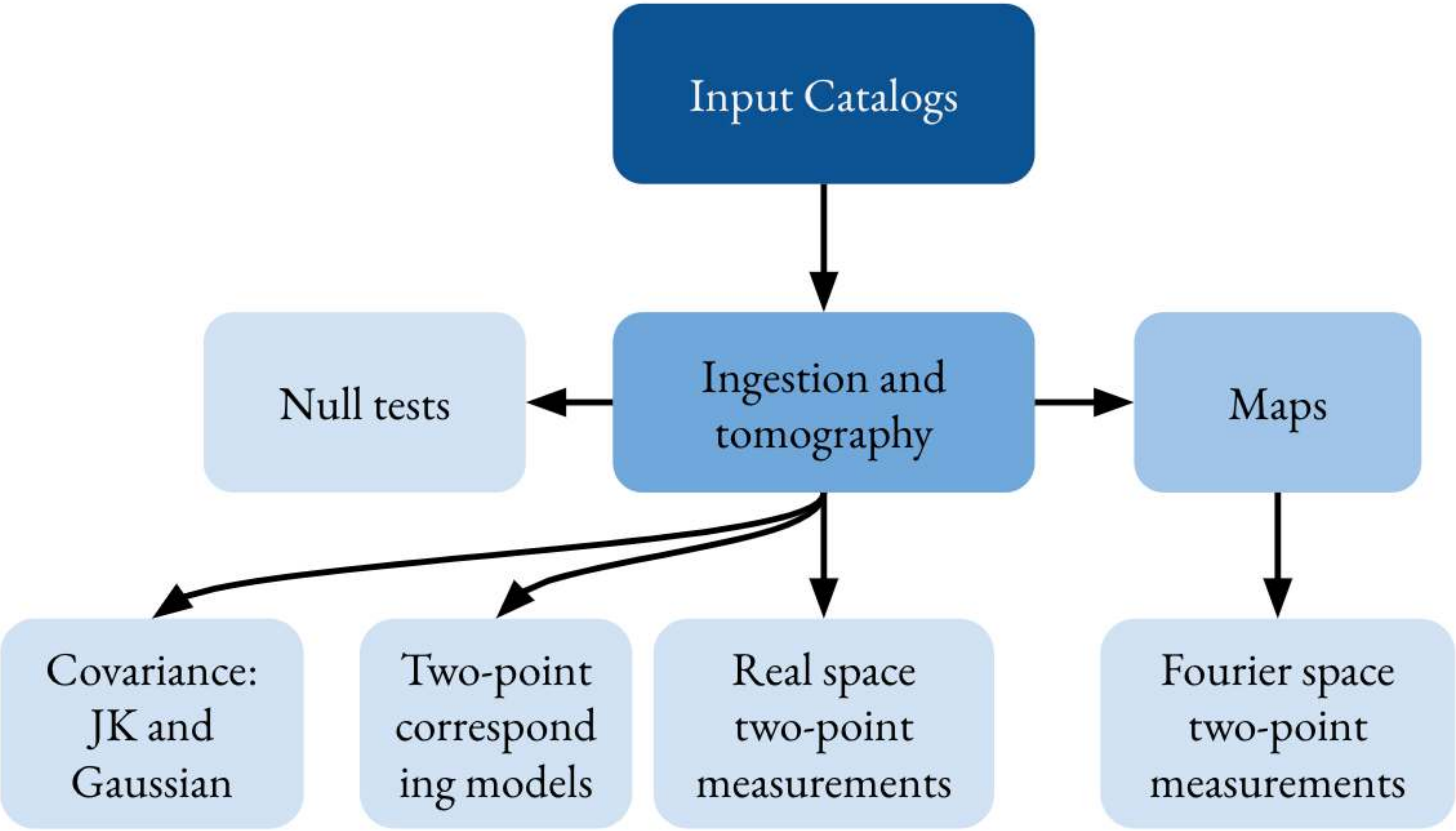
https://txpipe.readthedocs.io/en/latest/

Contributors 25

+ 14 contributors

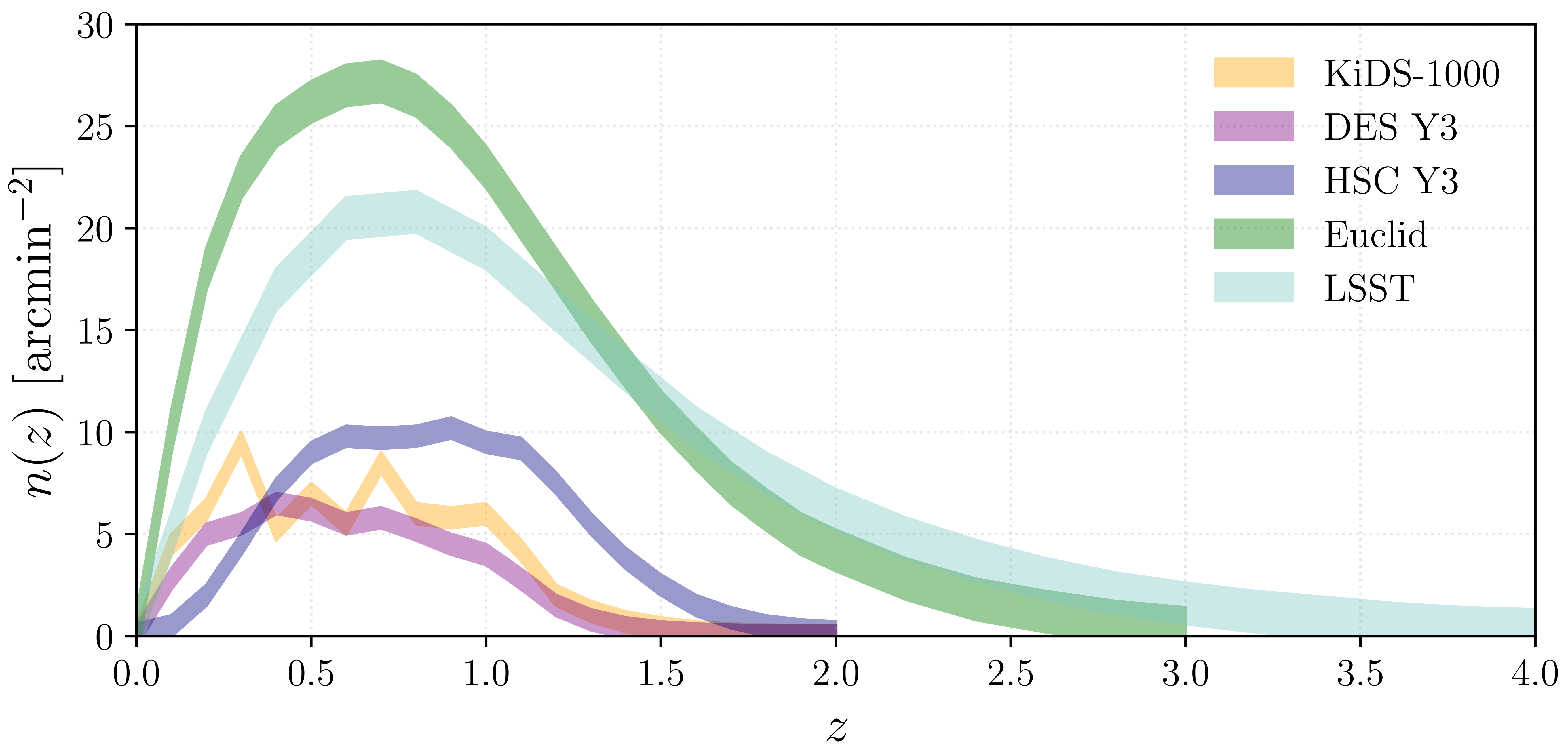
Prat, Zuntz et al. (2023): *2212.09345*

- An automatic and reproducible pipeline for the measurements within DESC in preparation for LSST data.
- Connects external codes, wraps each of these tools as a Python class, specifying input and output files required for each.
- Optimized to deal with large quantities of data, minimize memory usage and run in parallel.
- Can be extended as desired to include more features.



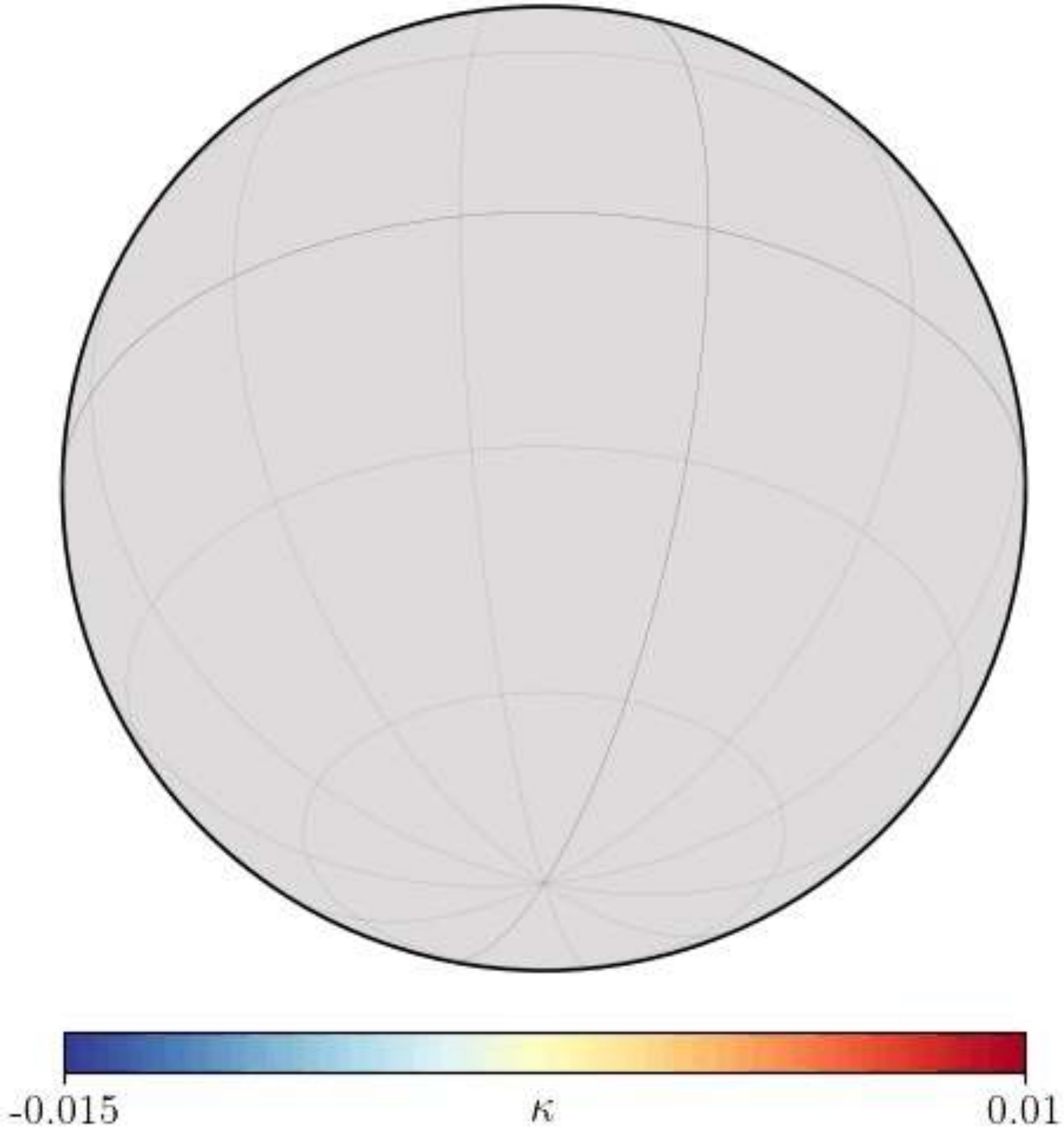
What's coming?

