cosmology with cosmos web

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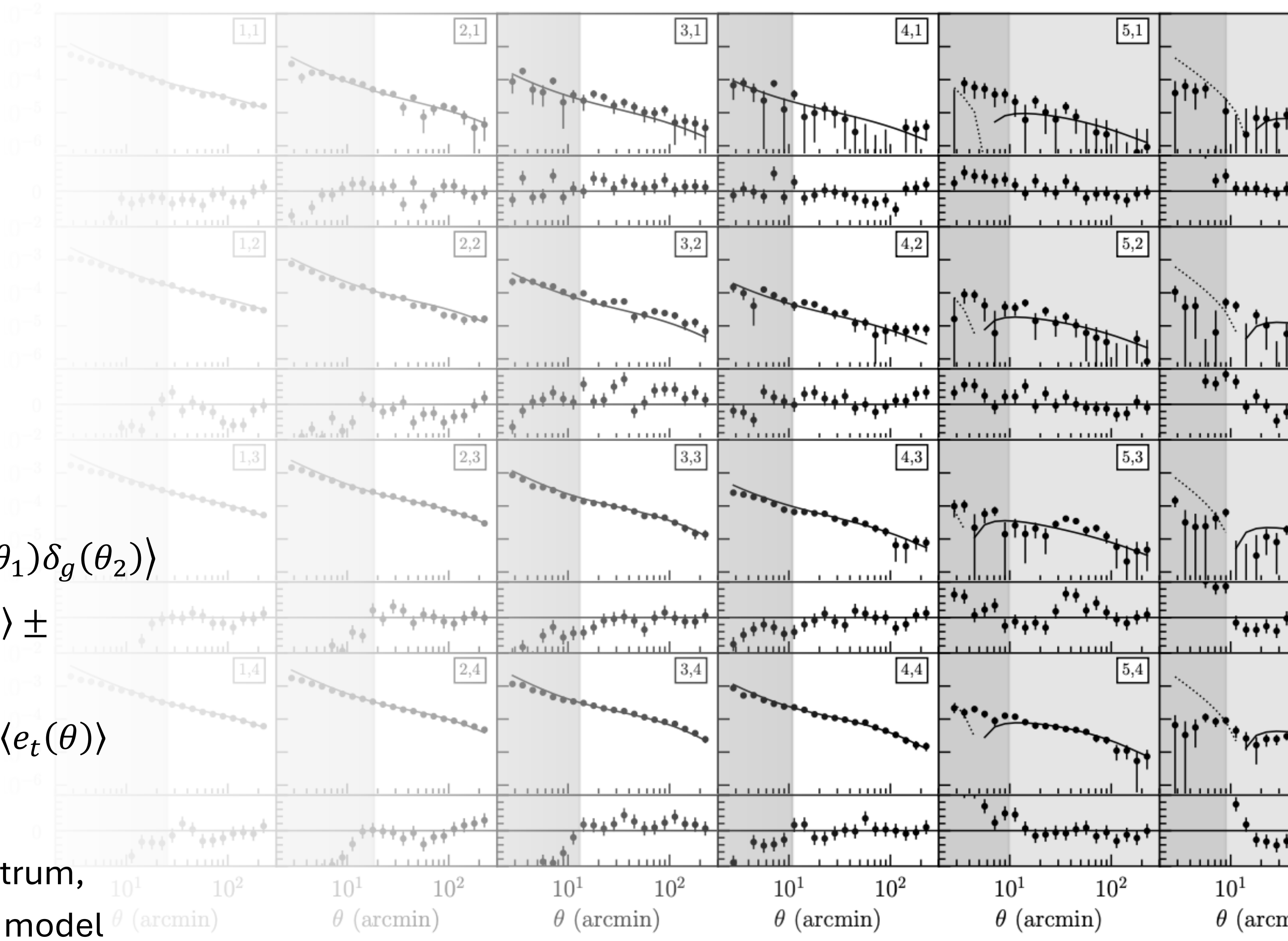
Lightning-quick review of 3x2 analyses

- **What are the 2-point correlation functions?**
  - galaxy clustering $w(\theta) = \langle \delta_g(\theta_1)\delta_g(\theta_2) \rangle$
  - cosmic shear $\xi^{\pm}(\theta) = \langle \gamma_t \times \gamma_t \rangle \pm \langle \gamma_t \times \gamma_t \rangle$
  - galaxy-galaxy lensing $\gamma_t(\theta) = \langle e_t(\theta) \rangle$
- **Why are they useful?**
  - Values depend on power spectrum, which depends on cosmology model

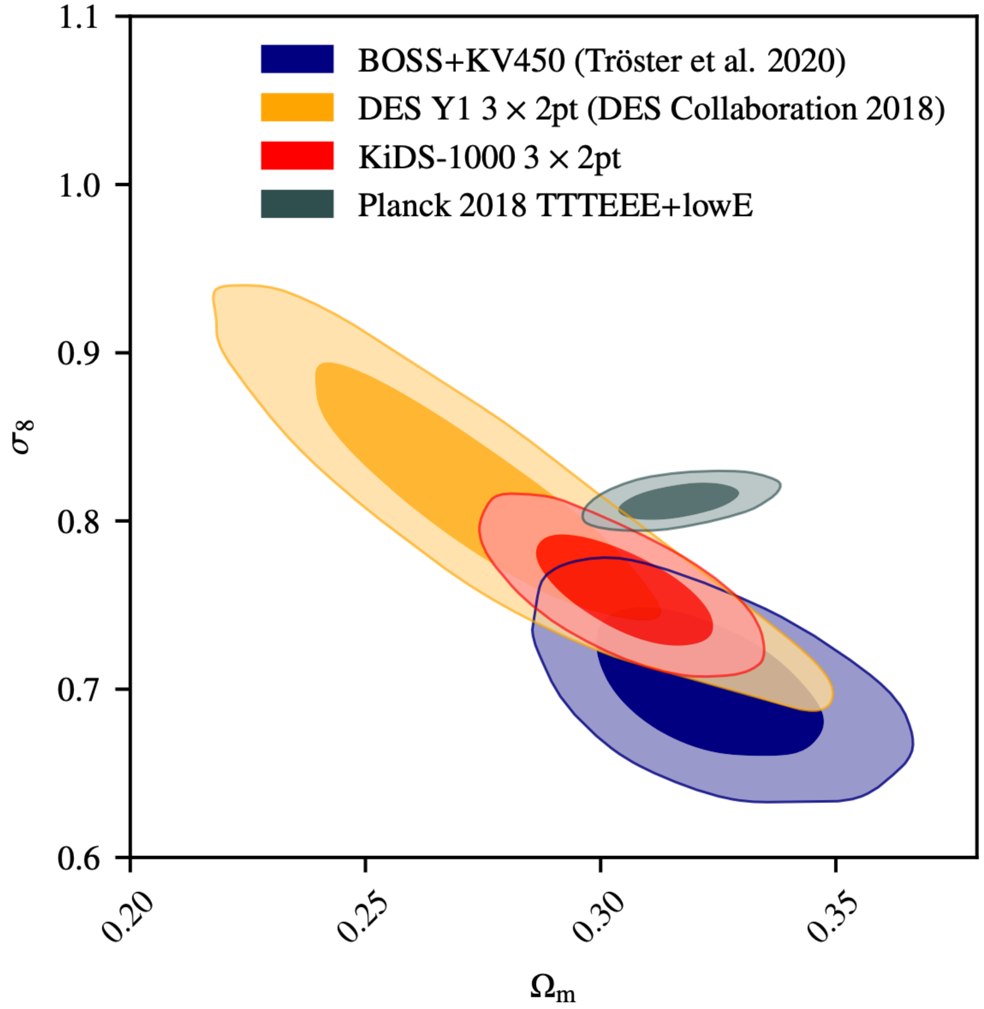


The measured $\gamma_t(\theta)$ correlation functions for each tomographic bin combination using the MagLim sample. In each panel rs to MagLim lens tomographic bin i and the source bin j The best-fit ΛCDM model from the fiducial 3×2pt analysis is plo in the top part of each panel, with dotted curves indicating a negative model fit. The bottom part of each panel shows the

Cosmological parameter tensions

- σ_8 : amplitude of mass fluctuations on scales of $8\ h^{-1}$ Mpc
- Ω_m: Matter density parameter
- Right: Constraints on σ_8 (amplitude of and Ω_m and its corresponding 1 and 2 sigma errors.

→ The values of S8 calculated from early-universe (CMB) and late-universe 3x2 probes are in 2-3 sigma conflict.

