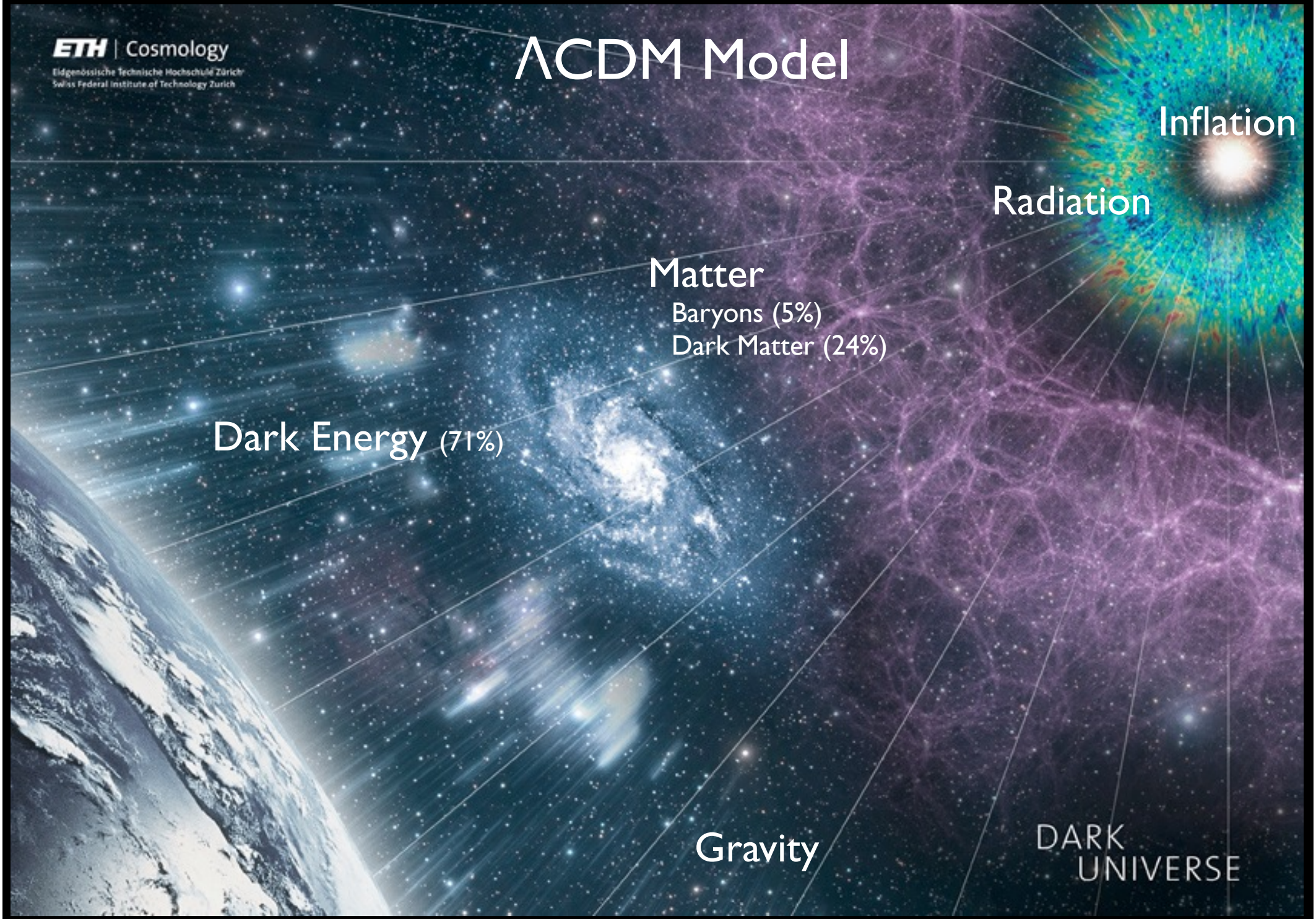
Integrated Approach to Cosmology

ETH Alexandre Refregier
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

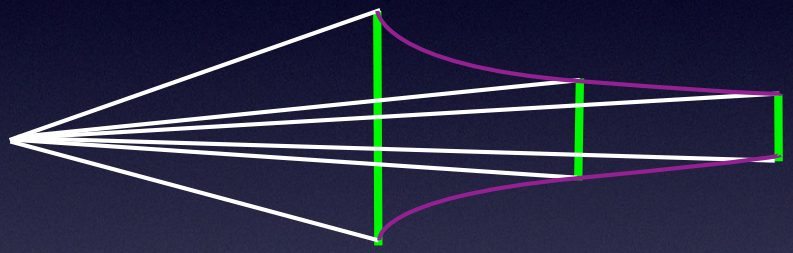
Collaborators: Andrina Nicola, Adam Amara (ETH)