Exciting times ahead!



	Survey	Area (deg^2)	Source density [arcmin^{-2}]	Redshift range	Observing Status
Stage III	DES Y3	4,143	5.59	0.2 - 1.3	Completed
	KiDS-1000	773	6.17	0.1 - 1.2	Completed
	HSC Y3	416	15	0.3 - 1.5	Ongoing
Stage IV	Euclid	14,000	~27	0 - 2+	Ongoing
	LSST	18,000	~27	0 - 3+	Future (2024+)
	Roman	2,000	~50	0 - 3+	Future (2027+)

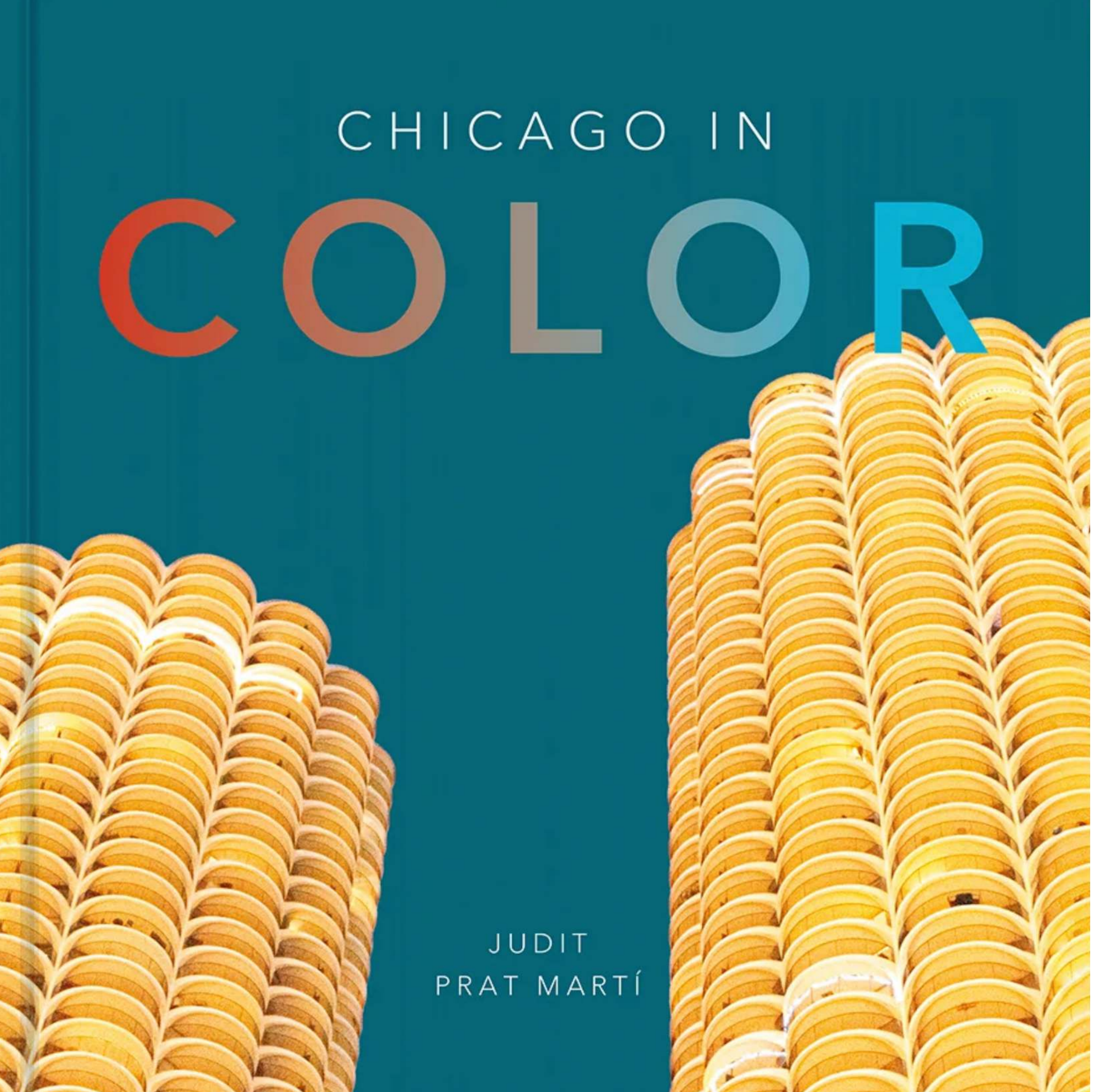
DES Y6: Stay tuned.. results coming soon



Credit: Chihway Chang, Marco Gatti, Masa Yamamoto, Theo Schutt, and all the DES Y6 shear team!

Conclusions and outlook

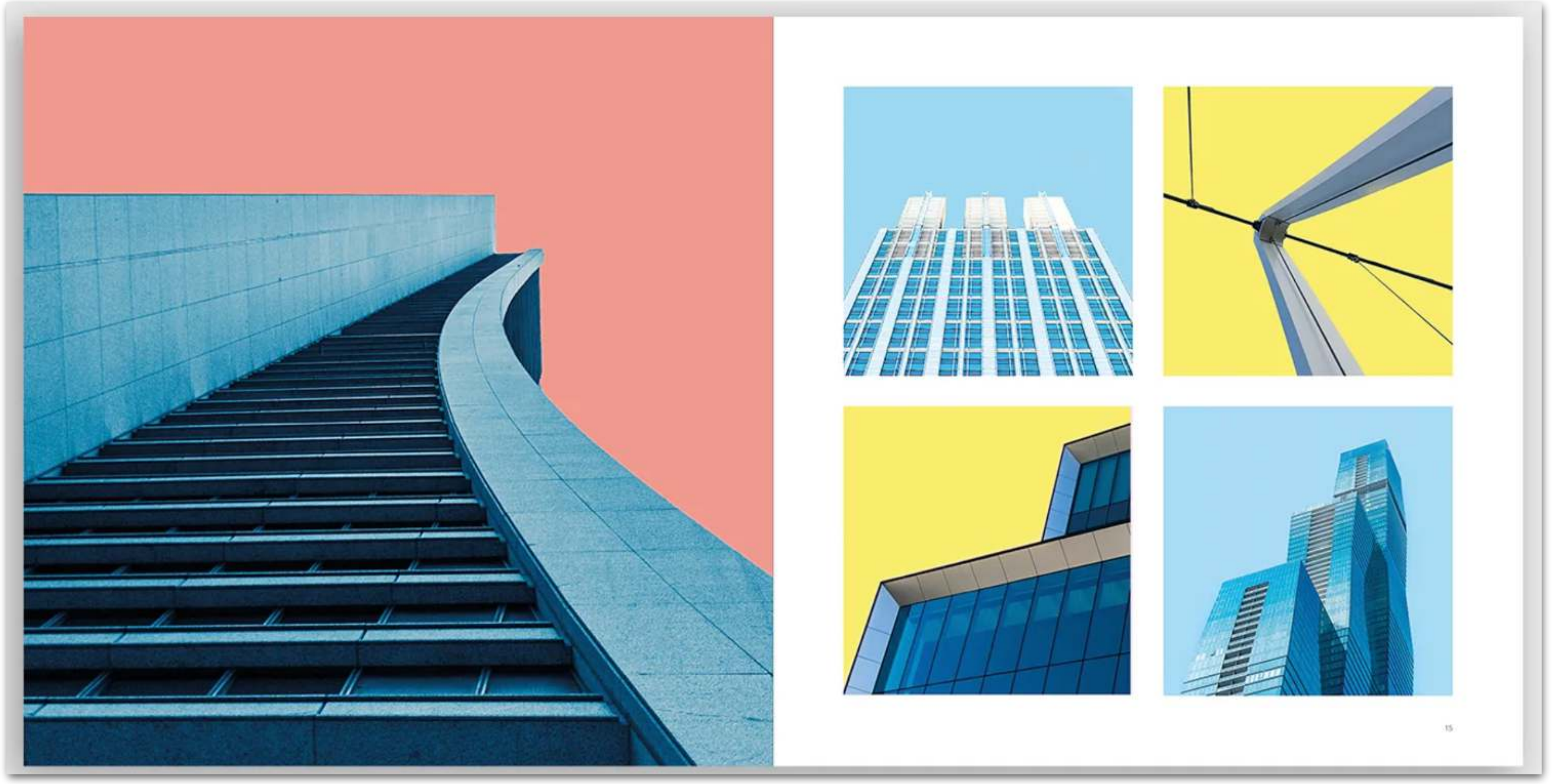
- The ΛCDM is still standing but there are hints indicating soon we'll reach enough precision that it might break.
- The late-time DES Y3 3x2pt cosmology results are in agreement with early-Universe predictions assuming the ΛCDM model at the 1.5σ level. This is a very important end-to-end test of ΛCDM. Keep an eye for the DES Y6 results coming this year!
- When combined with the other most constraining low-z probes (BAO and RSD from BOSS DR16, and Type Ia Supernova from Pantheon) the agreement is at the 0.9 sigma level, with smaller uncertainties.
- More stringent testing is needed to determine whether ΛCDM holds or not.
- A new generation of galaxy surveys, using more scales and higher order information and emerging probes (such as GW) and maturing of existing ones (such as strong lensing) will (hopefully) provide the answers.



Chicago in Color,

with **Trope Publishing Company**,

Last October.



Thanks!