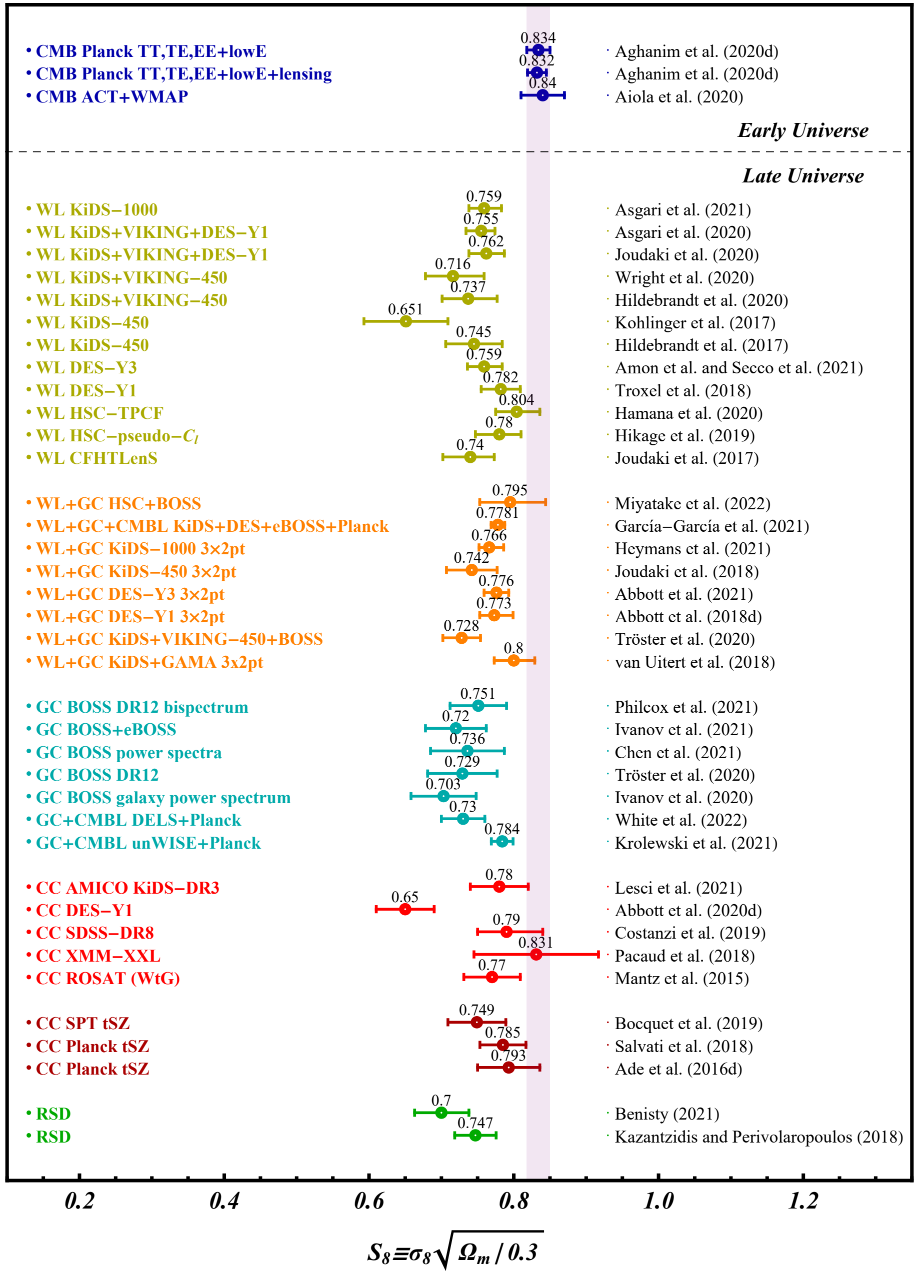


https://doi.org/10.1016/j.jheap.2022.04.002

Cosmology is getting interesting again

- Lensing constrains the "weighted amplitude of matter fluctuations" $S_8 \equiv \sigma_8\sqrt{\Omega_m/0.3}$
- Right: Constraints on S8 and its corresponding 68% error
- The values of S8 calculated from early-universe and late-universe probes are in ~3 σ_8 conflict
  - Combined CMB S_8: 0.832 ± 0.013
  - Weak lensing + galaxy clustering S_8 : 0.7781 ± 0.0094
  - Clusters S_8 : 0.789 ± 0.012
- This is unlikely attributable to a systematic in one single probe

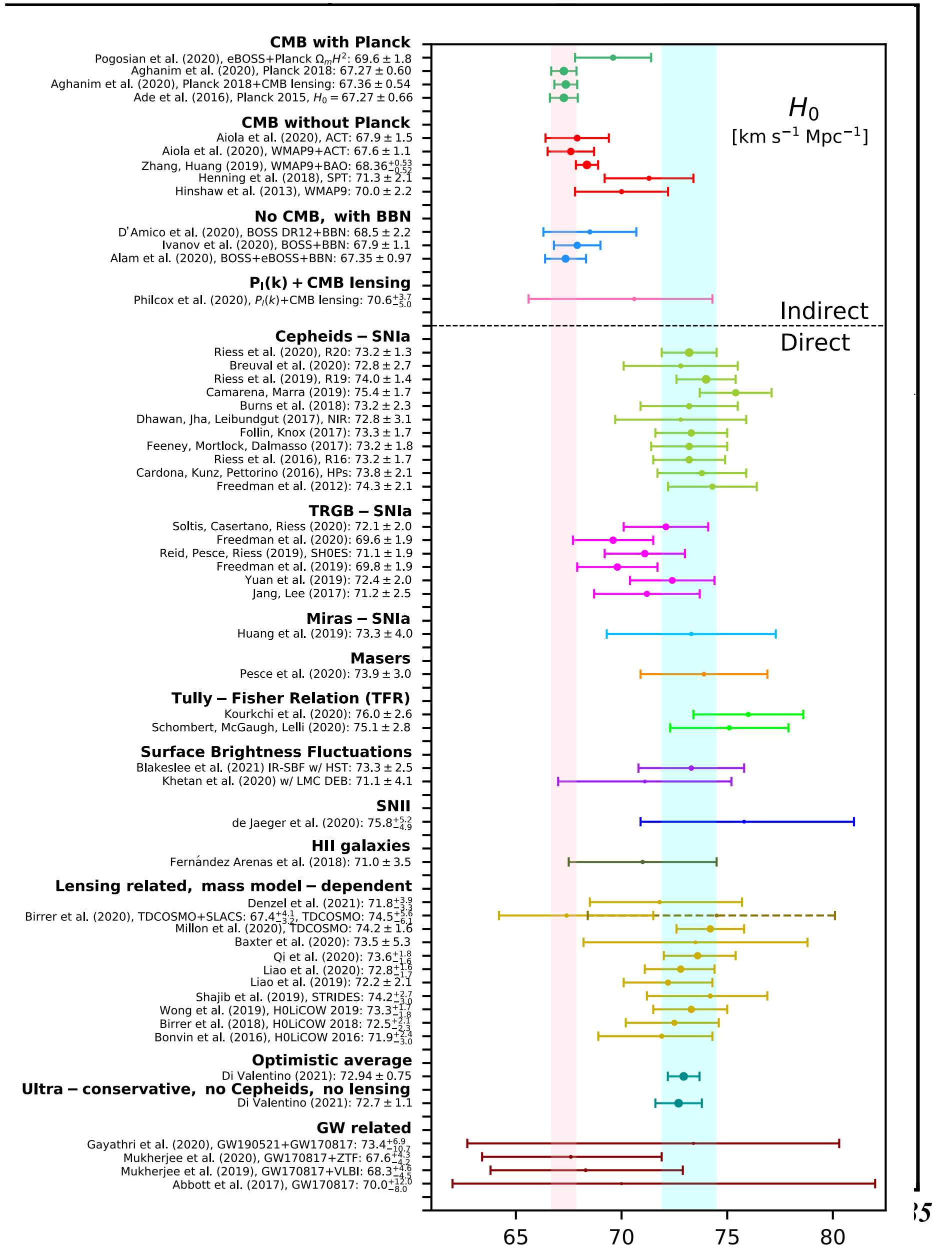
Note: the H_0 tension is even worse!



https://doi.org/10.1016/j.jheap.2022.04.002

The H0 tension

- Right: Constraints on H_0 and its corresponding 68% error
- Again, early-universe probes are in tension with late universe probes
- GW closer to early-universe!



https://doi.org/10.1016/j.jheap.2022.04.002

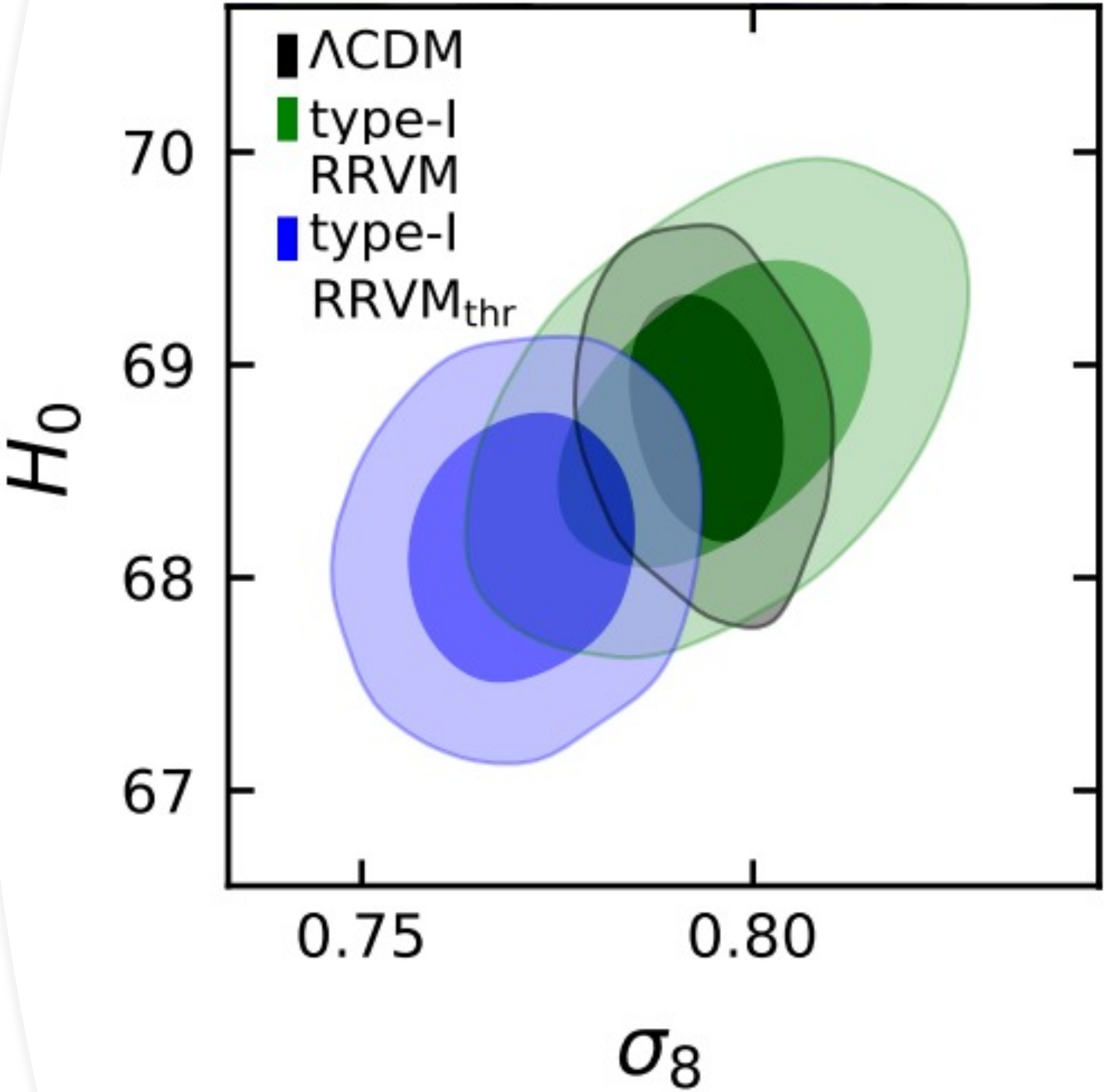
What does this mean?