TIFR
3.1.2017

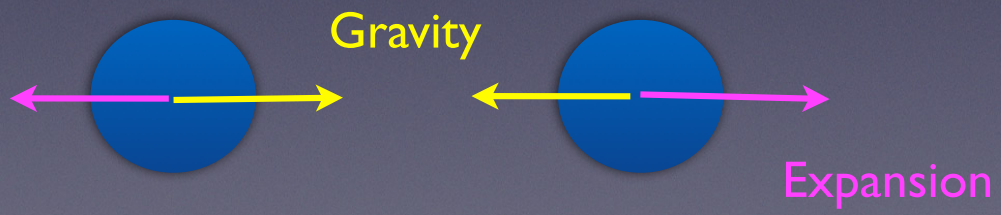

ETH | Cosmology
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
ΛCDM Model
Inflation
Radiation
Matter
Baryons (5%)
Dark Matter (24%)
Dark Energy (71%)
Gravity
DARK
UNIVERSE

Measuring the Dark Universe

- Geometry

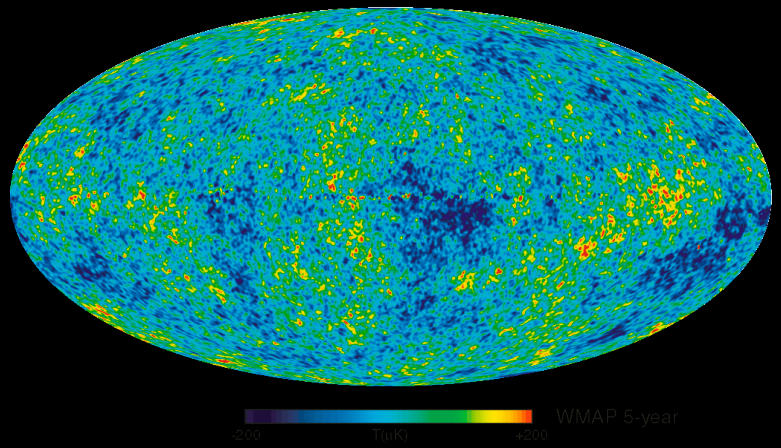


- Growth of structure

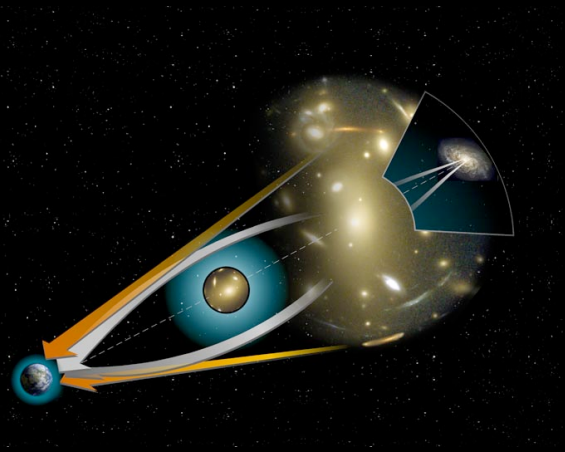


Cosmological Probes

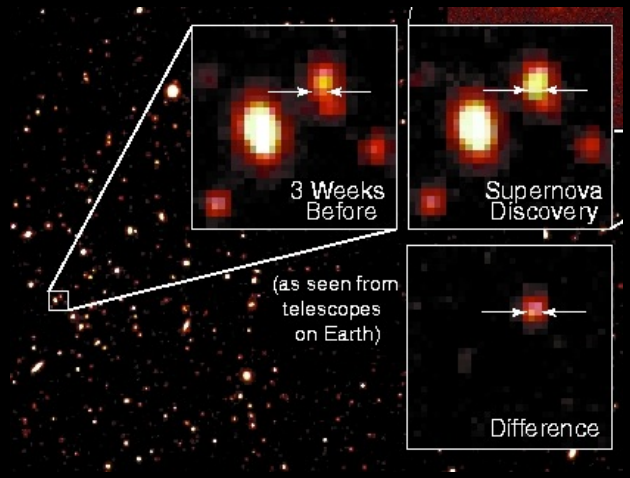
Cosmic Microwave Background



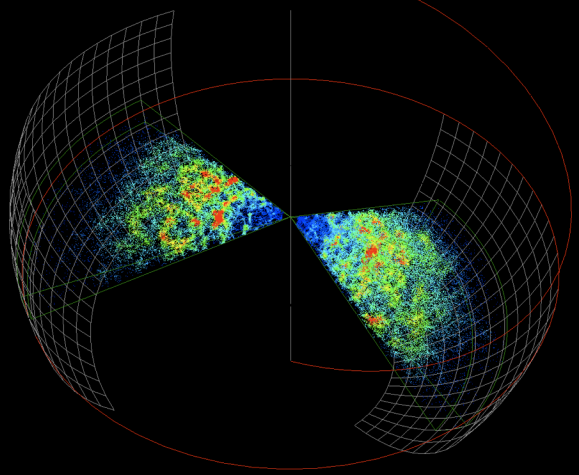
Gravitational Lensing



Supernovae



Galaxy Clustering (incl. Clusters)

