

Galaxy clustering and weak lensing with LSST



- **Dark Energy science with the LSST**
 - Main dark energy probes
 - Systematics-limited analyses
- **DESC projects and opportunities for engagement**
 - The Core Cosmology Library
 - The LSS loop
 - LSS with HSC DR1
 - The 3x2pt pipeline
 - TJP Cosmo
- **Summary**

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Dark Energy science with the LSST

Outstanding numbers:

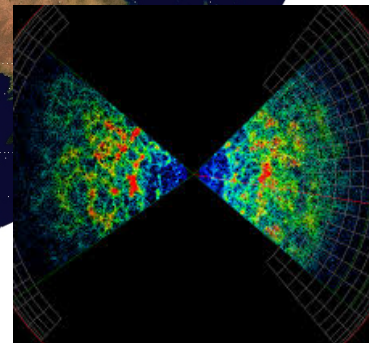
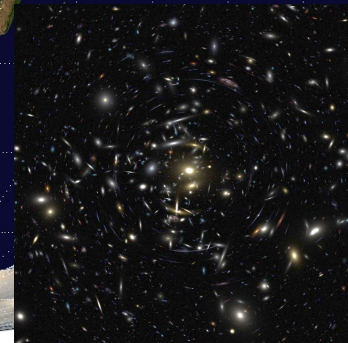
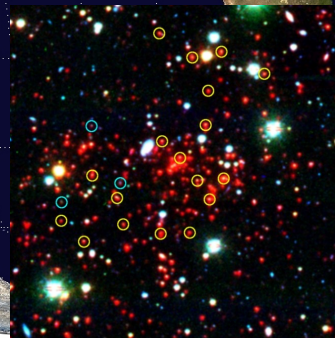
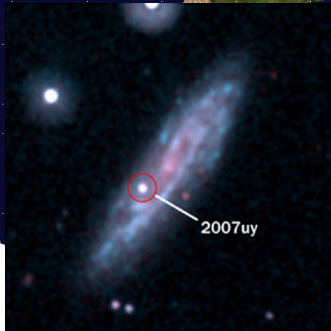
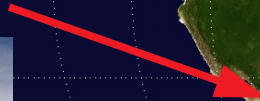
- World's largest imager
 - 8.4 m, 9.6 sq-deg FOV
- Wide: 20K sq-deg
- Deep: $r \sim 27$
- Fast: ~ 100 visits per year
- Big data: ~ 15 TB per day

Dark Energy Science Collaboration:

- Supernovae
- Cluster science
- Strong lensing
- Weak lensing
- Large-scale structure

LSST Coll. et al. 0912.0201

LSST



Main Dark Energy probes

Large-Scale Structure (DESC co-convener):

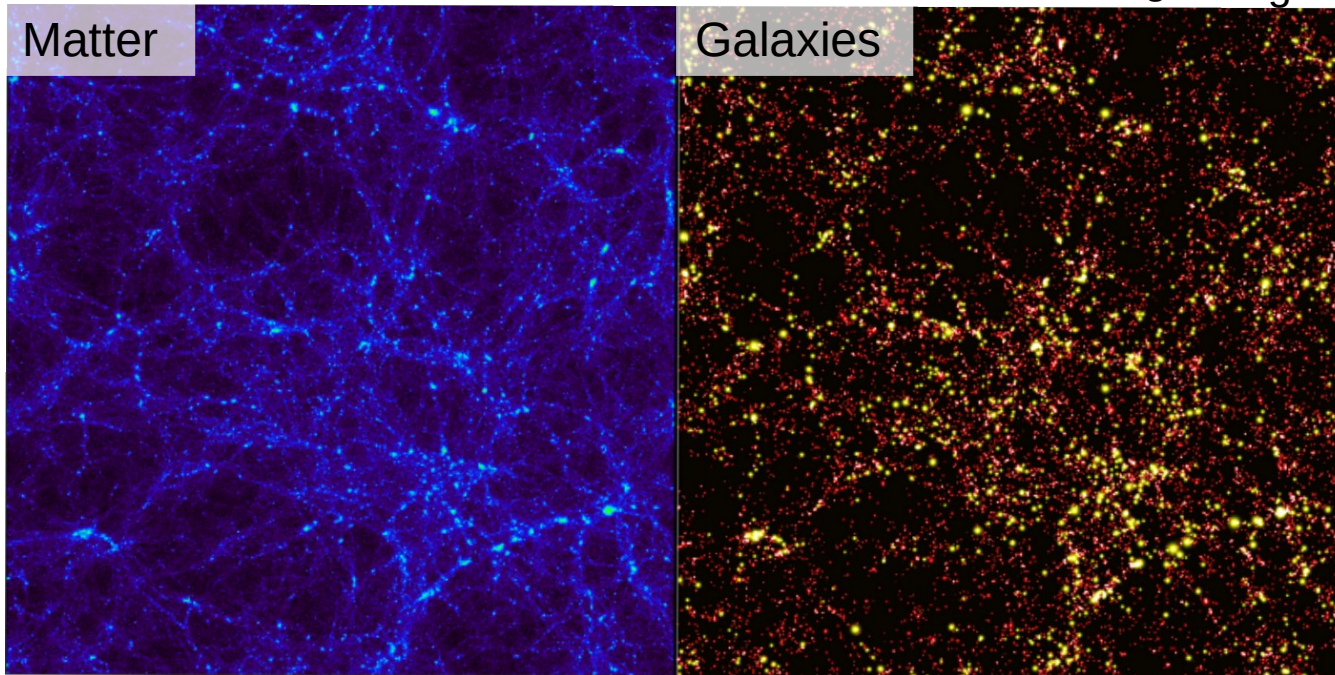
- DE affects cosmic density field
- Galaxy distribution \leftrightarrow matter density
- Main systematic \rightarrow galaxy-matter connection

- In general:

$$\delta_g(x) = f[\delta_M(y)] + \varepsilon(x)$$

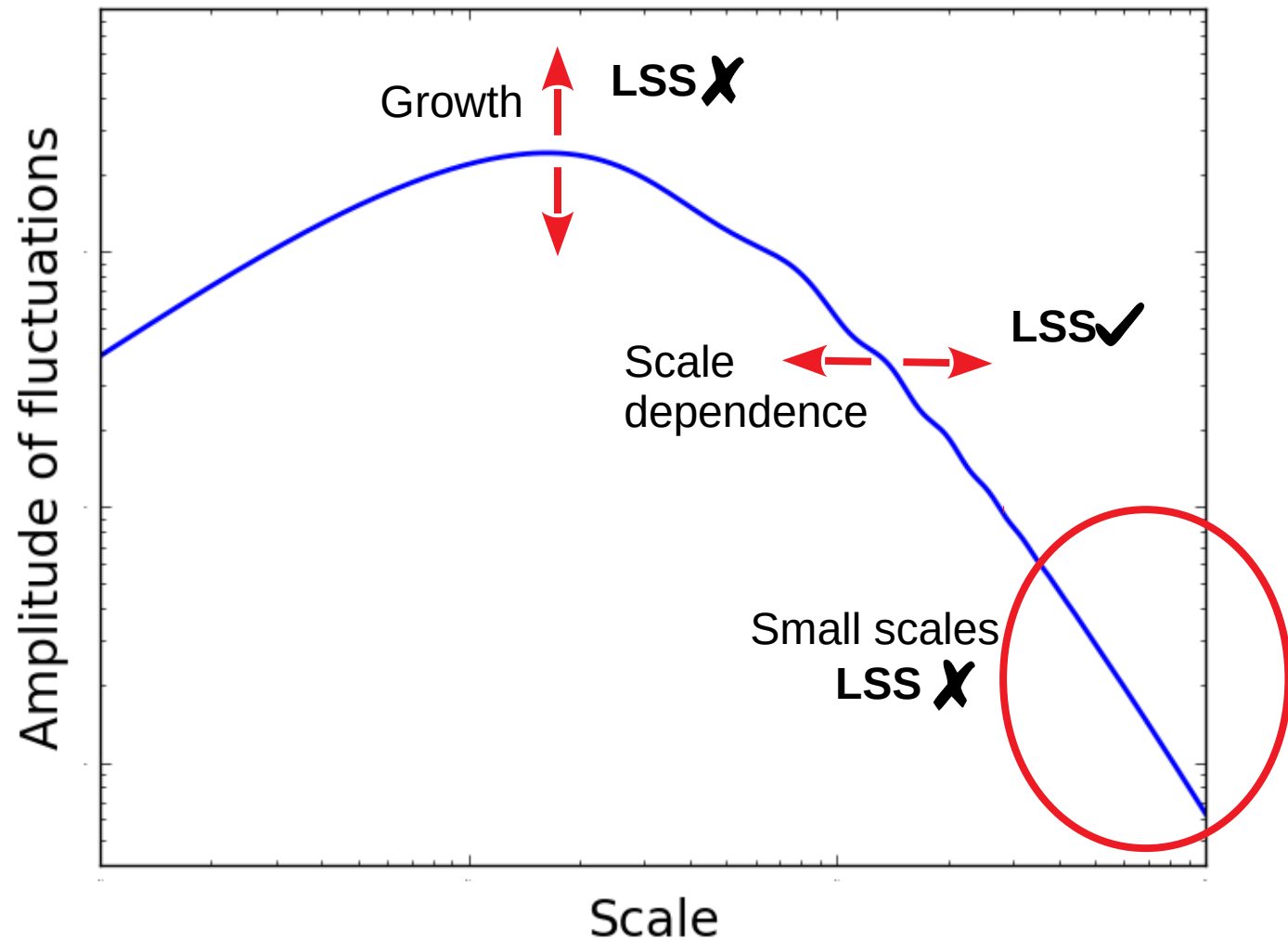
- On large scales:

$$\delta_g \sim b_g \delta_M$$



Credit: Herschel Space Observatory

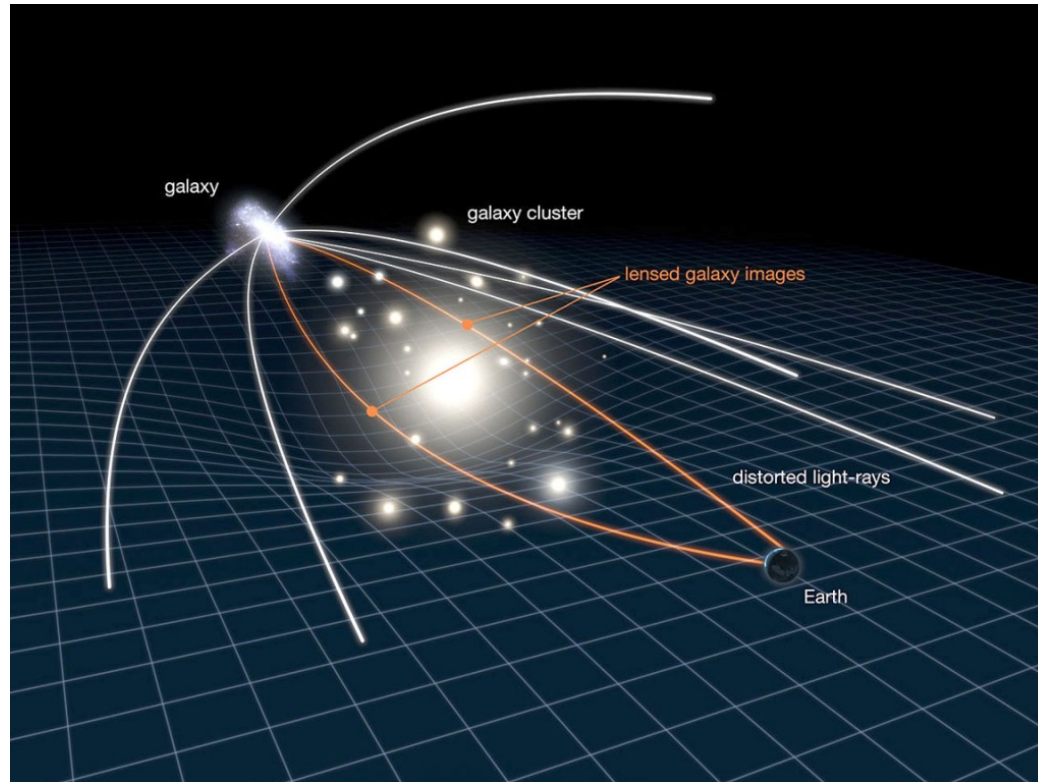
Main Dark Energy probes



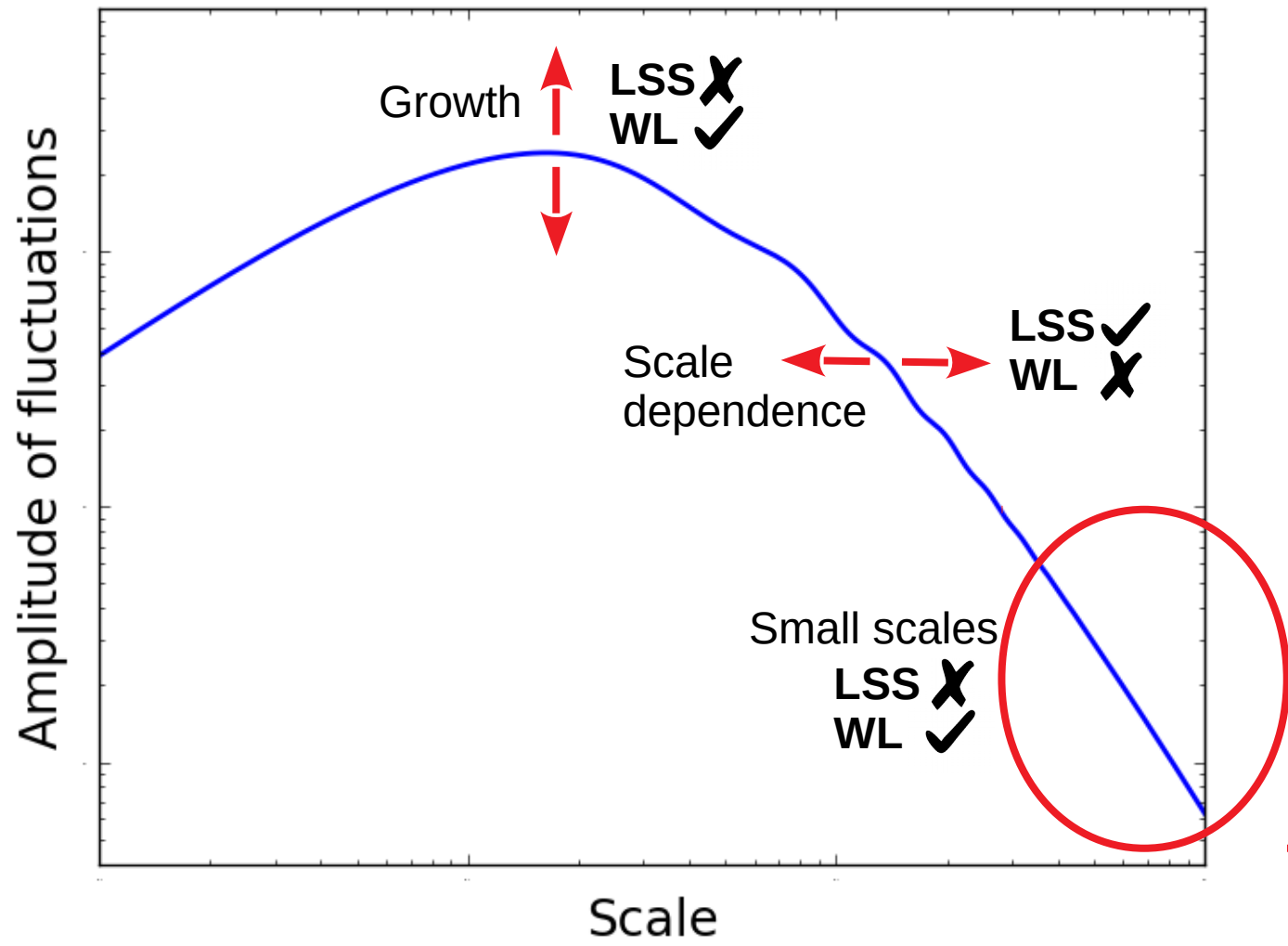
Main Dark Energy probes

Weak gravitational lensing:

- Intervening matter modifies observed galaxy shapes.
- Tracer of the true matter distribution → no bias!
- Large radial projection kernel → no scale-dependence

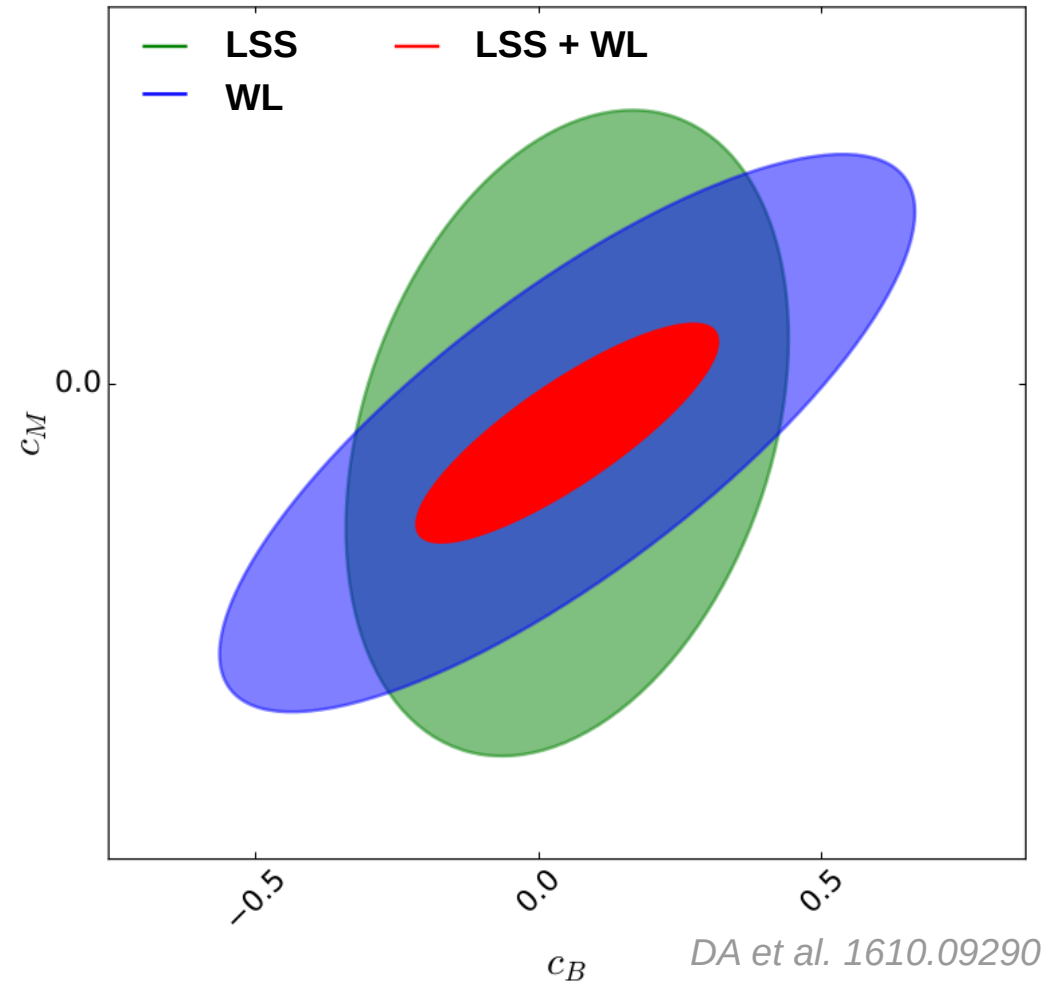
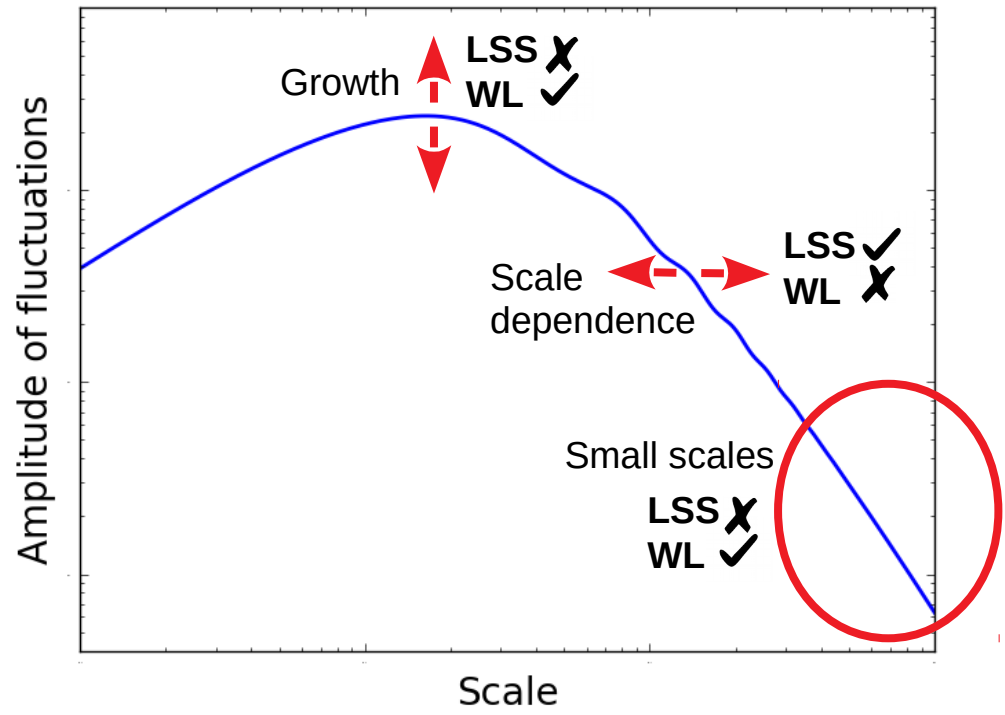


Main Dark Energy probes



Main Dark Energy probes

LSS-WL complementarity

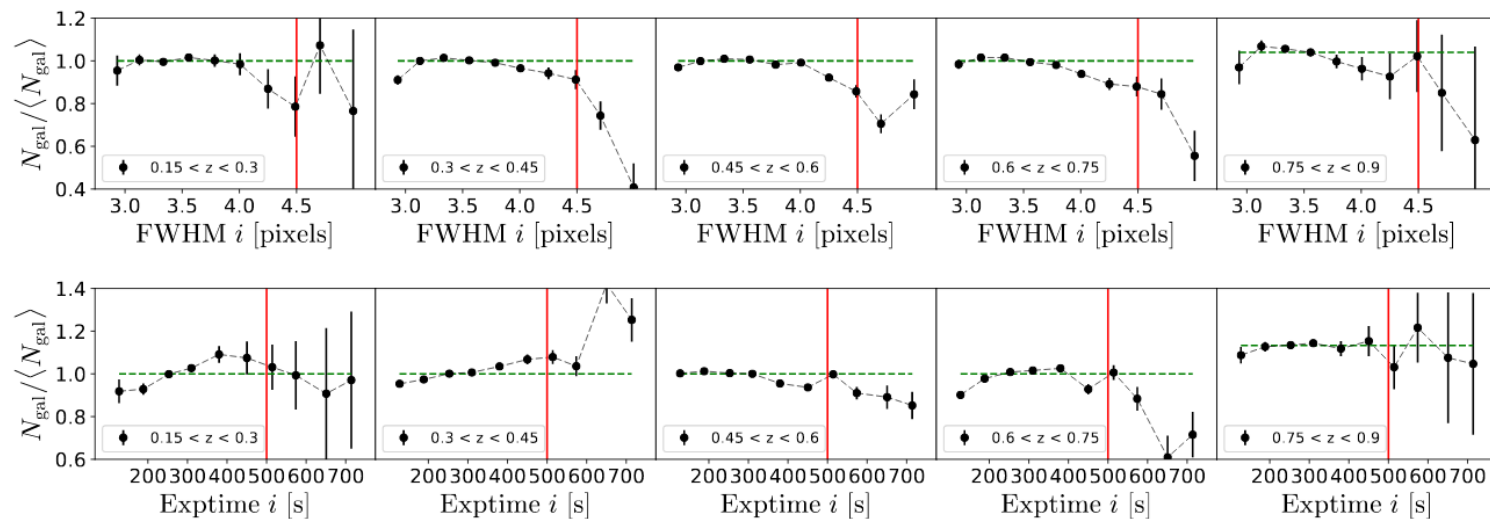


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Systematics-limited analyses: observational systematics

Sky systematics:

- Galactic dust
- Star contamination
- Star obscuration
- Airmass, seeing, depth



Elvin-Poole et al. 2017

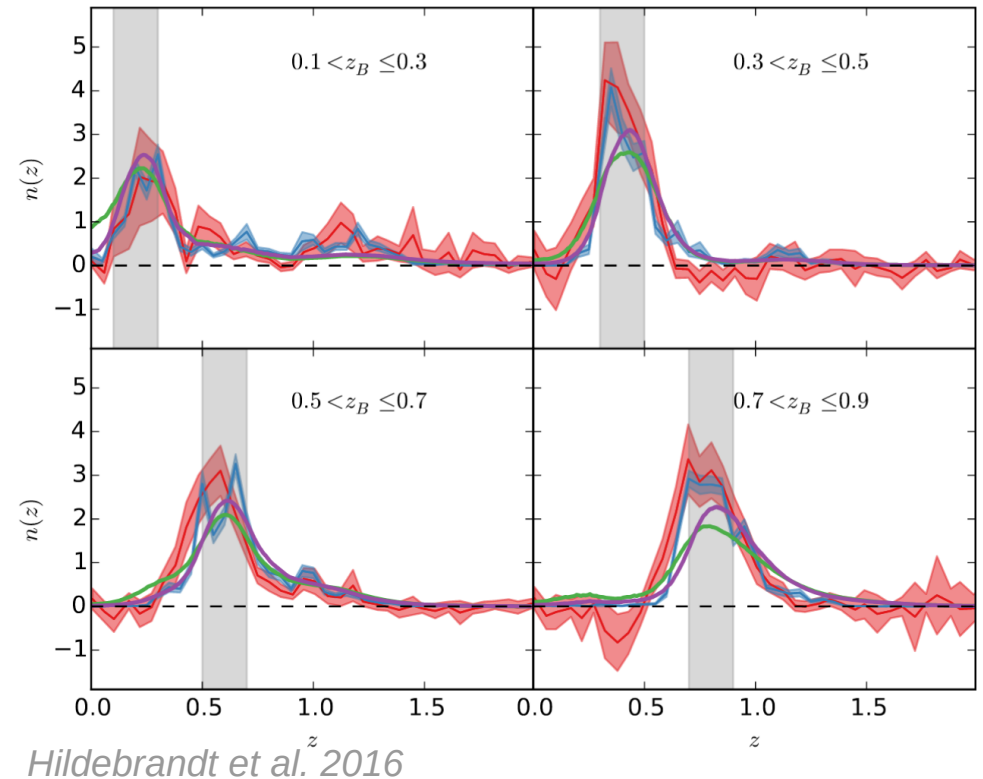
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Photometric redshifts:

- Loss of small radial scales
- Complicated 3D analysis
 - tomography
- Uncertain redshift distributions



Systematics-limited analyses: observational systematics

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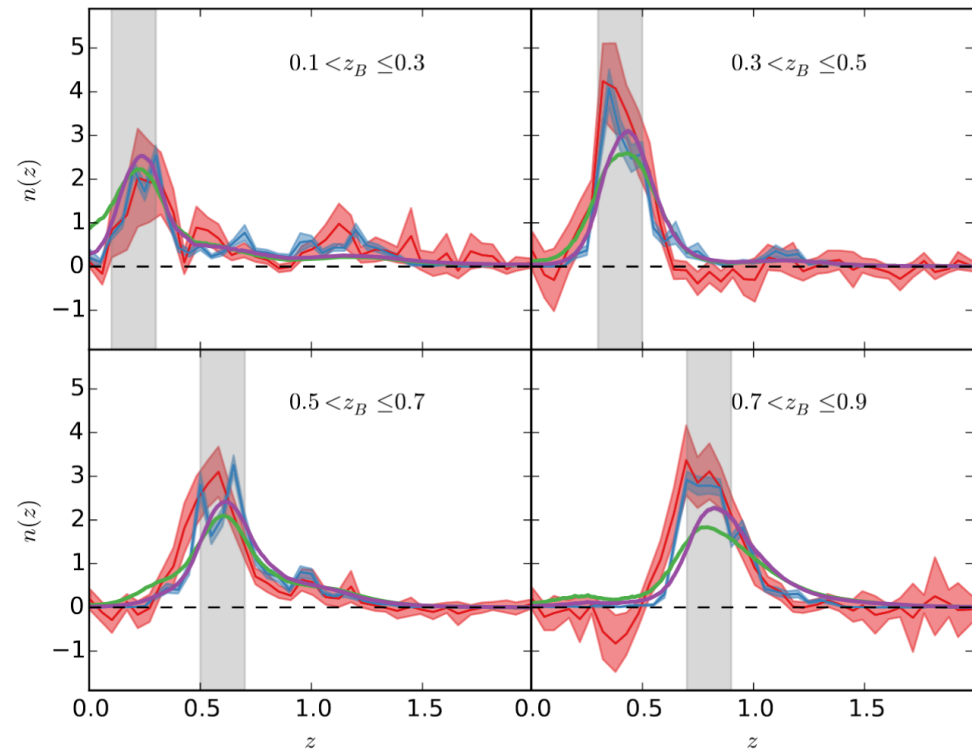
- Galactic dust
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Correlated systematics:

E.g. dust, blending etc.



