

Cosmological Weak Lensing

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Hamsa Padmanabhan (ETH)

Webinar
LIneA
9.11.2017

Λ CDM Model

Inflation

Radiation

Matter

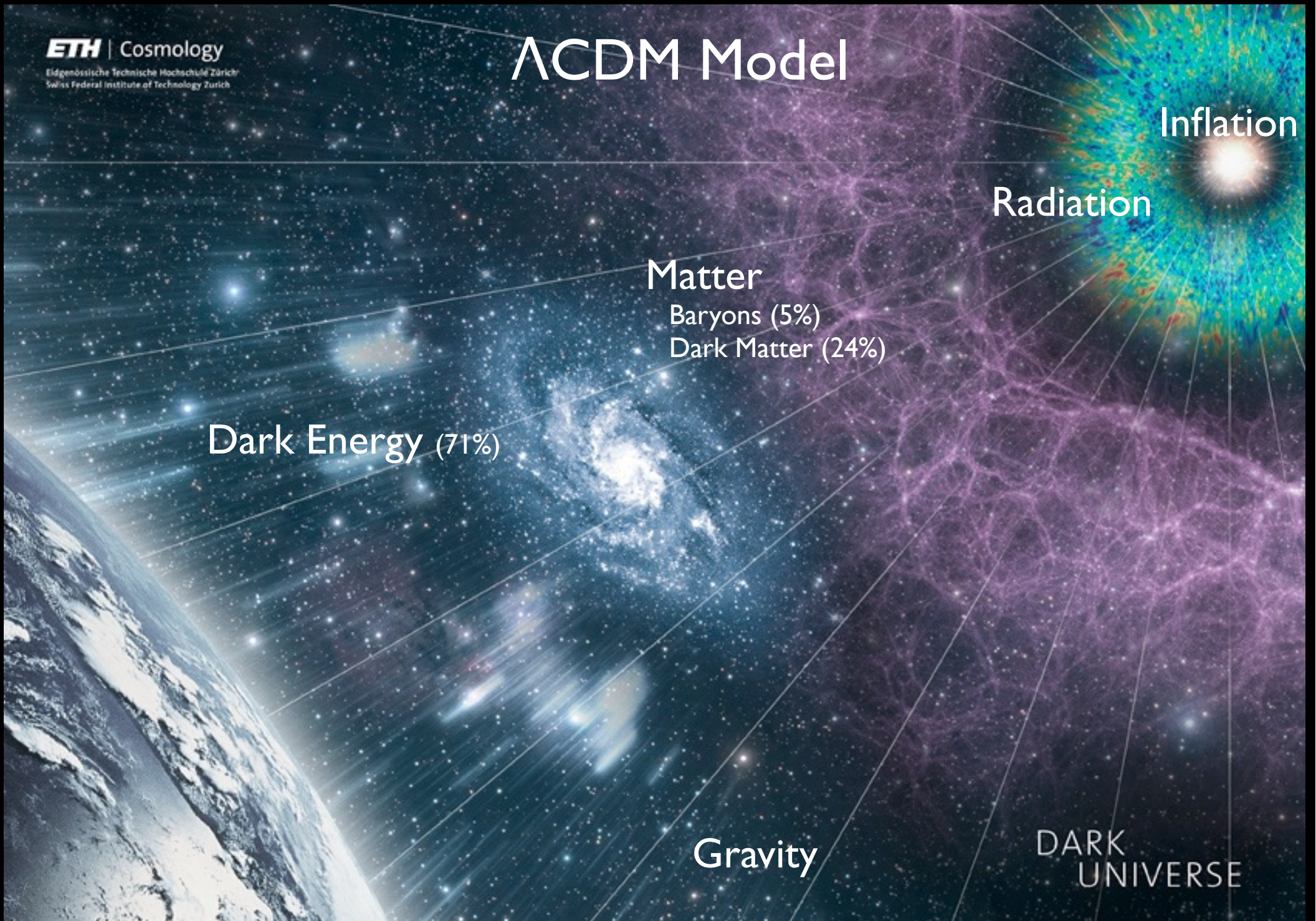
Baryons (5%)

Dark Matter (24%)

Dark Energy (71%)

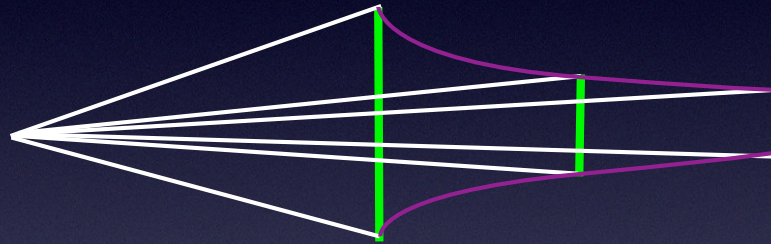
Gravity

DARK
UNIVERSE

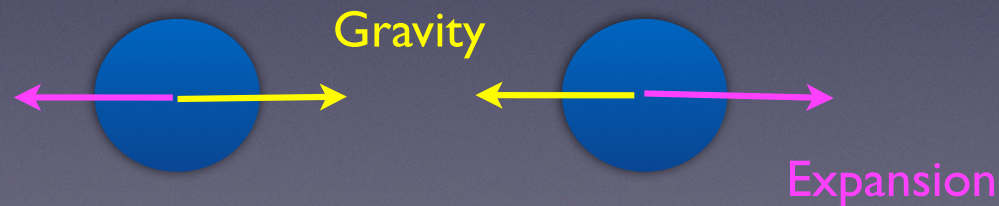


Measuring the Dark Universe

- Geometry

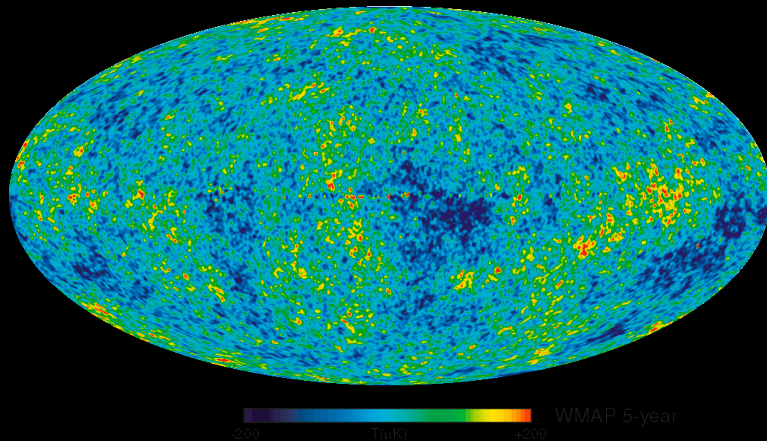


- Growth of structure

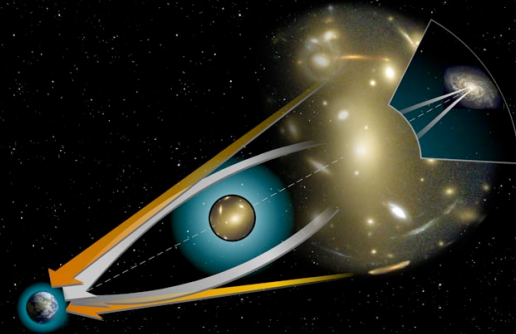


Cosmological Probes

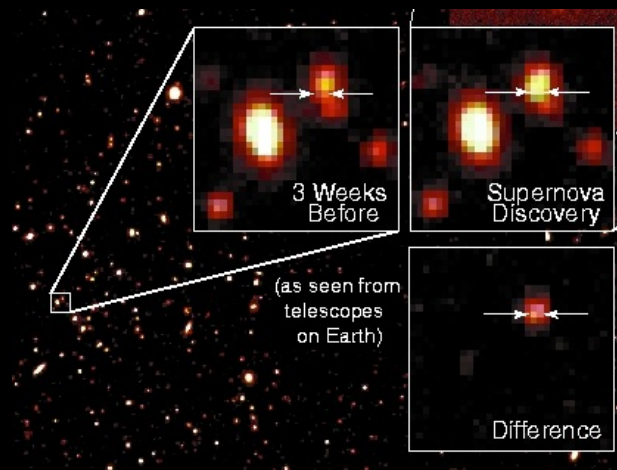
Cosmic Microwave Background



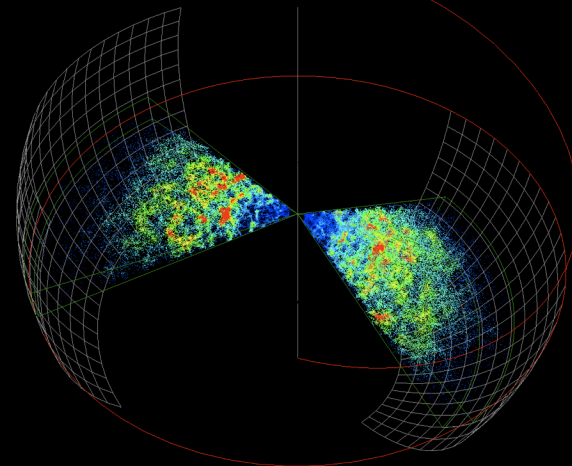
Gravitational Lensing



Supernovae



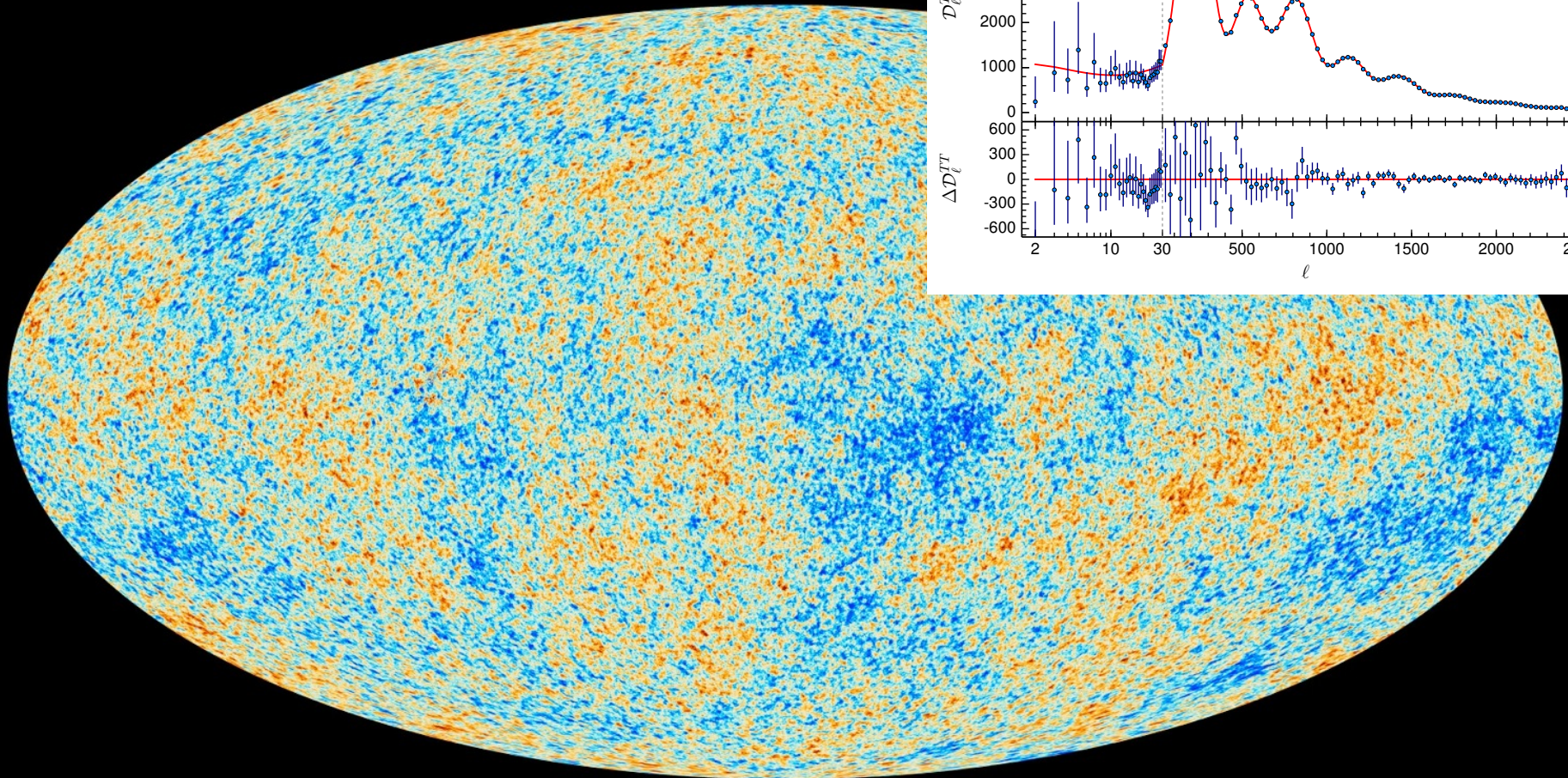
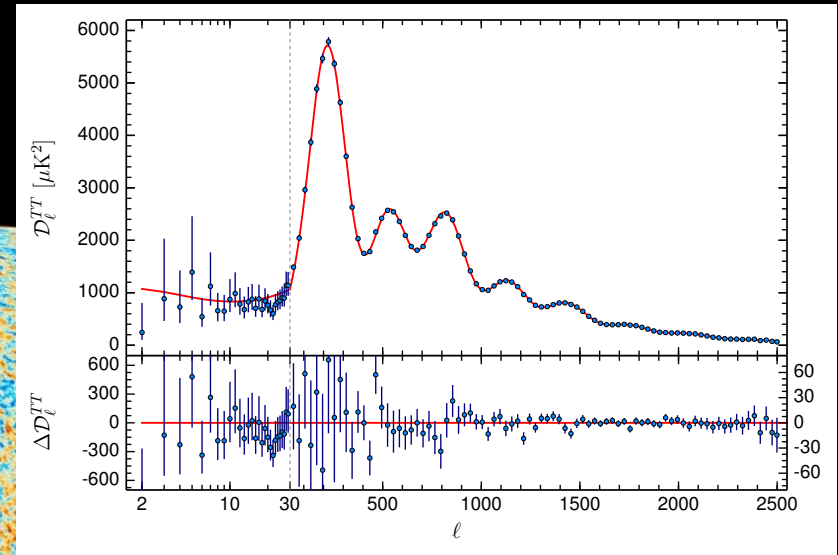
Galaxy Clustering (incl. Clusters)



Cosmic Microwave Background

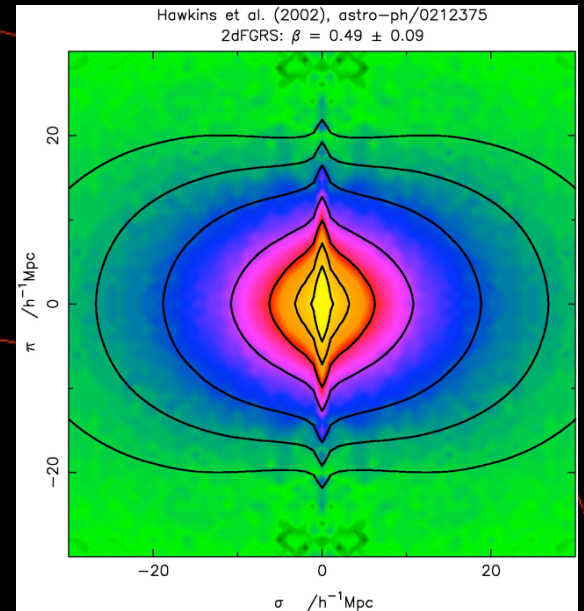
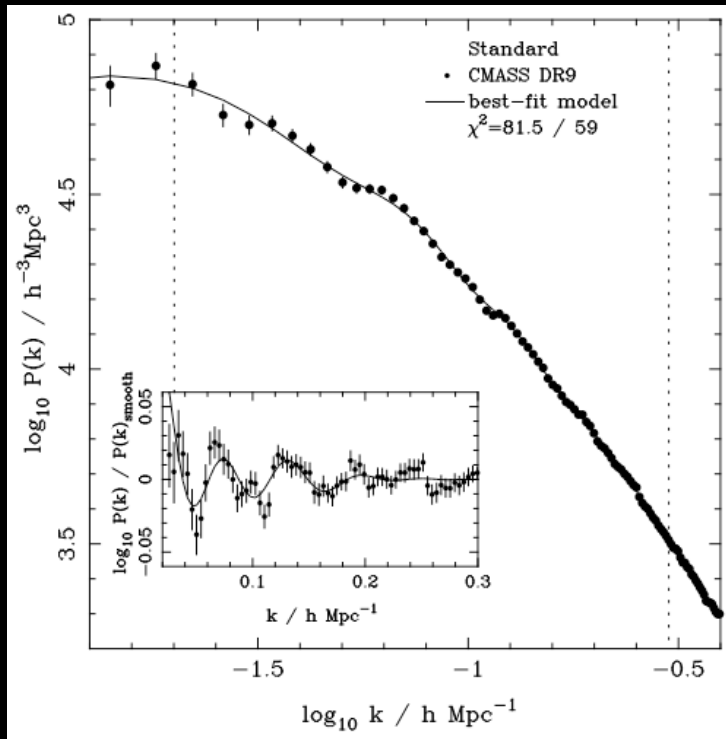
$T_{\text{CMB}} \approx 2.725\text{K}$
 $\Delta T/T \sim 10^{-4}$