The universe today *appears* to be expanding faster and has (somewhat) smaller fluctuations than decreed by LCDM + GR + CMB.

New Physics??

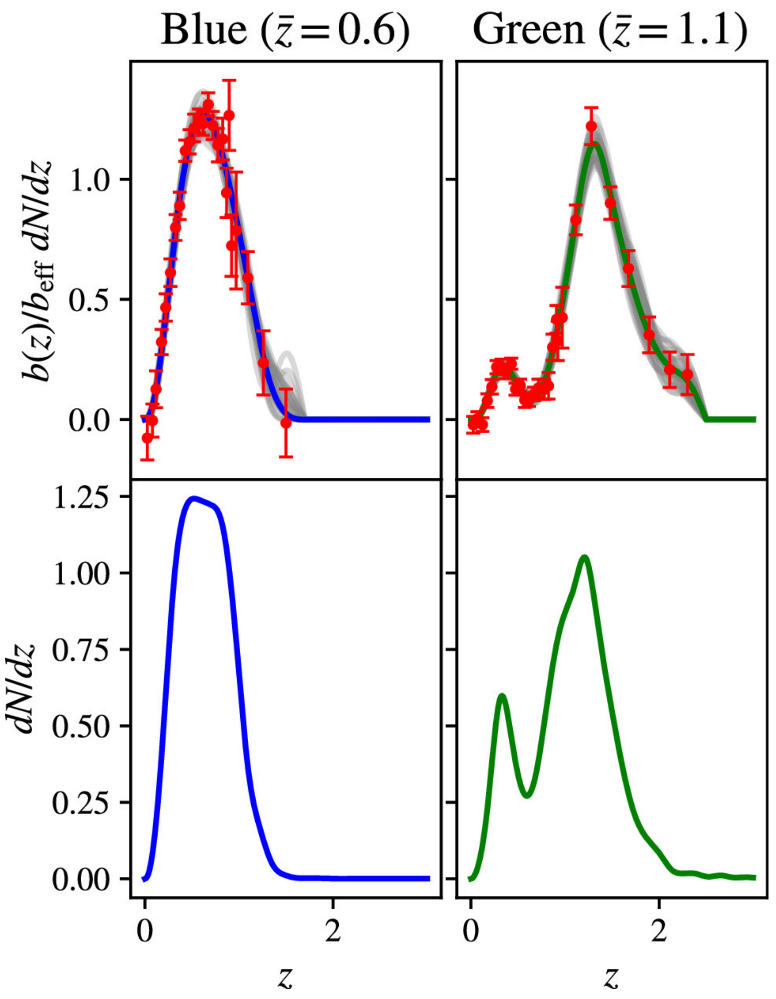
Probably not. It is very difficult to find a ΛCDM alternative model, e.g., decaying dark mater or early dark energy, that solves one tension without exacerbating another.

What else could be going on?



ACT CMB x unWISE Galaxy Lensing

- Tomographic measurements of structure growth using cross-correlation of unWISE galaxies (LSS) and ACT CMB lensing
- unWISE is IR: the "blue" sample of galaxies peaks at 0.5, the "green" peaks at 1.5
- Determine the amplitude of matter fluctuations at "low" redshifts (z ≃ 0.2–1.6, I call that intermediate) but linear scale and find $S_8 = 0.813 \pm 0.021$, completely consistent with Planck.
- **Find no evidence for S_8 tension at large (all-sky) scales above z > 0.2**



Lensing with no tensions

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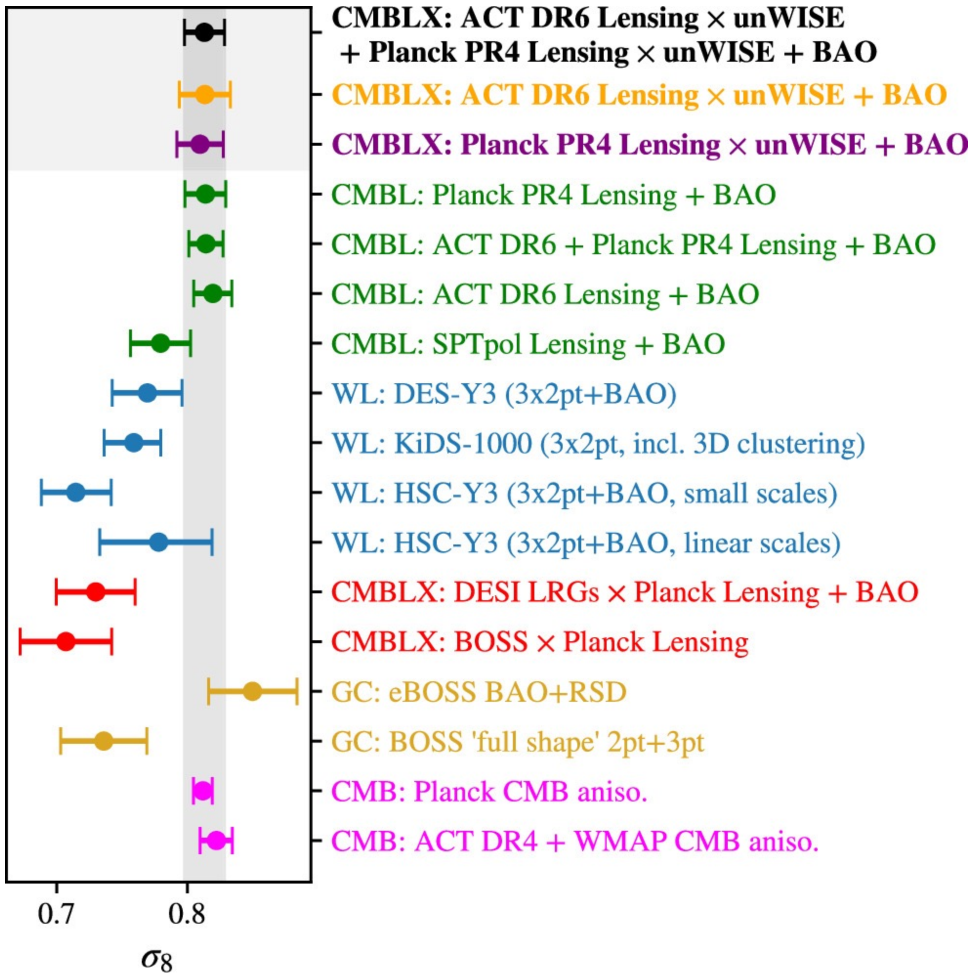
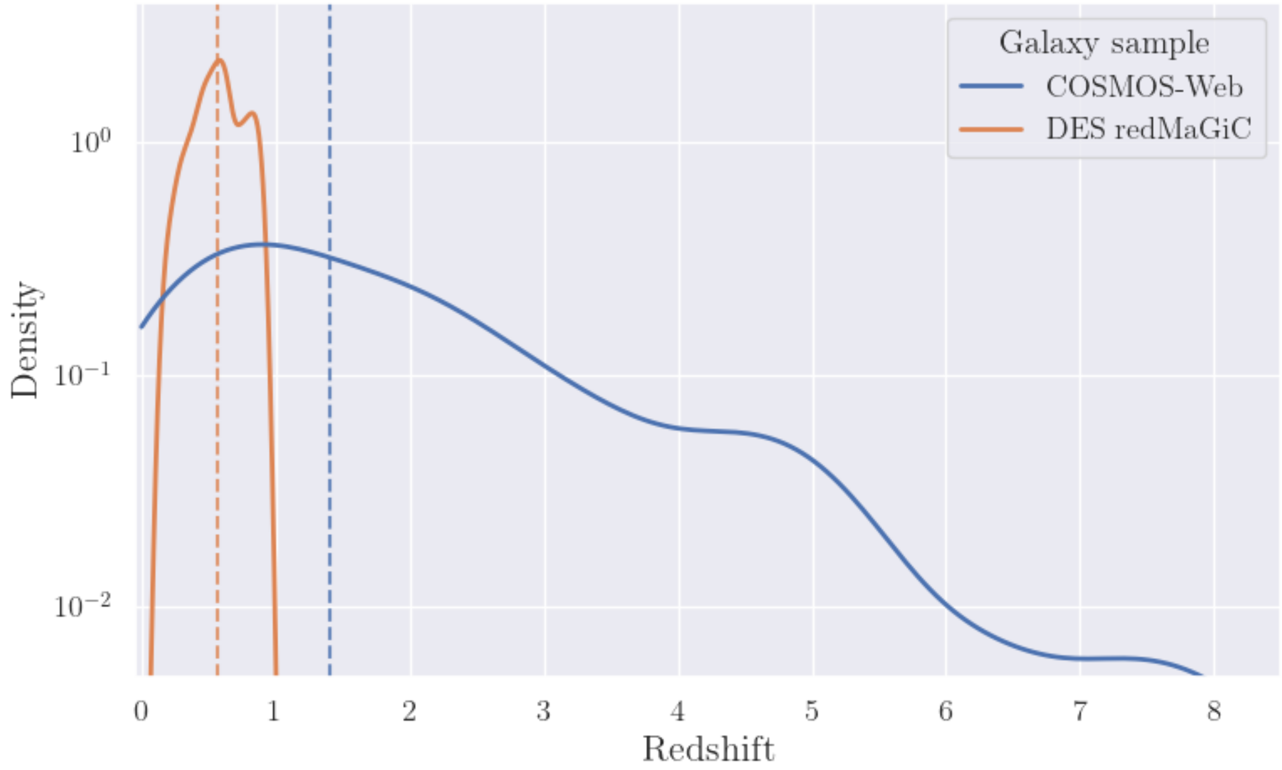


Let’s try this with COSMOS-Web

- redMaGiC: luminous red galaxies used for cosmology
  - Source density is low! 0.05 arcmin^{-1}
  - Low redshift: $\bar{z} = 0.57$
- Compare this with COSMOS-Web v2.0.1-v2
  - Much higher source density > 220 arcmin^{-1}
  - Much higher mean redshift $\bar{z} = 1.8$
- What we lack in size, we make up in galaxy density and redshift!