Hildebrandt et al. 2016

Systematics-limited analyses: astrophysical systematics

Credit: J. Blazek

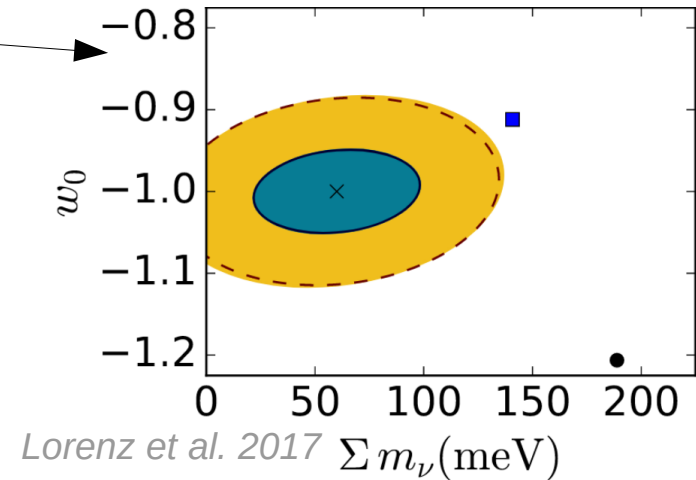
Galaxy clustering

- Galaxy bias
- Magnification bias

bias

IA

$$\delta_g(x) = b_1 \delta_m(x) + b_2 \delta_m^2(x) + b_s s^2(x) + \dots$$
$$\gamma_{ij}^I = C_1 s_{ij} + C_2 (s_{ik} s_{kj}) + C_\delta (\delta s_{ij}) + C_t t_{ij} + \dots$$



Weak lensing

- Baryonic effects
- Intrinsic alignments

Systematics-limited analyses: astrophysical systematics

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Galaxy clustering

- Galaxy bias
- Magnification bias

bias

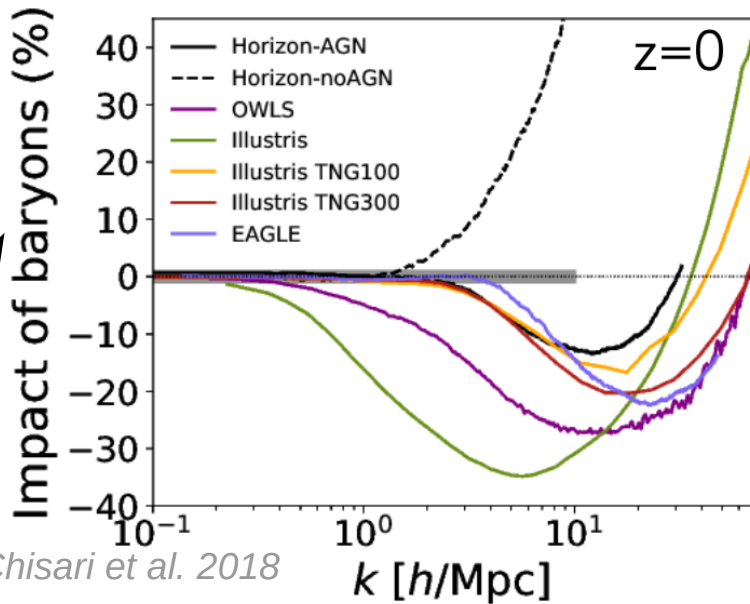
IA

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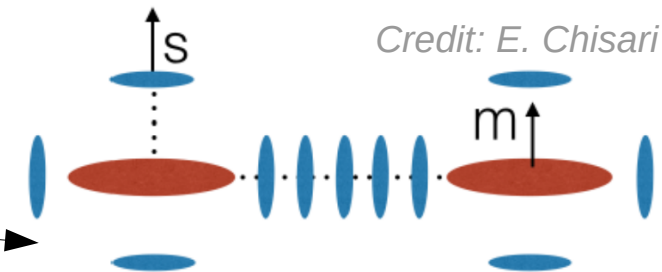
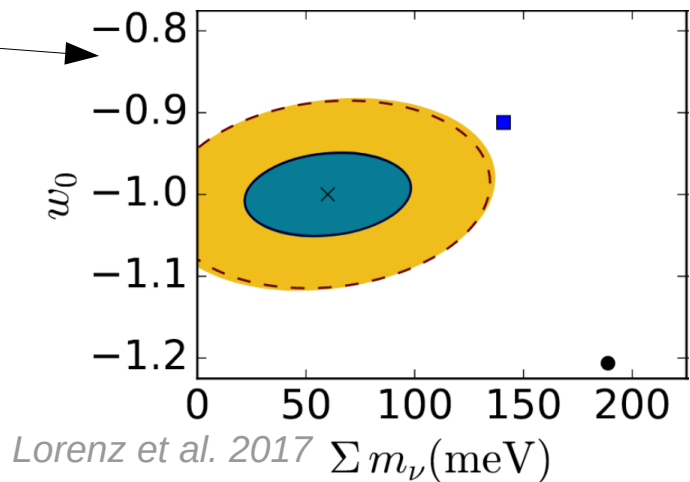
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Weak lensing

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- Intrinsic alignments

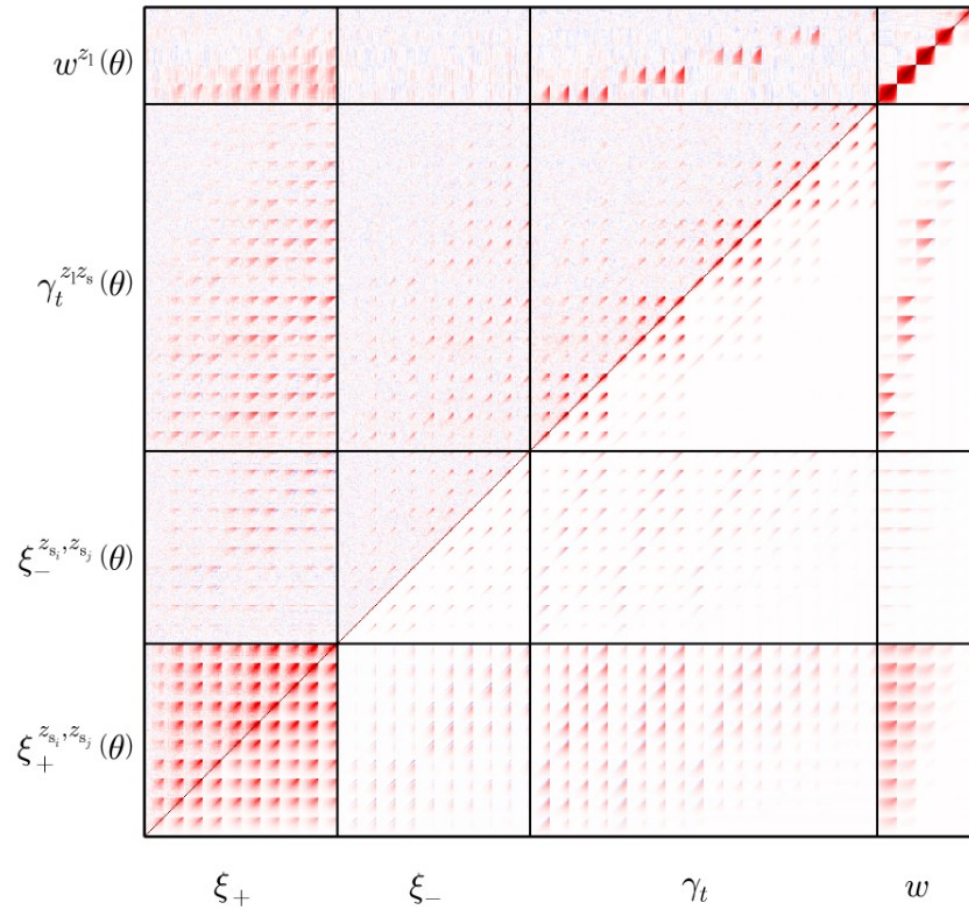


Chisari et al. 2018



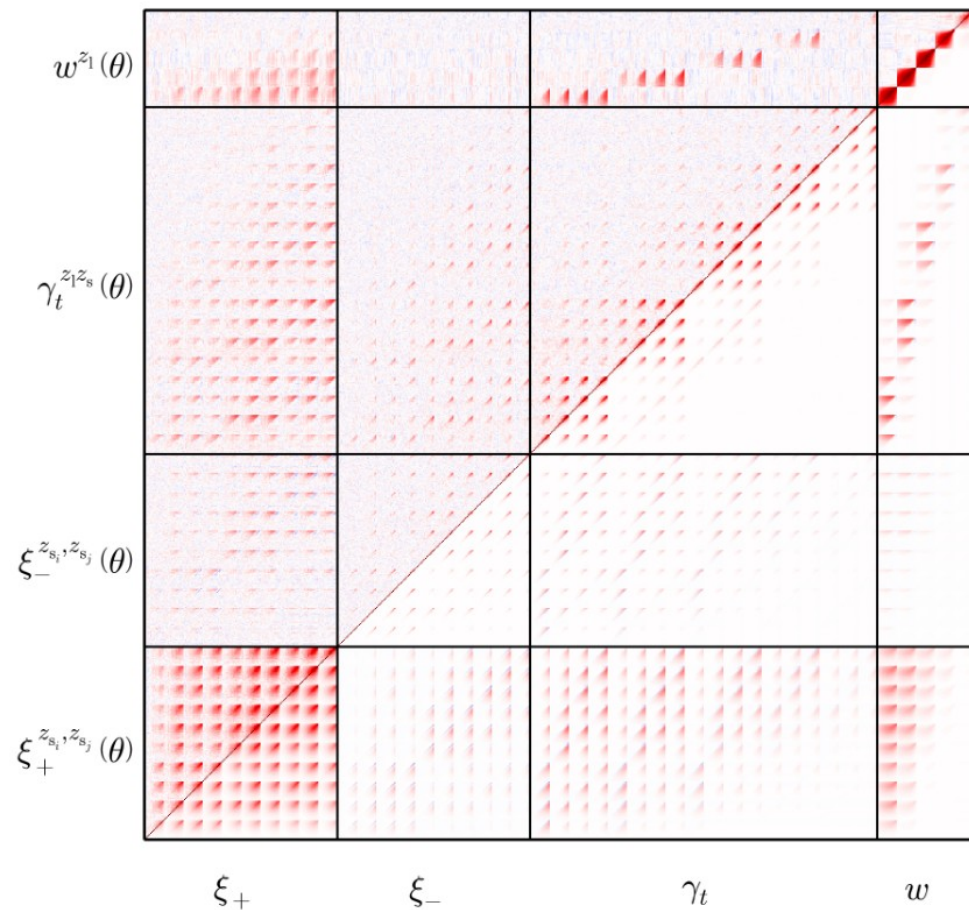
Systematics-limited analyses: likelihood systematics

- **Covariance matrices**
- **Correlated variables**
- **Non-Gaussian likelihoods**