Planck collab. 2015



Galaxy Redshift Surveys

Anderson et al. 2012



SDSS survey:

Eisenstein et al. 2004

2dF survey:

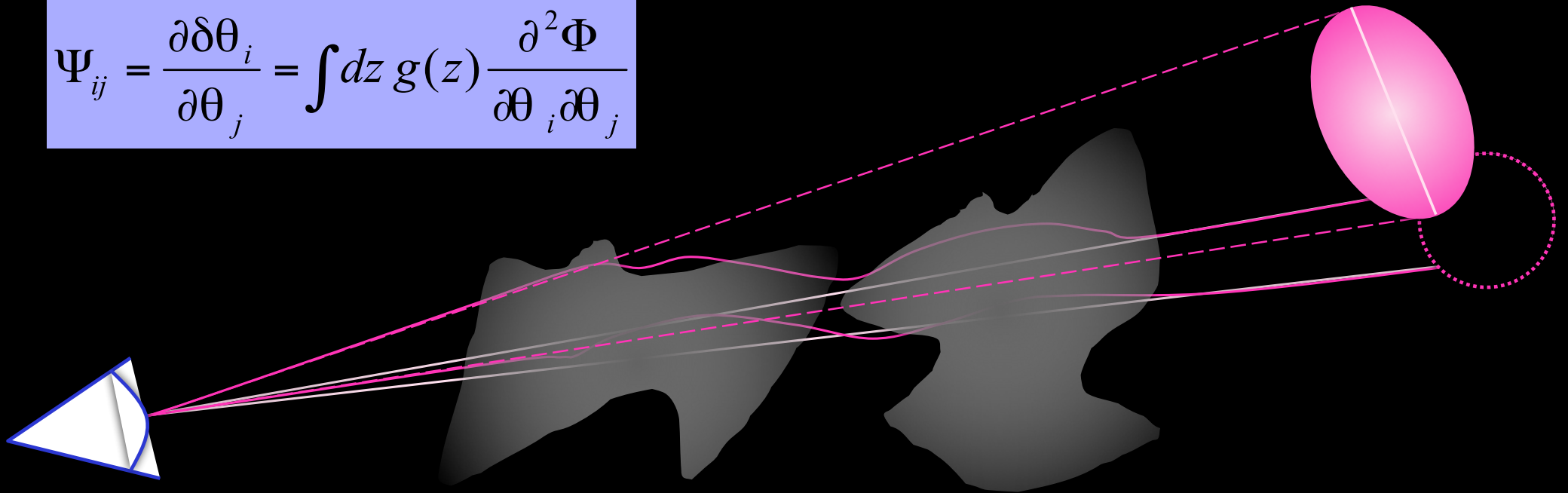
Percival et al 2004

Weak Gravitational Lensing

Massey et al.
review: Refregier 2003

Distortion matrix:

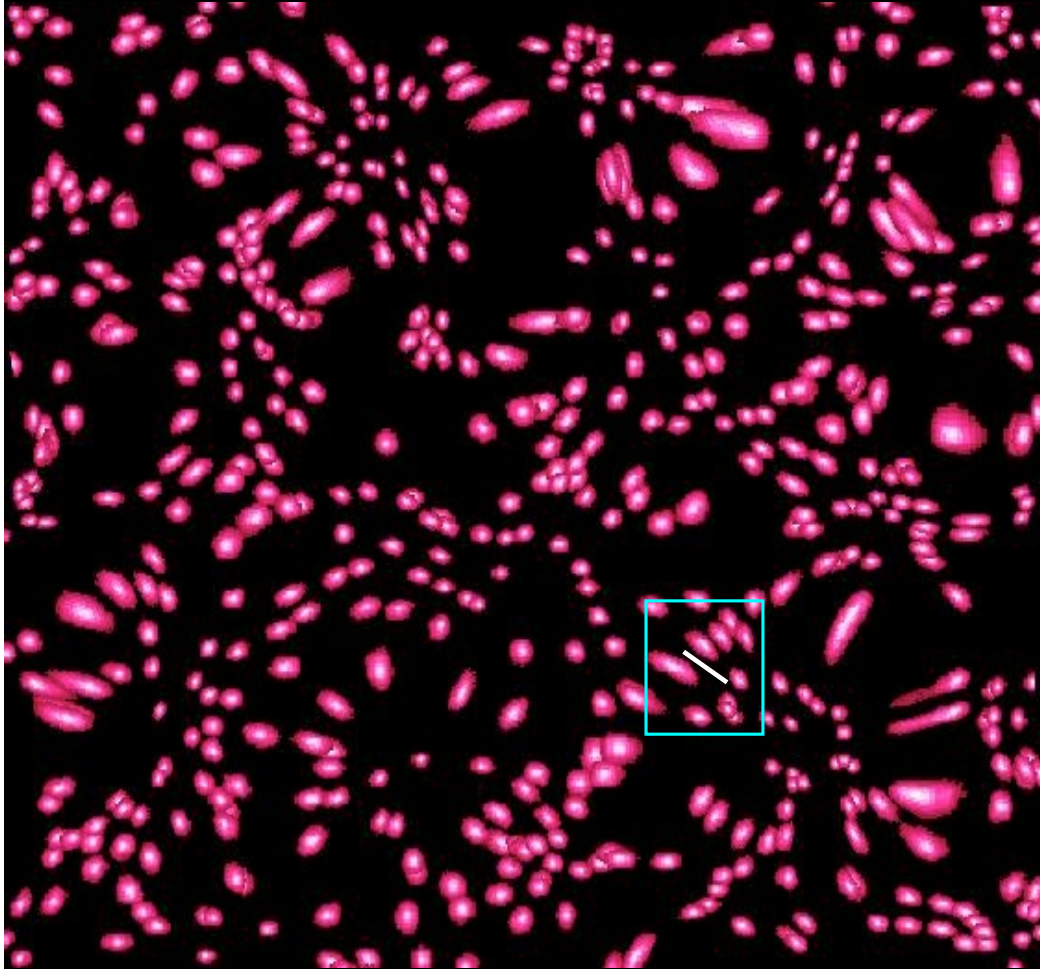
$$\Psi_{ij} = \frac{\partial \delta \theta_i}{\partial \theta_j} = \int dz g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$$



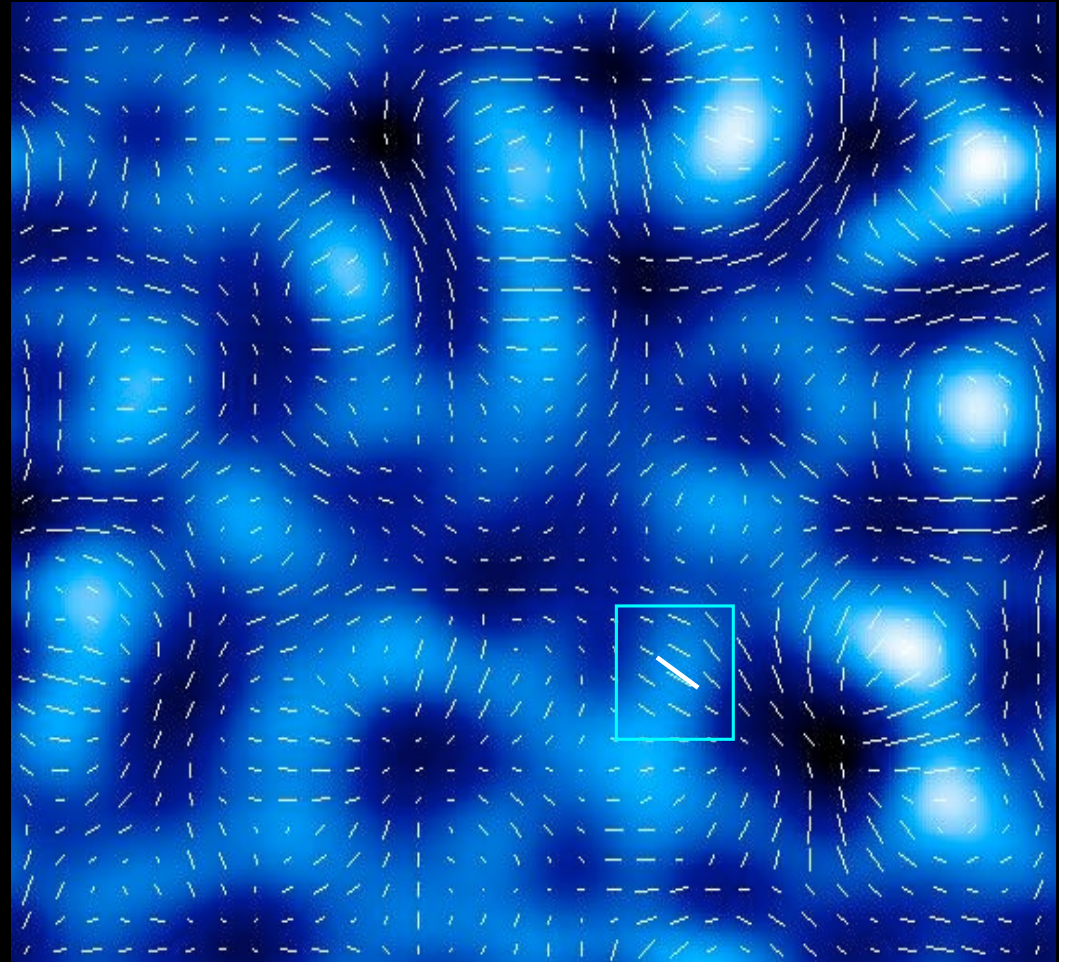
Direct measure of the distribution of **mass** in the universe, as opposed to the distribution of **light**

Theory

Weak Lensing Shear Measurement



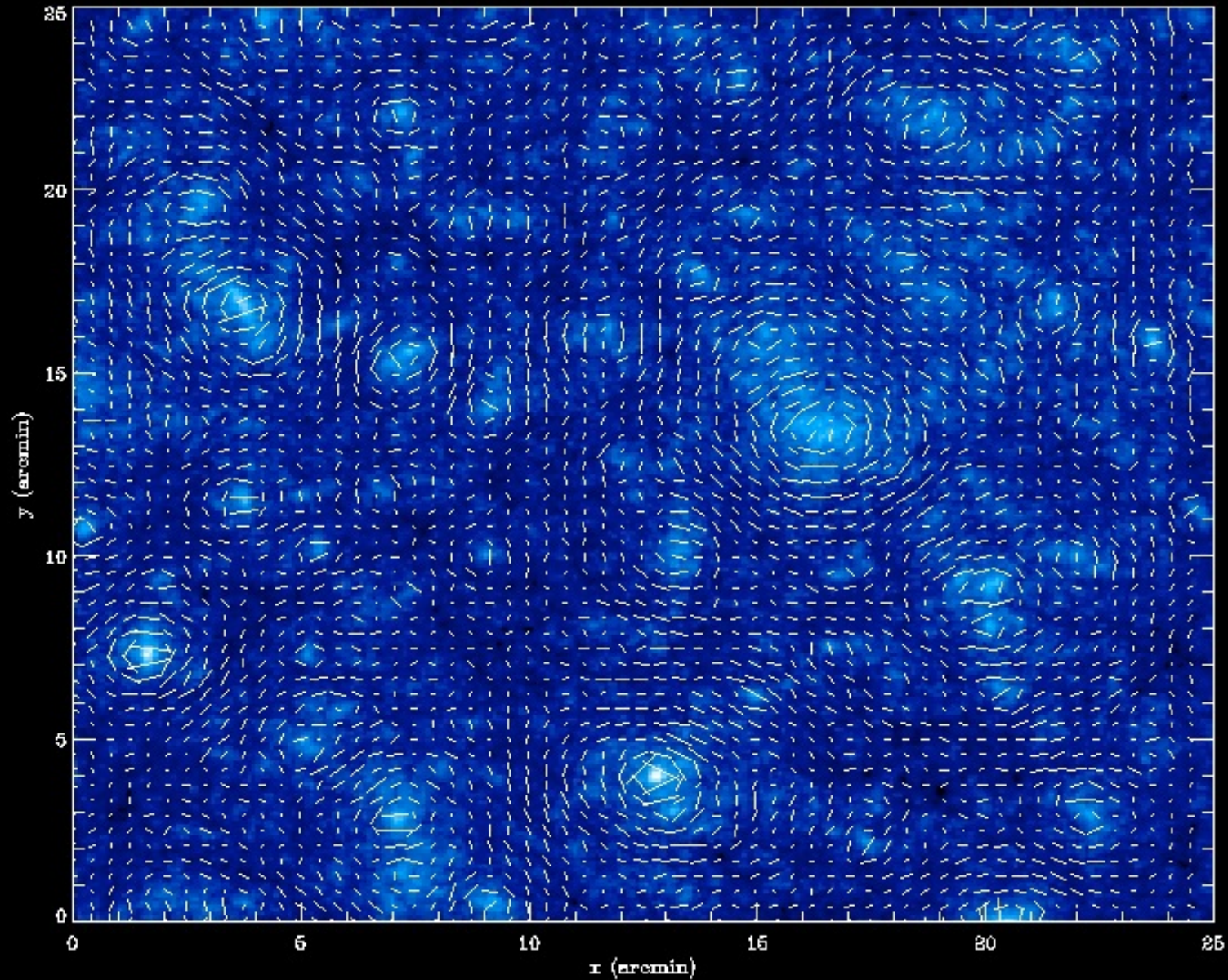
lensed background galaxies



mass and shear distribution

Simulated Shear Map

Jain, Seljak & White 1997, 25'x25', SCDM

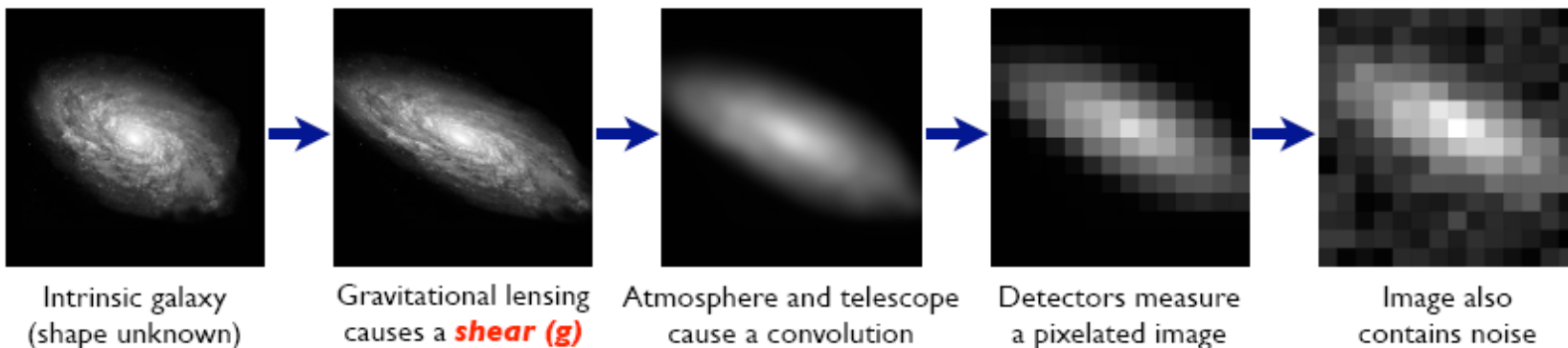


Shear Measurement Problem

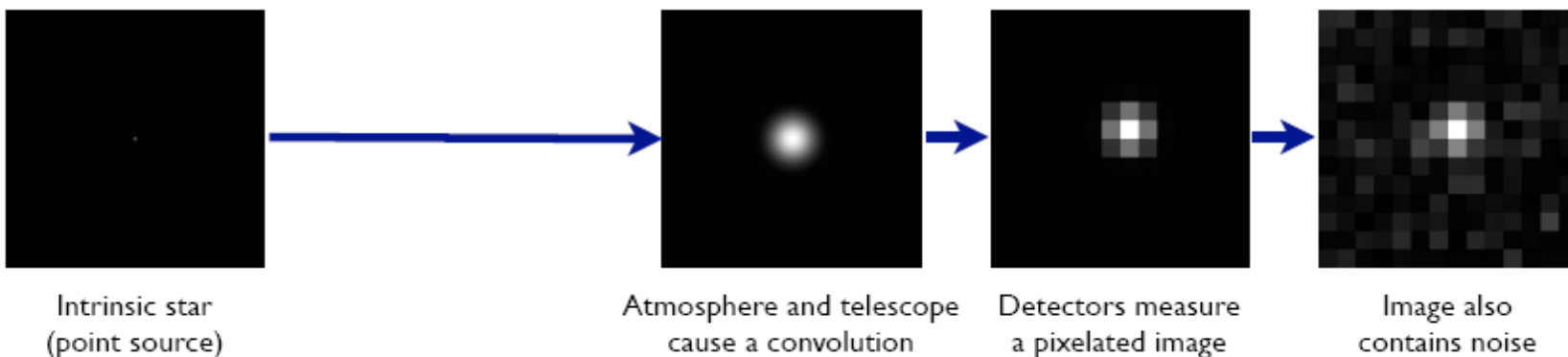
GREAT08 handbook, Bridle et al 08

The Forward Process.