Judit Prat

University of Iceland

March 2025

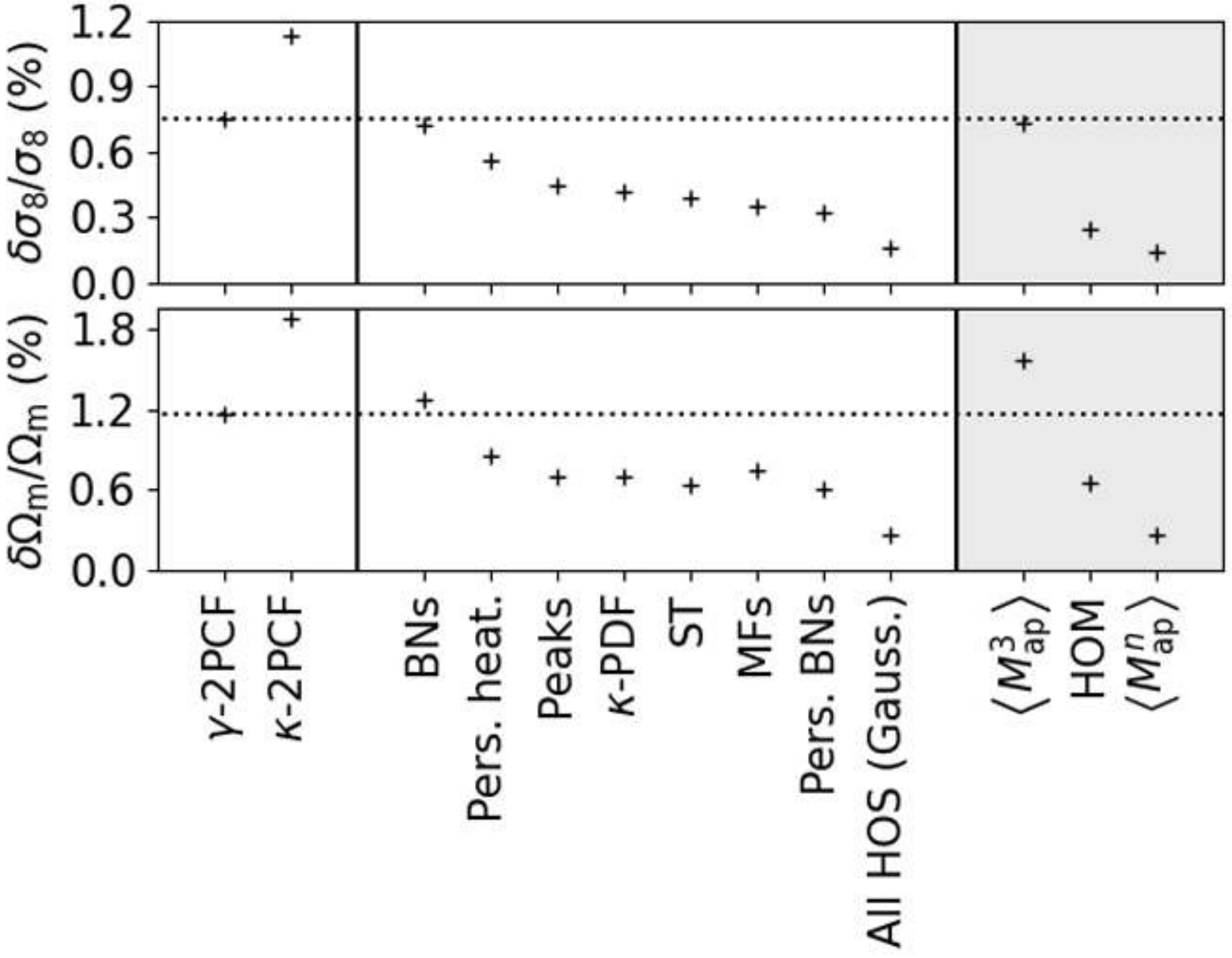
NORDITA

The Nordic Institute for Theoretical Physics

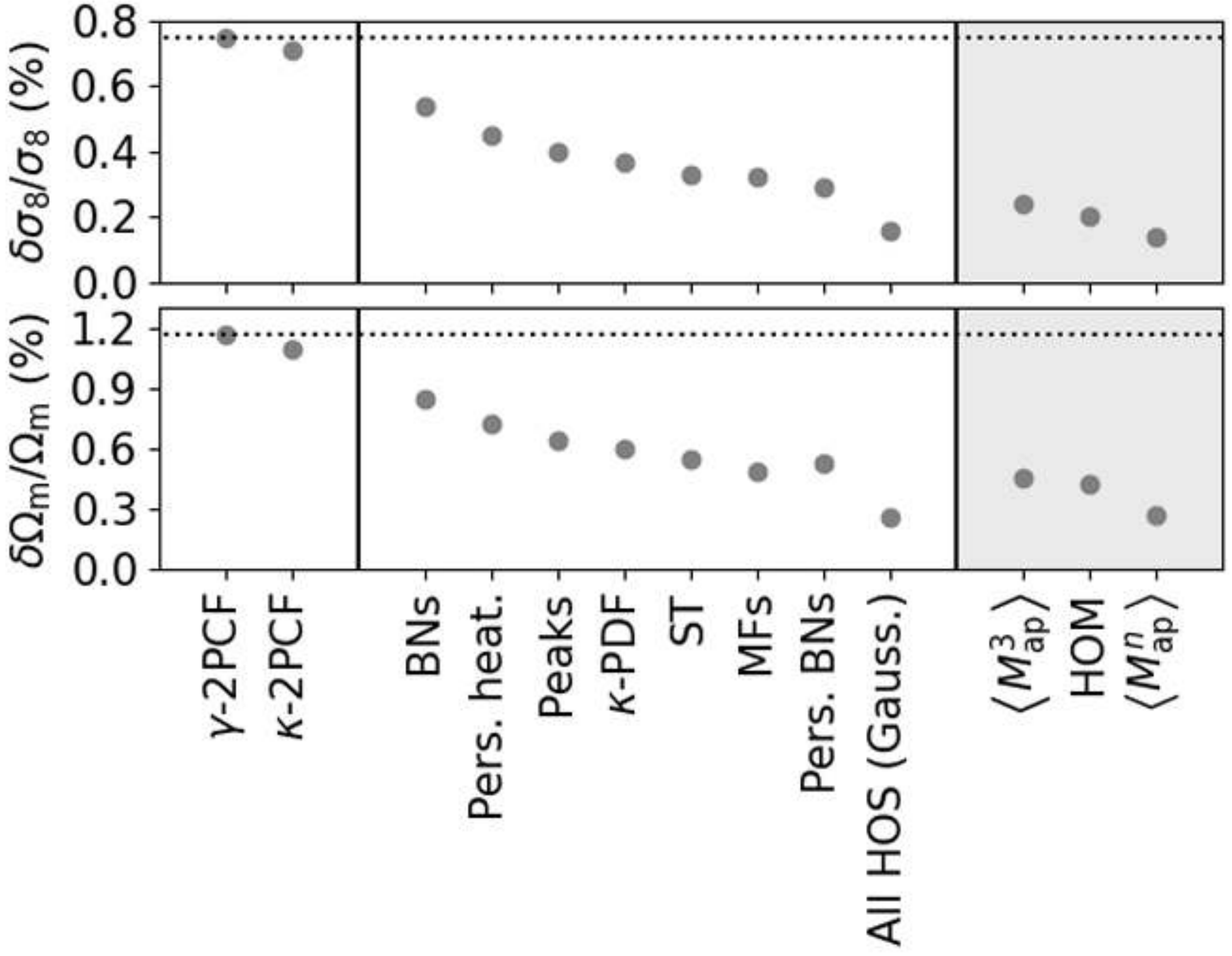
Extracting information from mass maps

Previous work on other collaborations

Higher order only



Higher order + 2pt

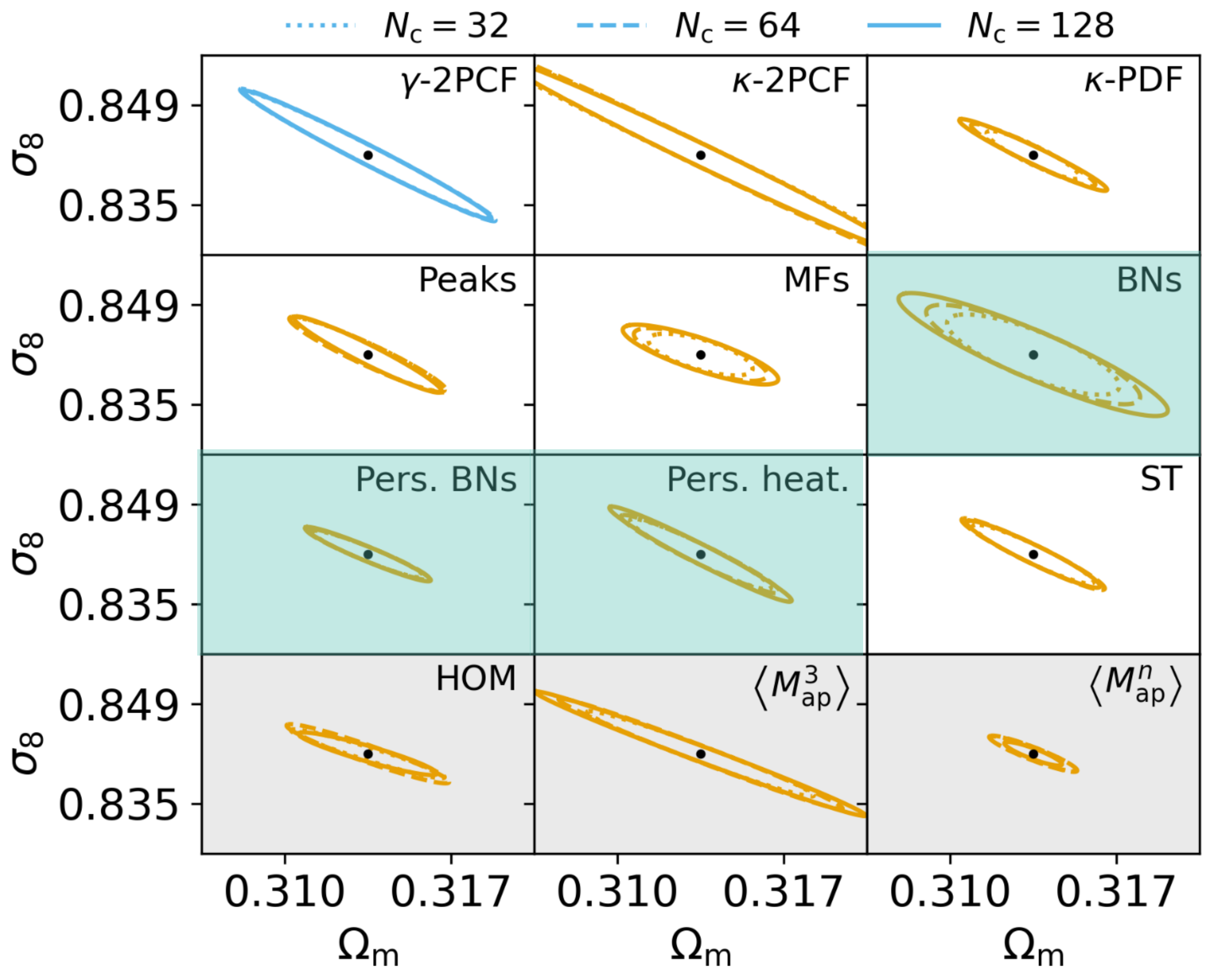


Euclid Collaboration: HOWLS team et al. (2022)