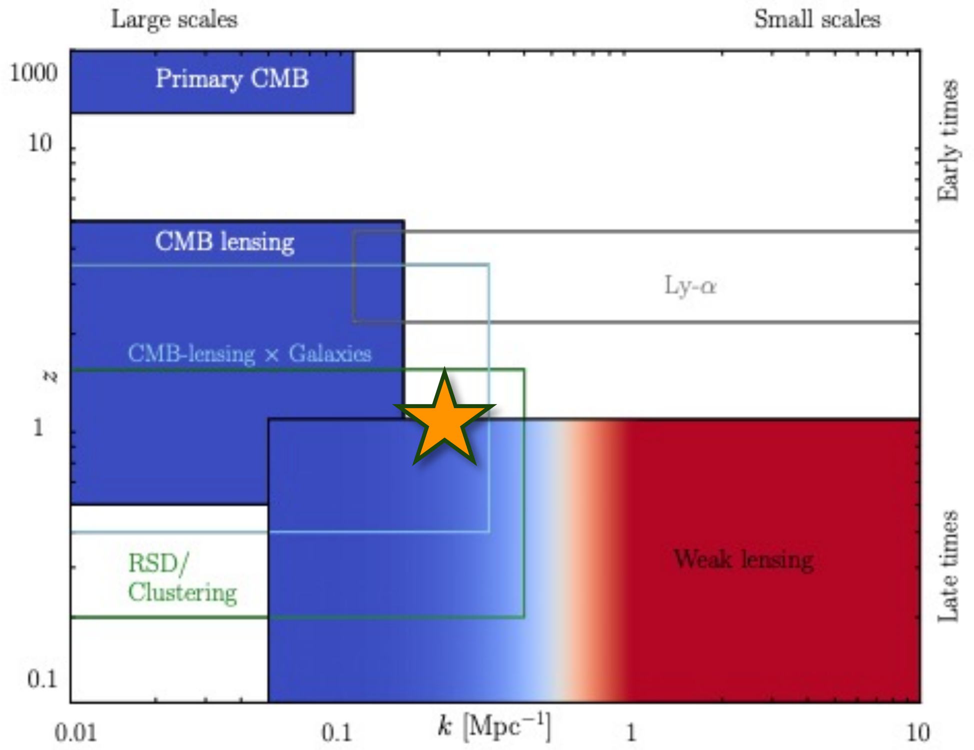
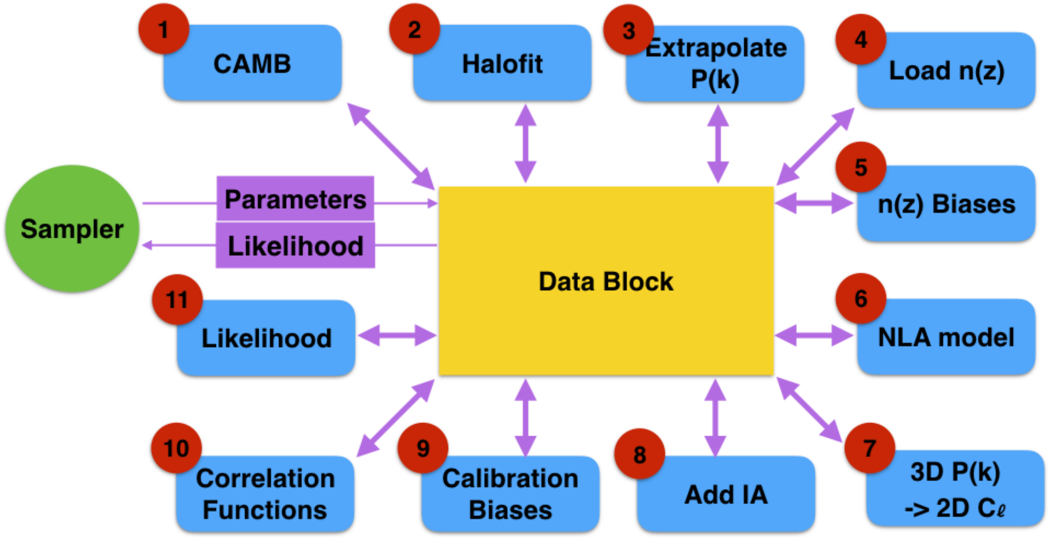


Figure 8. A rough guide to the approximate scale-dependence in terms of wavenumber, k, and redshift-dependence, z, of cosmological observations. CMB lensing measurements are consistent with *Planck* ΛCDM (both blue, filled) and have negligible sensitivity on non-linear modelling and span the range $z \sim 0.5 - 5$. Weak galaxy lensing is sensitive to a wide range of scales at $z < 1$, but primarily probes the non-linear regime (red, filled). With fu-

Scales being probed by different cosmological probes

- CMB: large scales and high redshift, obviously
- Ground-based lensing: mostly non-linear and low redshift.
- CMB x allWISE lensing: large scales, intermediate redshift
- **COSMOS-Web (orange star): quasi-linear, intermediate redshift?** There are few S8 measurements at this redshift

Likelihood calculation with CosmoSIS



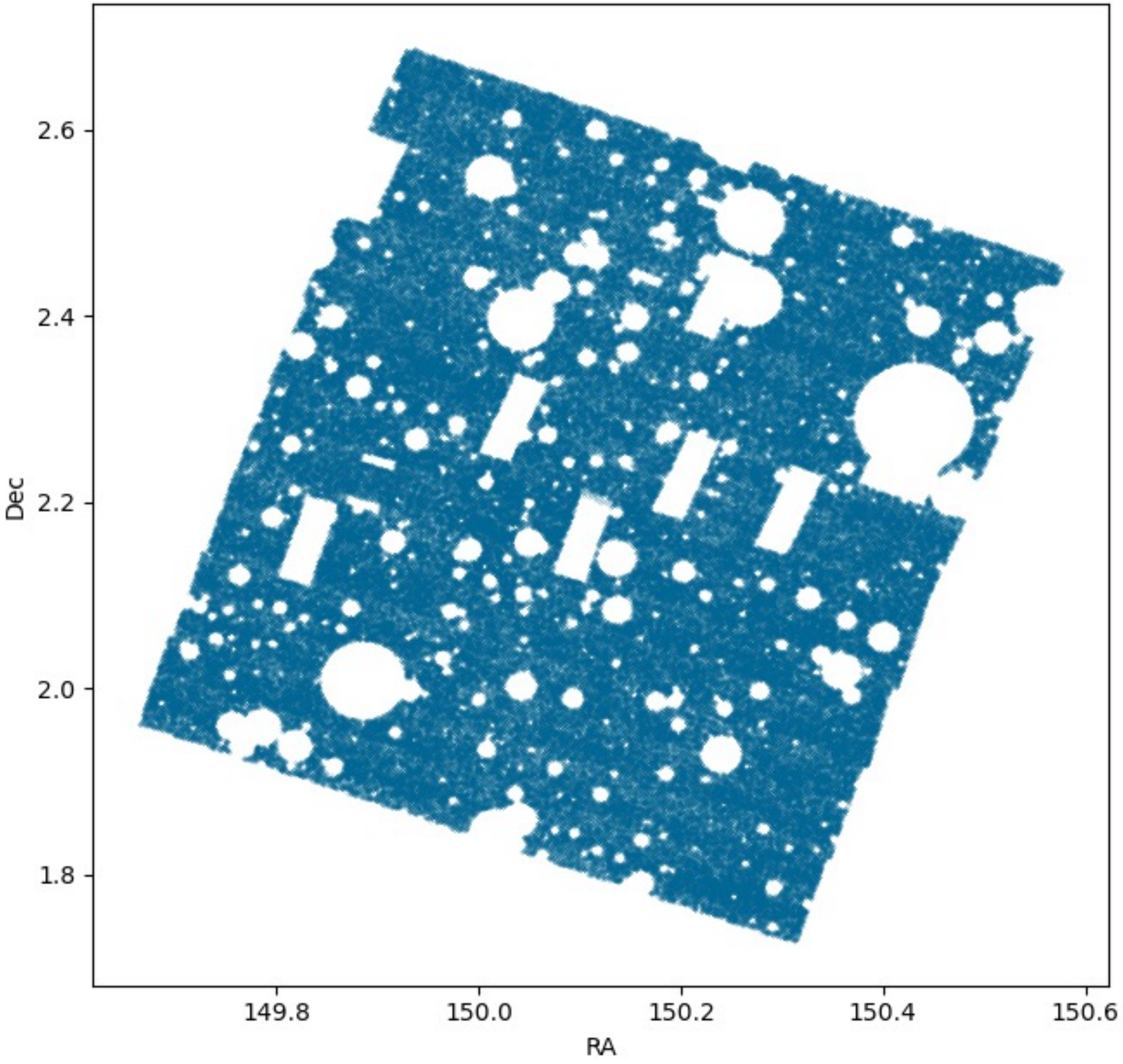
Computing the theoretical prediction of a cosmological model is long and complicated process with many steps. **CosmoSIS organizes each of those steps as a separate piece of code called a module**.