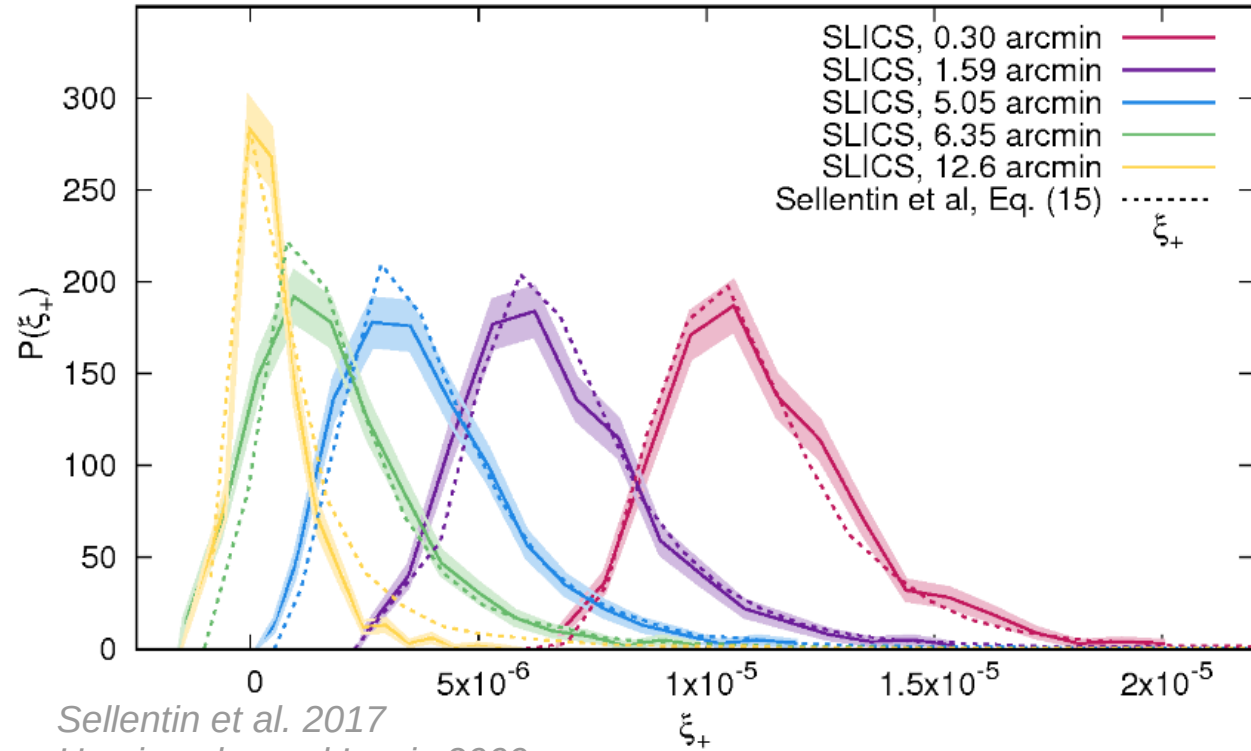
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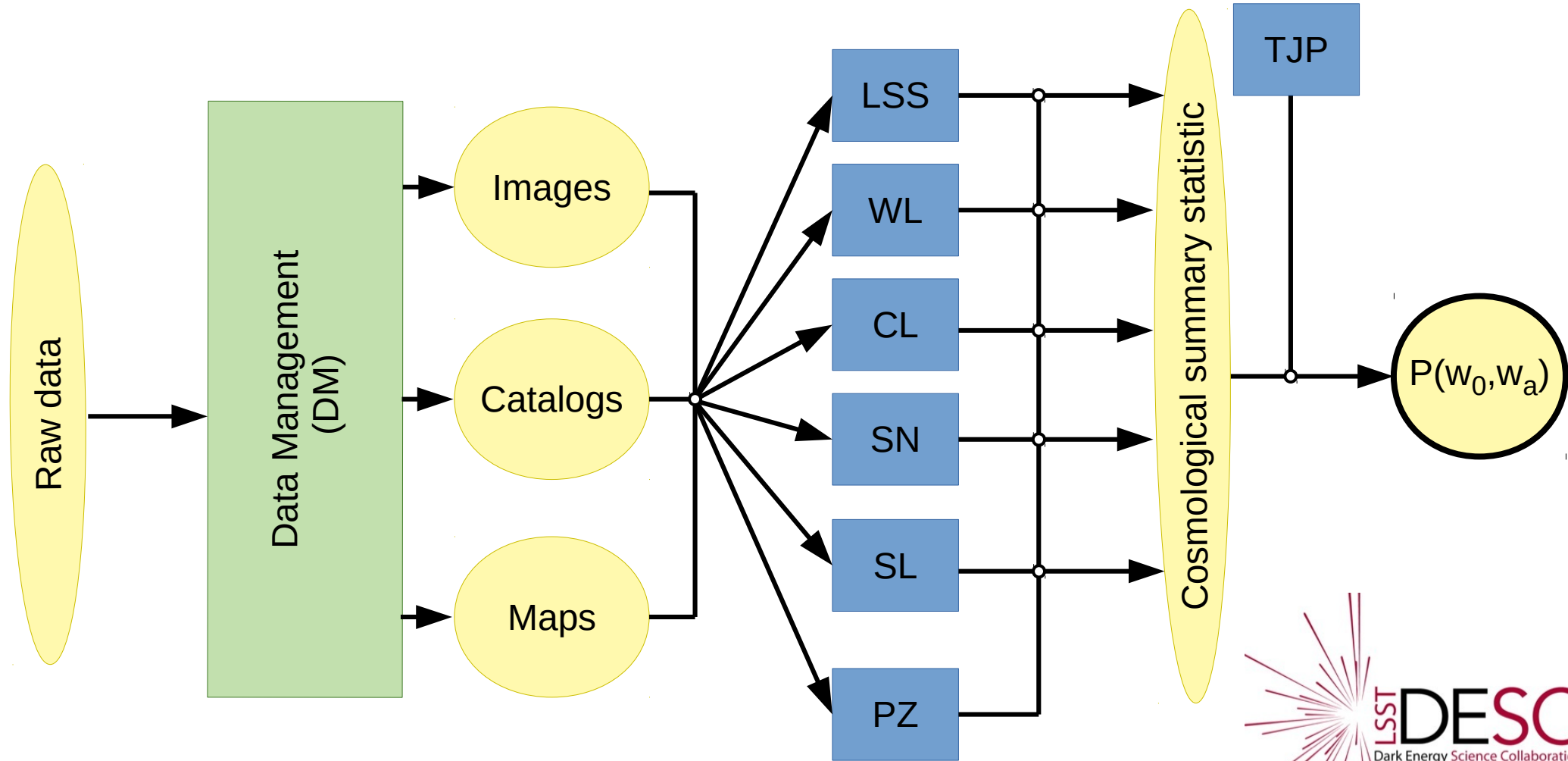
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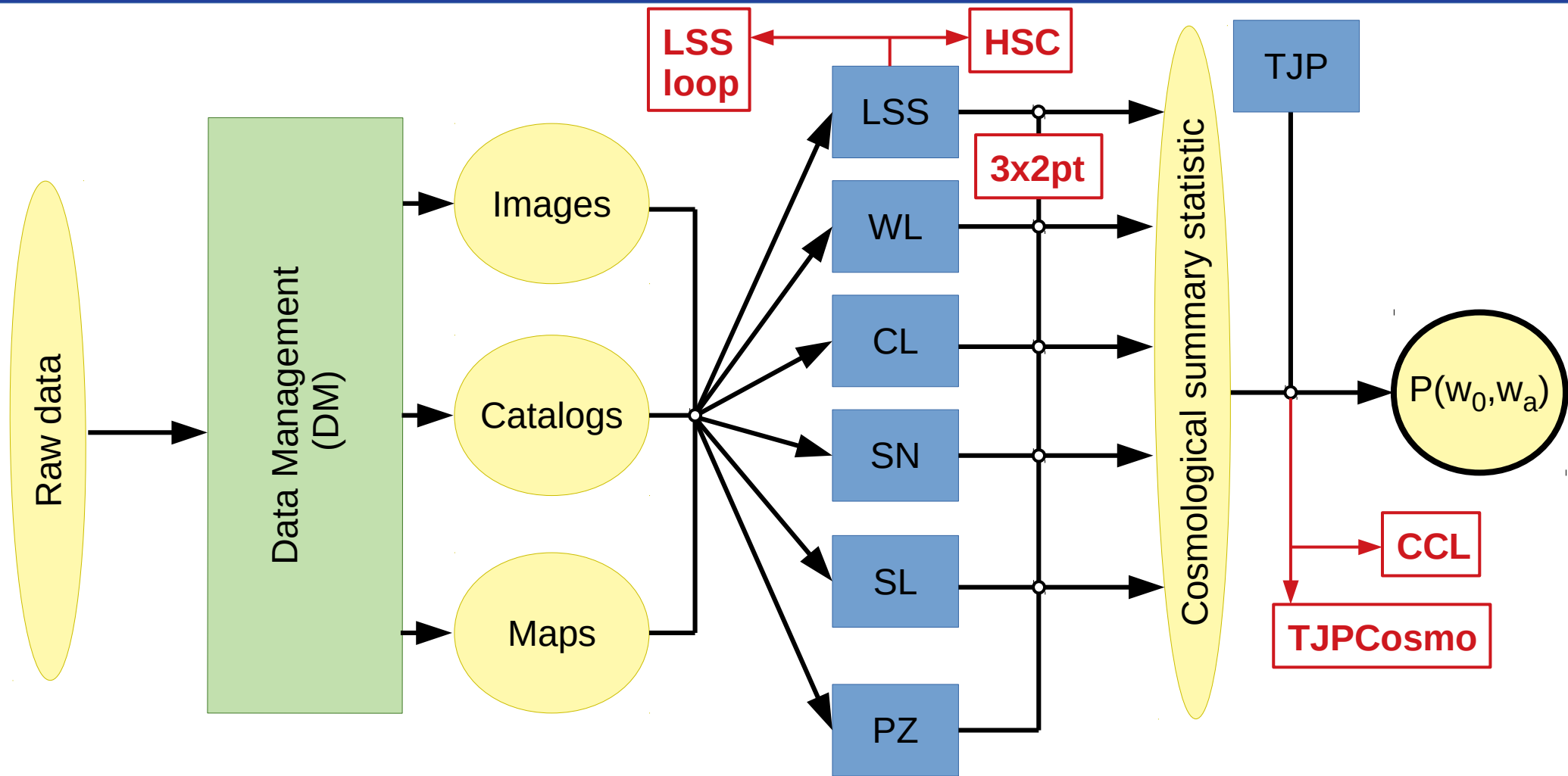


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The Dark Energy Science Collaboration (DESC)

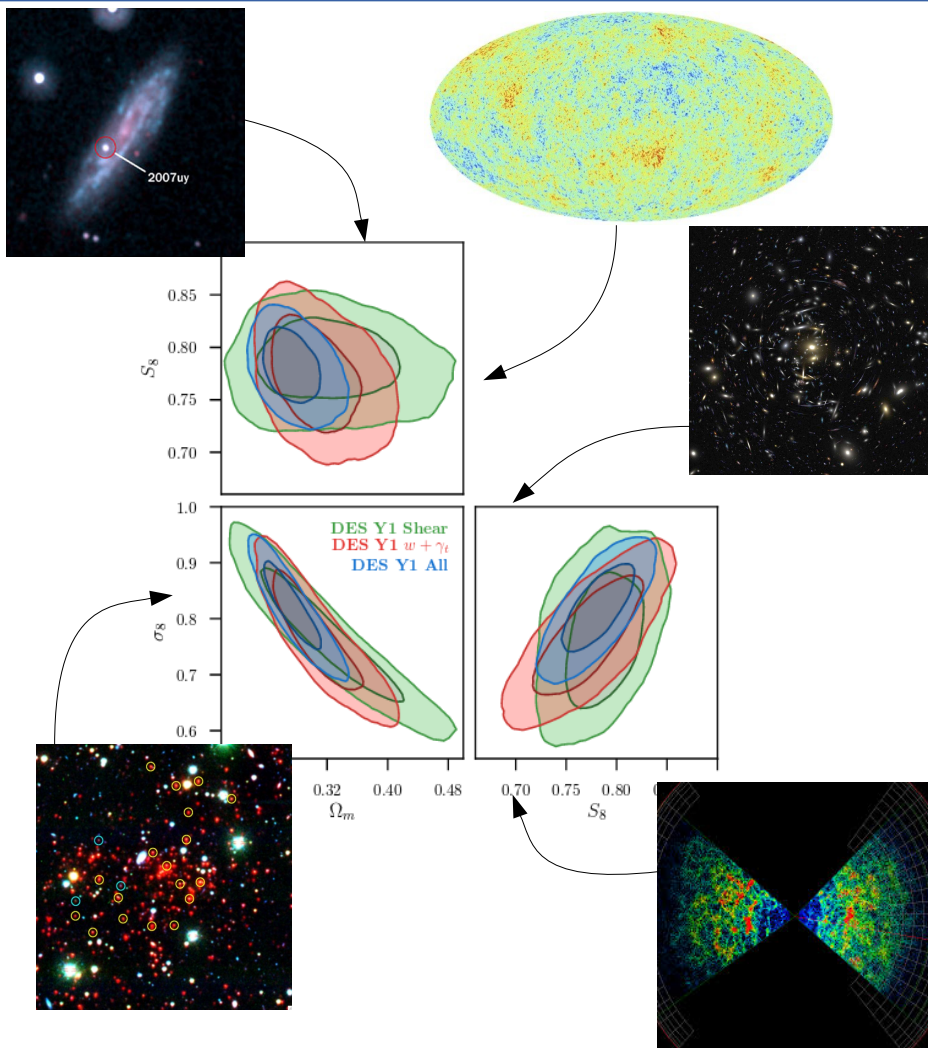


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The Core Cosmology Library (CCL)