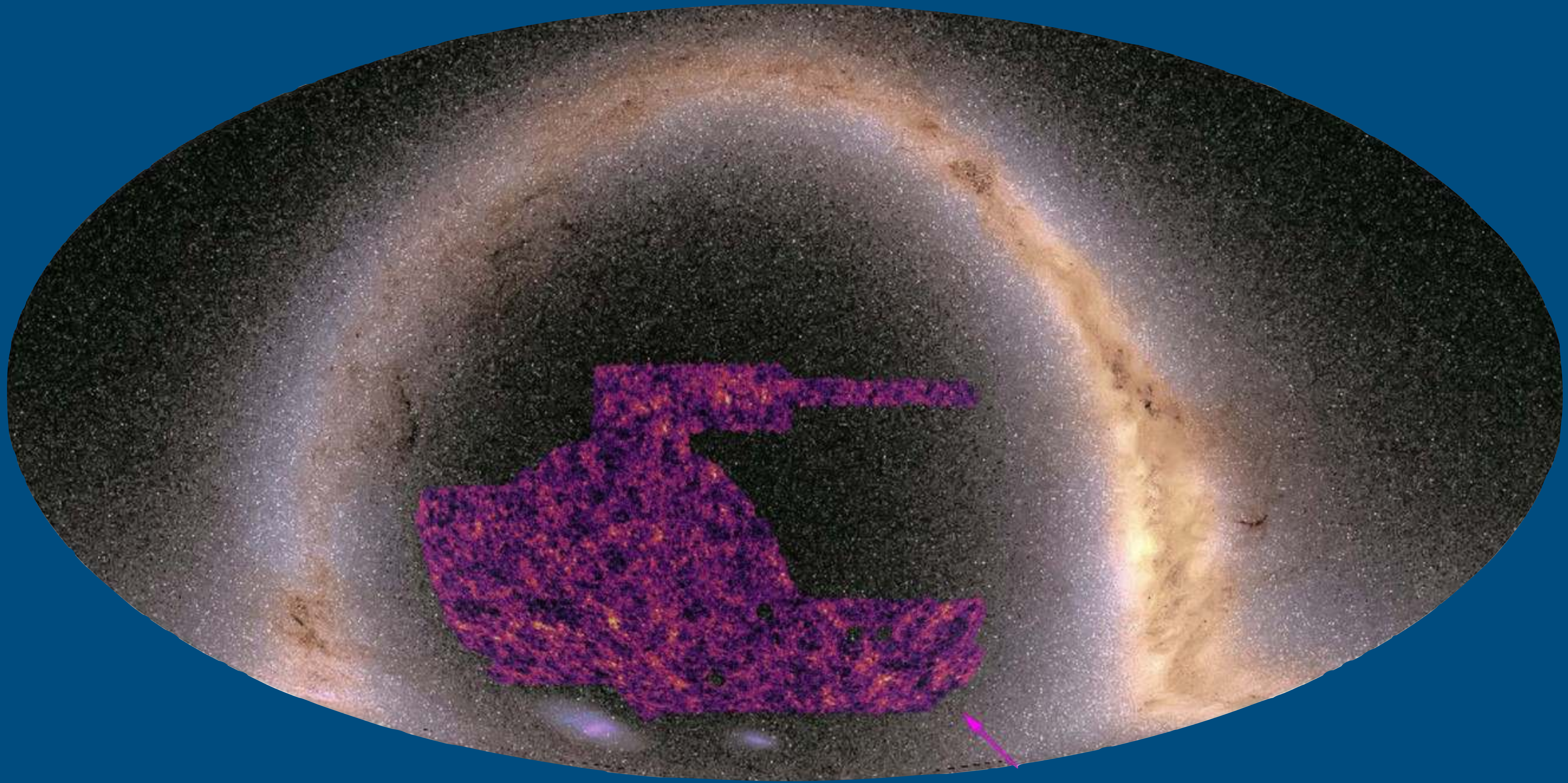
This work in context

Related persistent homology studies

- **Heydenreich et al. (2021, 2022)**: 2007.13724, 2204.11831.
  - Persistent homology applied to DES Y1 data. —> *We use DES Y3 data.*
  - Flat geometry (patches were used). —> *We use spherical geometry, full footprint can be analyzed at once.*
  - Cubical complexes —> *Complex (triangulation) is based on HEALPIX grid.*
- **Yip et al. (2024)**: 2403.13985.
  - Cosmology with Persistent Homology: a Fisher Forecast.
  - 3D LSS simulations, QUIJOTE SUITE.
- **Euclid Collaboration (2023):** 2301.12890.
  - Forecasts for ten different higher-order weak lensing statistics.
- **Pranav (2021):** 2111.15427
  - Using healpix complex applied to CMB data to find anomalies.



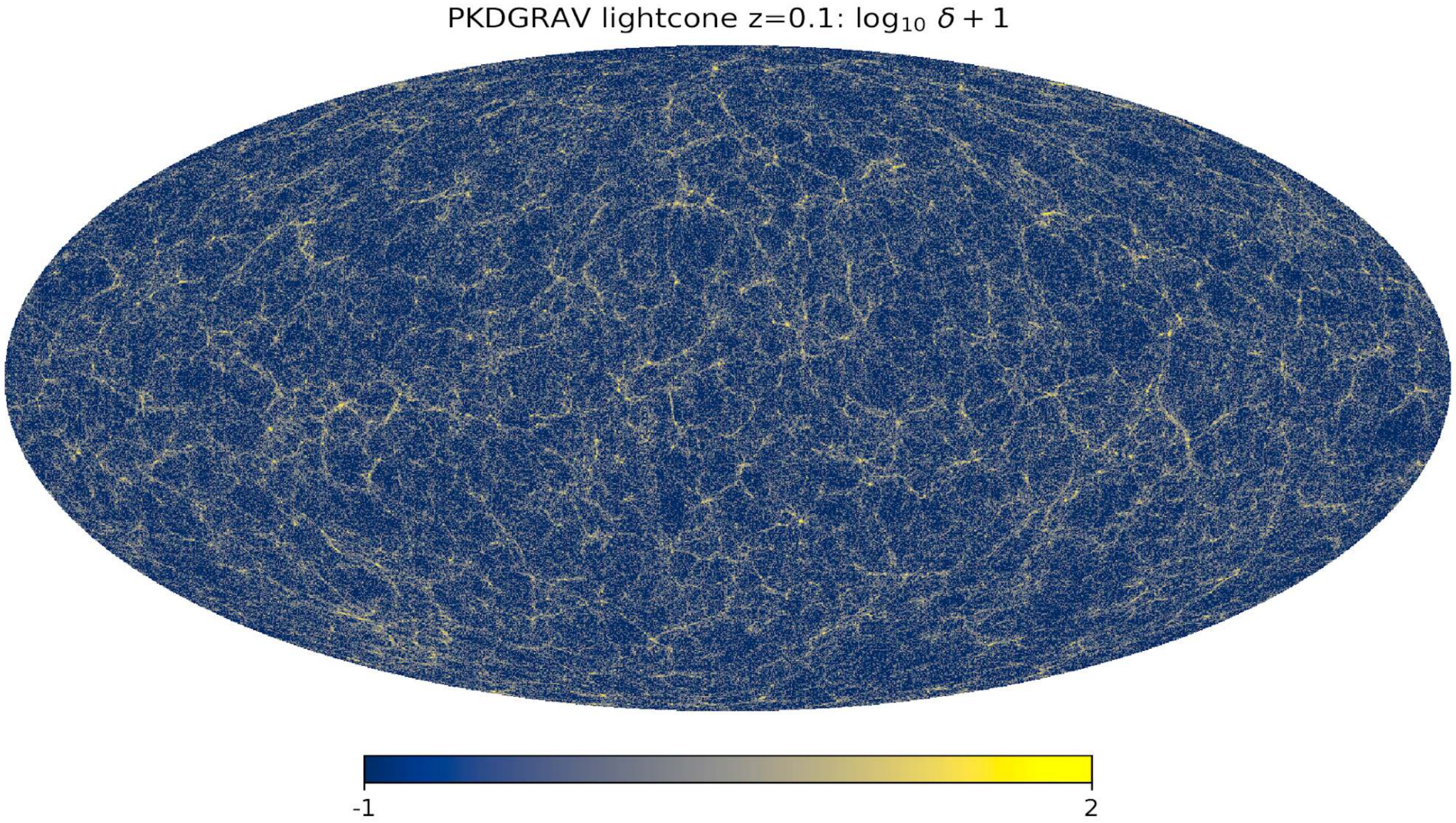
The data: DES Y3 WL mass map



~800 full sky dark matter simulations

Gower St Sims simulations

- Produced using the PKDGRAV3 code.
- 791 full-sky simulations (Over 3000 DES footprints)
- 1080^3 particles with box size 1250 Mpc/h

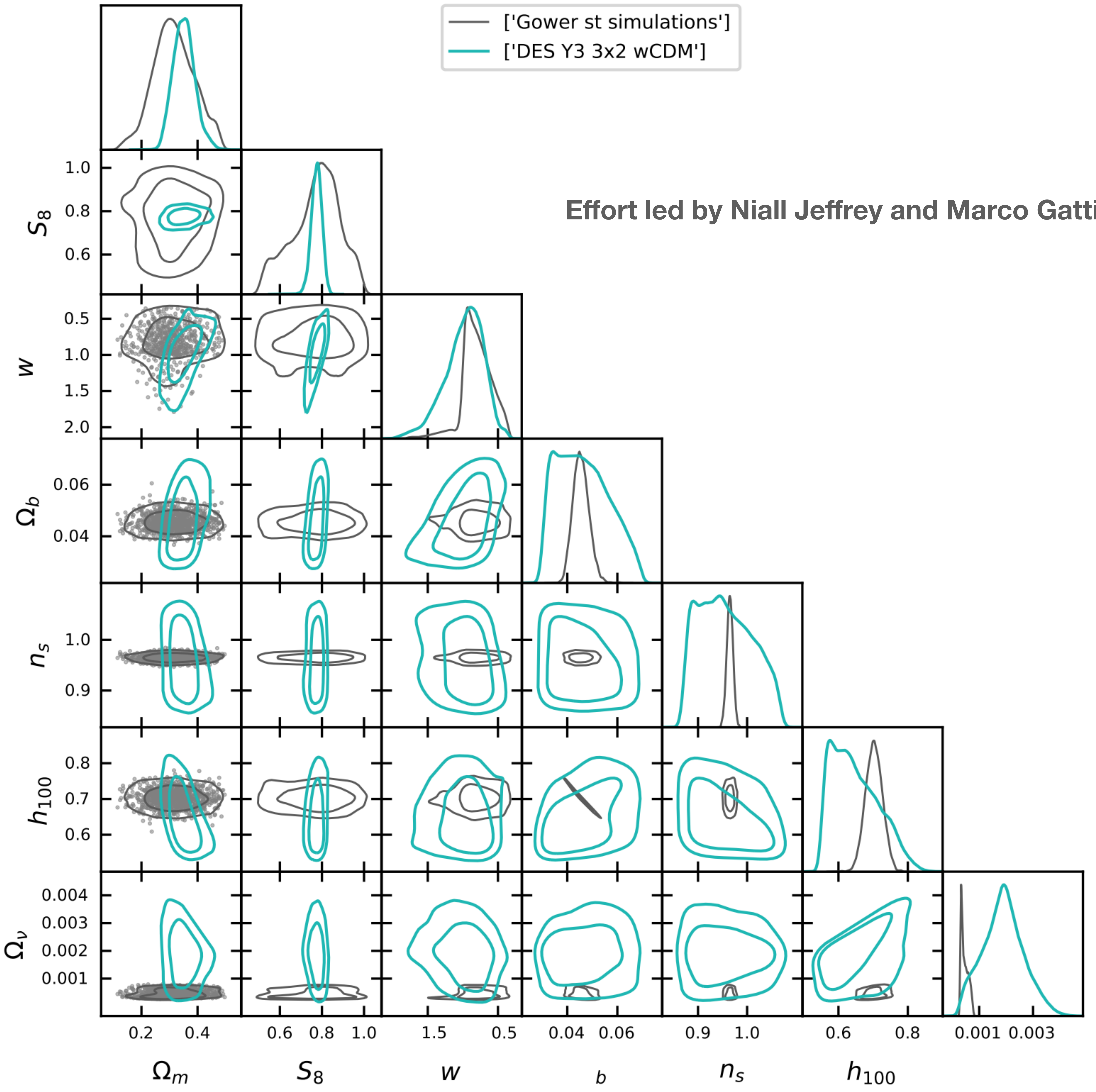


Effort led by Niall Jeffrey and Marco Gatti

Gower St Sims simulations

- Varying cosmological parameters: Ω_m, σ_8, w, Ω_b, H_0, n_s and m_ν.

• $n_s \sim \mathcal{N}(0.9649, 0.0063)$; from Planck (Aghanim et al. 2020) but with the standard deviation boosted by a factor of 1.5.
• $h \sim \mathcal{N}(0.7022, 0.0245)$; consistent with both SH0ES (Riess et al. 2022) and Planck (Aghanim et al. 2020).
• $\Omega_b h^2 \sim \mathcal{N}(0.02237, 0.00015)$; from Planck (Aghanim et al. 2020).
• $w \sim \mathcal{N}(-1, 1/3)$, but with values less than -1 or greater than $-1/3$ then discarded. However, for the first 128 runs (part of the 'science verification' runs), this discarding was not done (resulting in approximately 64 runs with $w < -1$. These runs have been kept as they help to smooth what would otherwise be the discontinuity at $w = -1$.