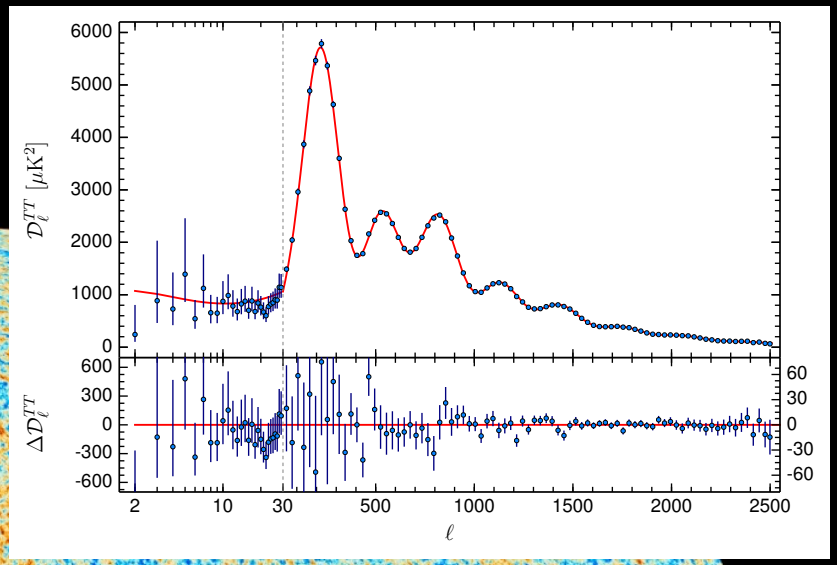


Cosmic Microwave Background

$T_{CMB} \approx 2.725K$

$\Delta T/T \sim 10^{-4}$

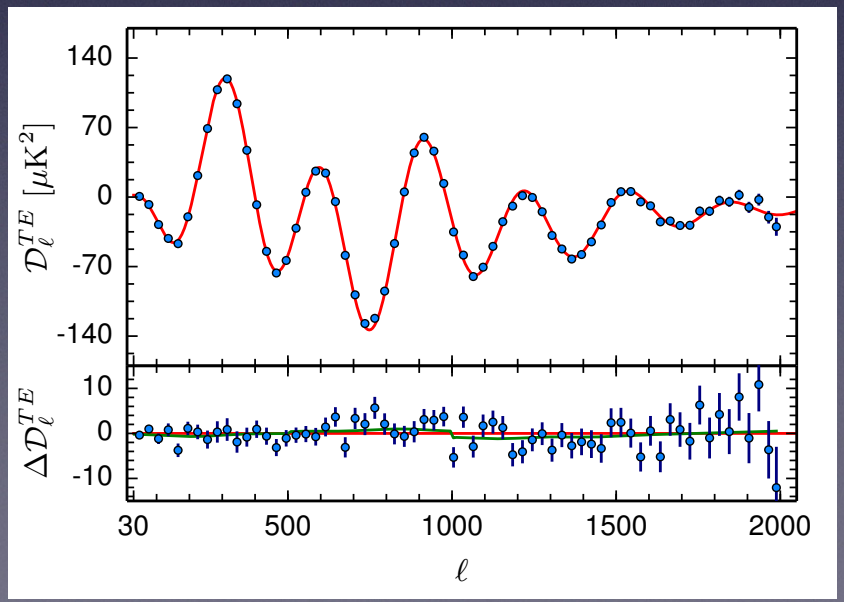
Planck collab. 2015

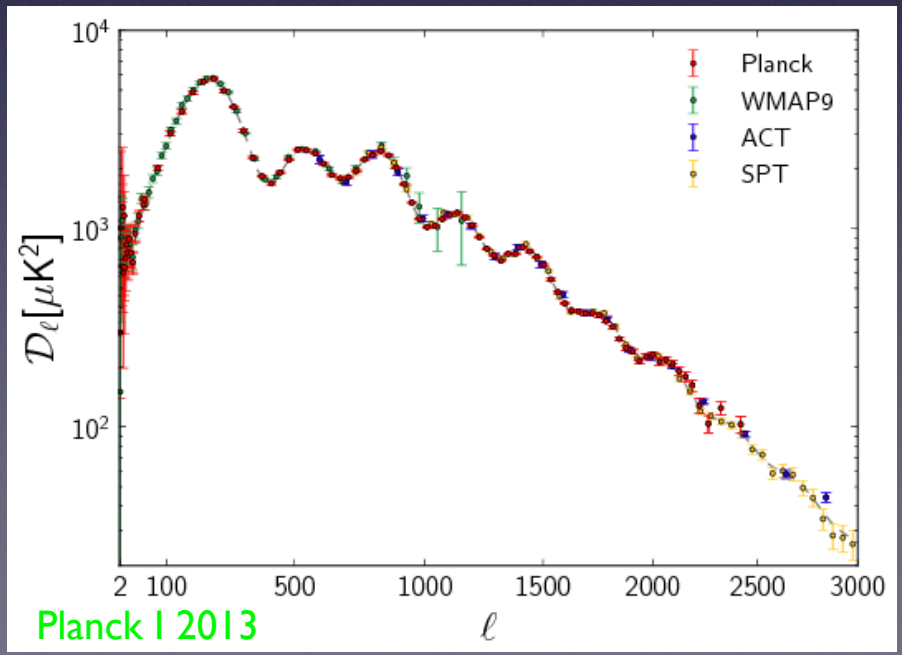


Planck 2015

Parameter	TT+lowP 68 % limits	TT+lowP+lensing 68 % limits	TT+lowP+lensing+ext 68 % limits	TT,TE,EE+lowP 68 % limits	TT,TE,EE+lowP+lensing 68 % limits	TT,TE,EE+lowP+lensing+ext 68 % limits
$\Omega_b h^2$	0.02222 ± 0.00023	0.02226 ± 0.00023	0.02227 ± 0.00020	0.02225 ± 0.00016	0.02226 ± 0.00016	0.02230 ± 0.00014
$\Omega_c h^2$	0.1197 ± 0.0022	0.1186 ± 0.0020	0.1184 ± 0.0012	0.1198 ± 0.0015	0.1193 ± 0.0014	0.1188 ± 0.0010
$100\theta_{MC}$	1.04085 ± 0.00047	1.04103 ± 0.00046	1.04106 ± 0.00041	1.04077 ± 0.00032	1.04087 ± 0.00032	1.04093 ± 0.00030