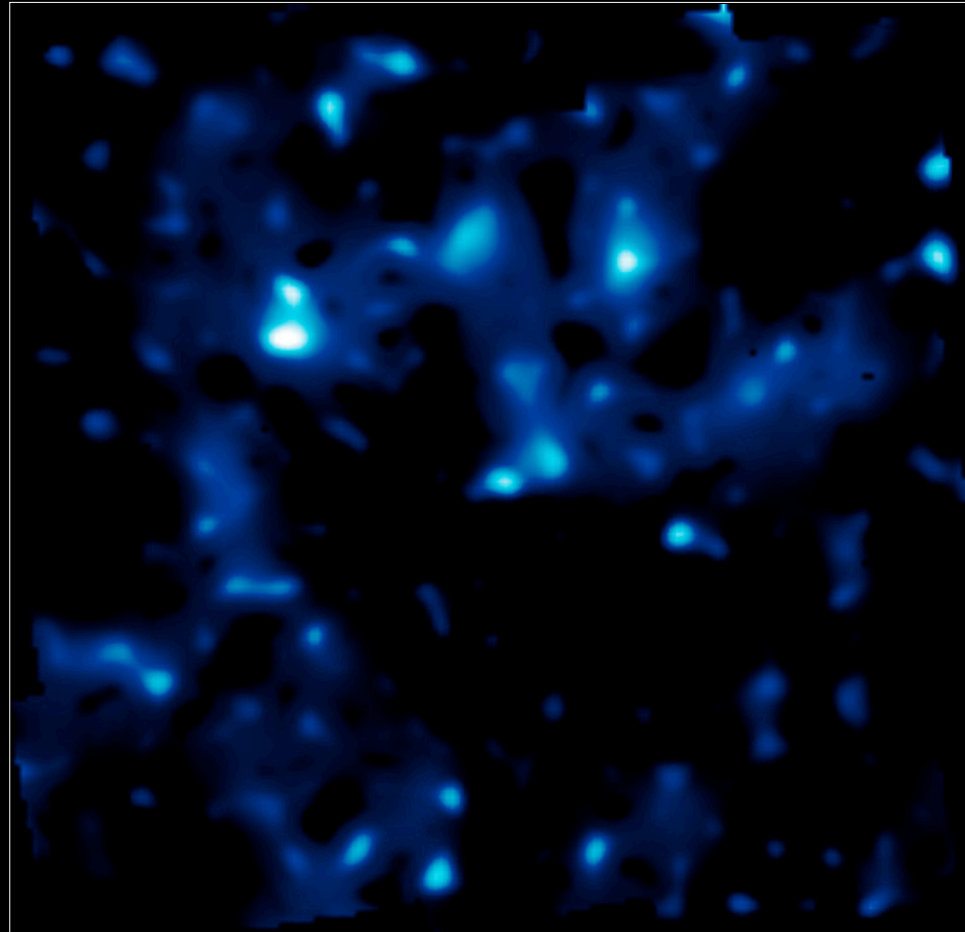
Galaxies: Intrinsic galaxy shapes to measured image:



Stars: Point sources to star images:



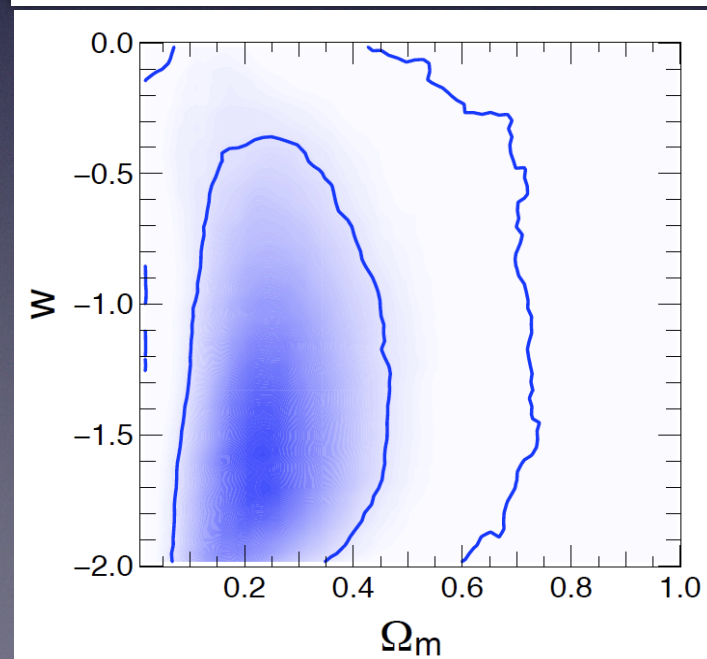
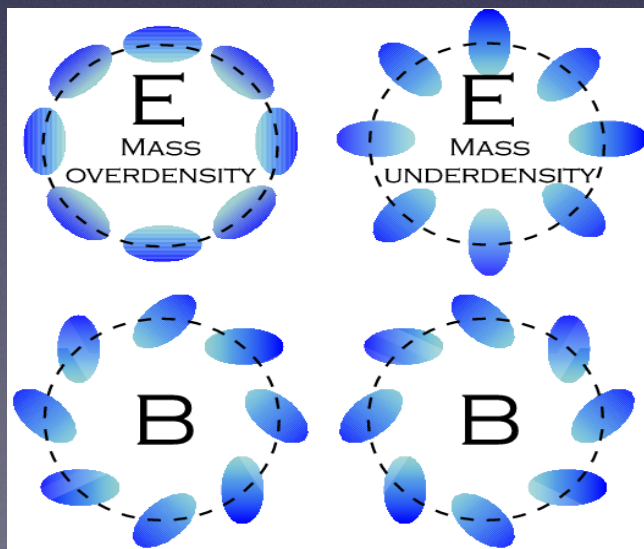
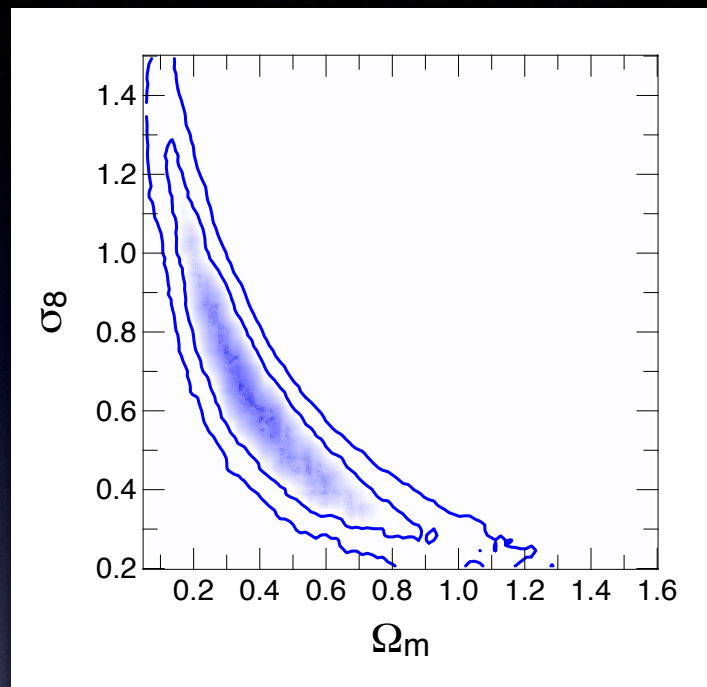
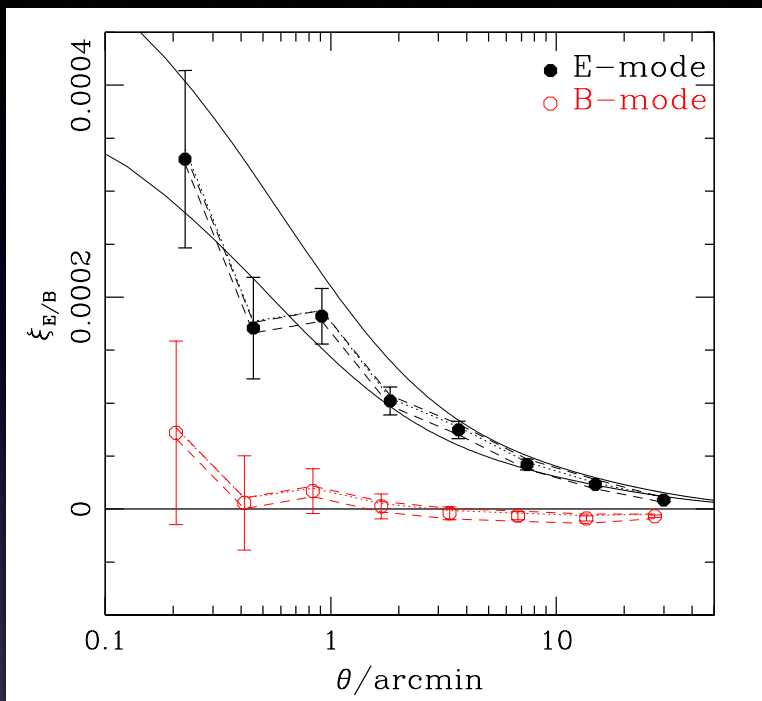
COSMOS Dark Matter Map



COSMOS HST
ACS survey
2 deg²
Massey et al.
2006, Nature

COSMOS

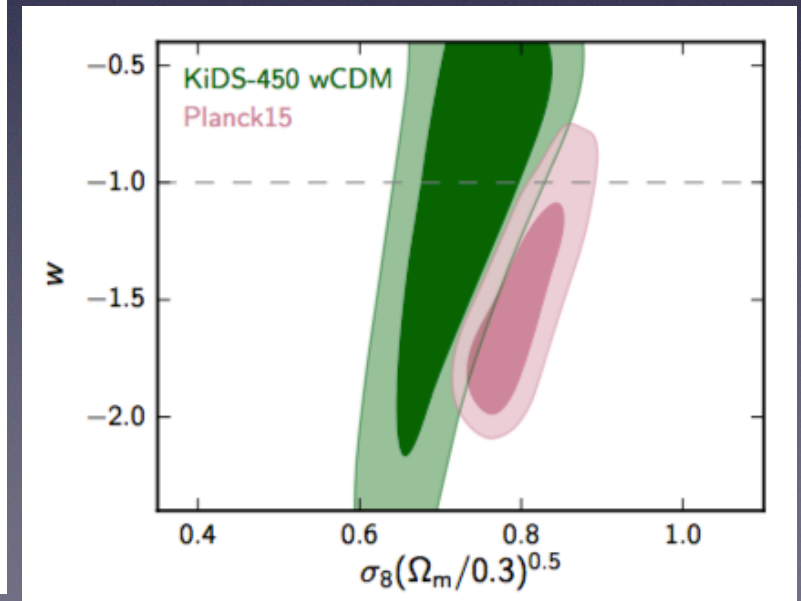
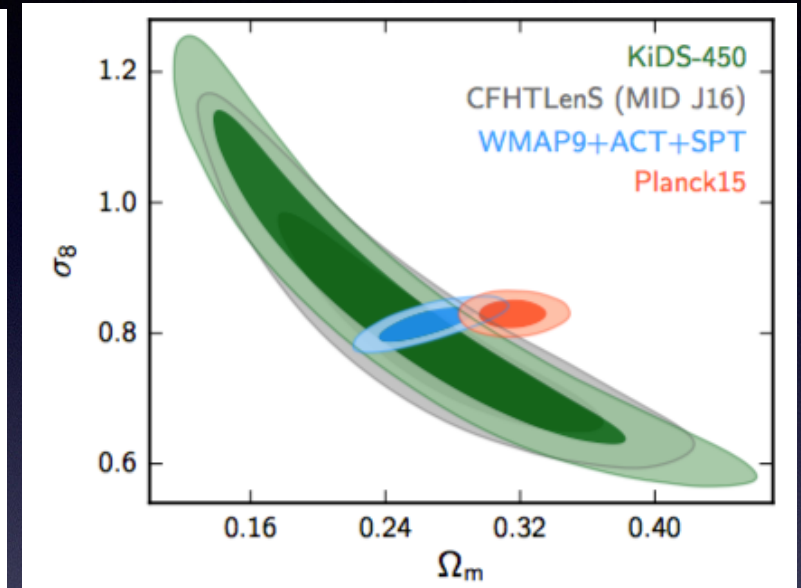
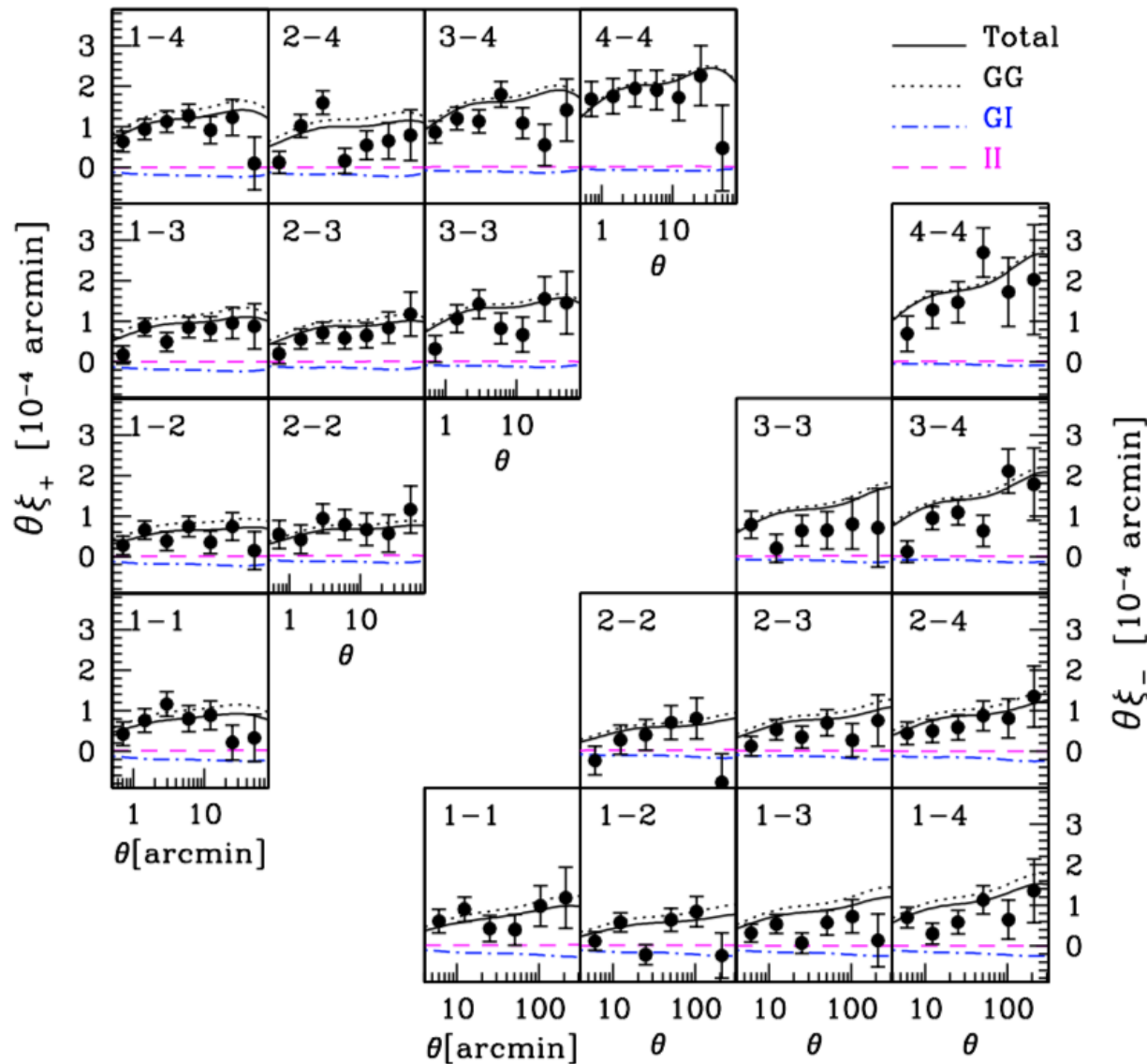
Schrabback et al. 2010