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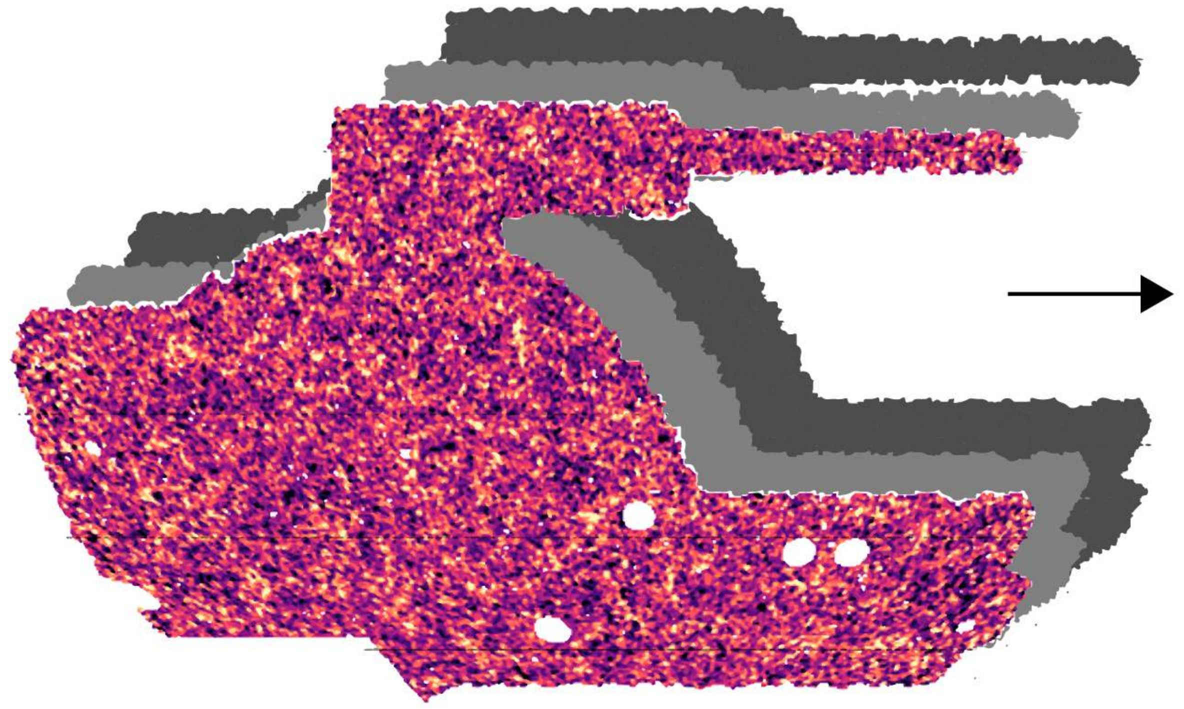
Simulation based inference: *In practice*

Persistent homology



Simulated DES Y3 Weak Lensing mass maps

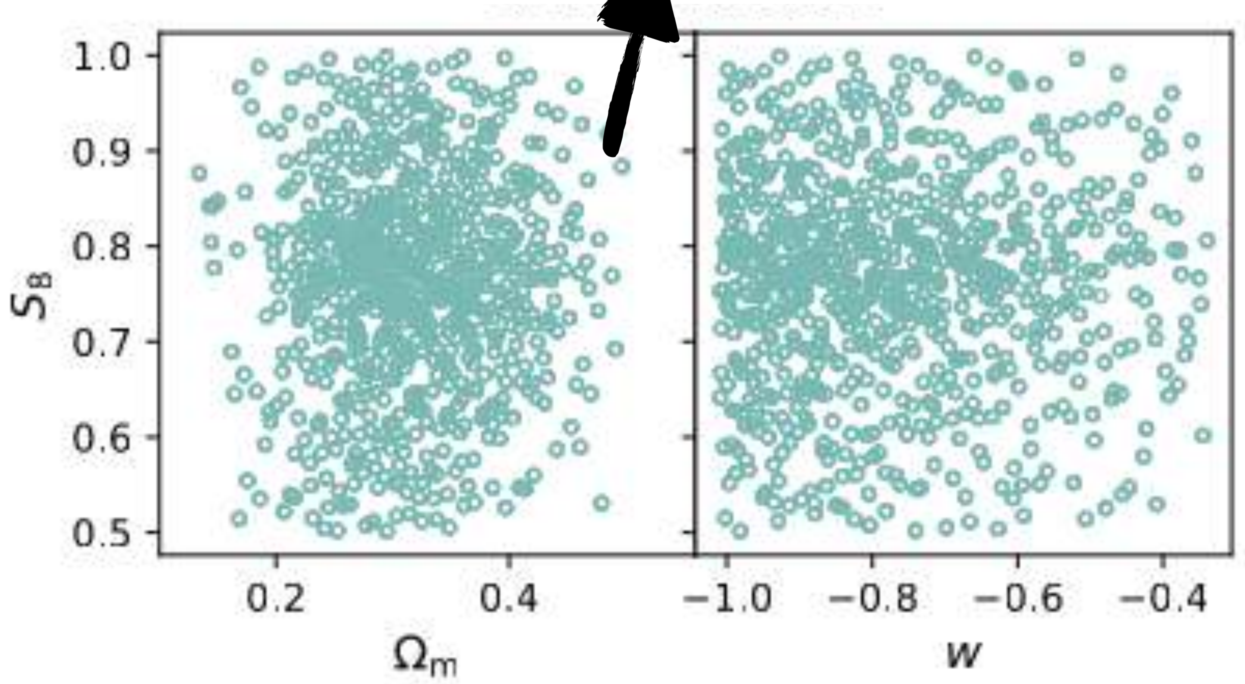
$$\{\mathbf{d}, \boldsymbol{\theta}\}$$

Summary statistic

To estimate the conditional distribution $p(x|\theta)$ we use the **`pyDELFI`** (Alsing et al. 2019) package with an ensemble of neural density estimators (NDEs). NDEs use neural networks to parametrize densities. A NDE gives an estimate of the probability $q(x|\theta,\varphi)$ by varying the φ neural network parameters (e.g. weights and biases) to minimize the loss function

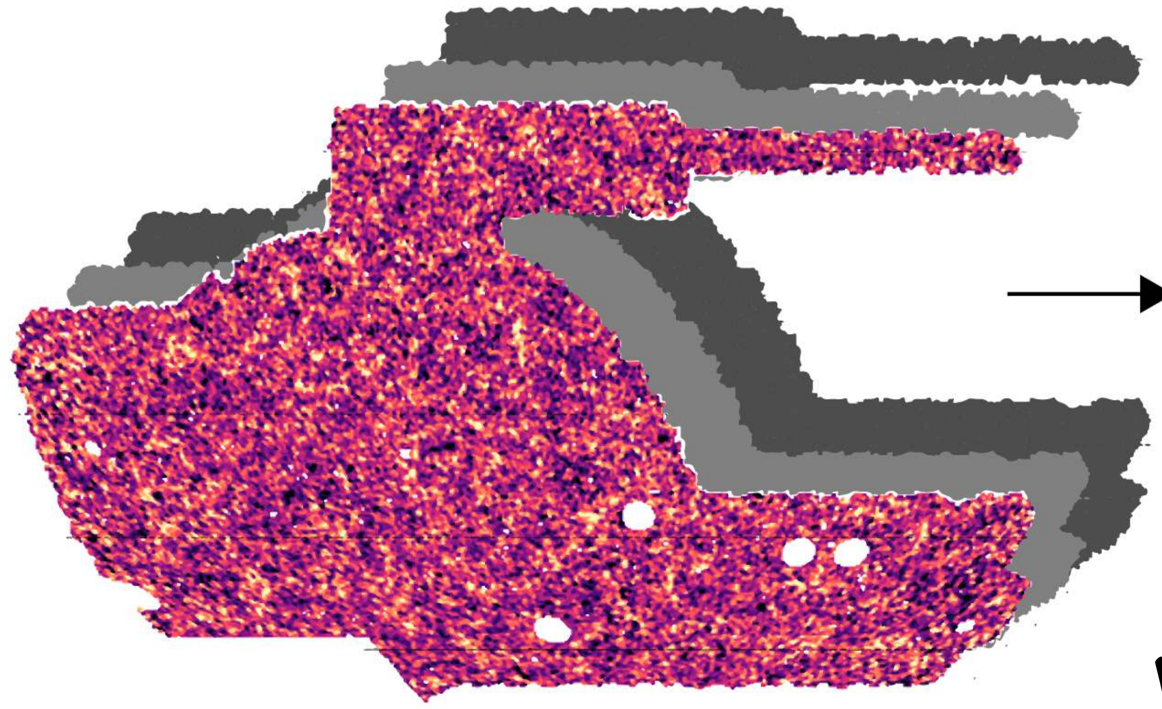
$$U(\varphi) = -\sum_{i=1}^{N} \log q(x_i|\theta_i;\varphi)$$

over the N forward-modelled mock data xi. This loss corresponds to minimizing the Kullback-Leibler divergence (Kullback & Leibler 1951), a measure of change from the estimate q to the target p.



Different initial cosmo parameters θ

Simulation based inference: *In practice*



Simulated DES Y3 Weak Lensing mass maps

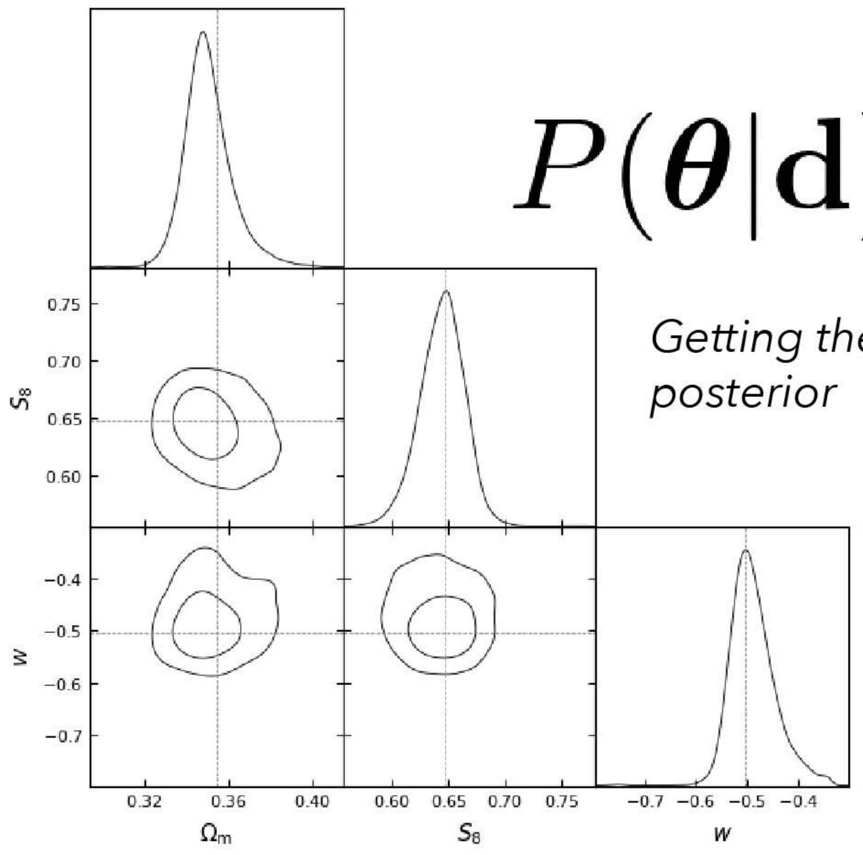
$\rightarrow$ $\{\mathbf{d}, \boldsymbol{\theta}\}$ $\rightarrow$ $\{\mathbf{t}, \boldsymbol{\theta}\}$ $\rightarrow$ **NDE** $\rightarrow$ $P(\mathbf{t}|\boldsymbol{\theta})$ $\rightarrow$