τ	0.078 ± 0.019	0.066 ± 0.016	0.067 ± 0.013	0.079 ± 0.017	0.063 ± 0.014	0.066 ± 0.012
$\ln(10^{10} A_s)$	3.089 ± 0.036	3.062 ± 0.029	3.064 ± 0.024	3.094 ± 0.034	3.059 ± 0.025	3.064 ± 0.023
n_s	0.9655 ± 0.0062	0.9677 ± 0.0060	0.9681 ± 0.0044	0.9645 ± 0.0049	0.9653 ± 0.0048	0.9667 ± 0.0040
H_0	67.31 ± 0.96	67.81 ± 0.92	67.90 ± 0.55	67.27 ± 0.66	67.51 ± 0.64	67.74 ± 0.46
Ω_Λ	0.685 ± 0.013	0.692 ± 0.012	0.6935 ± 0.0072	0.6844 ± 0.0091	0.6879 ± 0.0087	0.6911 ± 0.0062
Ω_m	0.315 ± 0.013	0.308 ± 0.012	0.3065 ± 0.0072	0.3156 ± 0.0091	0.3121 ± 0.0087	0.3089 ± 0.0062
σ_8	0.829 ± 0.014	0.8149 ± 0.0093	0.8154 ± 0.0090	0.831 ± 0.013	0.8150 ± 0.0087	0.8159 ± 0.0086
z_{re}	$9.9^{+1.8}_{-1.6}$	$8.8^{+1.7}_{-1.4}$	$8.9^{+1.3}_{-1.2}$	$10.0^{+1.7}_{-1.5}$	$8.5^{+1.4}_{-1.2}$	$8.8^{+1.2}_{-1.1}$