CosmoSIS connects together **samplers**, which decide how to explore a cosmological parameter space, with **pipelines** made from a sequence of **modules**, which calculate the steps needed to get a likelihood functions.

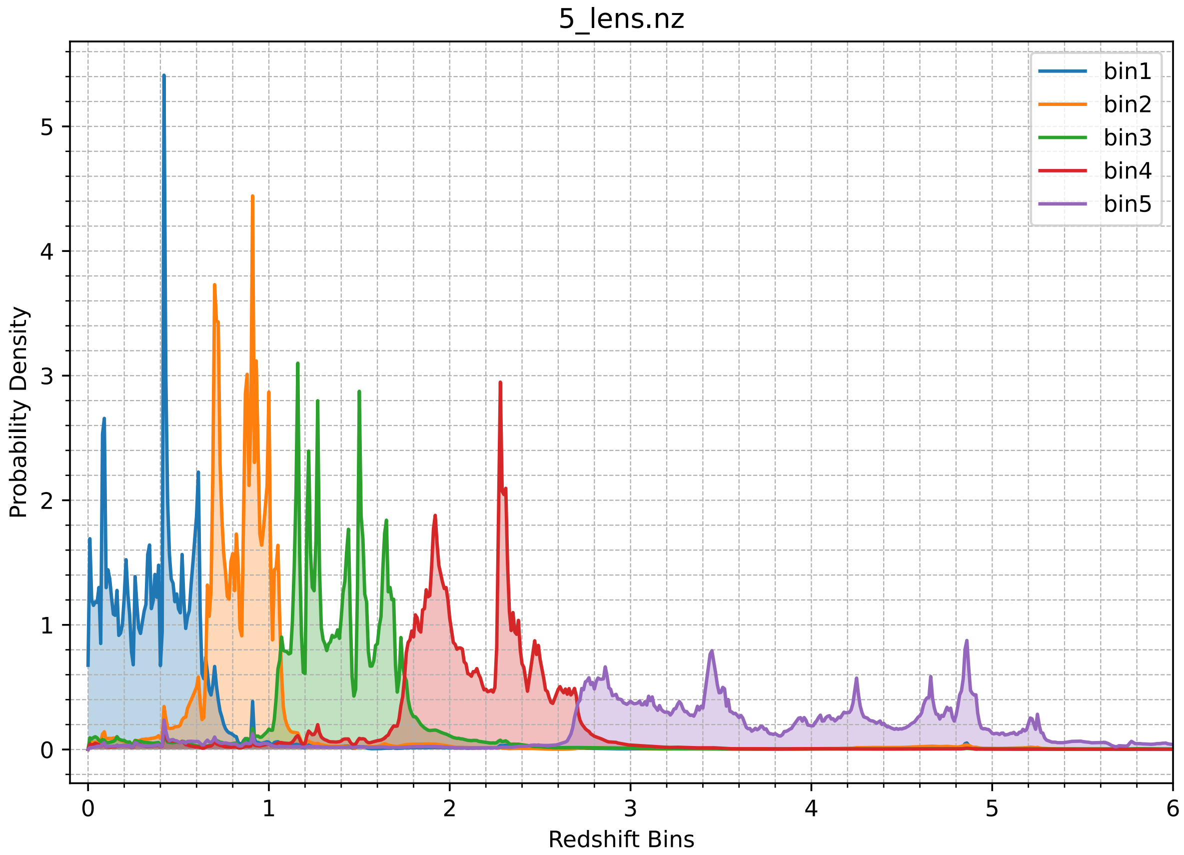
The CosmoSIS Standard Library comes with a large collection of popular cosmology codes packaged as modules. Organization is user's choice!

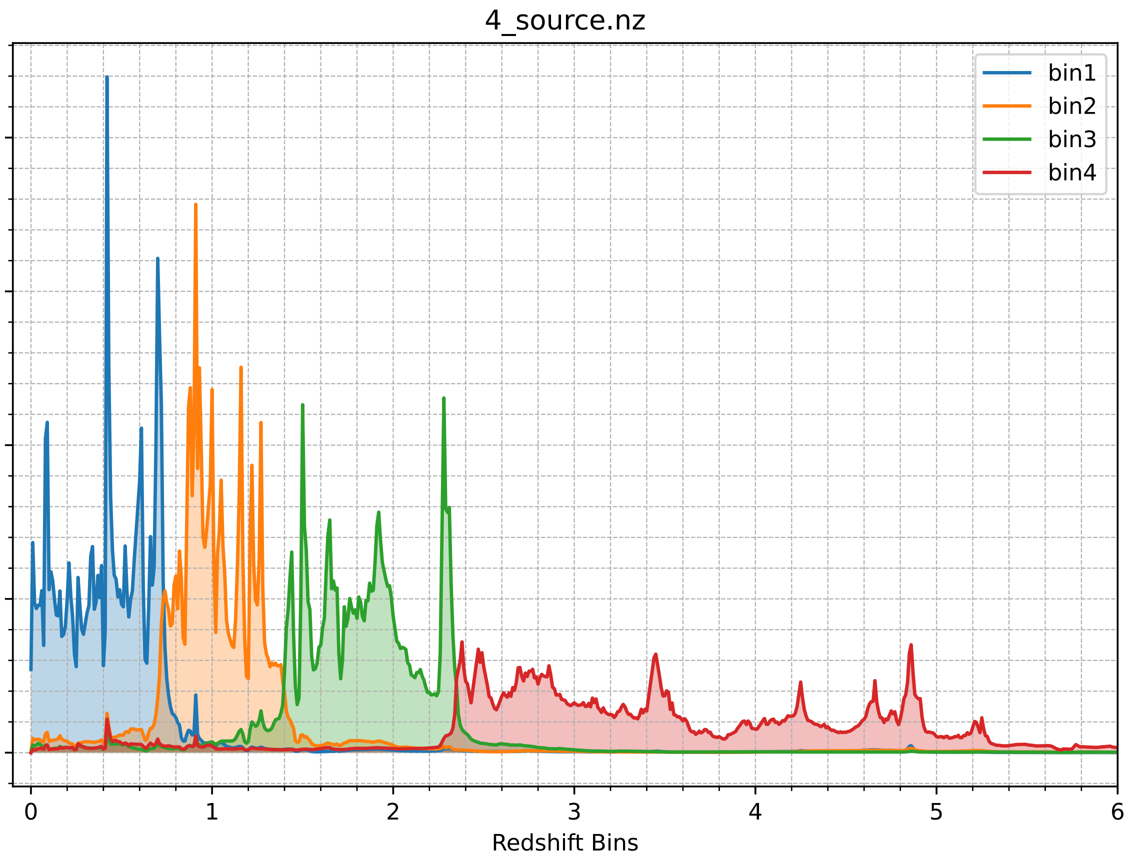
Getting galaxy redshift distributions

- **Important input for CosmoSIS**
- Using PDFs from LePhare (ty Olivier!) and binning by `LP_zfinal`
- Selections:
  - `FLAG_STAR_JWST == 0`
  - `& LP_warn_fl == 0`
  - `& LP_zfinal > 0`
- Leaves 451,800/ 642,833 objects (70%)