Summary statistic

Compression with regression network

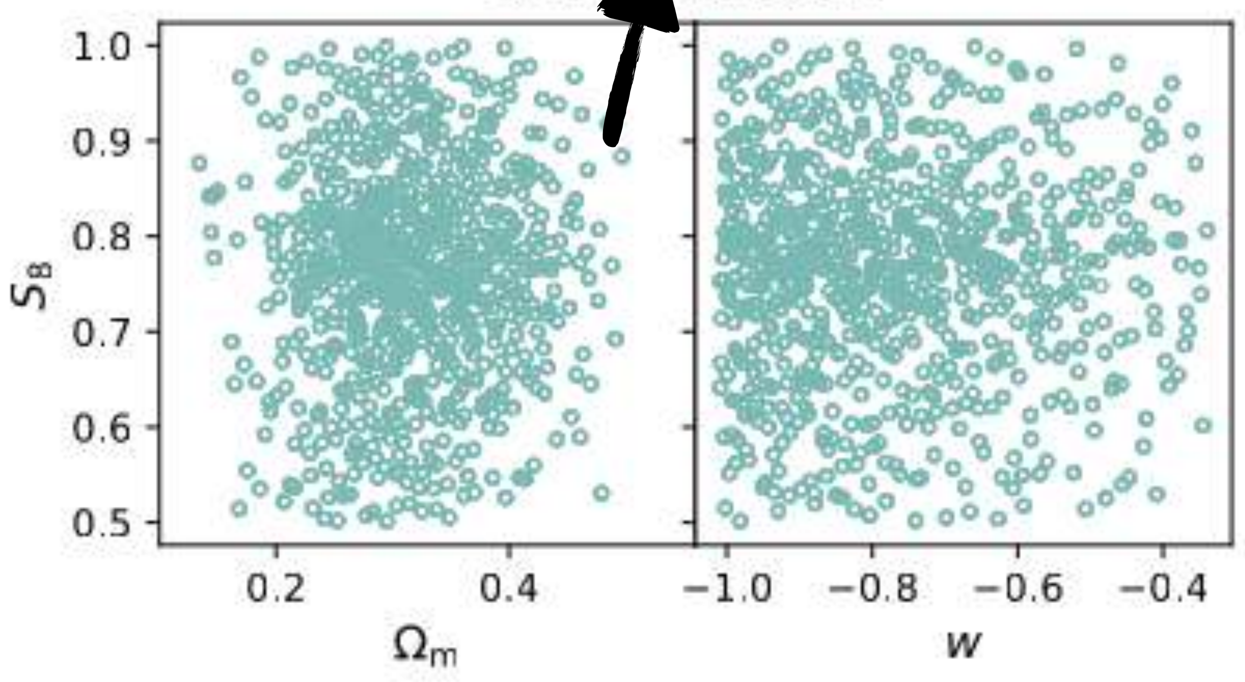
Neural density estimation with normalizing flows

Learning the likelihood



$$P(\boldsymbol{\theta}|\mathbf{d})$$

Getting the posterior



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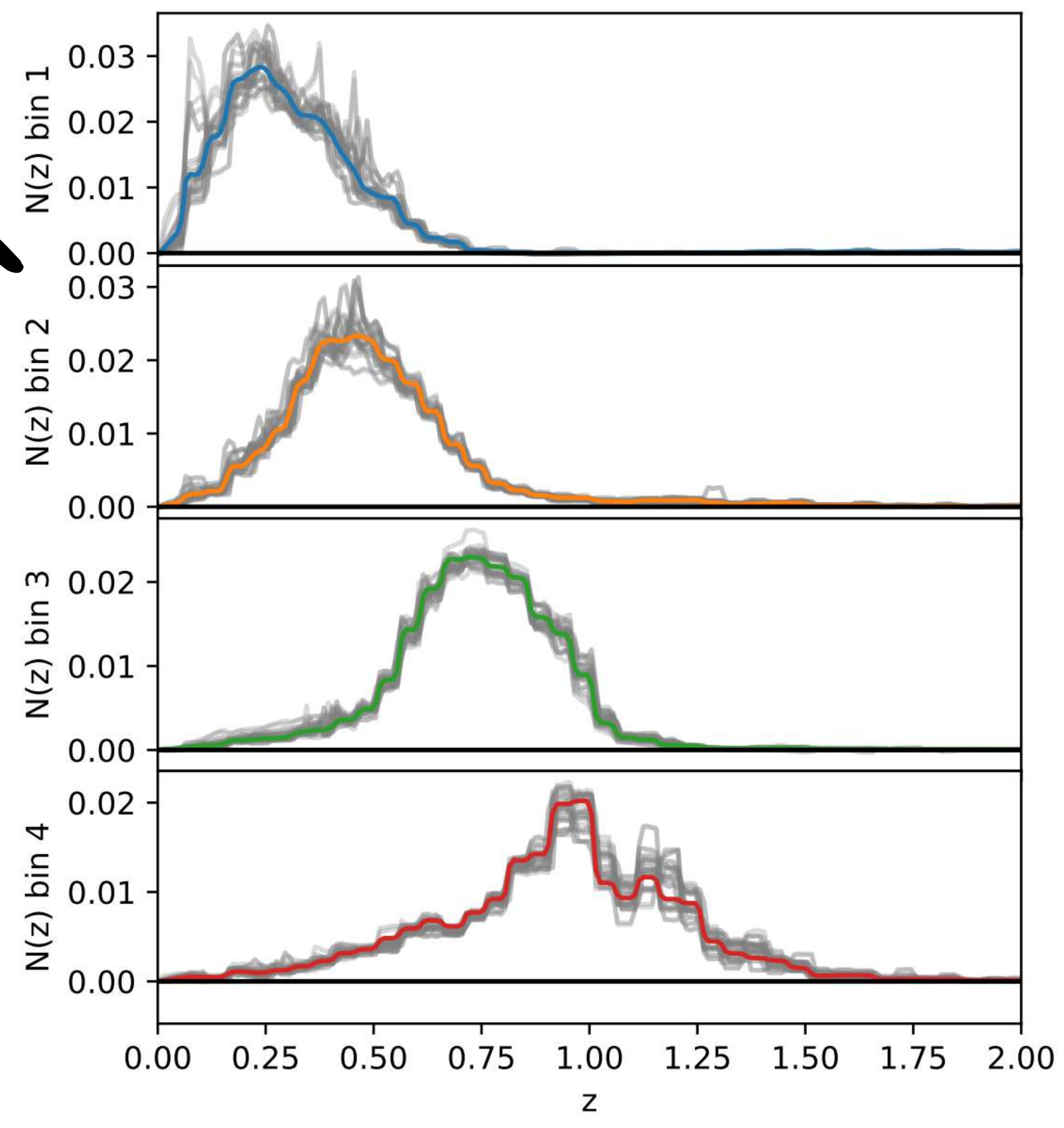

Different initial nuisance parameters too.

Persistent homology

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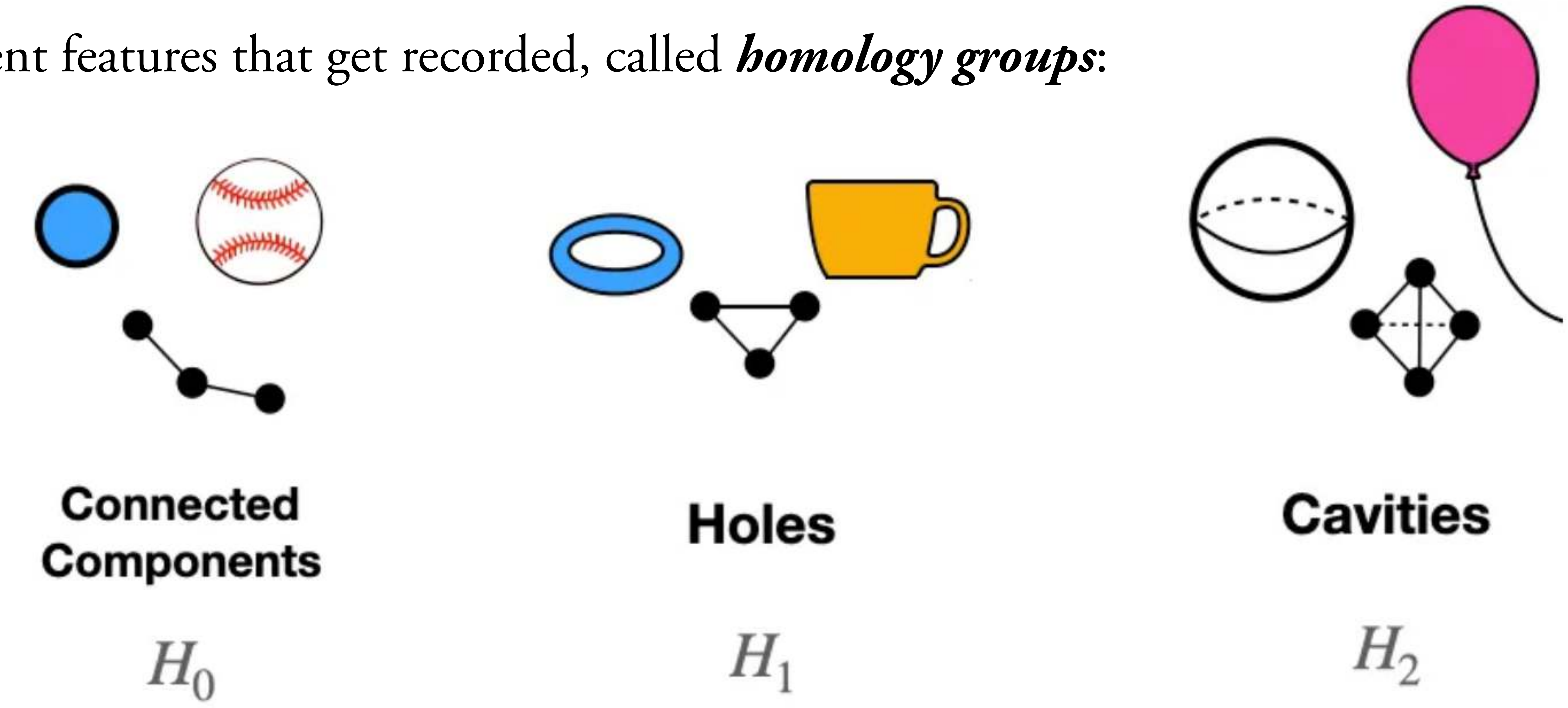