KiDS 450

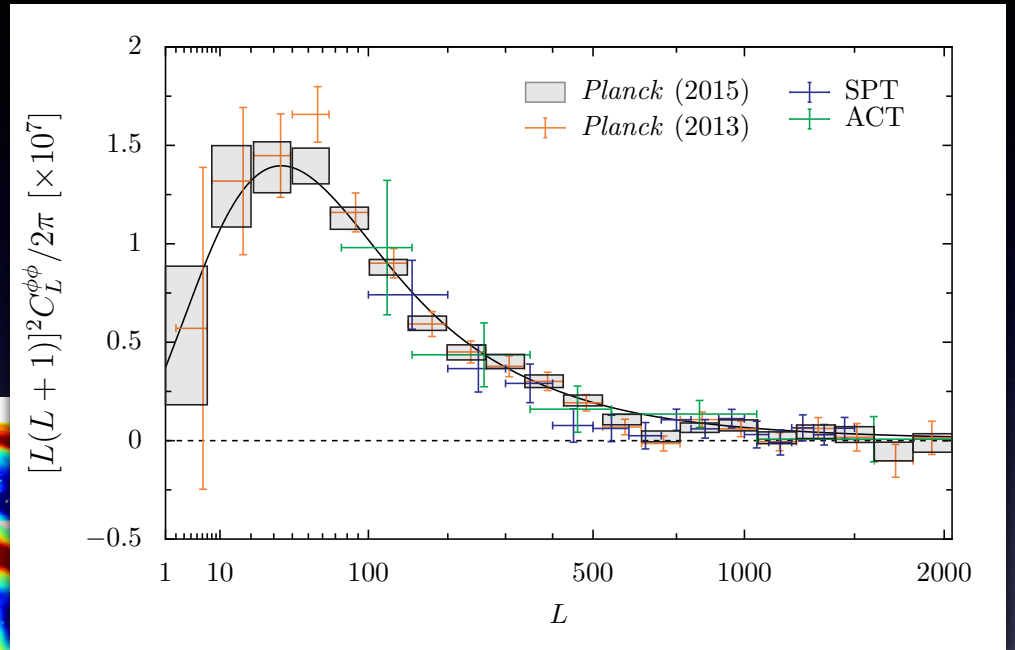
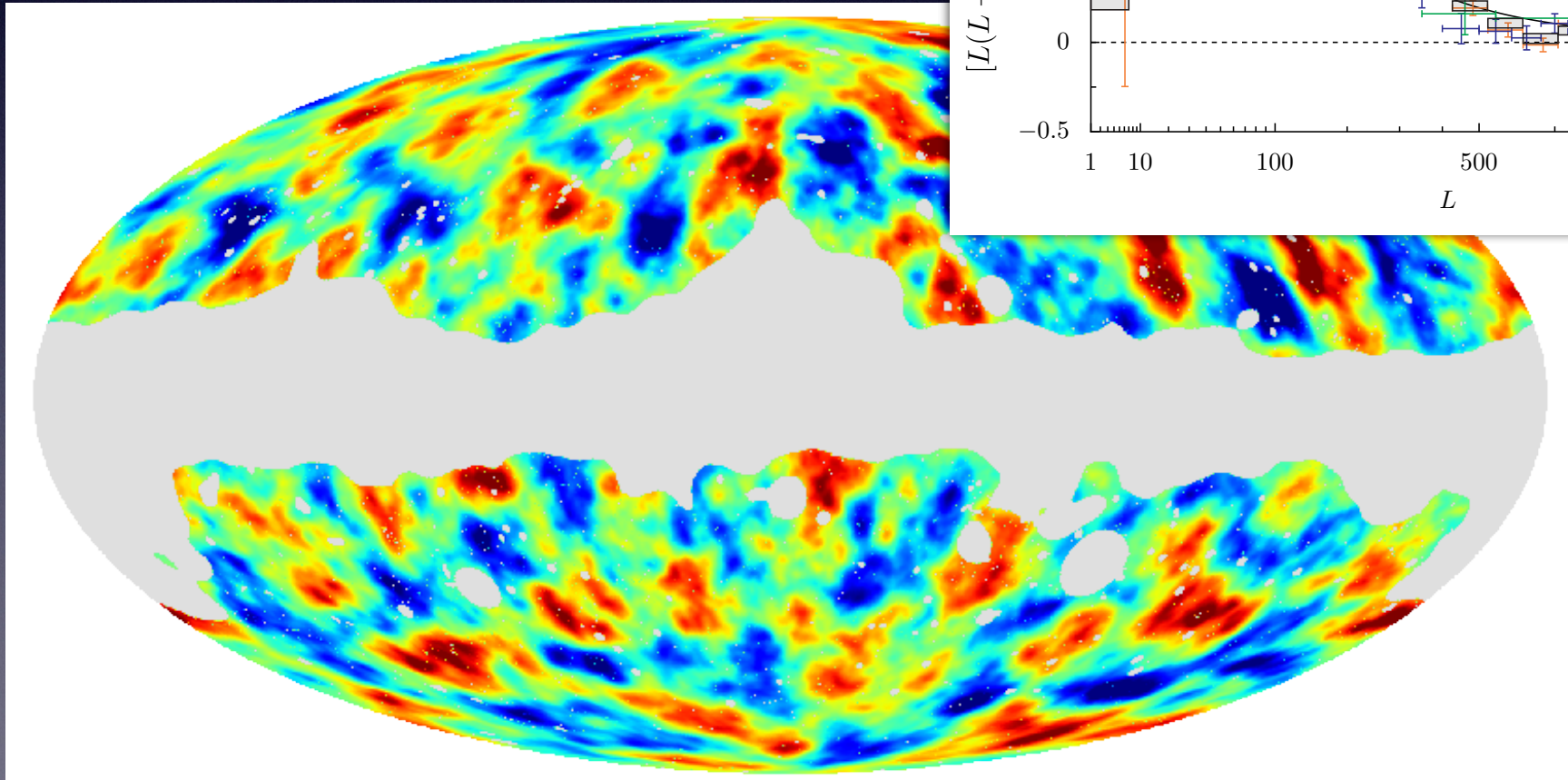
Hildebrandt et al. 2017

VST, first 450 deg², ugr, r band: mag<24.9(5 σ), z_m~0.5, seeing~0.7''



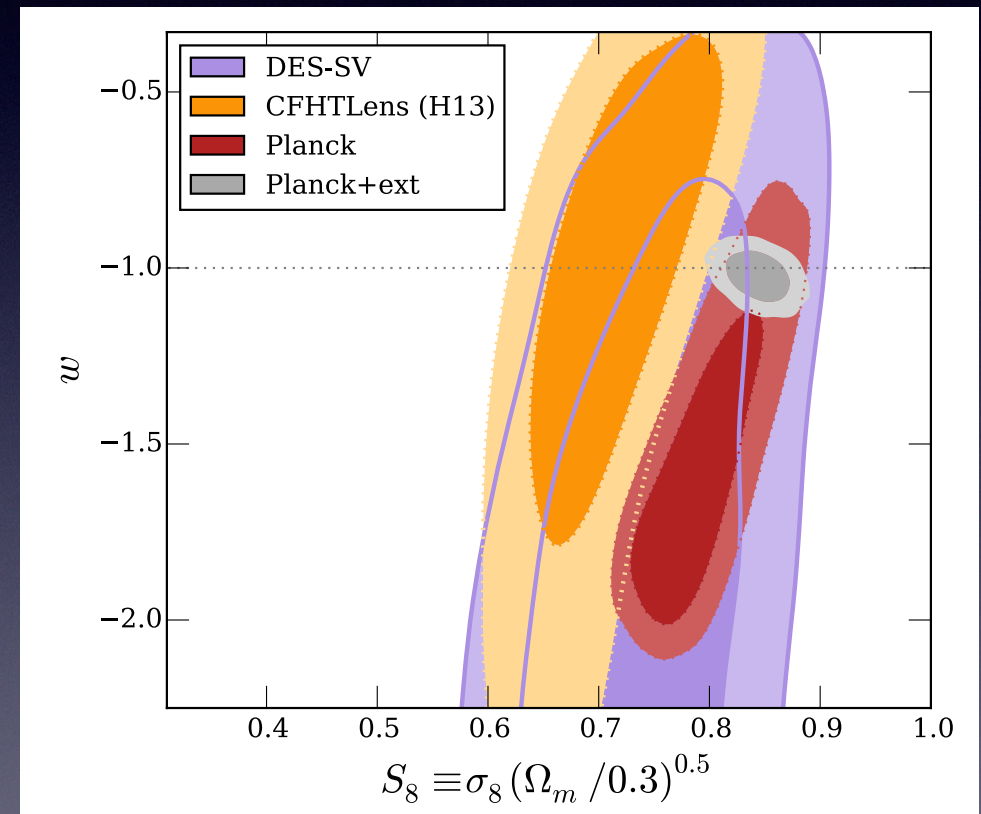
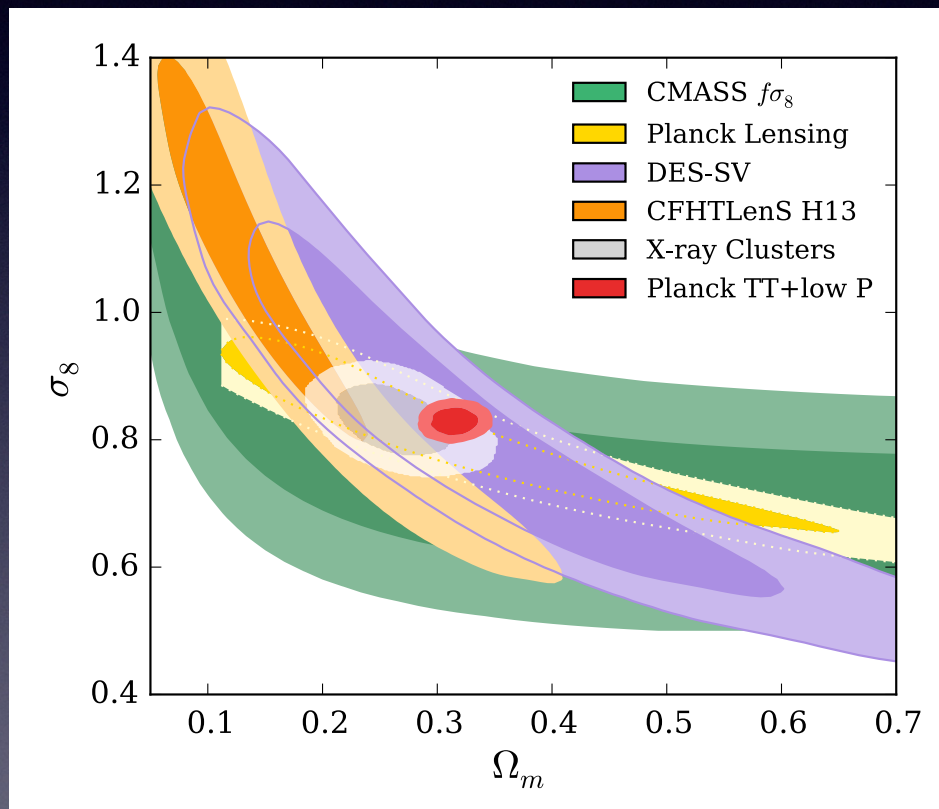
CMB Lensing

Planck XV, 2015



Probe Comparison

DES Collab 2015

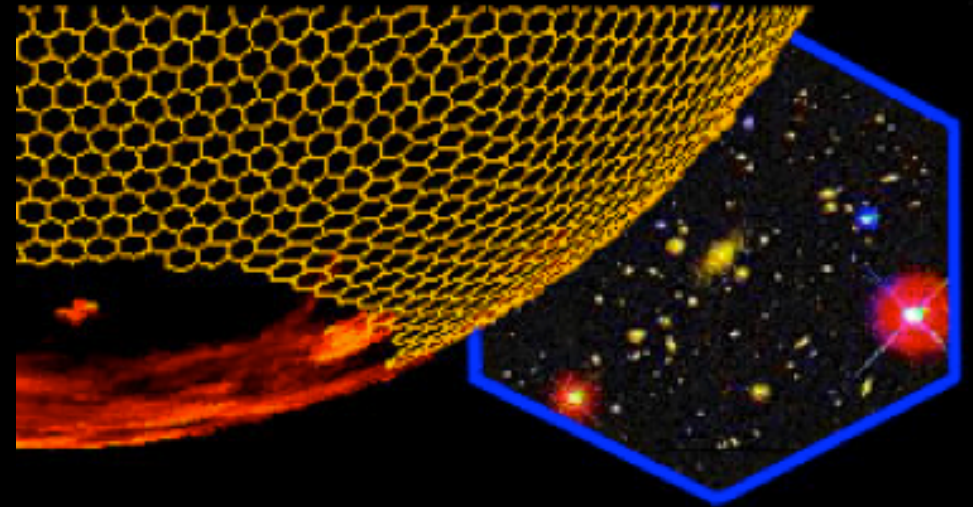


Dark Energy Survey



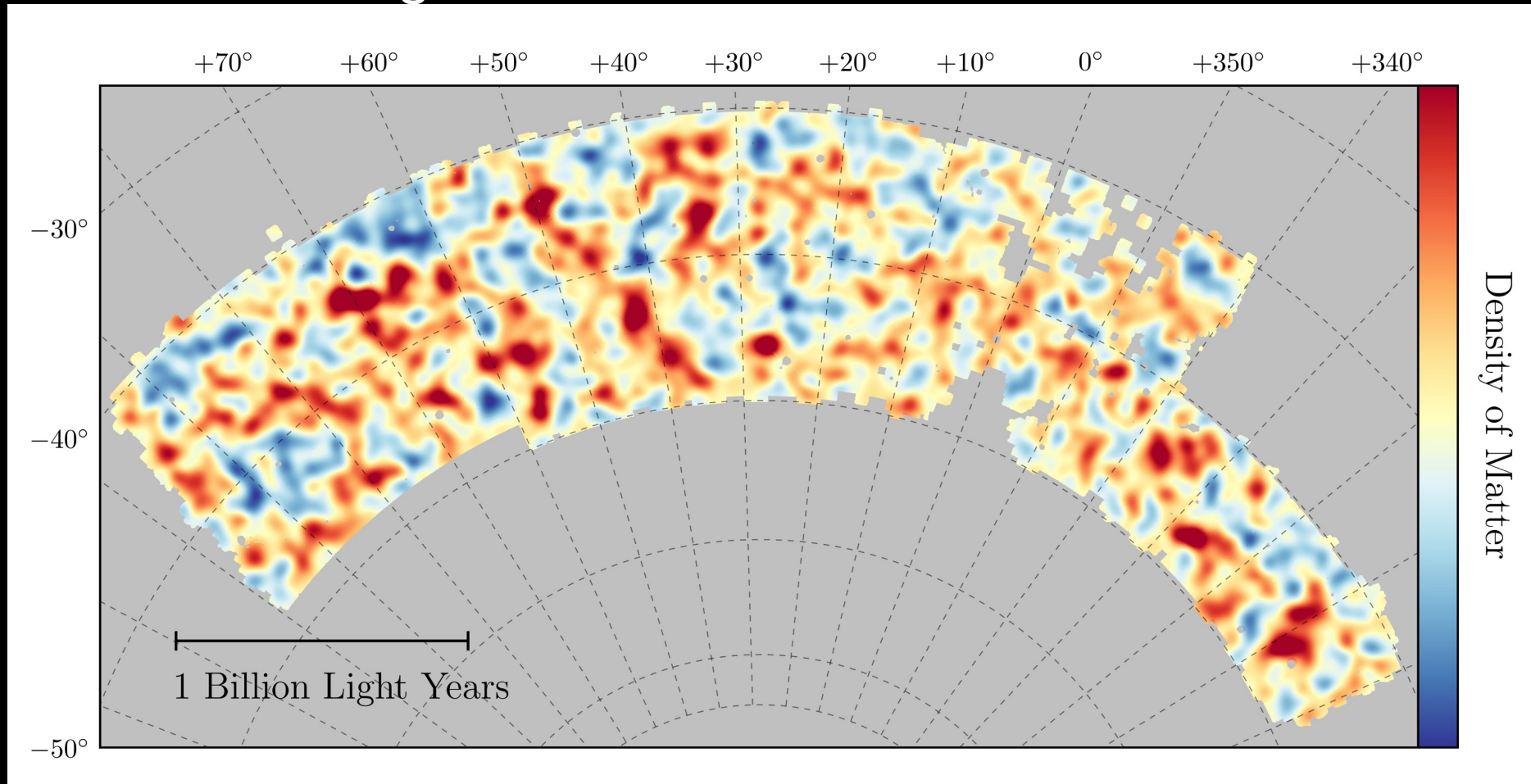
Blanco 4m at CTIO
74 2k×4k CCDs, 0.27"/pix
2.2 deg² FOV
5000 deg² survey (+SNe survey)
g,r,i,z,y to mag 24
200M galaxies