Redshift PDFs for COSMOS-Web

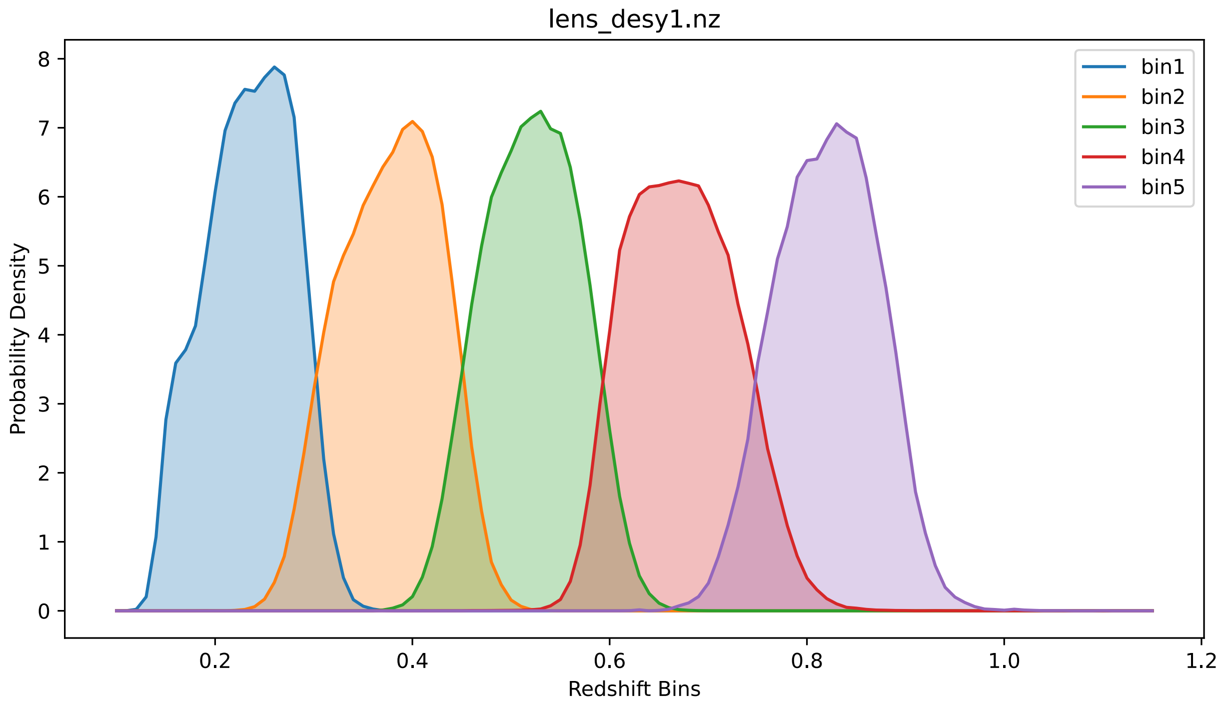


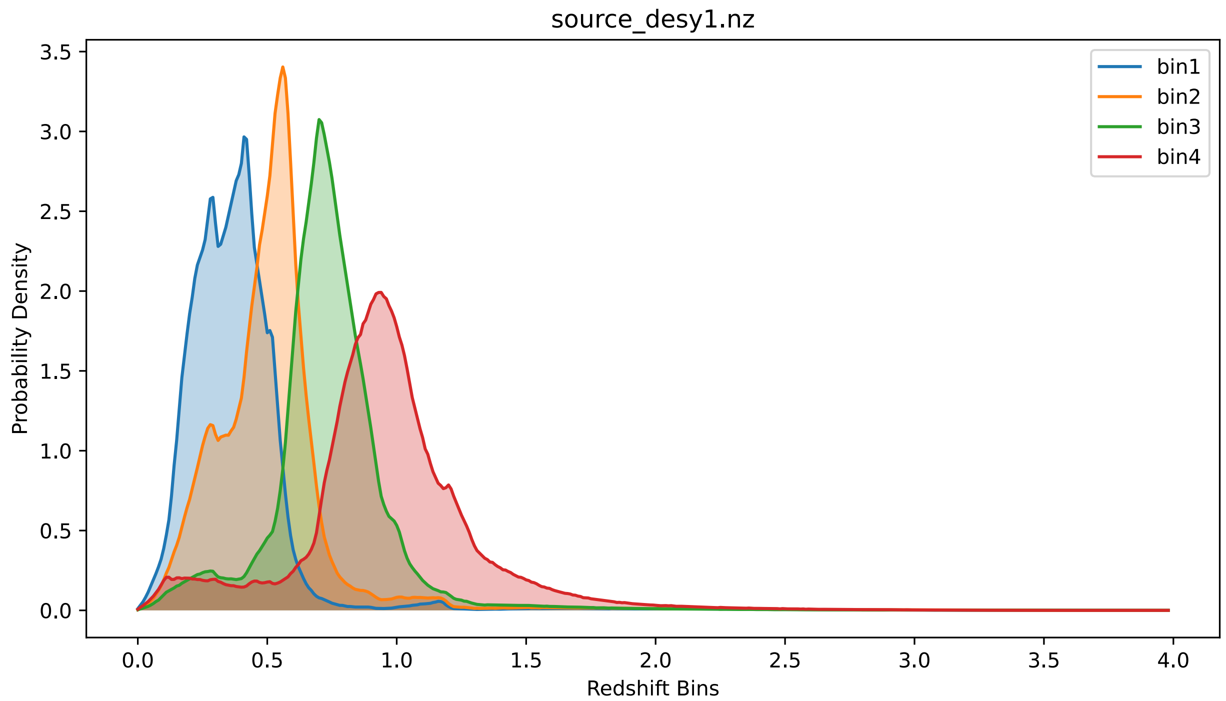


	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5
z_{median}	0.39	0.87	1.4	2.11	3.97
N_{gal}/ arcmin^{-2}	45.12	45.12	45.12	45.12	45.12

	Bin 1	Bin 2	Bin 3	Bin 4
z_{median}	0.44	1.00	1.85	3.47
N_{gal}/ arcmin^{-2}	56.39	56.41	56.40	56.4

Redshift PDFs for DES Y1 3x2 analysis





	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5
z_{median}	0.2	0.35	0.5	0.65	0.85
N_{gal}/ arcmin^{-2}	0.0134	0. 0343	0.0505	0.0301	0.0089

	Bin 1	Bin 2	Bin 3	Bin 4
z_{median}	0.34	0.6	0.74	1.1
N_{gal}/ arcmin^{-2}	1.50	1.52	1.6	0.80

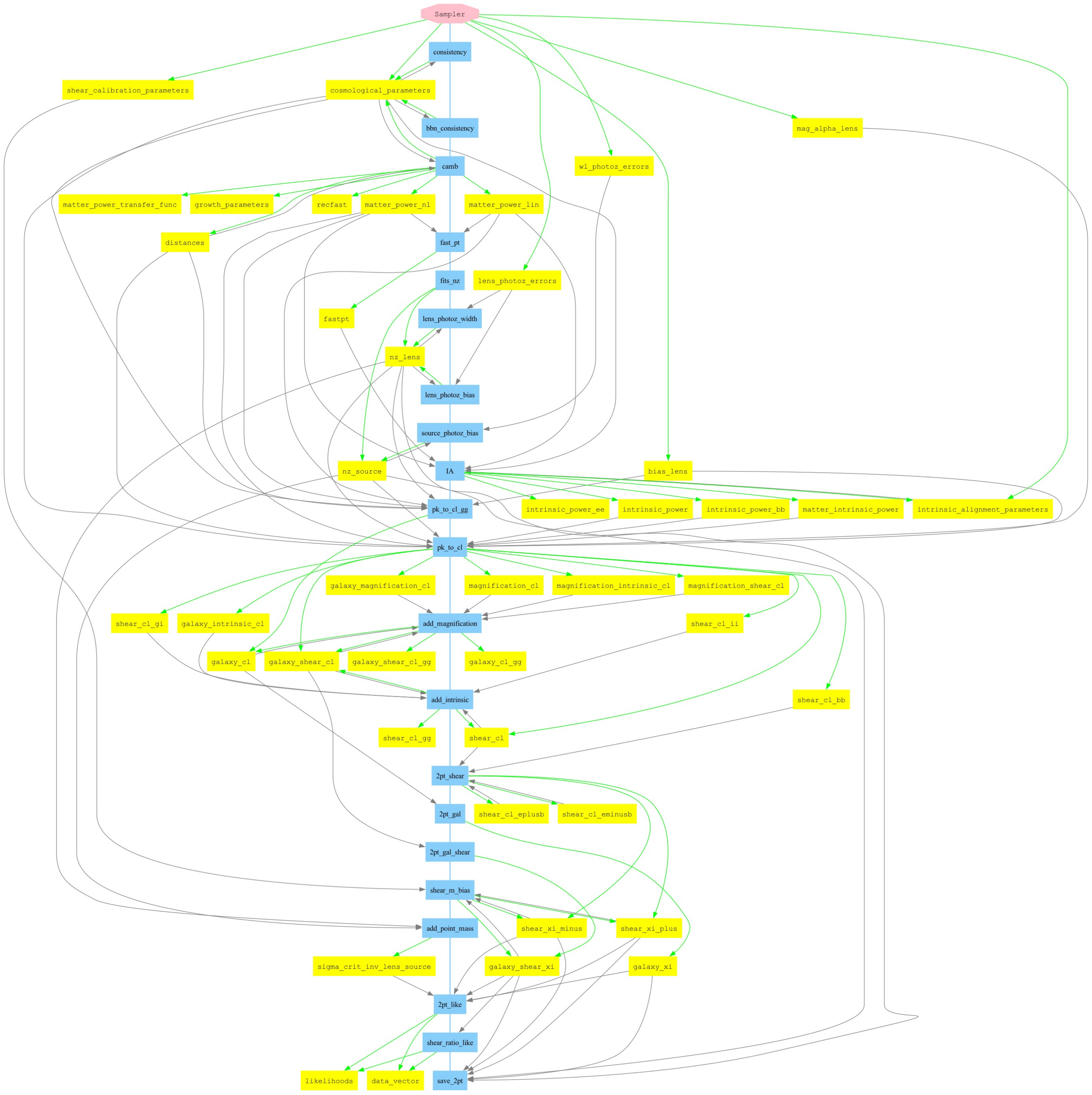
A sample 3x2-pt CosmoSIS pipeline for COSMOS-Web data

Many, many moving parts!

This is based on DES Y3 pipeline

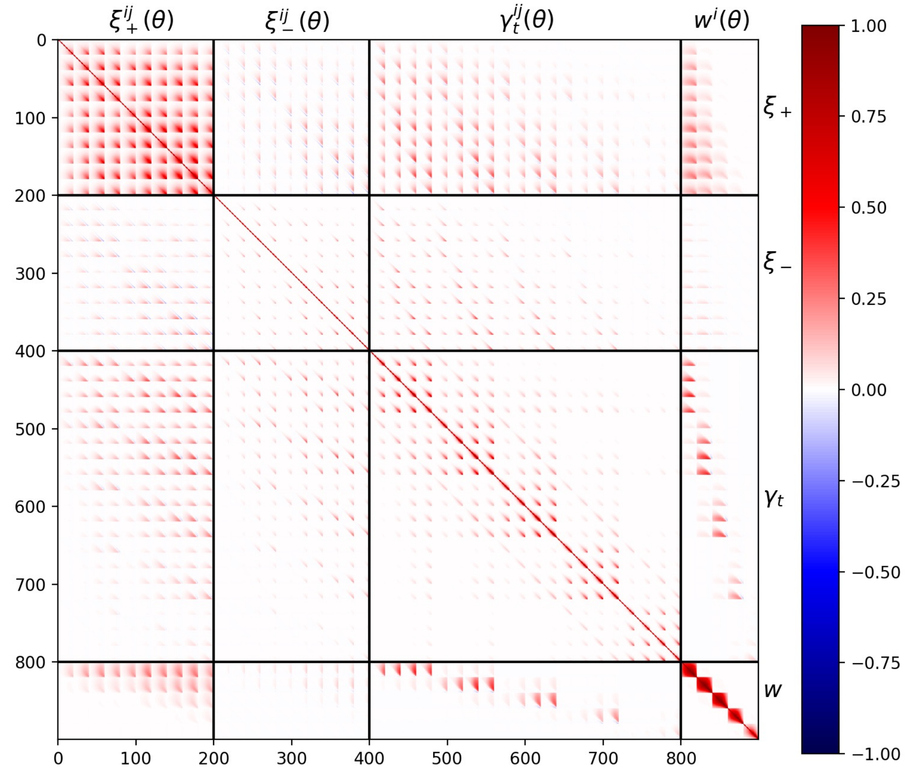
To a greater or lesser extent, all of these 2-point pipelines are similar, so structure won't change very much overall