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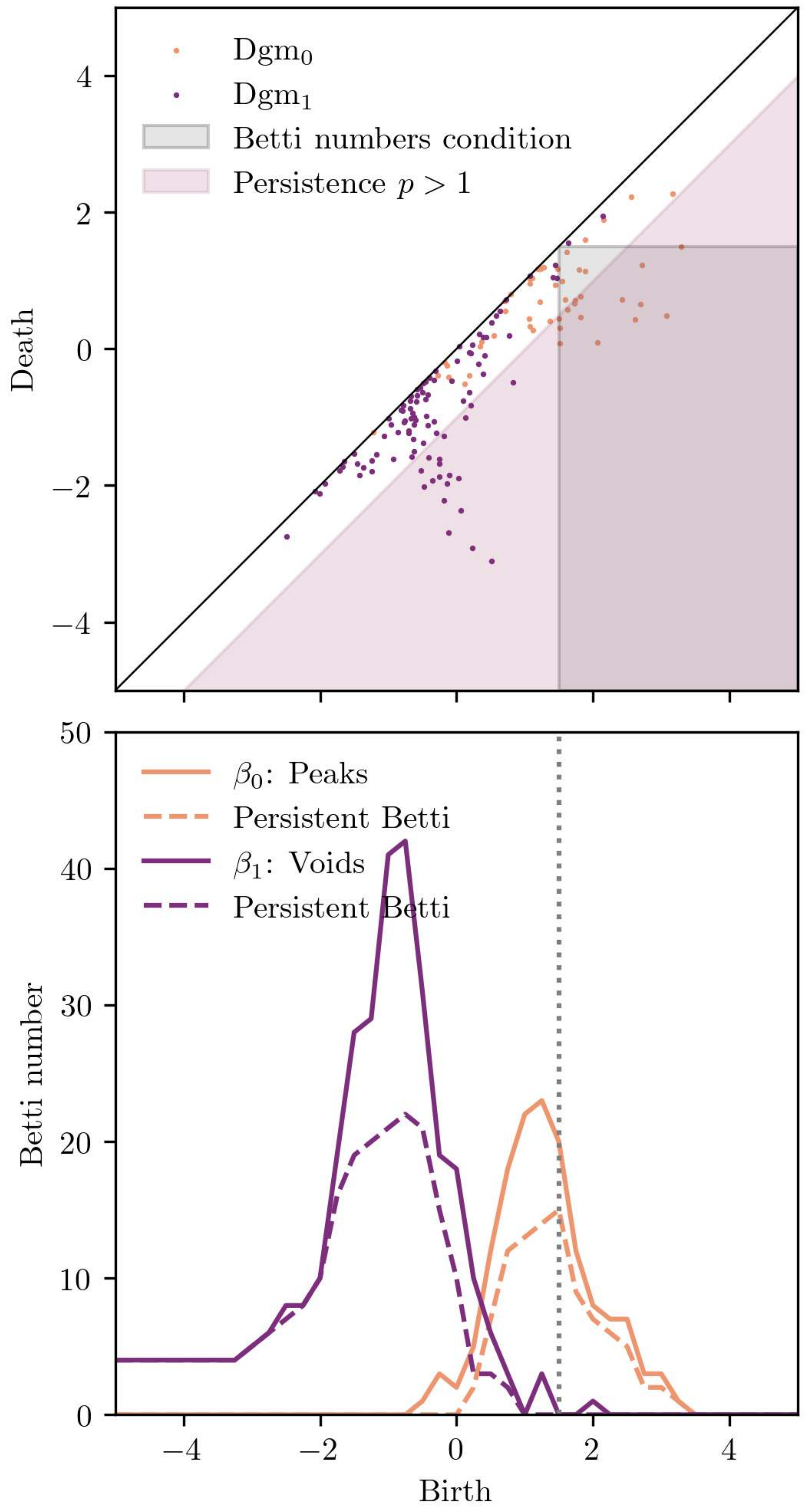
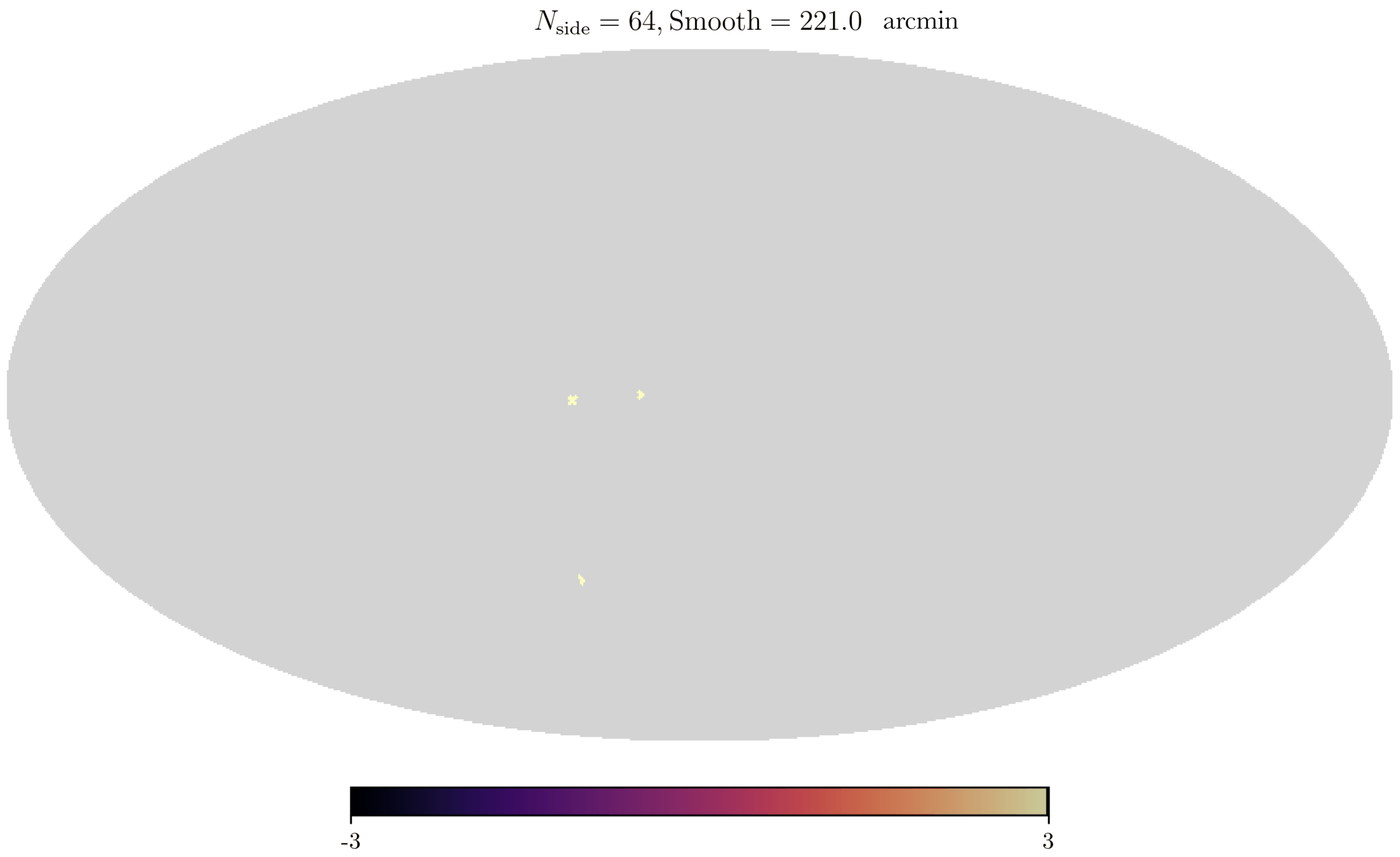
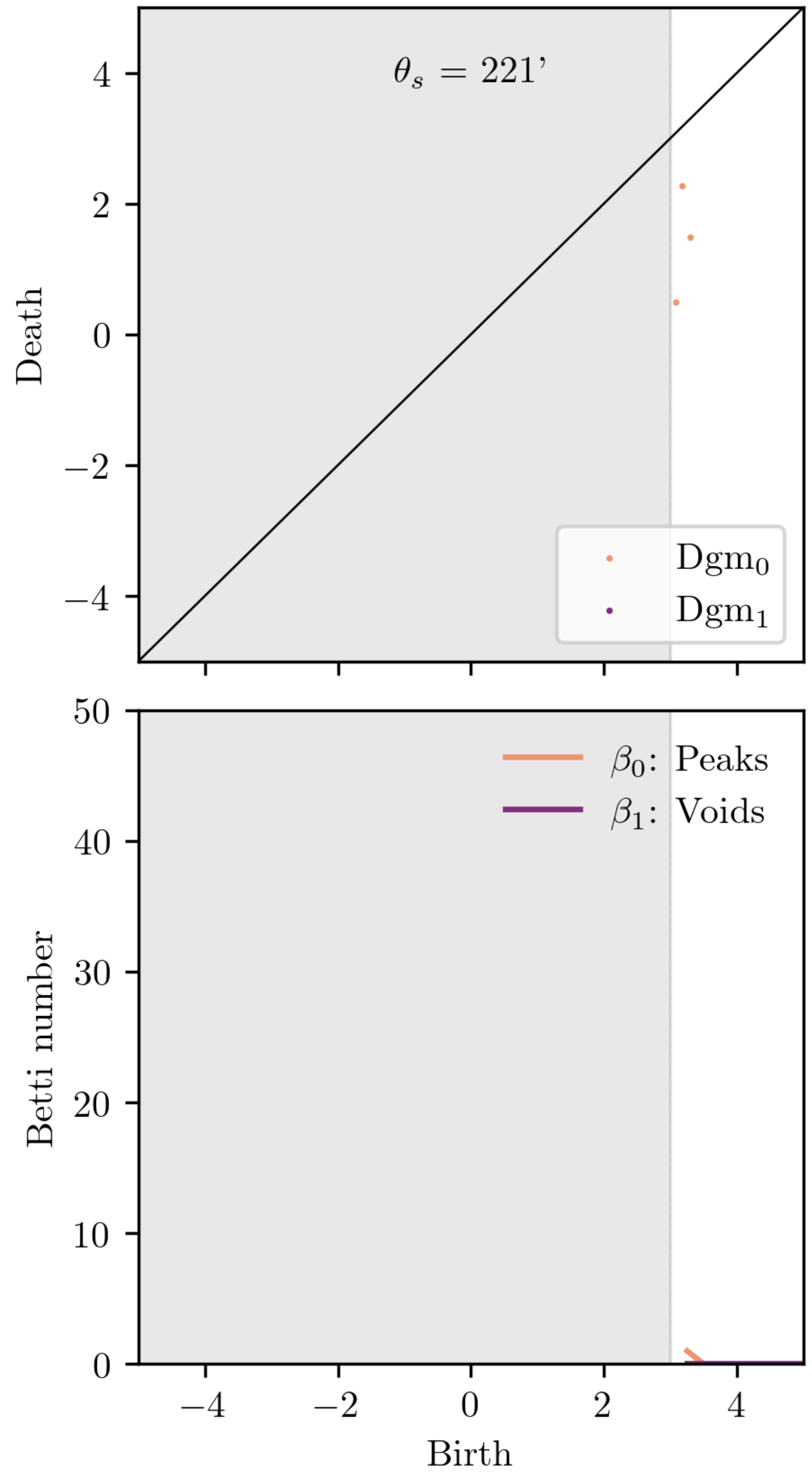