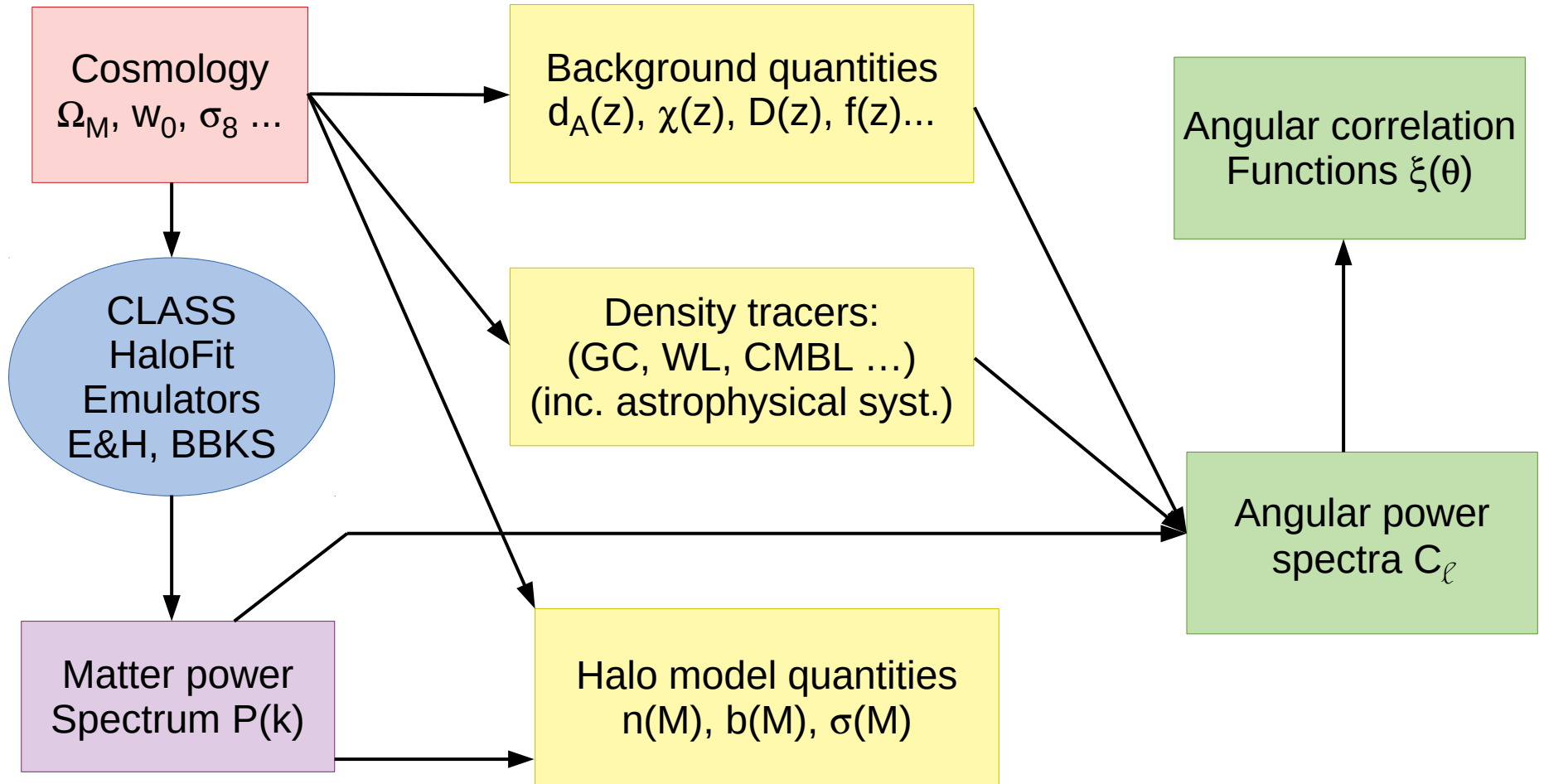
Concept:

“LSST DESC Core Cosmology Library (CCL) provides routines to compute general cosmological observables with validated numerical accuracy.”

Motivation:

- Precision cosmology → controlled accuracy
- Multiple probes → consistency
- Synergies → generality

CCL: science capabilities



CCL: software implementation

LSSTDESC / CCL

Unwatch 144

Unstar 25

Fork 5

Code

Issues 67

Pull requests 8

Projects 0

Wiki

Insights

Settings

DESC Core Cosmology Library: cosmology routines with validated numerical accuracy

Edit

Add topics

1,541 commits

90 branches

4 releases

31 contributors

Branch: master

New pull request

Create new file

Upload files

Find file

Clone or download

CCL

build passing

coverage 94%

LSST DESC Core Cosmology Library (CCL) provides routines to compute basic cosmological observables with validated numerical accuracy.

The library is written in C99 and all functionality is directly callable from C and C++ code. We also provide python bindings for higher-level functions.

CCL: software implementation

LSSTDESC / CCL

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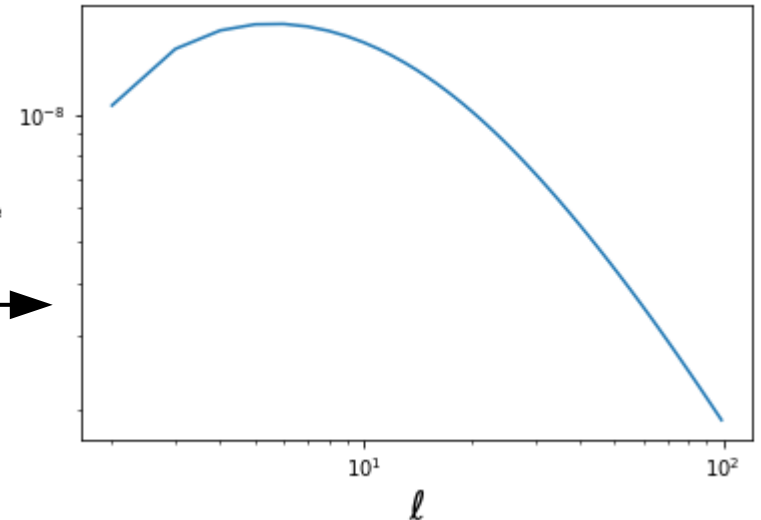
31 contributors

Branch: master

New pull request

```
In [1]: import numpy as np
import pylab as plt
import pyccel as ccl
%matplotlib inline
cosmo = ccl.Cosmology(Omega_c=0.27, Omega_b=0.045,
                    h=0.67, A_s=2.1e-9, n_s=0.96)
z = np.linspace(0., 1., 200)
dNdz = np.exp(-(z - 0.5)**2)
lens = ccl.ClTracerLensing(cosmo, False, z=z, n=dNdz)
ell = np.arange(2, 100)
cls = ccl.angular_cl(cosmo, lens, lens, ell)
```

C_l



CCL: software implementation

LSSTDESC / CCL

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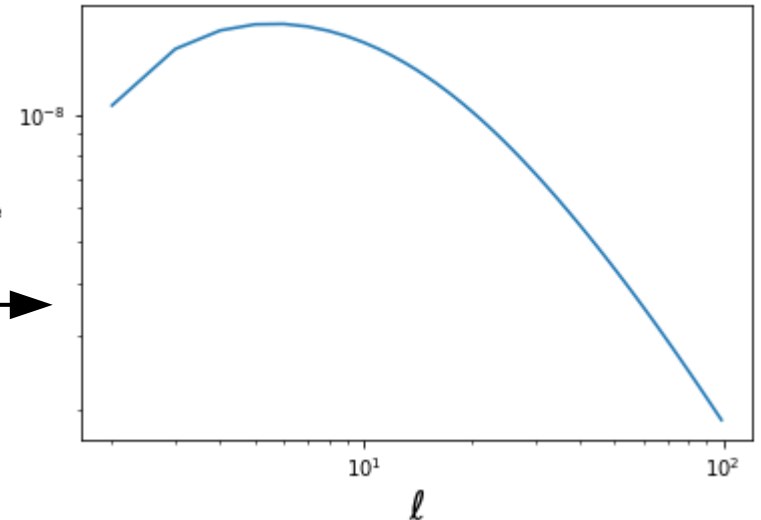
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C_l



CCL: coding with a bunch of physicists



+23 others!

- Work through github
- Contributions through pull requests
- Strict code review
- New science subject to external benchmarks
- Unit tests!
- More unit tests!
- Bi-weekly telecons
- Crucial project management
- Paper out soon!



CCL: coding with a bunch of physicists



+23 others!

E. Chisari

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CCL: open projects. Contribute!

- Generic non-linear formalisms for 2-point functions
- Halo models
- Beyond w CDM
- Beyond 2-point functions
- Consistent LSS-CMB correlations
- Primordial non-Gaussianity

<https://github.com/DarkEnergyScienceCollaboration/CCL>

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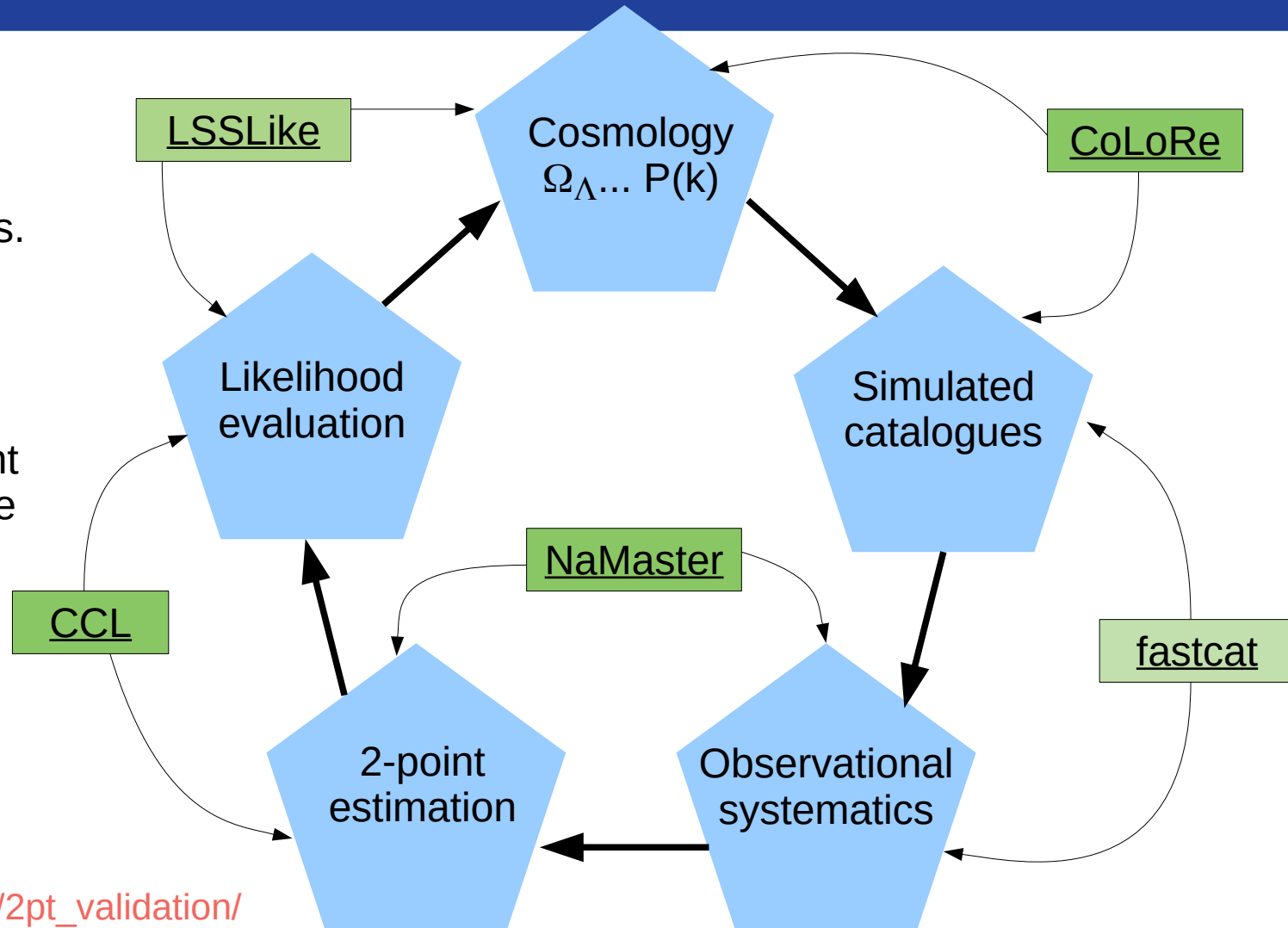
The LSS loop

Idea:

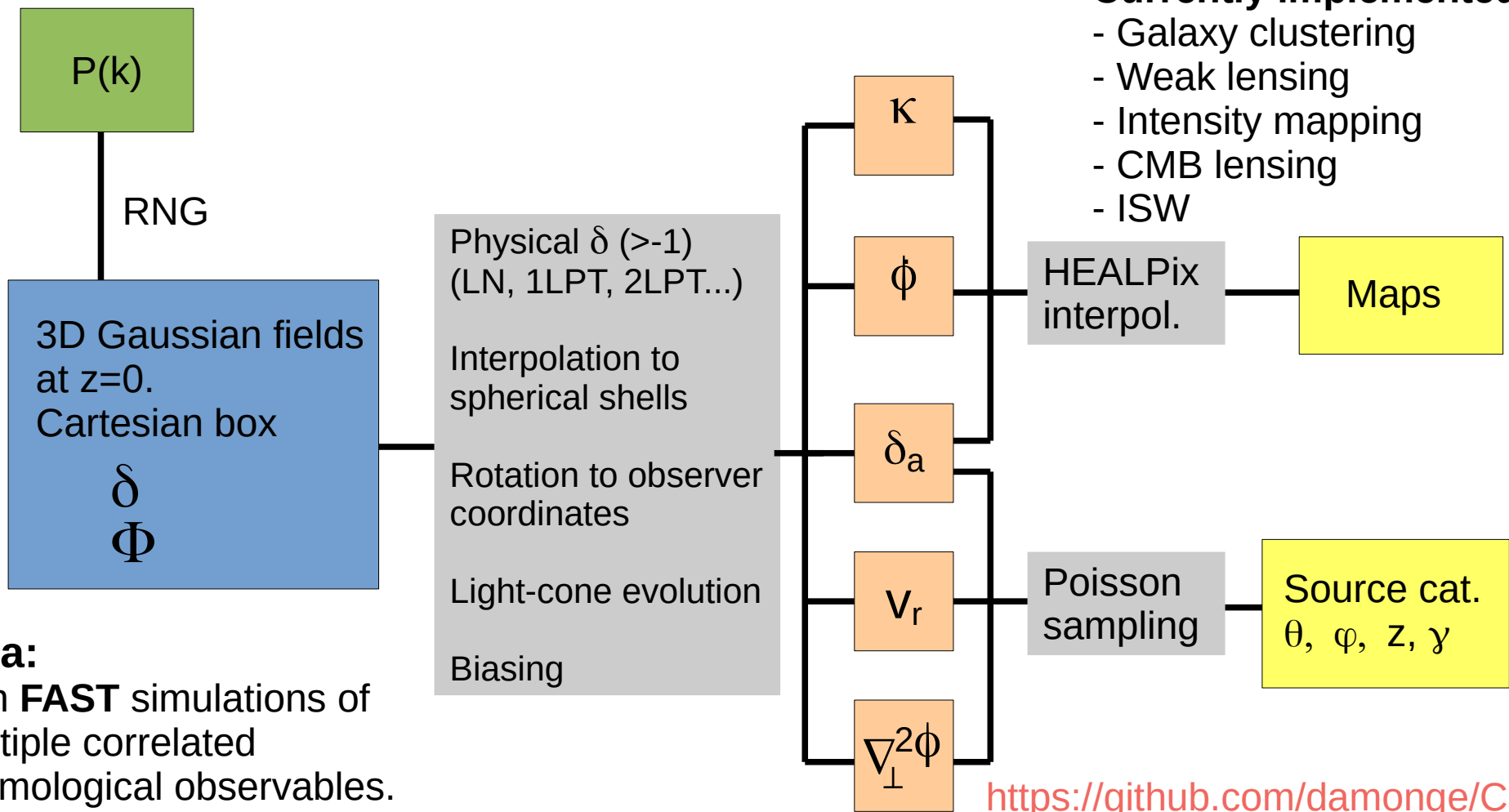
Fast round-trip loop that allows us to validate our pipeline with good statistics.