Note: CosmoSIS only generates Gaussian covariances

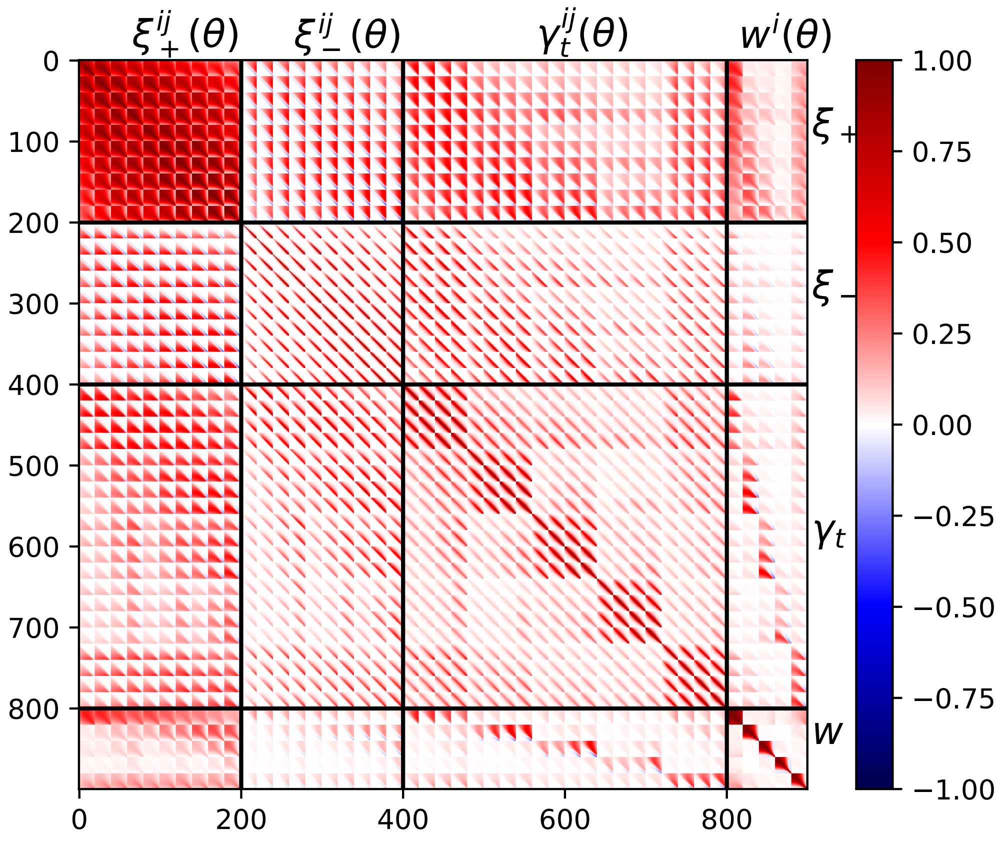


Gaussian covariance

DES Y3

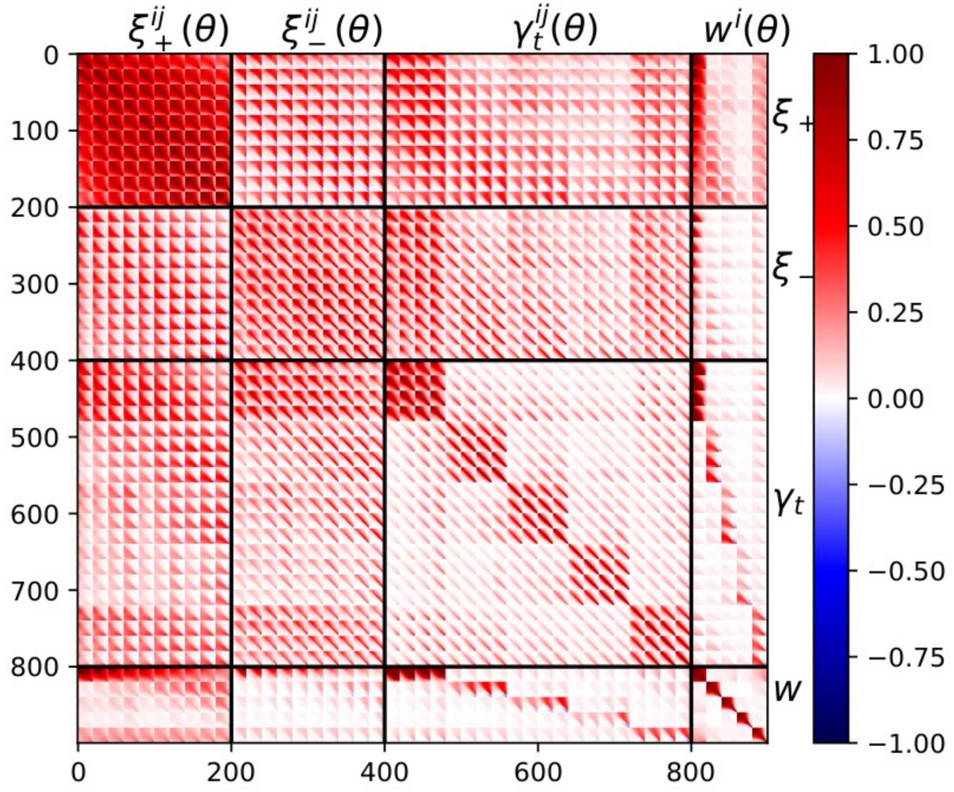


COSMOS-Web

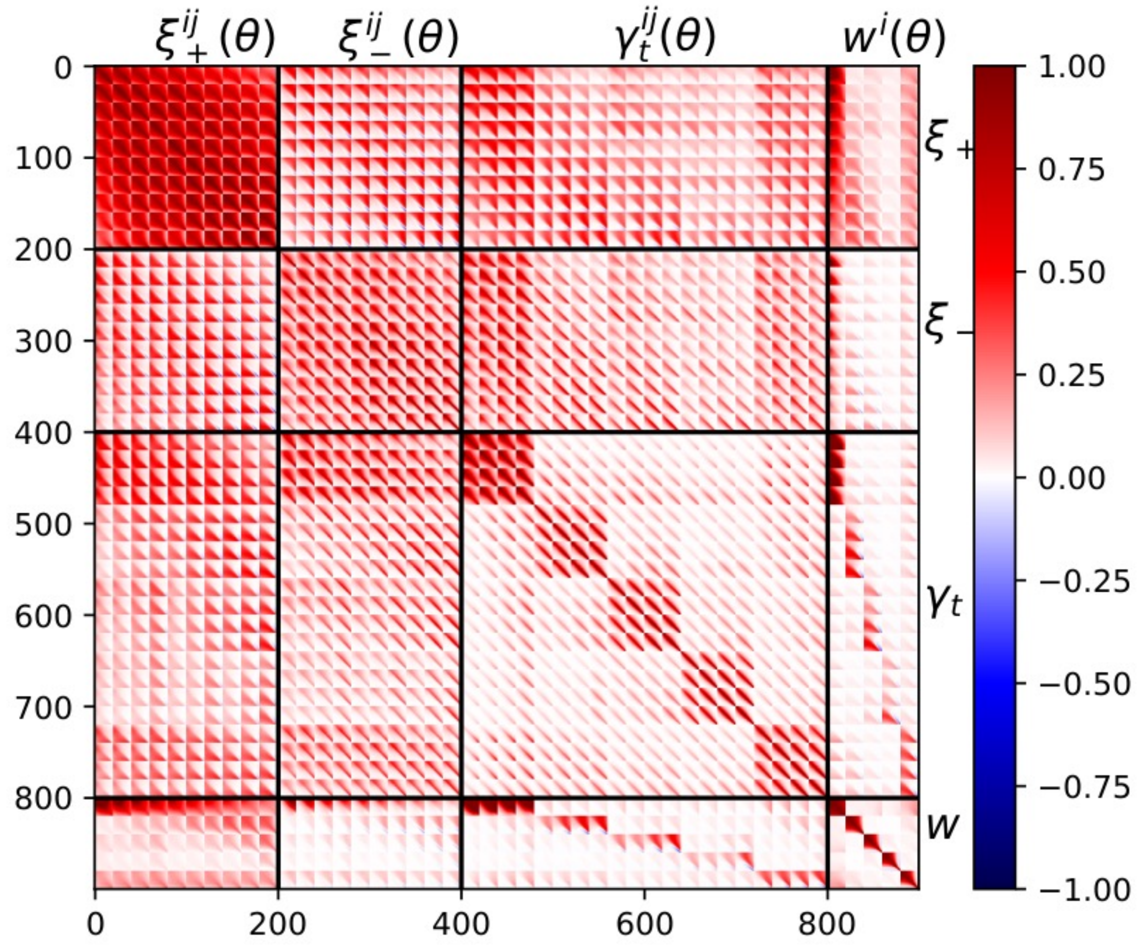


Non-Gaussian covariance

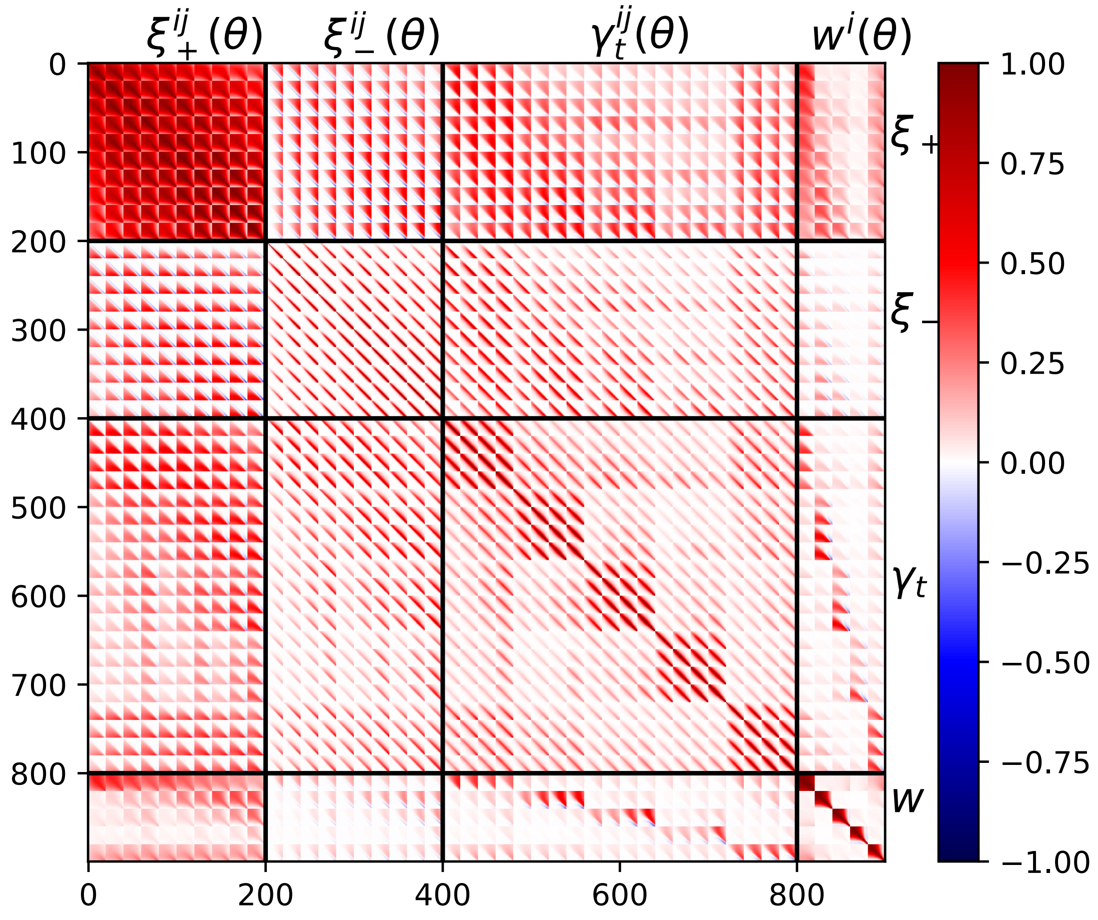
- Due to our very small surface area (by cosmology standards!), we will be entirely cosmic-variance dominated.
- Small scales also mean that we can't assume a Gaussian covariance of parameters – not averaging over enough pairs
- Use **CosmoCov** library to generate NG covariances
- Note: example at left is purely illustrative – missing important pieces like realistic scale cuts



Non-Gaussian covariance



Gaussian covariance



The COSMOS-Web CosmoSIS workflow

Step 1

Generate likelihood (data block) from 3x2 data with placeholder covariance in CosmoSIS; this stores theoretical predictions for your area, n(z), etc.

Step 2

Use CosmoCov to generate non-Gaussian covariance… in text files

Step 3

Reformat and reshape CosmoCov output to match CosmoSIS format

Replace existing CosmoSIS data block covariance with new CosmoCov covariance

Step 4

Run pipeline with updated covariance

Generate plots!

Is a COSMOS-Web 3x2 point worth the effort?

The answer is to run a forecast

A COSMOS-Web CosmoSIS forecast workflow

Step 0

Run CosmoSIS in "dummy" mode, saving the theoretical output as a data set to be used in a subsequent analysis

Step 2

Use CosmoCov to generate non-Gaussian covariance… in text files

Step 3

Reformat and reshape CosmoCov output to match CosmoSIS format

Replace existing CosmoSIS data block covariance with new CosmoCov covariance

Step 4

Run pipeline with updated covariance