Building a filtration

Persistent diagram and Betti numbers





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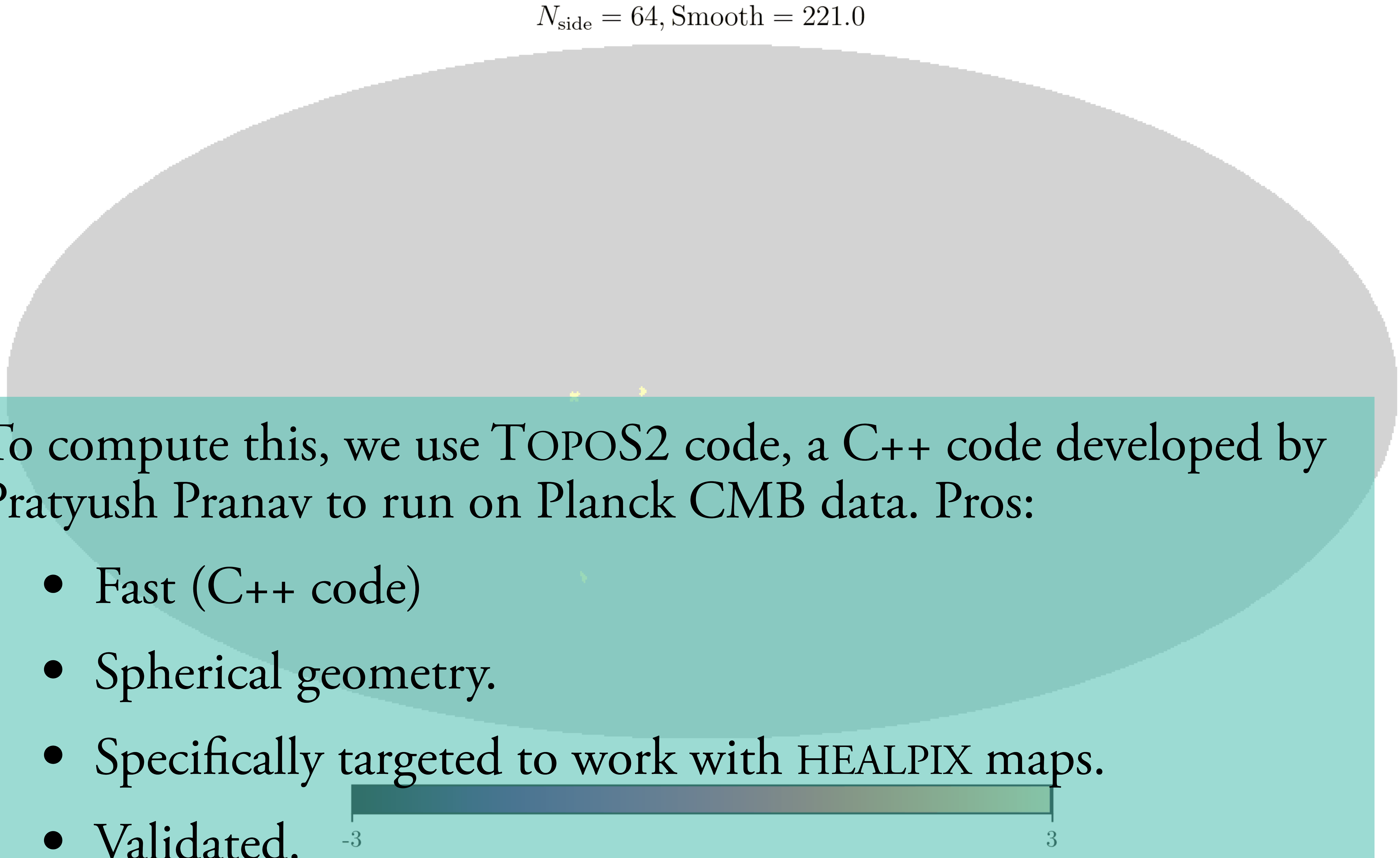
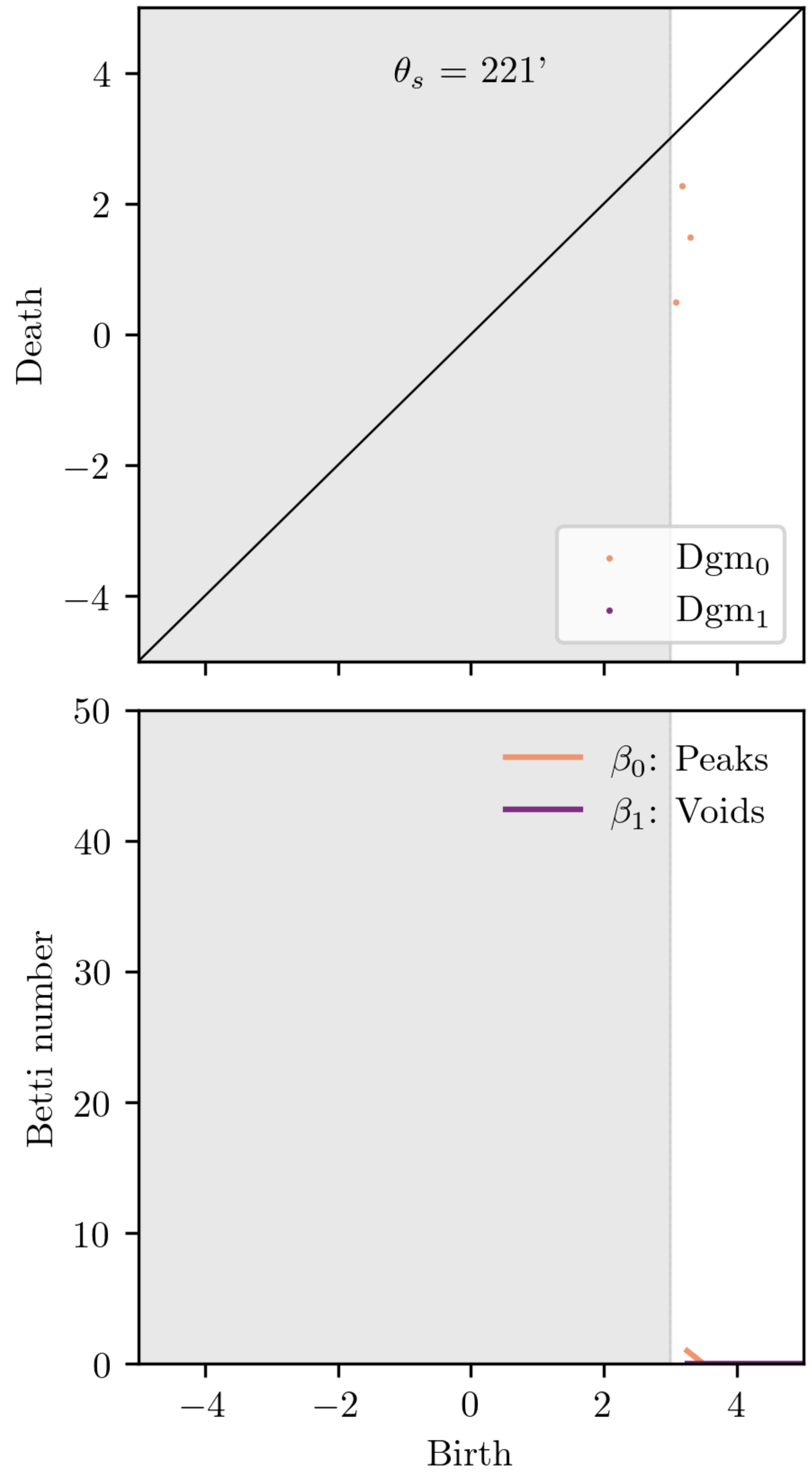
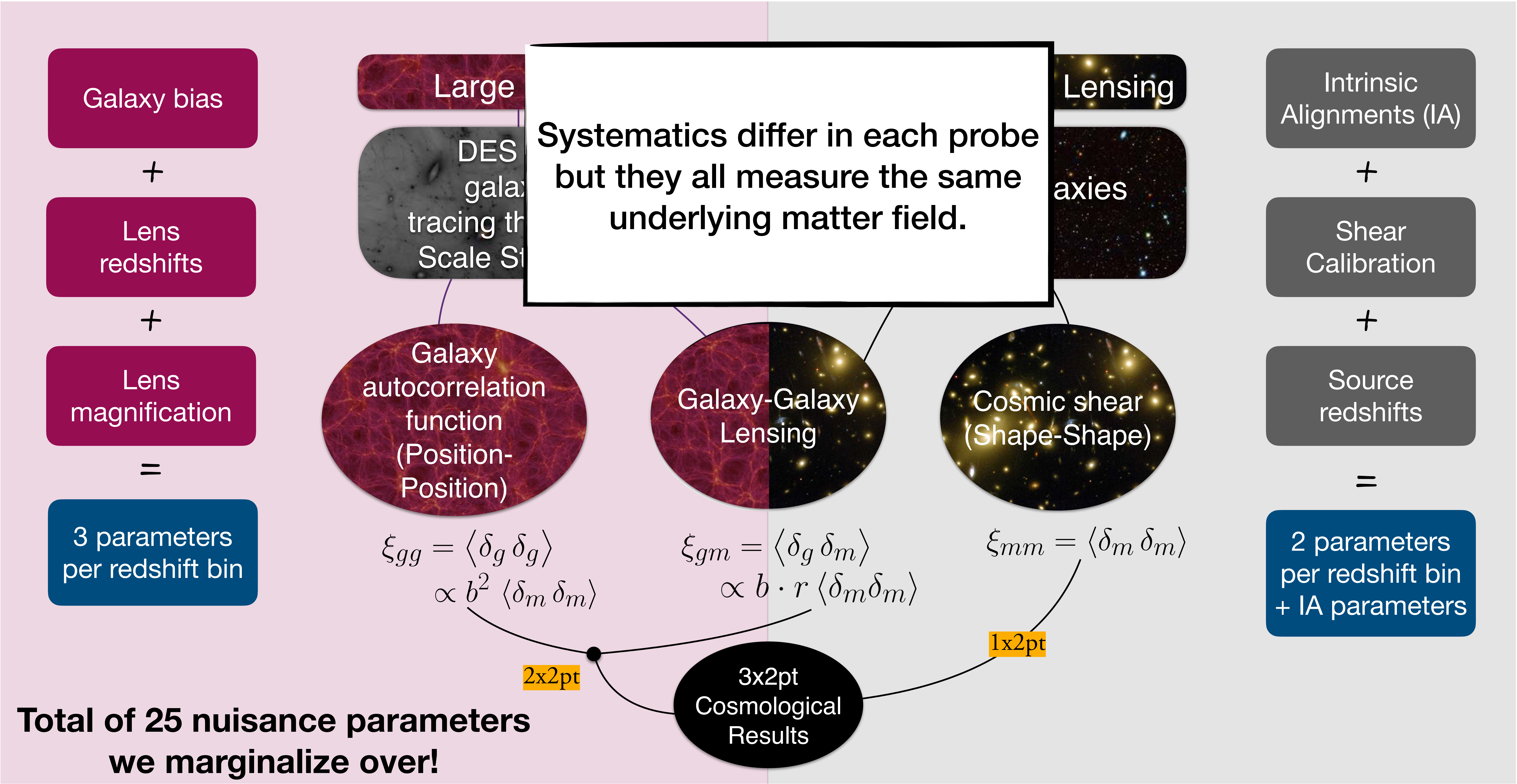
Persistent diagram and Betti numbers



To compute this, we use TOPOS2 code, a C++ code developed by Pratyush Pranav to run on Planck CMB data. Pros:

- Fast (C++ code)
- Spherical geometry.
- Specifically targeted to work with HEALPIX maps.
- Validated.




Galaxy bias
+
Lens redshifts
+
Lens magnification
=
3 parameters per redshift bin
Large
DES
gala
tracing th
Scale St
Systematics differ in each probe but they all measure the same underlying matter field.
Lensing
axies
Intrinsic Alignments (IA)
+
Shear Calibration
+
Source redshifts
=
2 parameters per redshift bin + IA parameters
Galaxy autocorrelation function (Position-Position)
Galaxy-Galaxy Lensing
Cosmic shear (Shape-Shape)
$\xi_{gg} = \langle \delta_g \, \delta_g \rangle \propto b^2 \, \langle \delta_m \, \delta_m \rangle$
$\xi_{gm} = \langle \delta_g \, \delta_m \rangle \propto b \cdot r \, \langle \delta_m \delta_m \rangle$
$\xi_{mm} = \langle \delta_m \, \delta_m \rangle$
2x2pt
1x2pt
3x2pt Cosmological Results
Total of 25 nuisance parameters we marginalize over!

My most relevant research outputs

A validated end-to-end pipeline to perform cosmological analyses in DESC, for the LSST

Prat, Zuntz, et al. (2022)

Today in the arXiv!

The most precise **cosmological results from the combination of weak lensing and galaxy clustering**

DES Y3 results:
Phys. Rev. D 105, 023520, 2022
DES Y1 Results:
Phys. Rev. D 98, 043526, 2018

Improvement of the **galaxy-halo connection** understanding

HOD in small scales galaxy-galaxy lensing (and upcoming galaxy clustering)

Zacharegkas , Chang, Prat et al. (2022)

Halo mass of **low-surface brightness galaxies** from weak lensing measurements

Chicoine, Prat et al. (in prep)

The development of a new methodology to use small-scale information in cosmological analyses called "**Lensing ratios**"

DES Y3: *Sánchez, Prat et al. (2018)*

Validated **galaxy-galaxy lensing** two-point correlation measurements and model, using DES Y3 and DES Y1 data

DES Y3: *Prat et al. (2022)*
DES Y1: *Prat, Sánchez, et al. (2018).*
Published as Phys. Rev. D Editors' Suggestion