Motivation:

- Make sure we have all the necessary pieces.
- Incremental improvement by gradually adding more realism.
- Science! Quantitative analysis of the impact of different systematics.



The LSS loop: CoLoRe



Currently implemented:

- Galaxy clustering
- Weak lensing
- Intensity mapping
- CMB lensing
- ISW

Idea:

Run **FAST** simulations of multiple correlated cosmological observables.

The LSS loop: fastcat

Idea:

Software to post-process clean galaxy catalogs and add “dirt” (sky systematics, photo-z uncertainties, stars etc.)

Currently implemented

- Different photo-z models
- Depth variations through input window function

Wishlist

- Scale to LSST-like sample sizes
- Realistic dust models (e.g. correlation with PZ).
- Realistic star contamination.

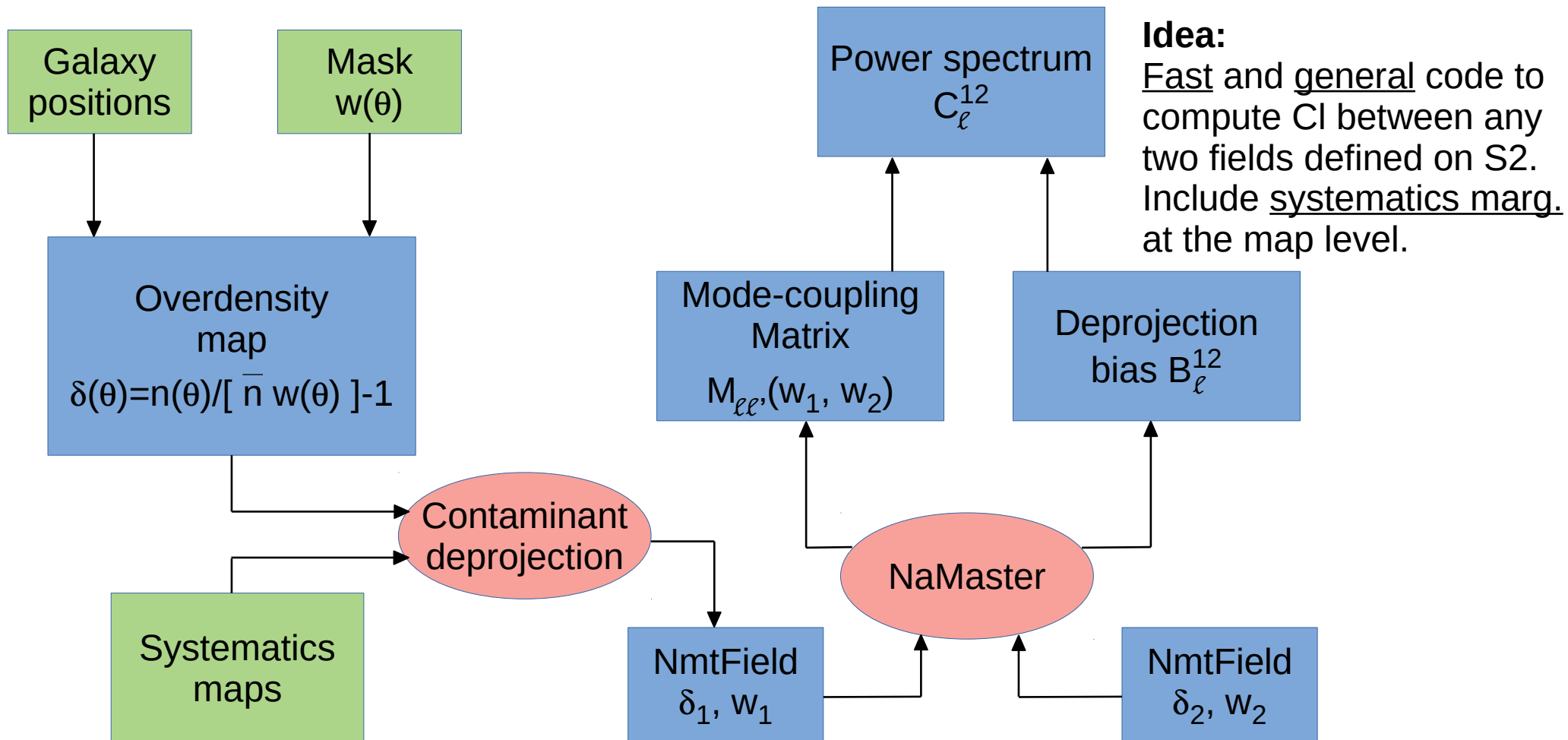
📖 README.md

fastcat

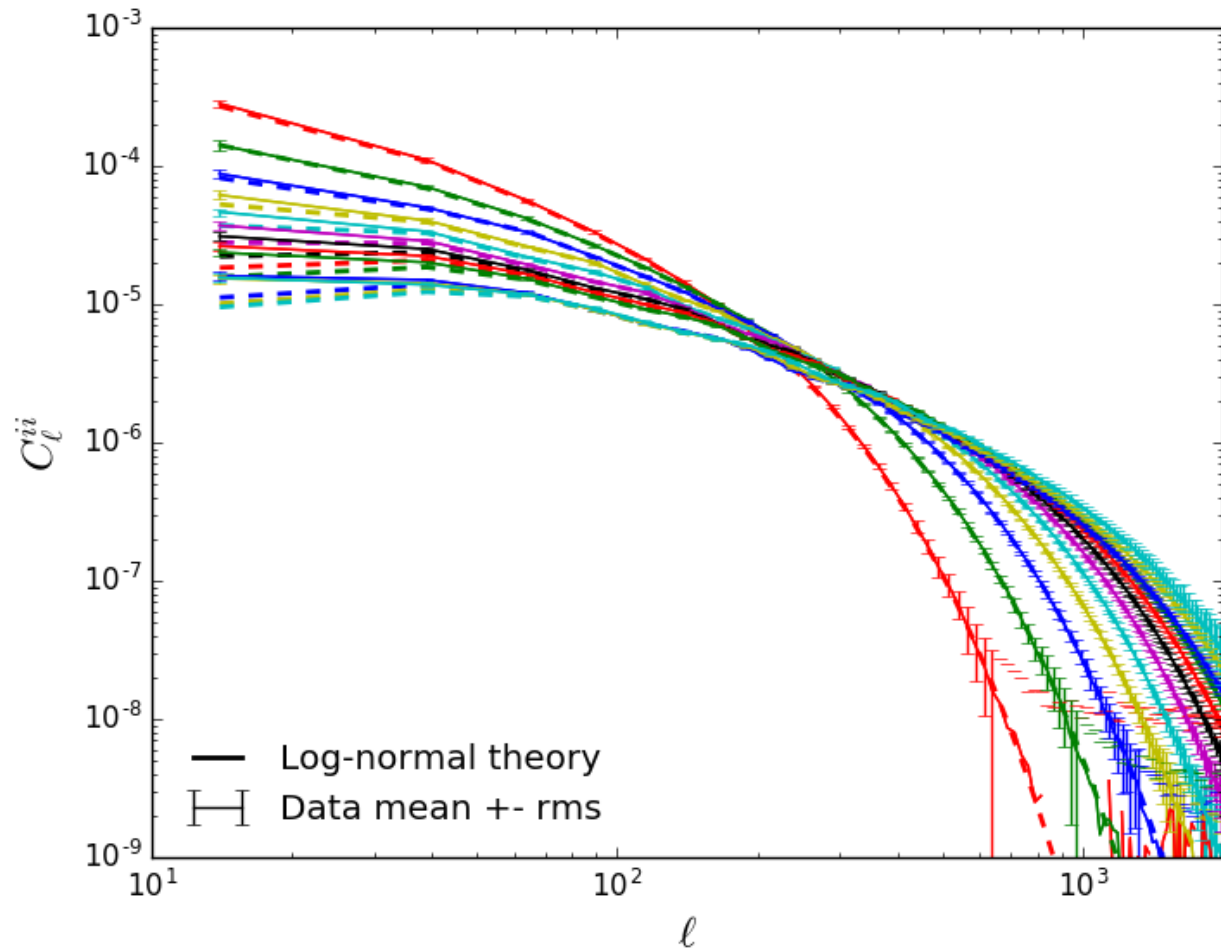
Fast and dirty creation of fast and dirty mock galaxy catalogs

<https://github.com/slosar/fastcat>

The LSS loop: NaMaster



The LSS loop: Current status



Validated:

- CoLoRe
- NaMaster
- CCL
- fastcat

First chains run during hack day (Feb. SLAC meeting).

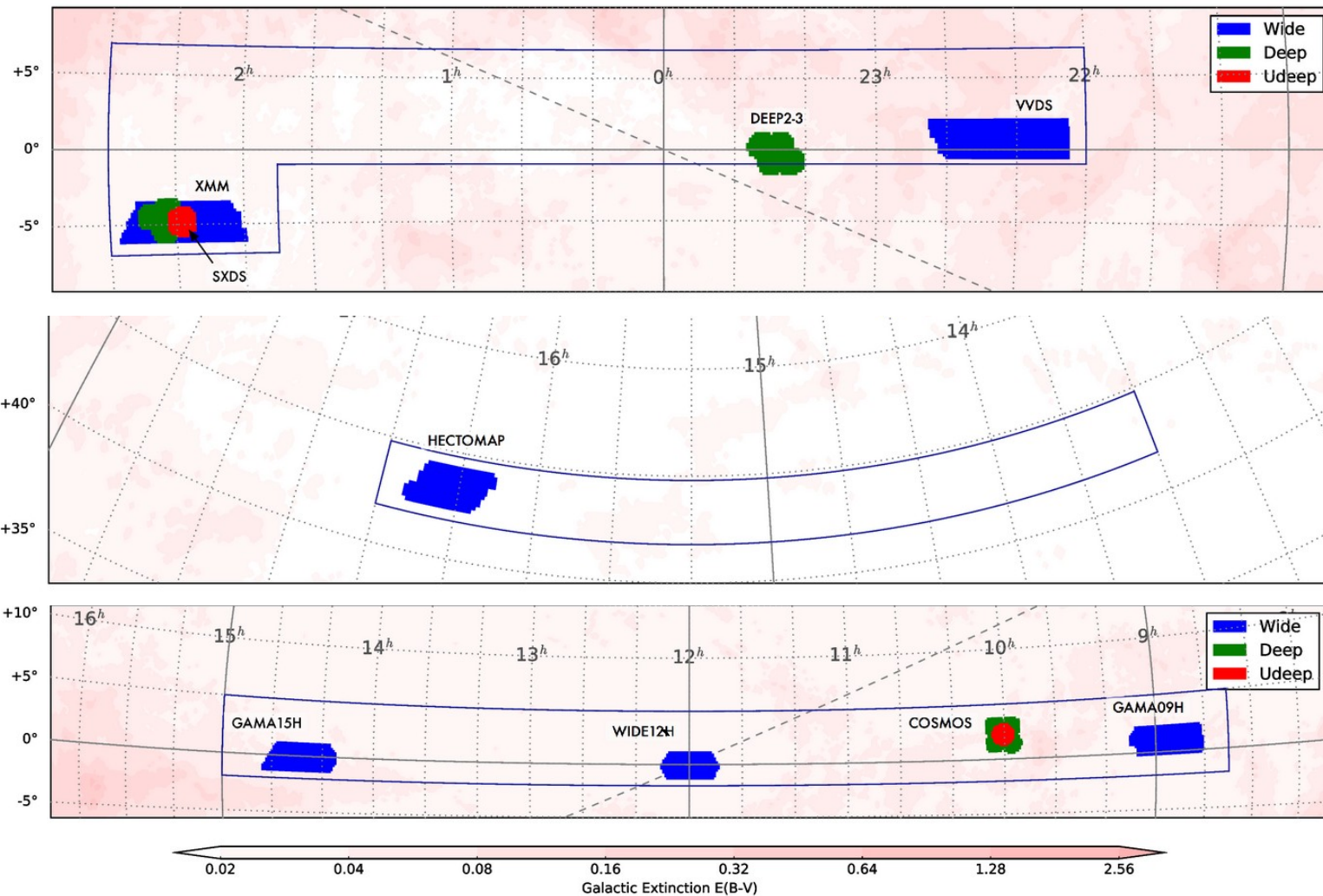
The LSS loop: open projects. Contribute!

- Finish validation at the likelihood level
- Implement more complex systematics in fastcat
- Scale fastcat up
- Start using it for **science!**
 - Dust-photo-z correlation
 - Photo-z – Clustering strength correlation
 - Dust resolution needs for LSST galaxy clustering

https://github.com/LSSTDESC/2pt_validation/

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LSS with HSC DR1



Idea:

Use public HSC data to perform galaxy clustering analysis.