Generate plots!

Big parameter space to explore...

Covariance parameters

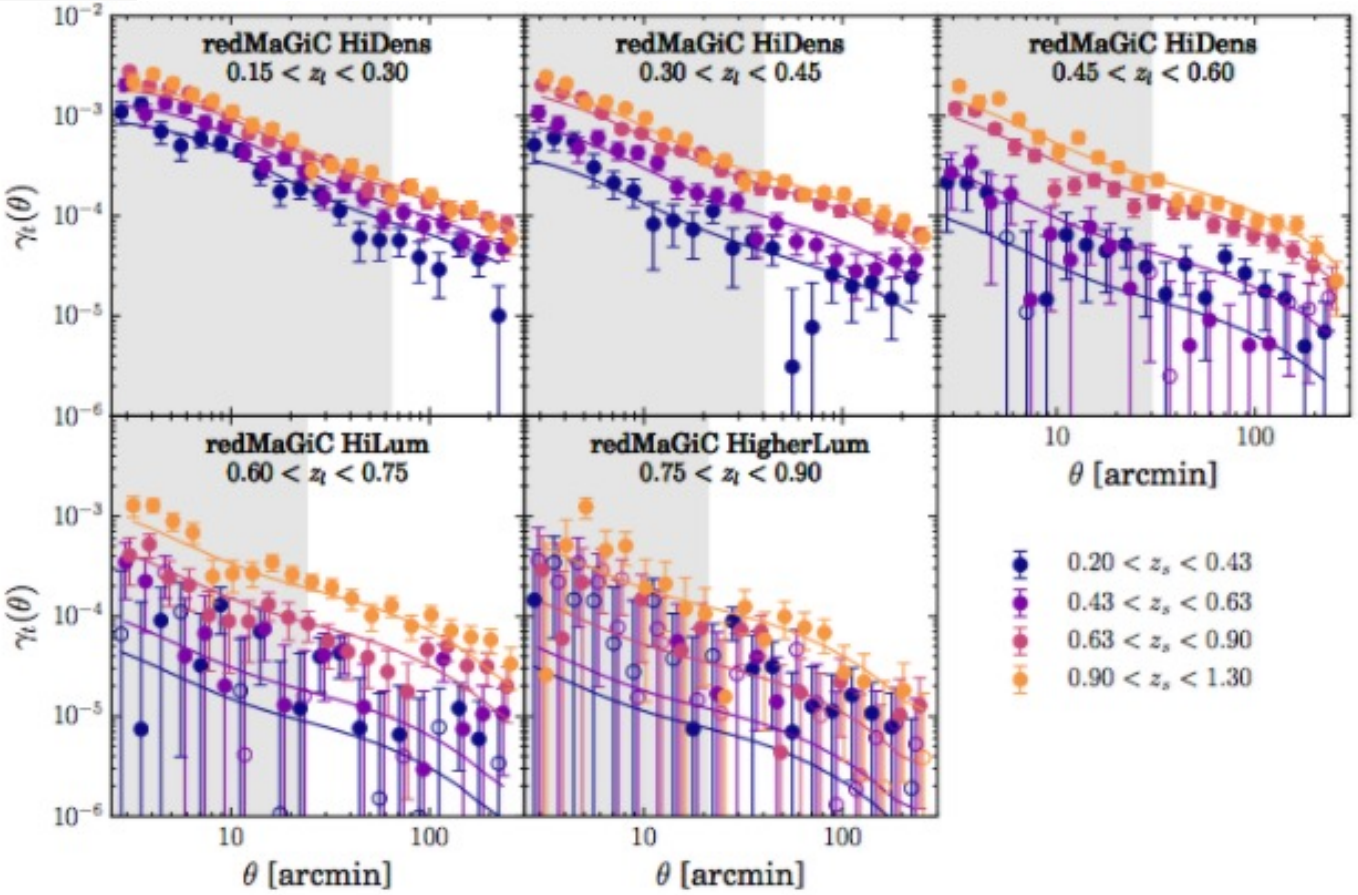
```
##
## Survey and galaxy parameters
##
## n_gal,lens_n_gal in gals/arcmin^2
source_tomobins : 4
lens_tomobins : 5
sigma_e : 0.39441348451
shear_REDSHIFT_FILE : zdistris/source_desy1.nz
clustering_REDSHIFT_FILE : zdistris/lens_desy1.nz
source_n_gal : 1.496,1.5189,1.5949,0.7949
lens_n_gal : 0.0134,0.0343,0.0505,0.0301,0.0089
lens_tomogbias : 1.44,1.70,1.698,1.997,2.058
lens_tomo_bmag : 0.0,0.0,0.0,0.0,0.0
# IA parameters
IA : 1
A_ia : 0.0
eta_ia : 0.0
##
## Covariance paramters
##
## tmin,tmax in arcminutes
tmin : 2.5
tmax : 250.0
ntheta : 20
ng : 1
cng : 1
```

Scale cuts

```
[2pt_like]
angle_range_xip_1_1 = 2.475 999.0
angle_range_xip_1_2 = 6.21691892 999.0
angle_range_xip_1_3 = 6.21691892 999.0
angle_range_xip_1_4 = 4.93827423 999.0
angle_range_xip_2_2 = 6.21691892 999.0
angle_range_xip_2_3 = 6.21691892 999.0
angle_range_xip_2_4 = 6.21691892 999.0
angle_range_xip_3_3 = 6.21691892 999.0
angle_range_xip_3_4 = 6.21691892 999.0
angle_range_xip_4_4 = 4.93827423 999.0

angle_range_xim_1_1 = 24.75 999.0
angle_range_xim_1_2 = 62.16918918 999.0
angle_range_xim_1_3 = 62.16918918 999.0
angle_range_xim_1_4 = 49.3827423 999.0
angle_range_xim_2_2 = 62.16918918 999.0
angle_range_xim_2_3 = 78.26637209 999.0
angle_range_xim_2_4 = 78.26637209 999.0
angle_range_xim_3_3 = 78.26637209 999.0
angle_range_xim_3_4 = 78.26637209 999.0
angle_range_xim_4_4 = 62.16918918 999.0

angle_range_gammat_1_1 = 24.75 999.0
angle_range_gammat_1_2 = 24.75 999.0
angle_range_gammat_1_3 = 24.75 999.0
...
```



Scale cuts

Inner: Where do baryons start to matter (very non-linear)

Outer: Systematics, minimal sampling