First light Sept 2012



Dark Energy Survey

DES Y1: 1500 deg²

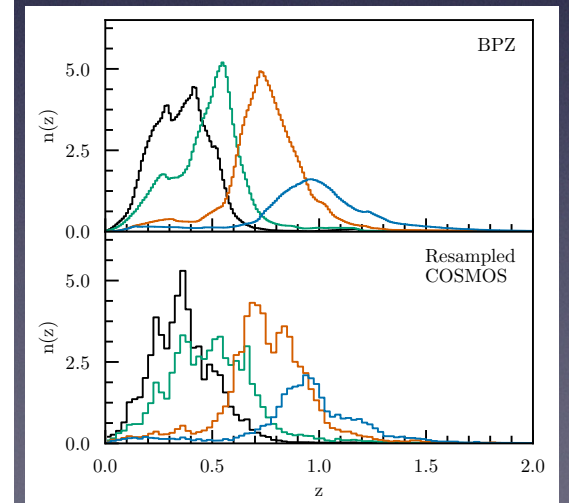
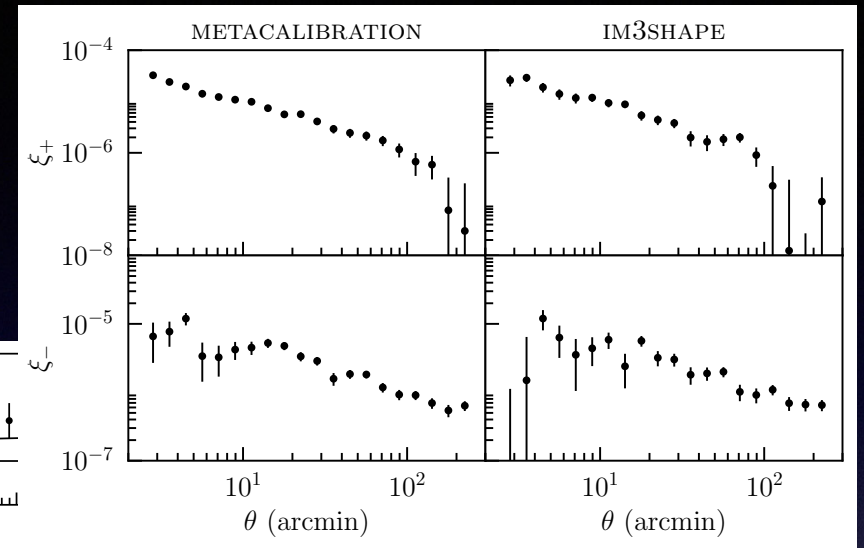
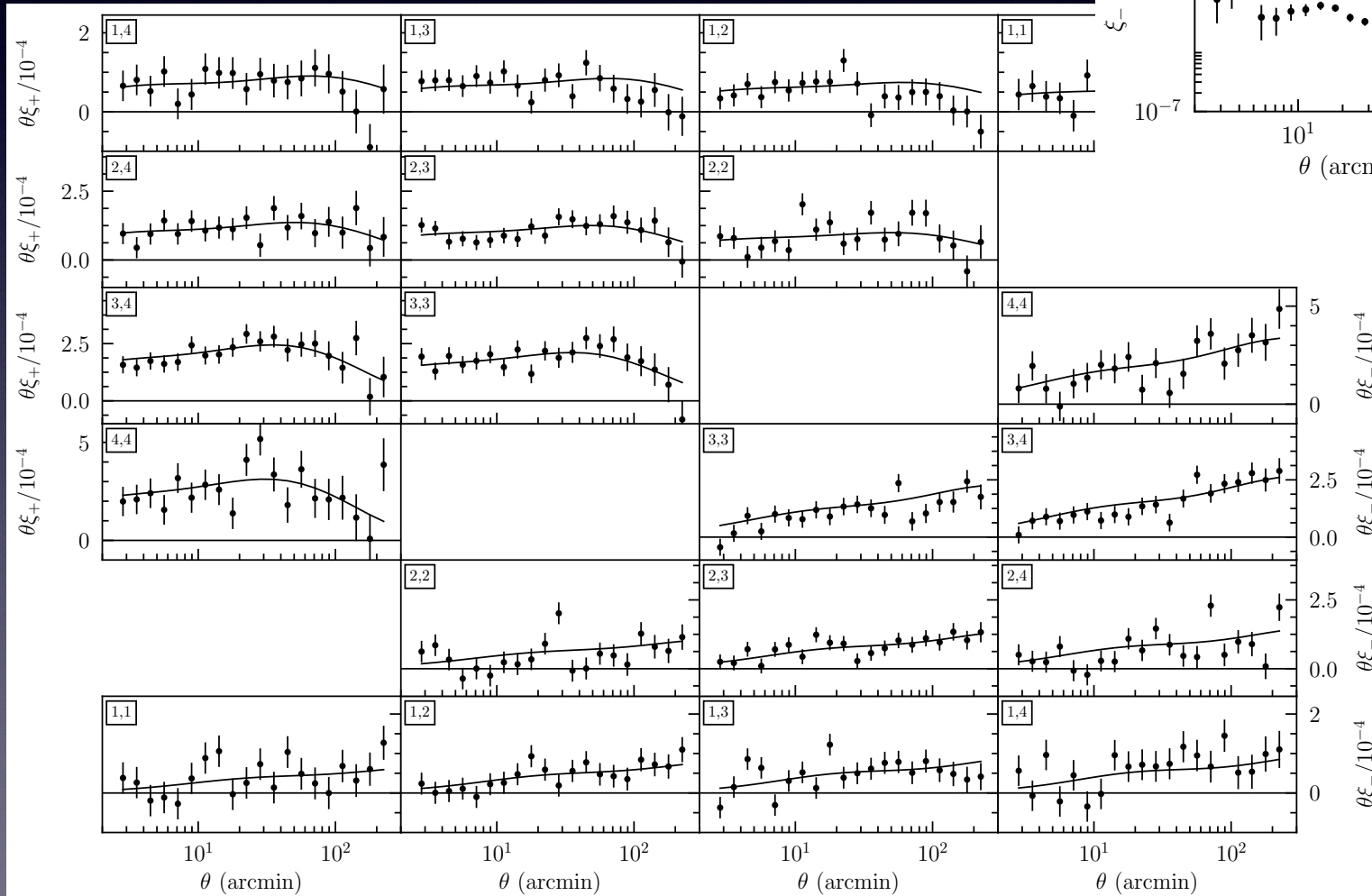


Chang et al. 2017

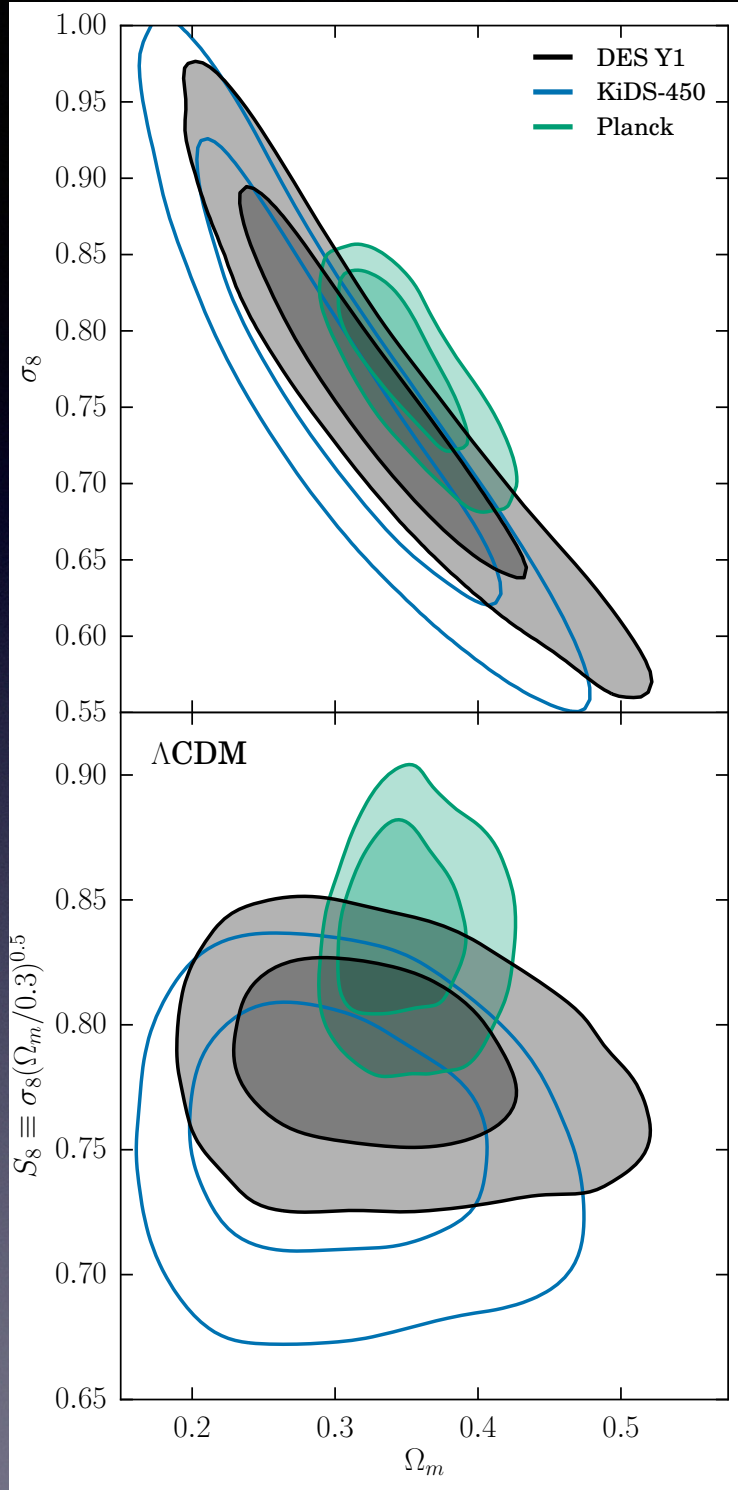
DES Y1

1321 deg²

Troxel et al. 2017

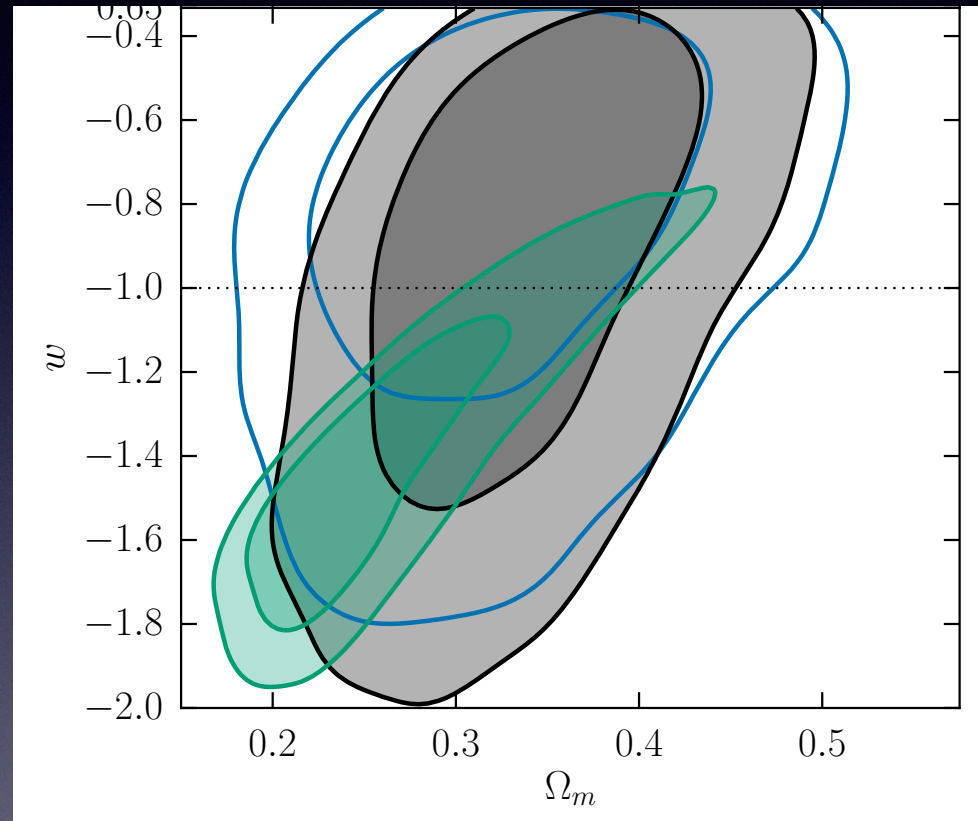


Λ CDM

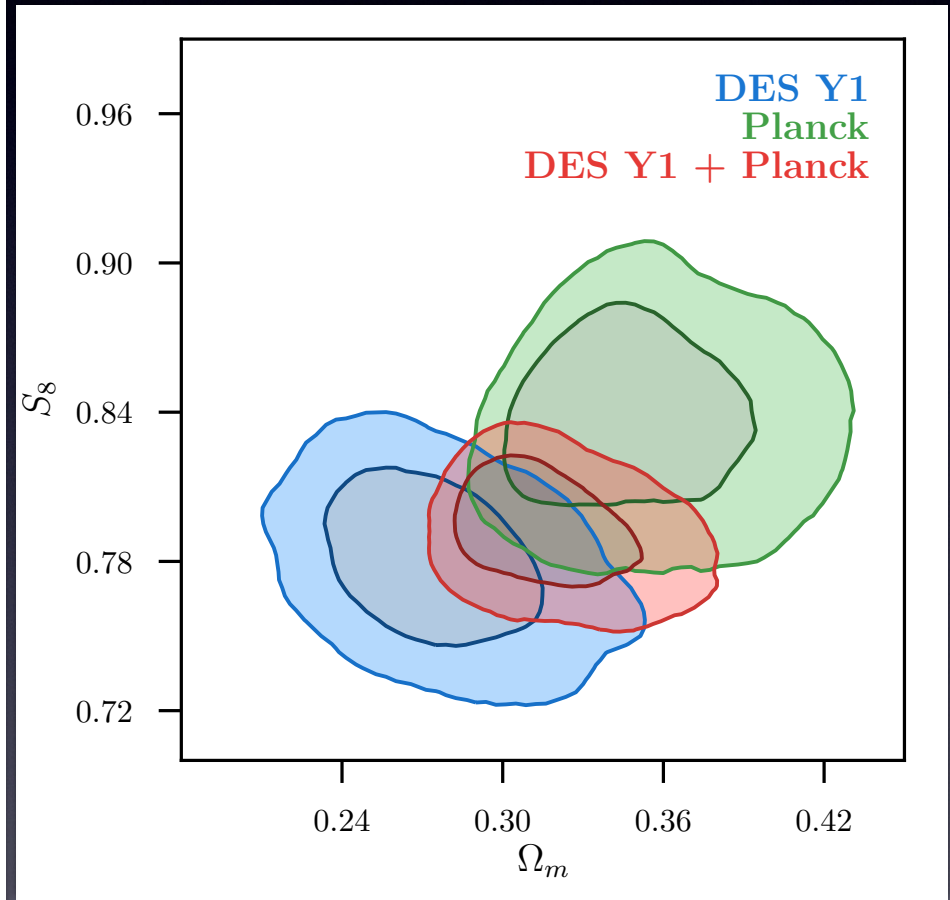
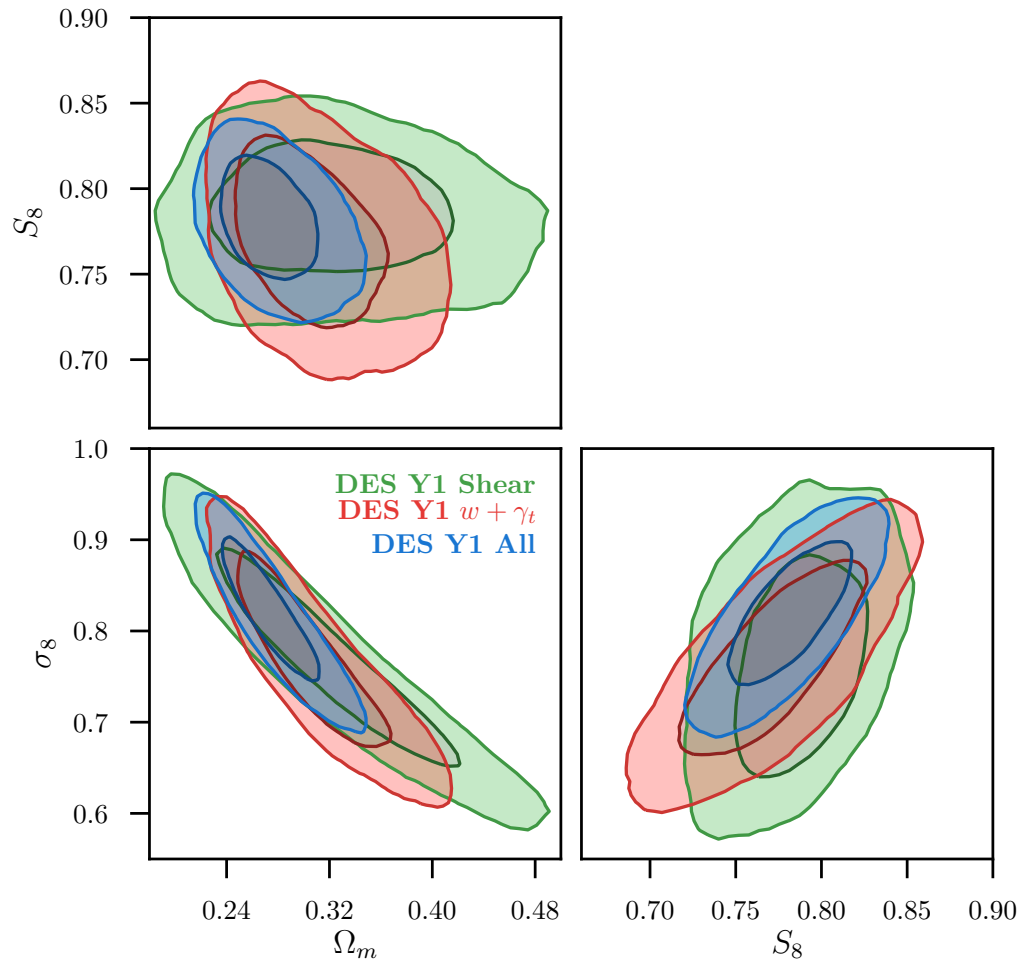