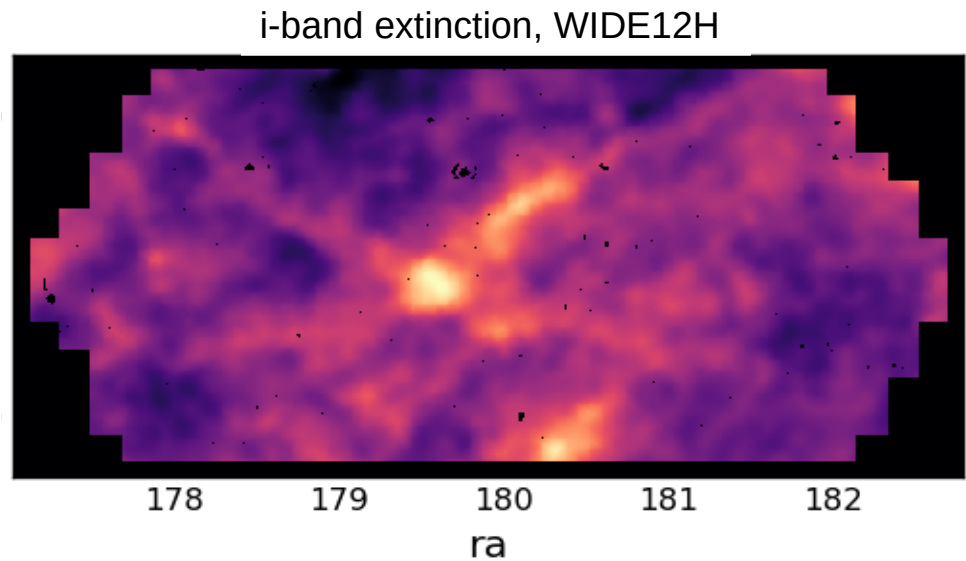
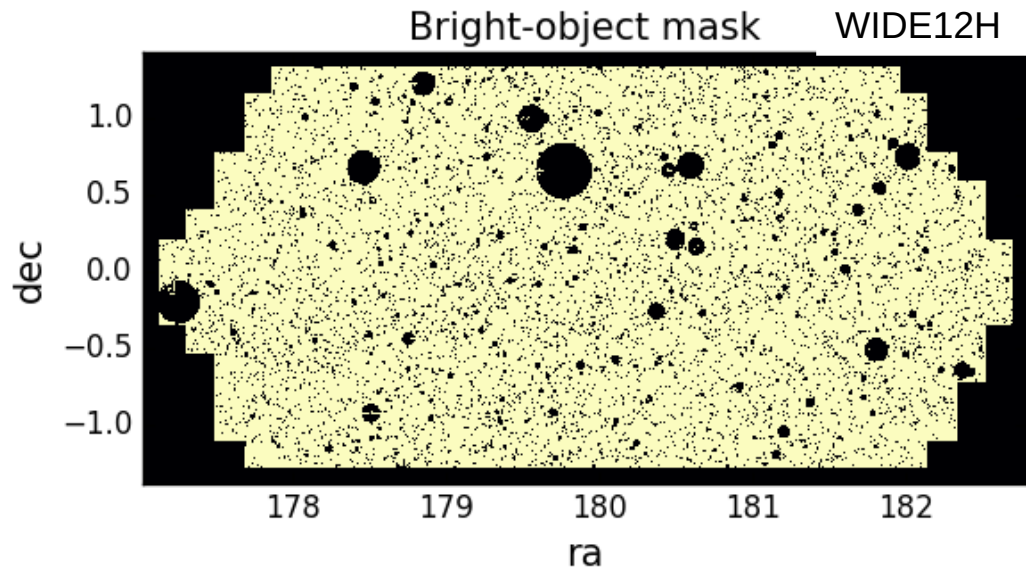
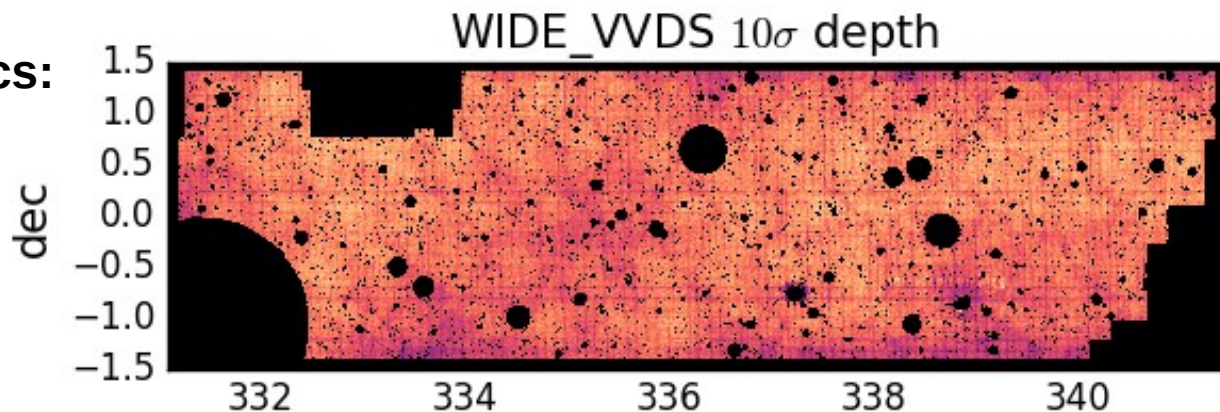
Motivation:

- Same DM pipeline and data format as LSST.
- Learn from these data and use them to improve LSST DM.
- Unused state-of-the-art data!
- New regime of depth and systematics
- Prove that C_ℓ pipelines can deal with this.

LSS with HSC: work done

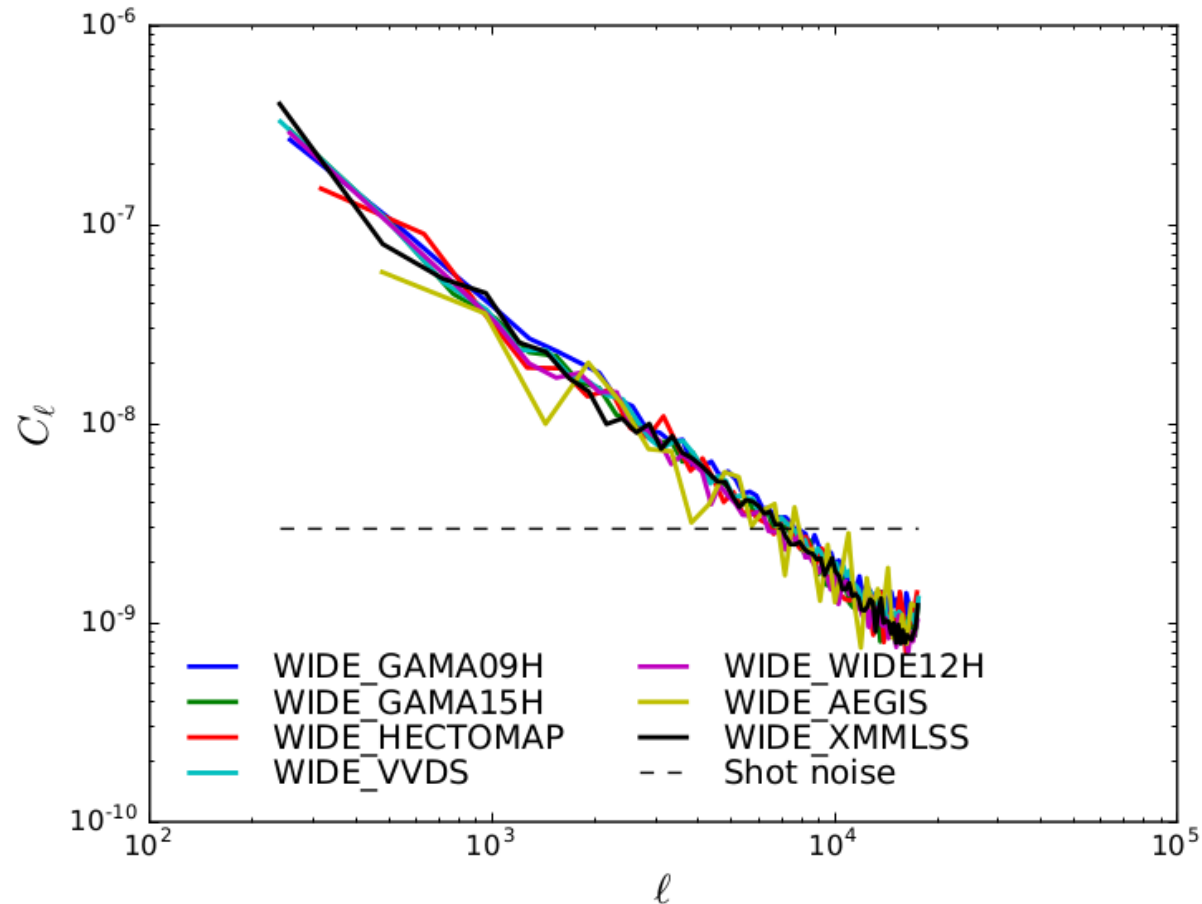
Characterized global sky systematics:

- Dust extinction
- Star contamination
- Depth variations
- Bright-object mask



LSS with HSC: work done

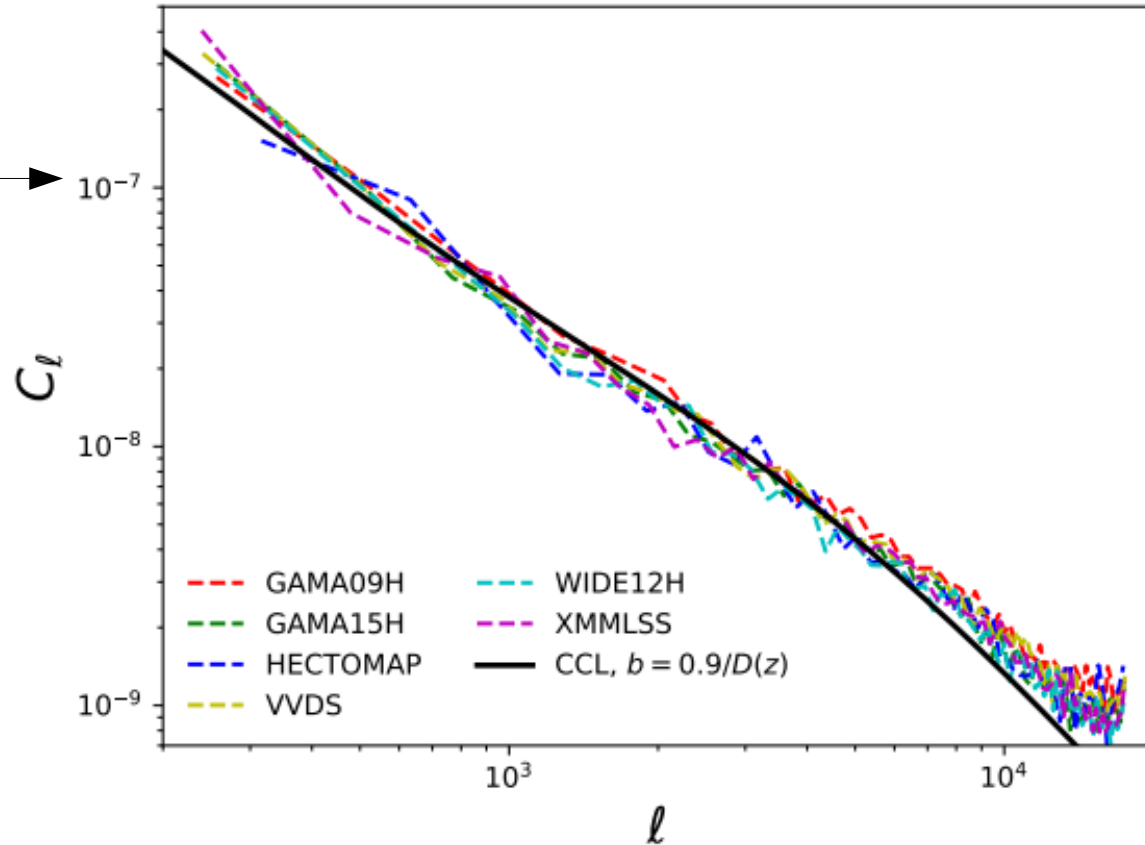
Measured un-binned power spectra:



LSS with HSC: work done

Compared against simplest theory!

Photo-z characterization +
linear bias + CCL



LSS with HSC: work to be done. Contribute!

- Characterize per-exposure systematics (airmass, PSF etc.)
- Study photo-z binning and per-bin systematics
- ...
- Full cosmological analysis!

<https://github.com/LSSTDESC/HyperSupremeStructure-HSC-LSS>

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The 3x2pt pipeline

3x2pt stands for the three most relevant 2-point correlation functions for cosmology:

Galaxy - Galaxy

Galaxy - Lensing

Lensing - Lensing

Idea: develop a joint analysis pipeline between LSS and WL with 3x2pt as data vector.

Motivation:

- WL and LSS will only constrain DE if combined
- Similar observables: two-point functions of different fields
- Shared systematics (photo-z, sky, astrophysics)

The 3x2pt pipeline

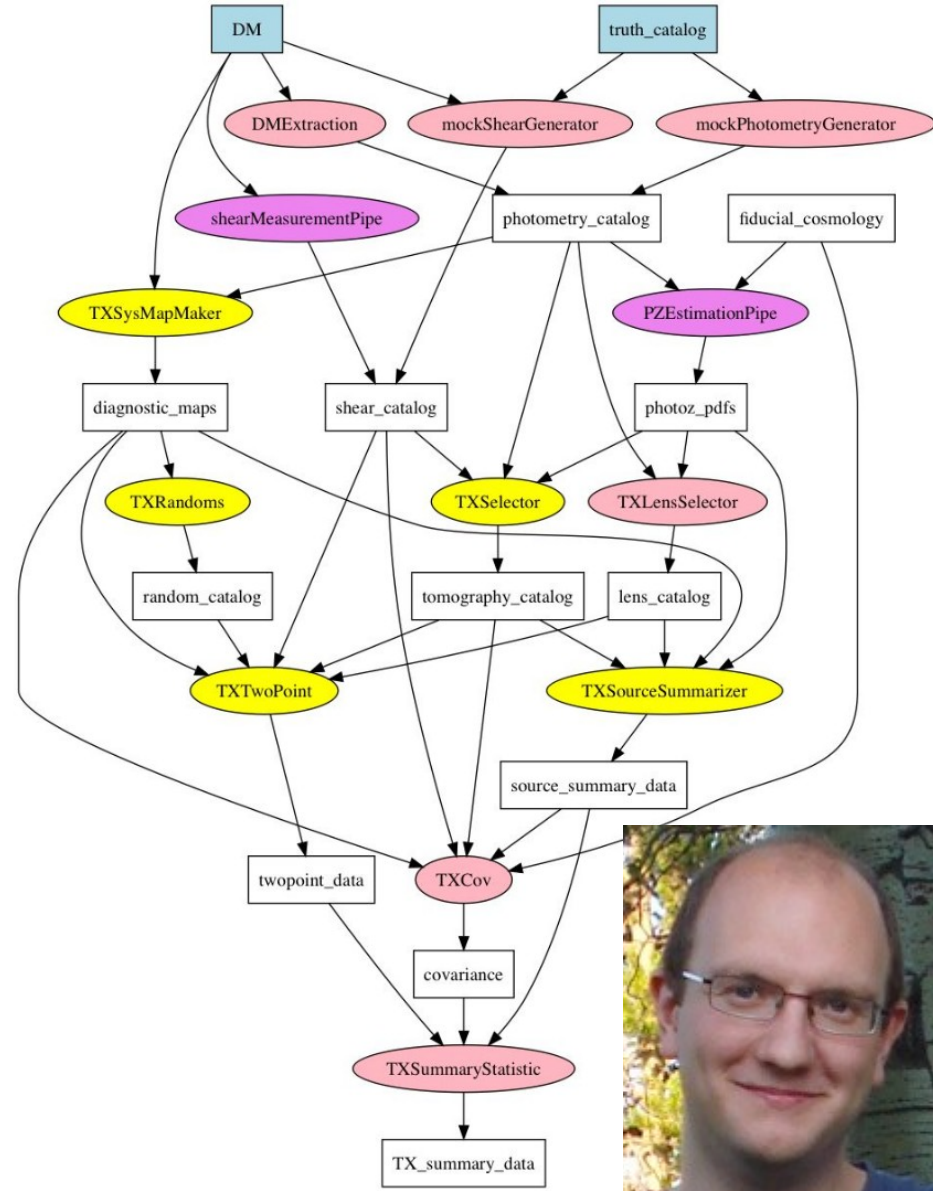
Tonnes of things to be done!

- Data formats (maps, catalogs, 2-points)
- Systematics mapper
- Masks and random catalog
- Sample selectors
- ...

Tonnes of applications!

- Consistent analysis of existing data
- Analysis of LSST DC2-3 and commissioning data
- Extensions to Nx2pt (Clusters, CMB lensing, tSZ) or even NxMpt

<https://github.com/LSSTDESC/TXPipe>



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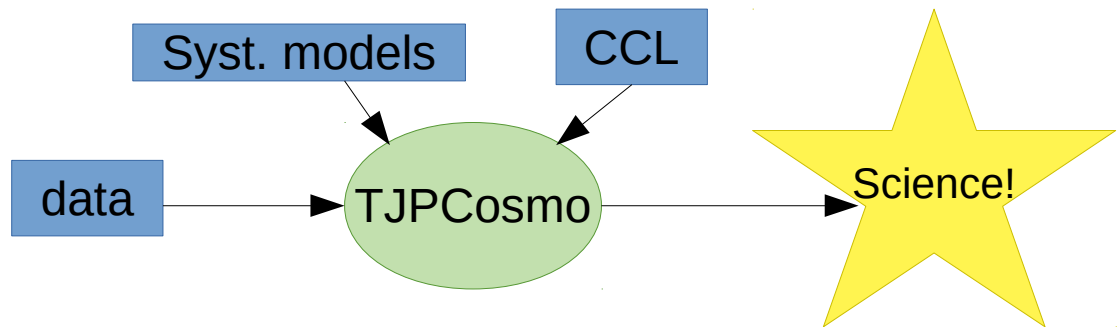
Idea:

Likelihood module that can combine multiple cosmological probes with theory predictions to obtain joint constraints on cosmological parameters.

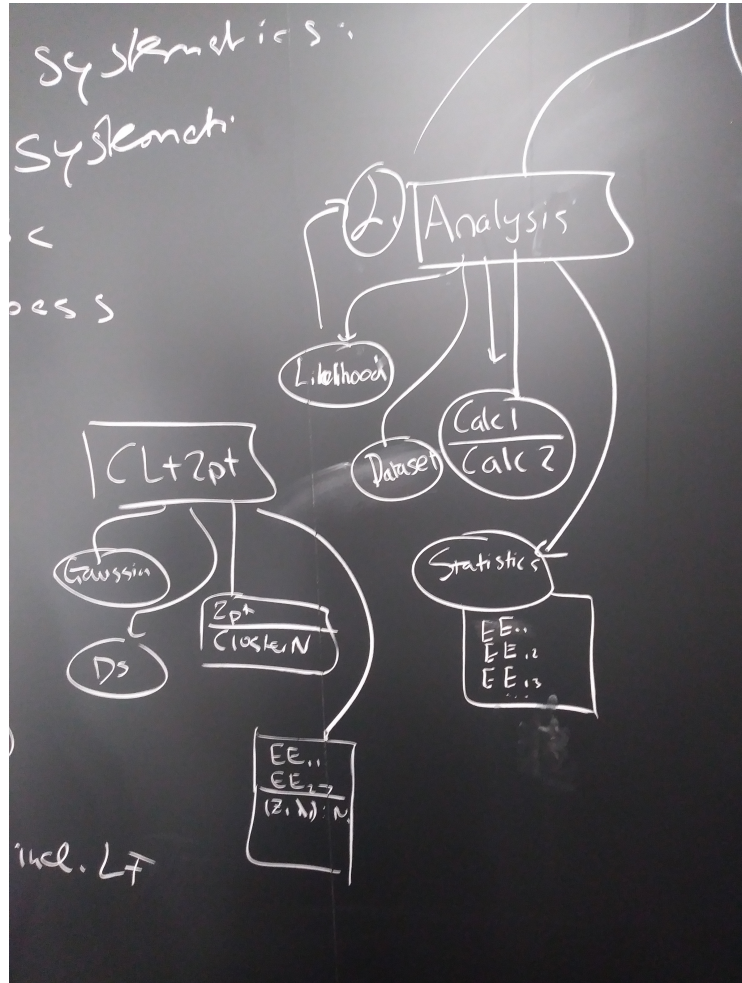
Motivation:

- Non-trivial endeavour: multiple probes (>5!) with correlated signal, noise and systematics.
- Generic analysis models for different probe combinations.
- Generic implementation of systematic models that can easily grow in complexity.
- Avoid inconsistencies between probes in terms of theory or systematics.

Note: TJPCosmo != CCL



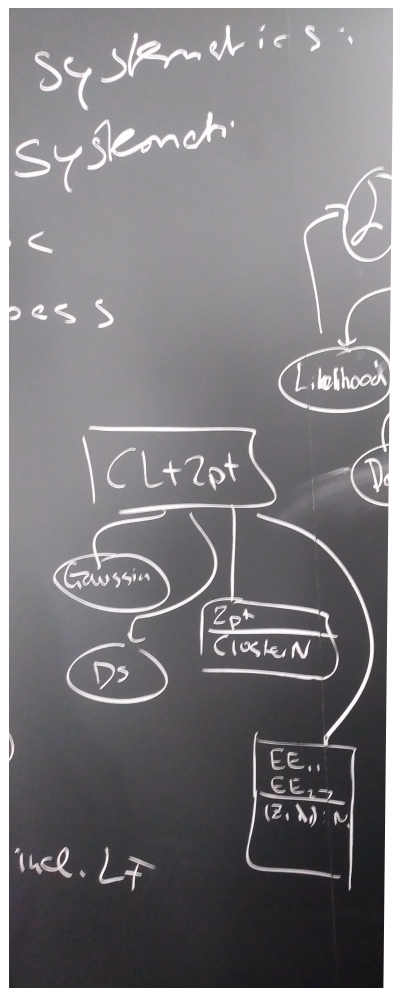
TJPCosmo: status and plans



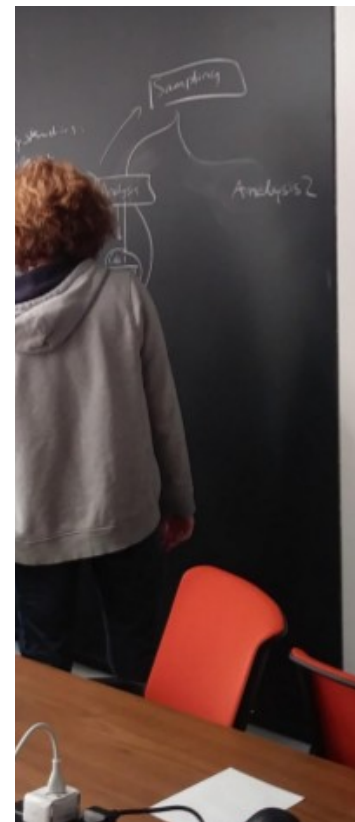
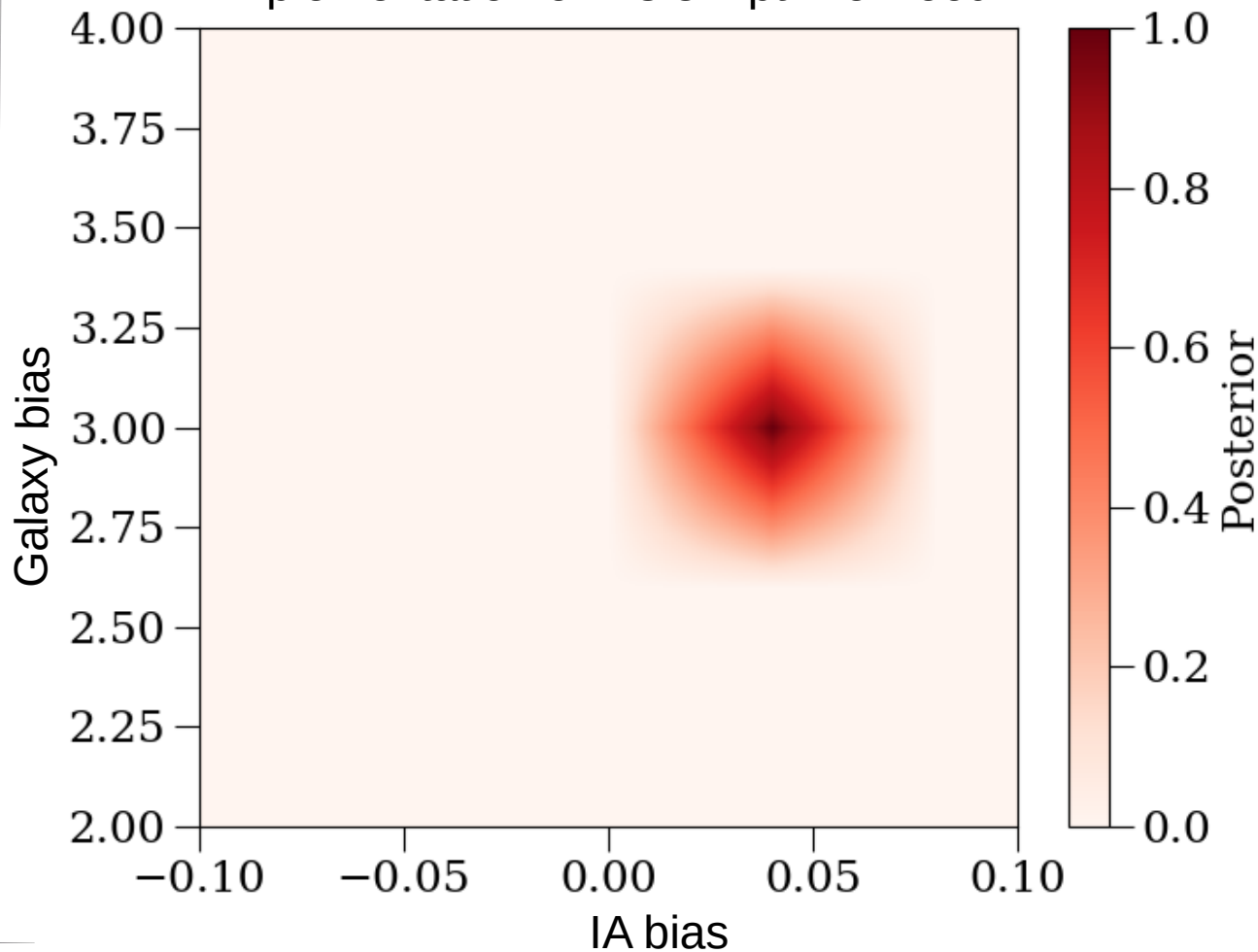
First hack at Oxford
~3 weeks ago



TJPCosmo: status and plans



Implementation of first 3x2pt likelihood!



Summary

- Dark Energy from LSST from 5 different probes
- Huge potential for LSS+WL (3x2pt)
- Lots of work going on:
 - **CCL**: theory calculator
 - **LSS loop**: fast simulations for LSS pipeline tests (and science!)
 - **LSS with HSC**: new data, new challenges
 - **3x2pt** pipeline: flagship analysis for LSST
 - **TJPCosmo**: robust parameter inference for multi-probe experiments
- Open and friendly work environment. Contribute!

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Obrigado!