DES Y1

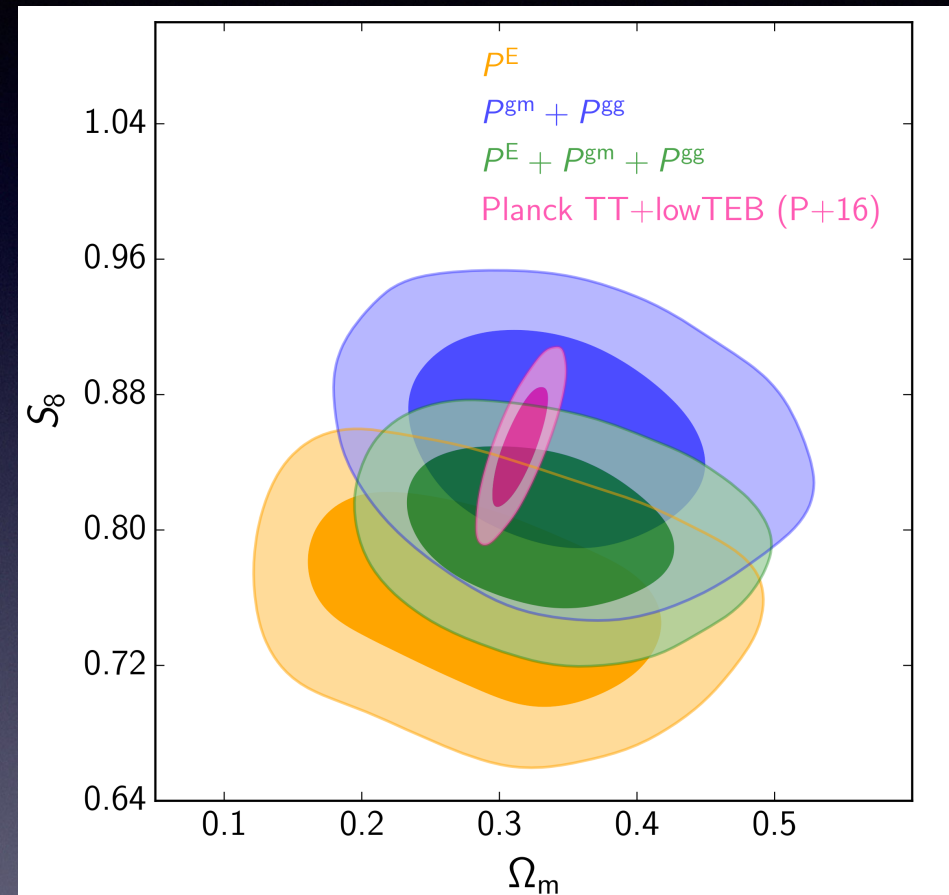
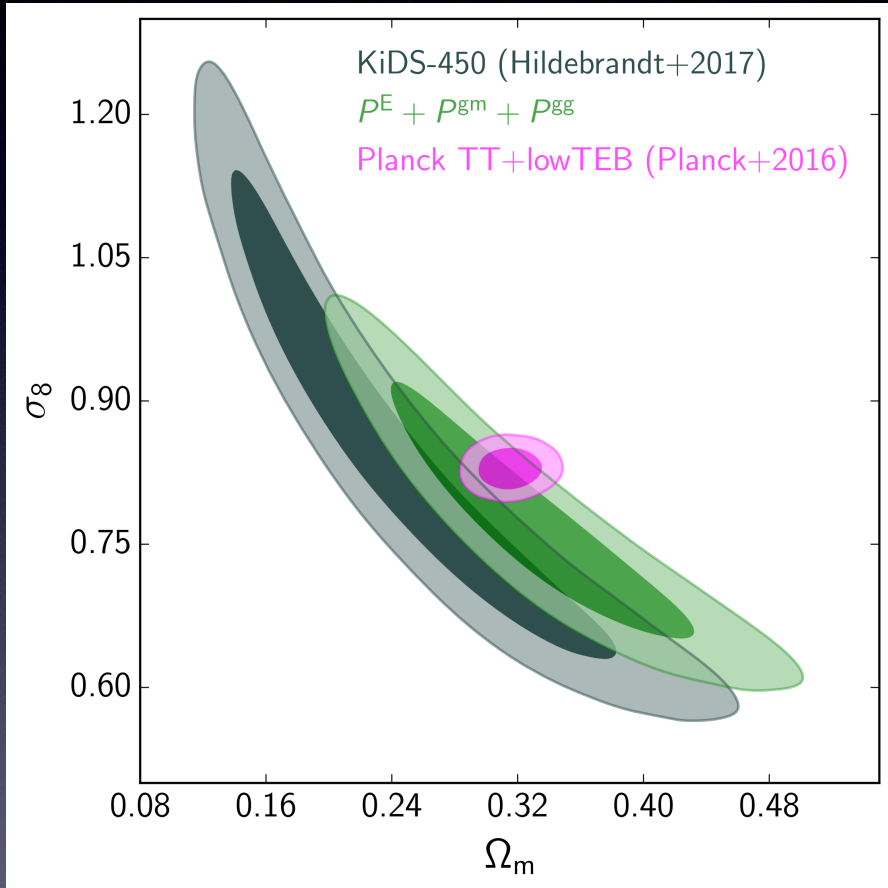
wCDM



DES Y1:WL+Clustering



KIDS+GAMA:WL+Clustering



Wide-Field Instruments

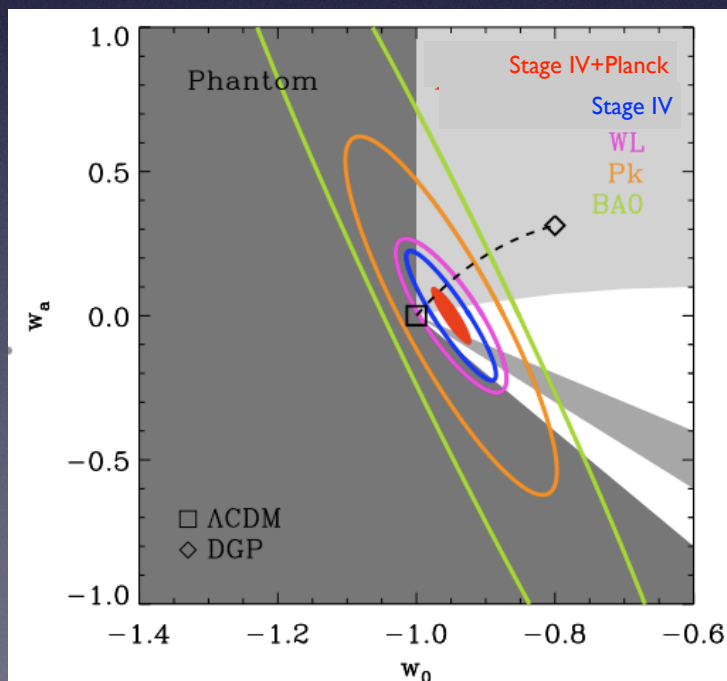
CMB		Planck, SPT, ACT, Keck
VIS/NIR	Imaging	VST, DES, Pan-STARRS, LSST Euclid, WFIRST, Subaru Boss, Wigglez, DESI, HETDEX
	Spectro	
Radio		LOFAR, GBT, Chimes, BINGO, GMRT, BAORadio, ASKAP, MeerKAT, SKA



Impact on Cosmology

Amara et al. 2008

	Δw_p	Δw_a	$\Delta \Omega_m$	$\Delta \Omega_\Lambda$	$\Delta \Omega_b$	$\Delta \sigma_8$	Δn_s	Δh	DE FoM
Current+WMAP	0.13	-	0.01	0.015	0.0015	0.026	0.013	0.013	~10
Planck	-	-	0.008	-	0.0007	0.05	0.005	0.007	-
Weak Lensing	0.03	0.17	0.006	0.04	0.012	0.013	0.02	0.1	180
Imaging Probes	0.018	0.15	0.004	0.02	0.007	0.0009	0.014	0.07	400
Stage IV	0.016	0.13	0.003	0.012	0.005	0.003	0.006	0.020	500
Stage IV+Planck	0.01	0.066	0.0008	0.003	0.0004	0.0015	0.003	0.002	1500
Factor Gain	13	>15	13	5	4	17	4	7	150



Stage IV Surveys will challenge all sectors of the cosmological model:

- **Dark Energy:** w_p and w_a with an error of 2% and 13% respectively (no prior)
 - **Dark Matter:** test of CDM paradigm, precision of 0.04eV on sum of neutrino masses (with Planck)
 - **Initial Conditions:** constrain shape of primordial power spectrum, primordial non-gaussianity
 - **Gravity:** test GR by reaching a precision of 2% on the growth exponent ($d \ln \sigma_8 / d \ln a_m$)
- Uncover new physics and map LSS at $0 < z < 2$:
Low redshift counterpart to CMB surveys

Integrated Probes

Probe Combination:

Usually done at last stage of analysis by combining likelihoods assuming they are independent

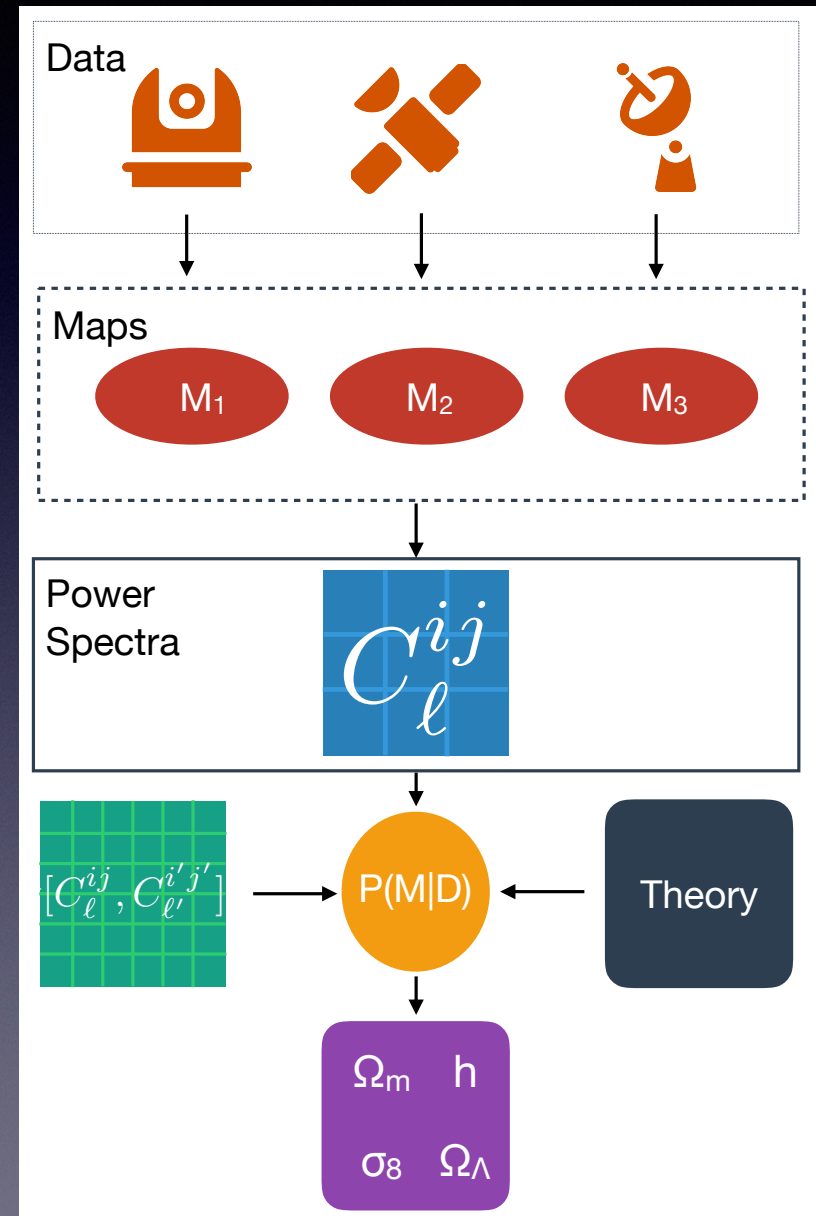
Integrated Approach:

Combine probes at early stage in common framework at the map level

Takes full account of correlation between probes

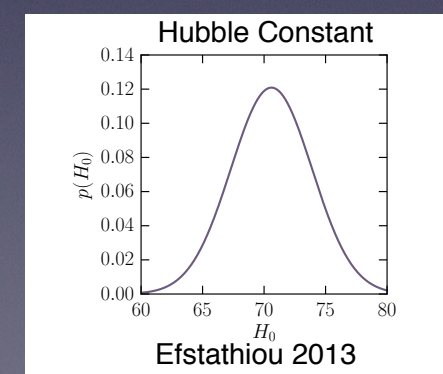
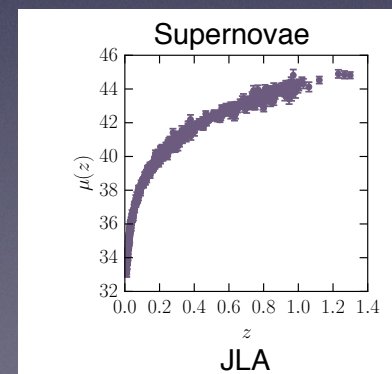
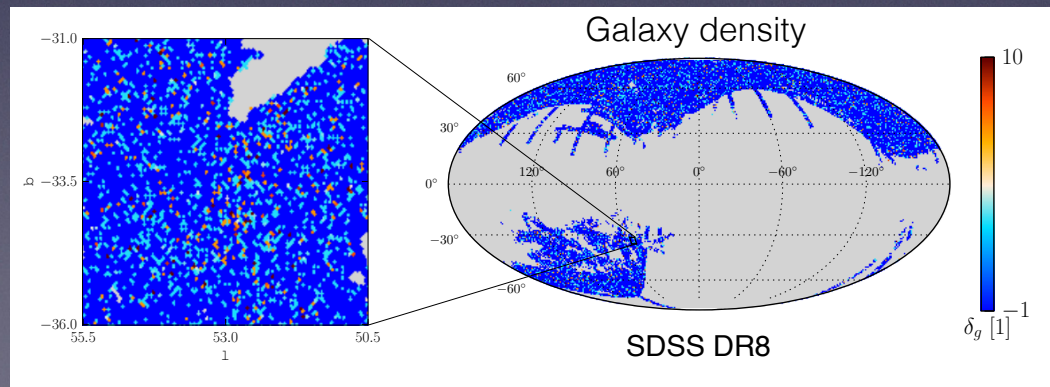
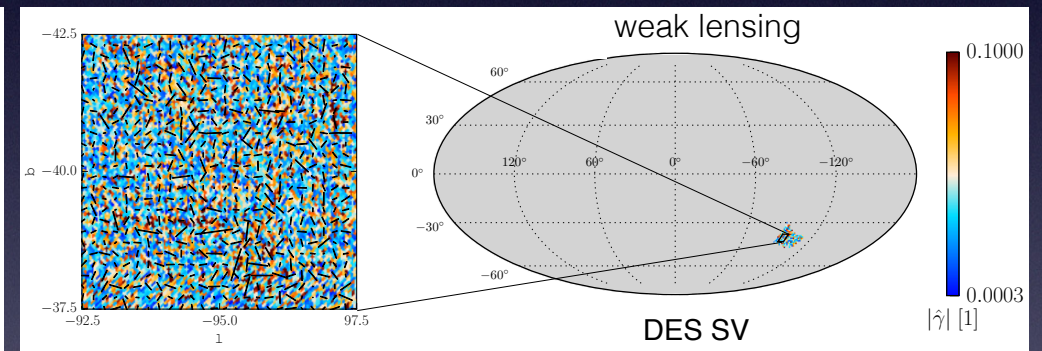
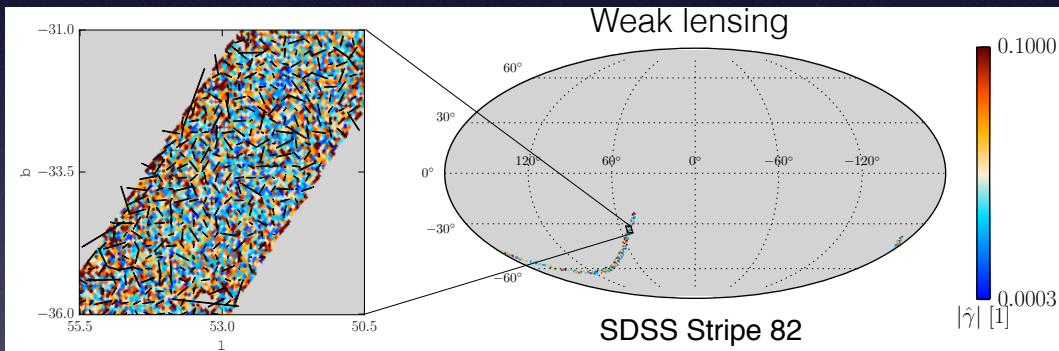
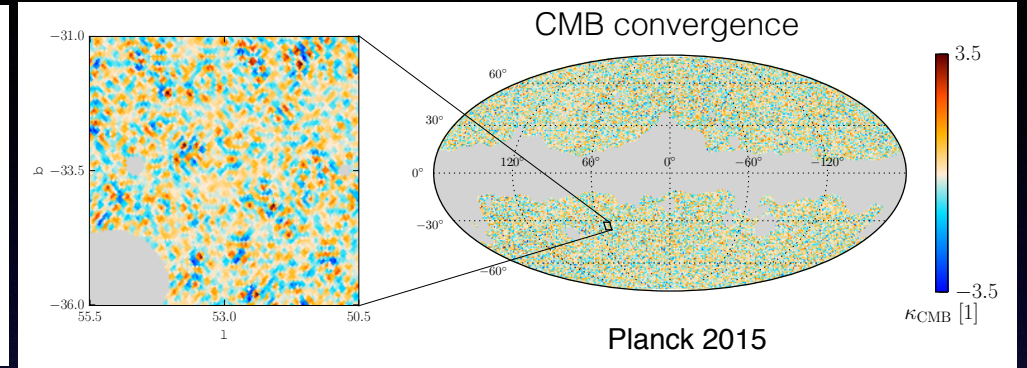
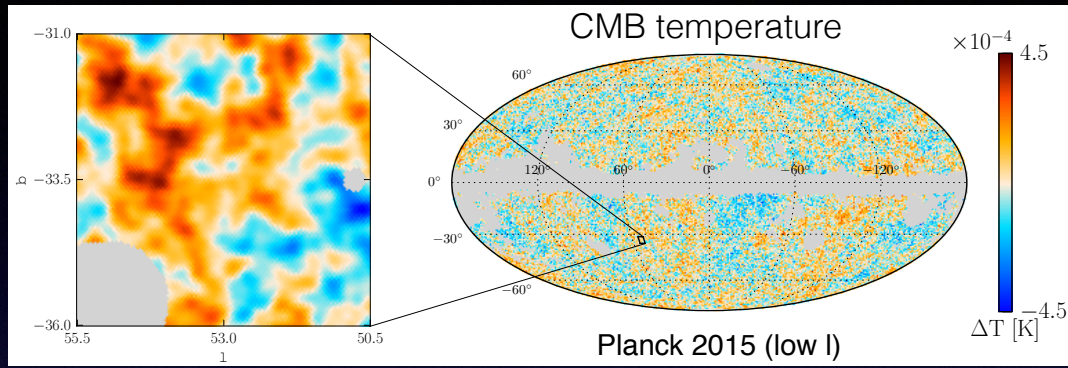
Provides test of systematics and of model

Nicola, Refregier & Amara, 2016a,b

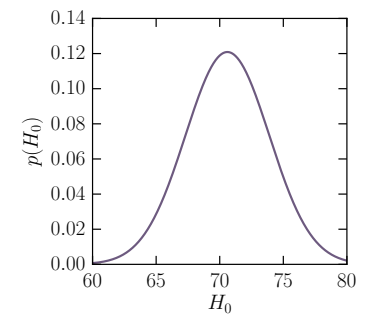
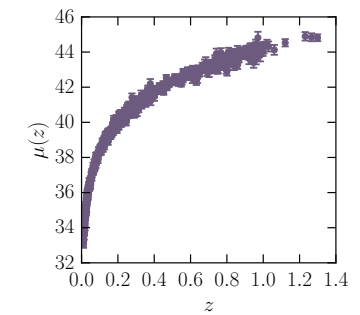
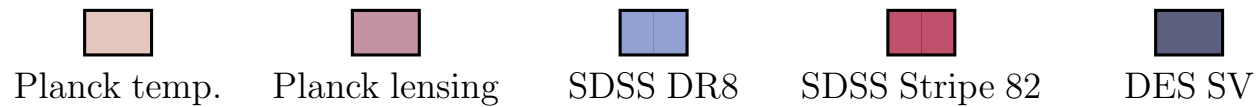
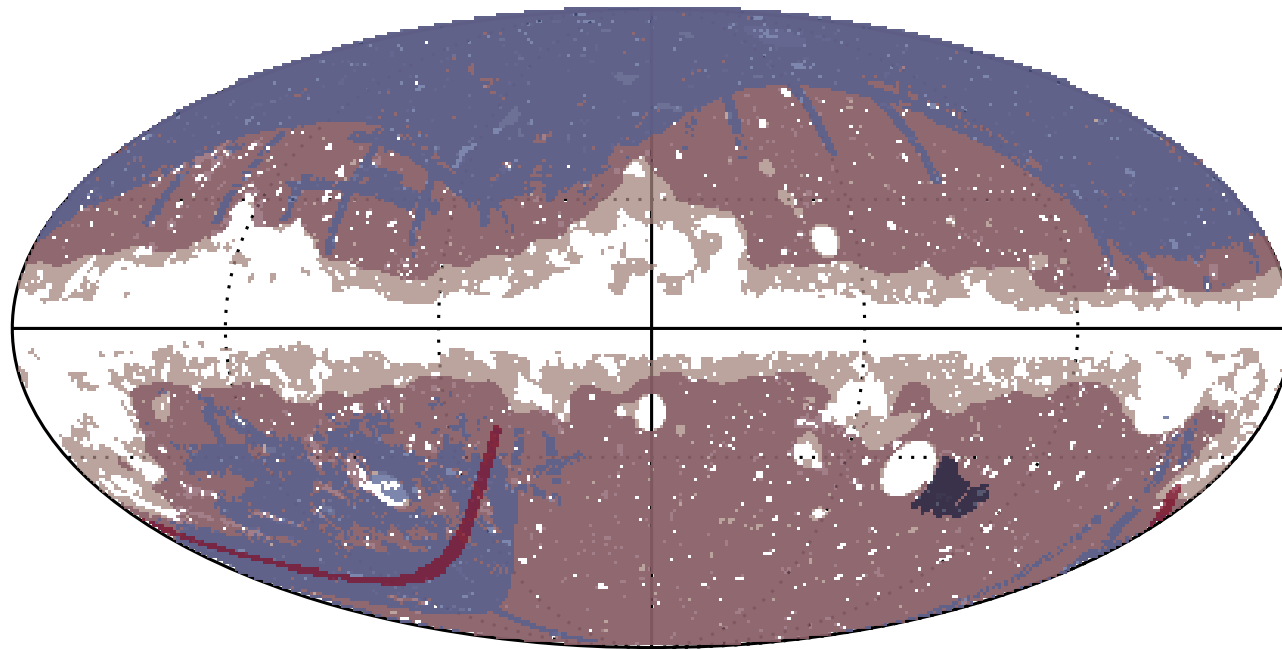


Implementation

Nicola, Refregier & Amara, 2016a,b; Nicola et al. 2017

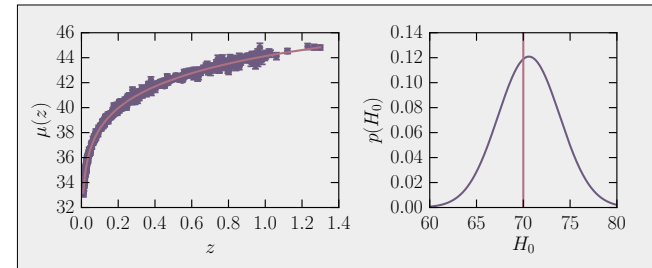
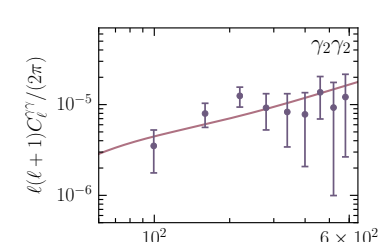
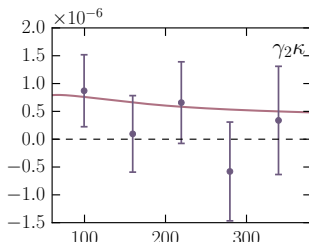
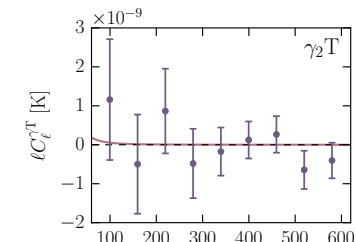
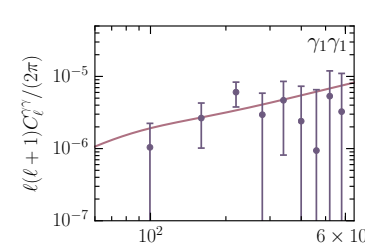
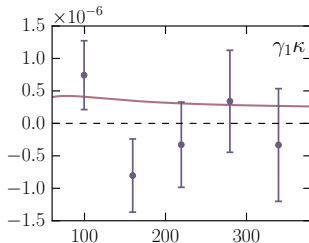
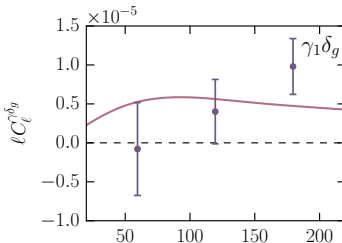
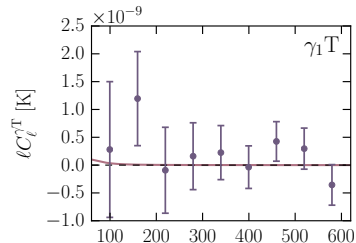
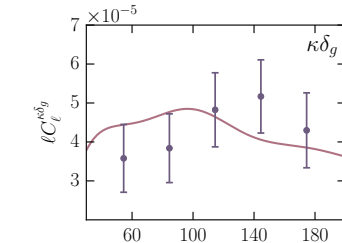
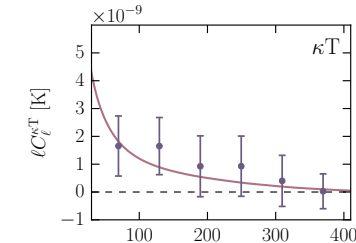
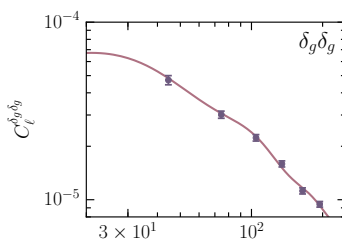
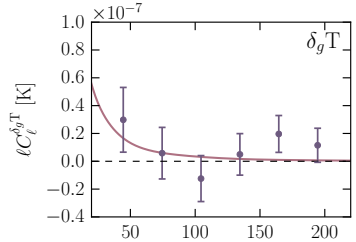
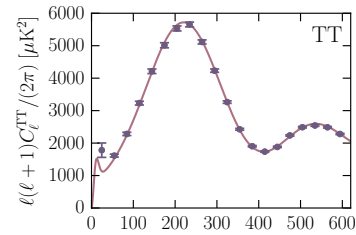


Survey Areas

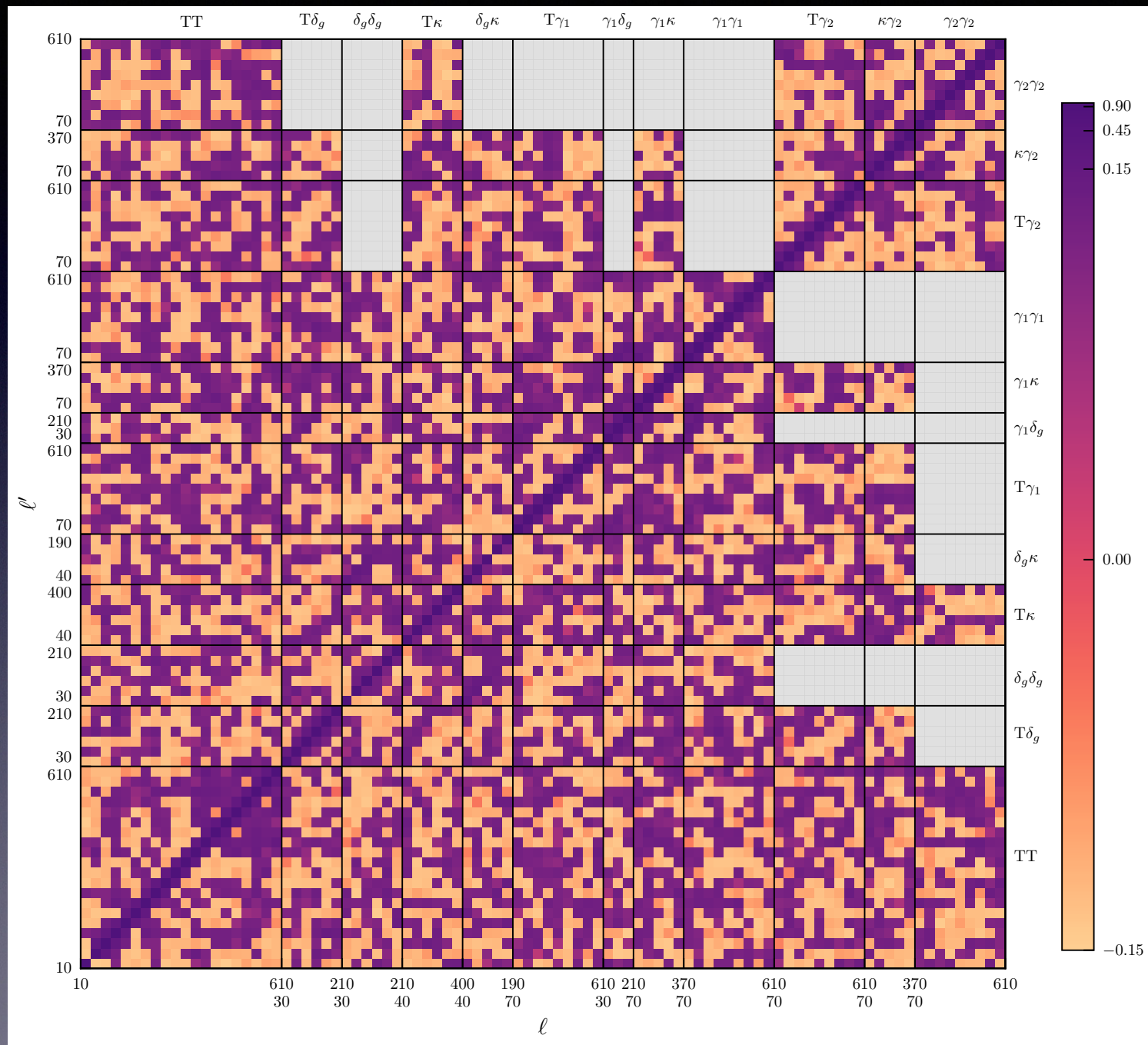


Power Spectra

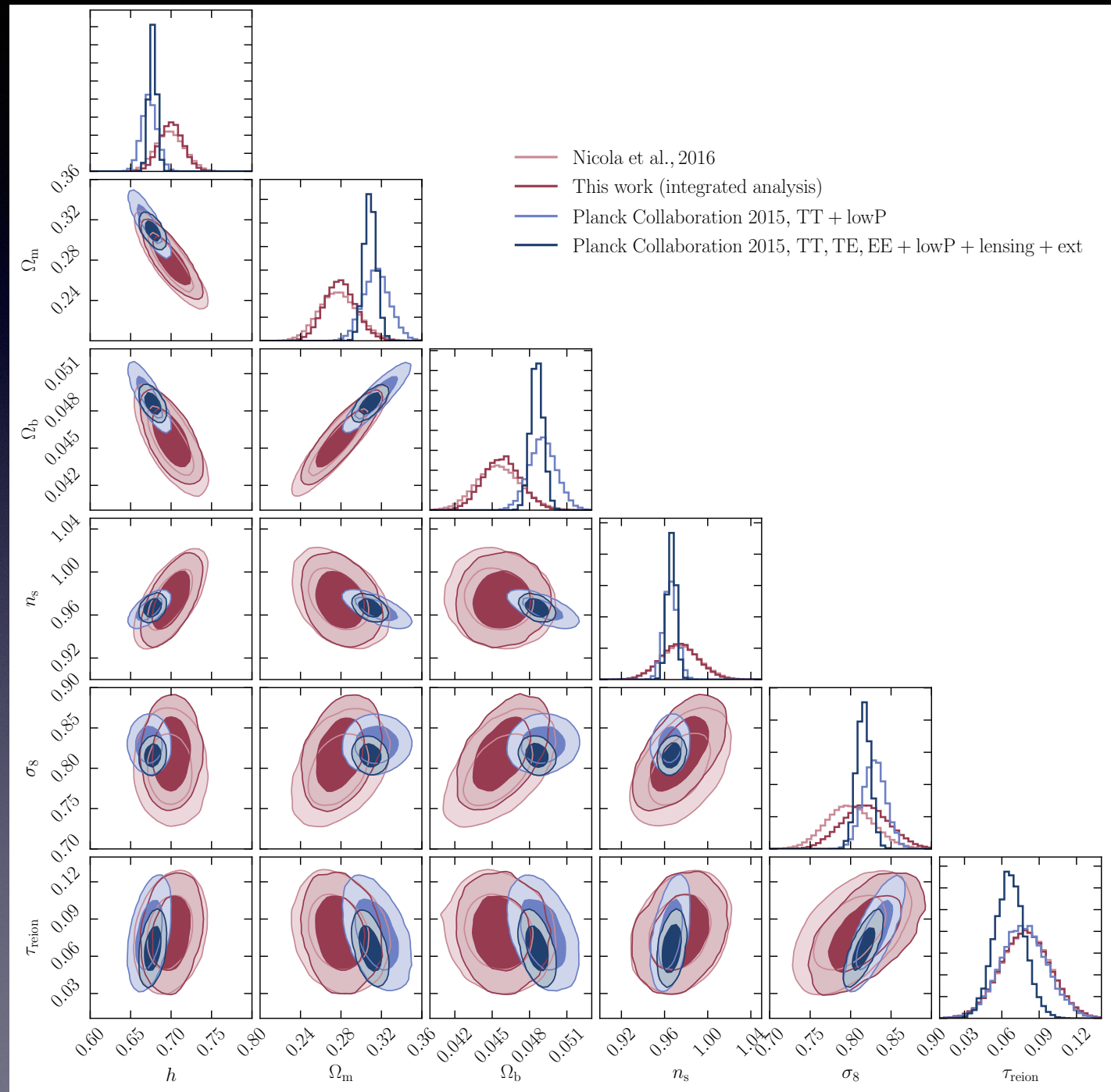
Nicola, Refregier & Amara, 2016a,b



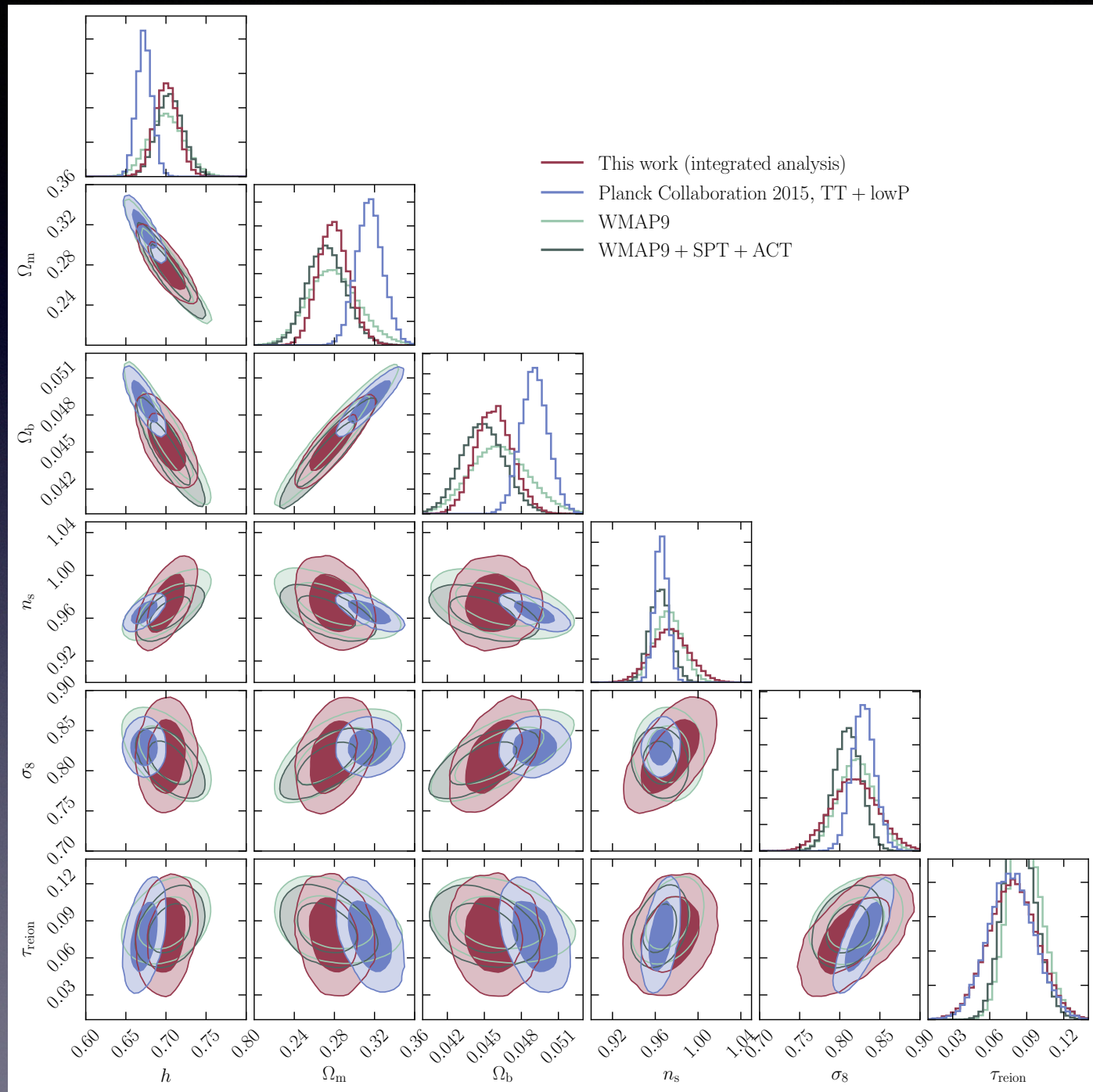
Covariance Matrix



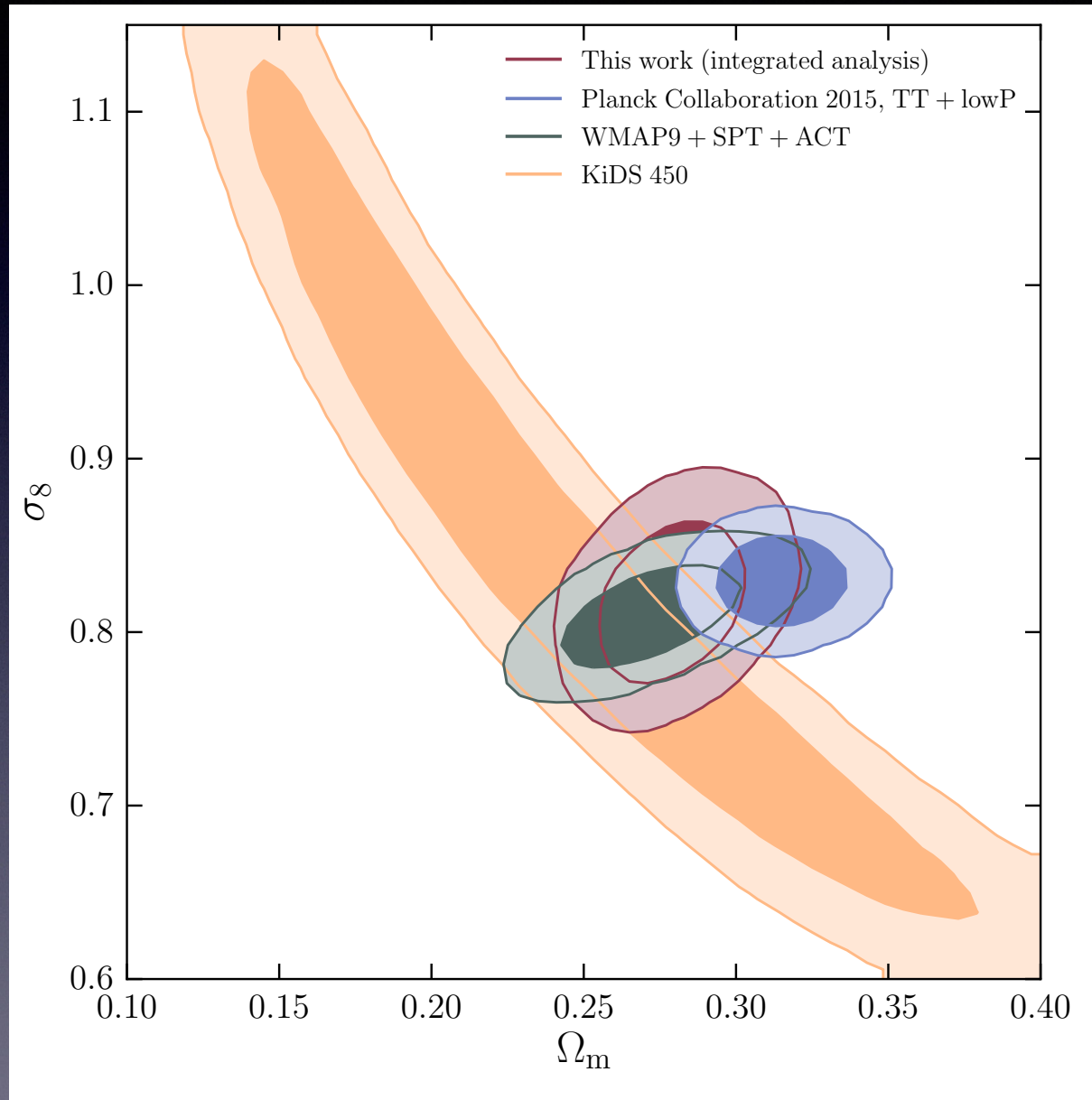
Cosmological Constraints



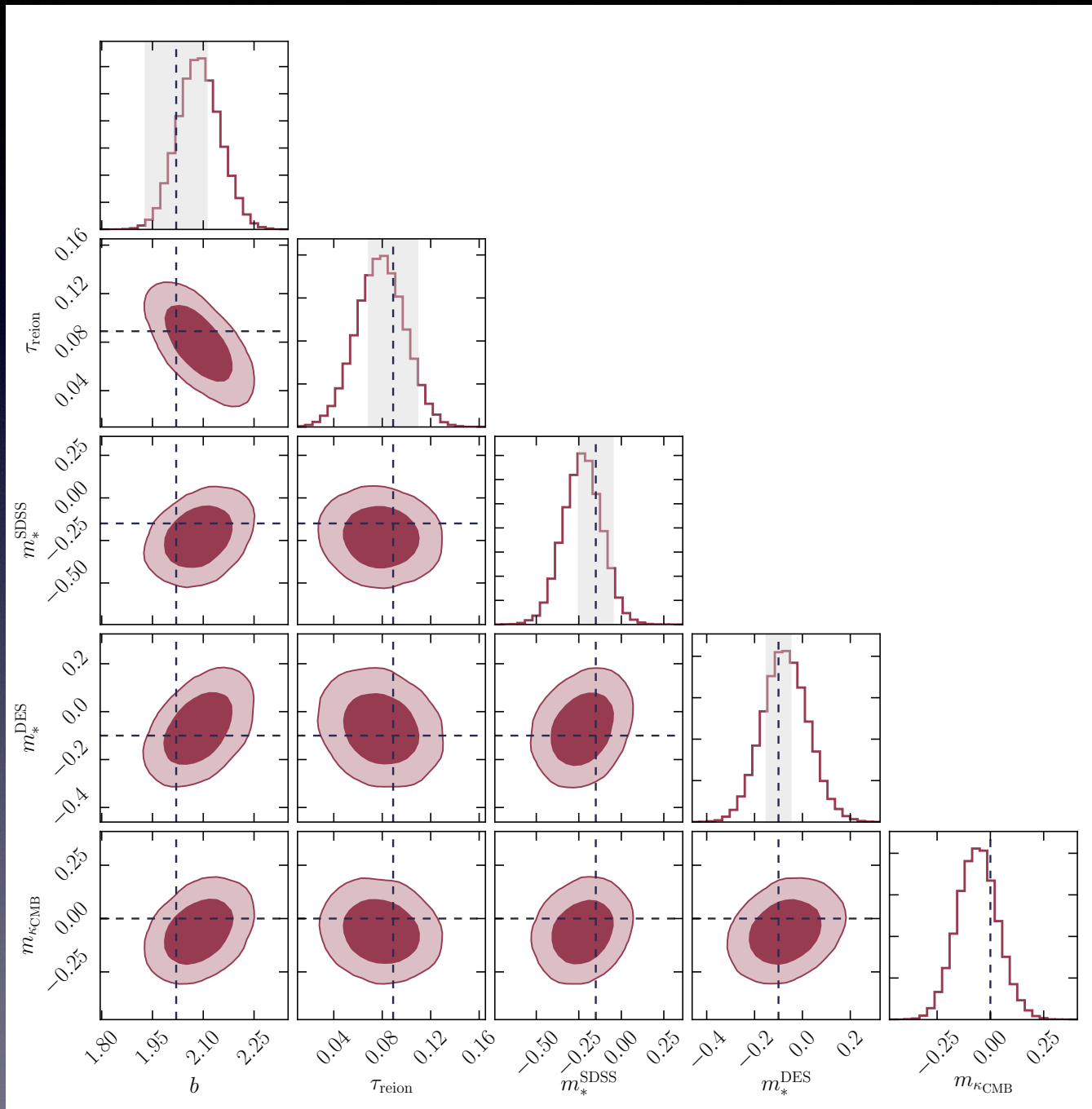
Cosmological Constraints



Power Spectrum Amplitude



Probe Calibrations



Conclusions

- ▶ Weak Lensing is a special probe of the dark universe and is undergoing rapid progress
- ▶ Integrated Cosmological probe approach takes full account of probe correlations, provides a stringent test of systematics and of cosmological model
- ▶ Upcoming Surveys will soon provide higher precision measurements for these different probes