Planck XIII 2015

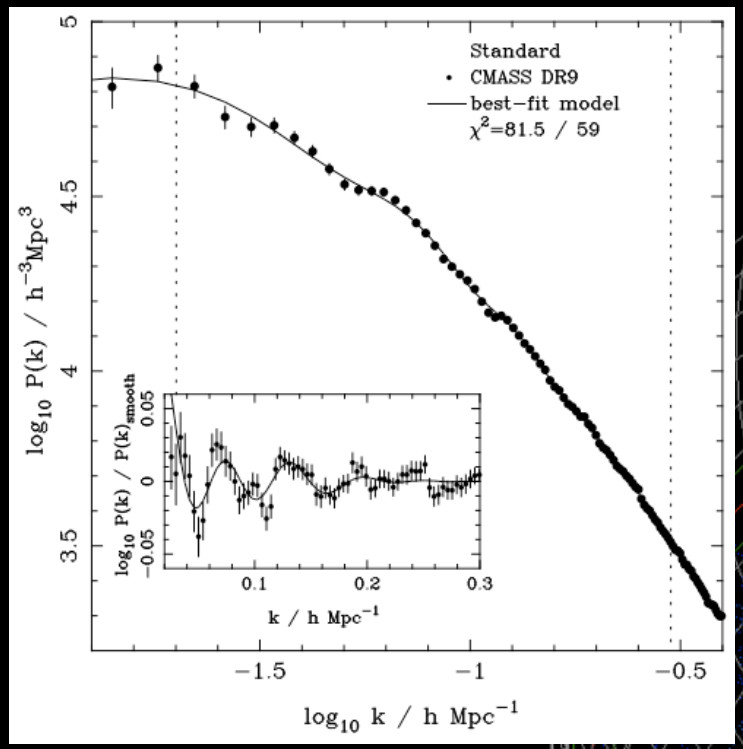


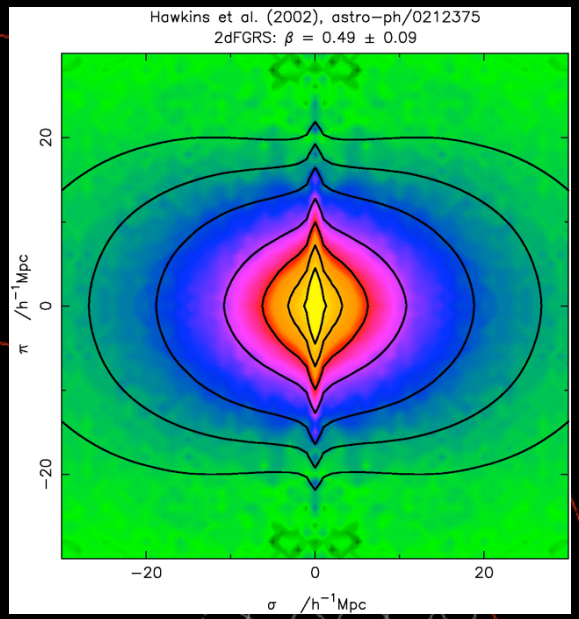


Planck I 2013

Galaxy Redshift Surveys

Anderson et al. 2012

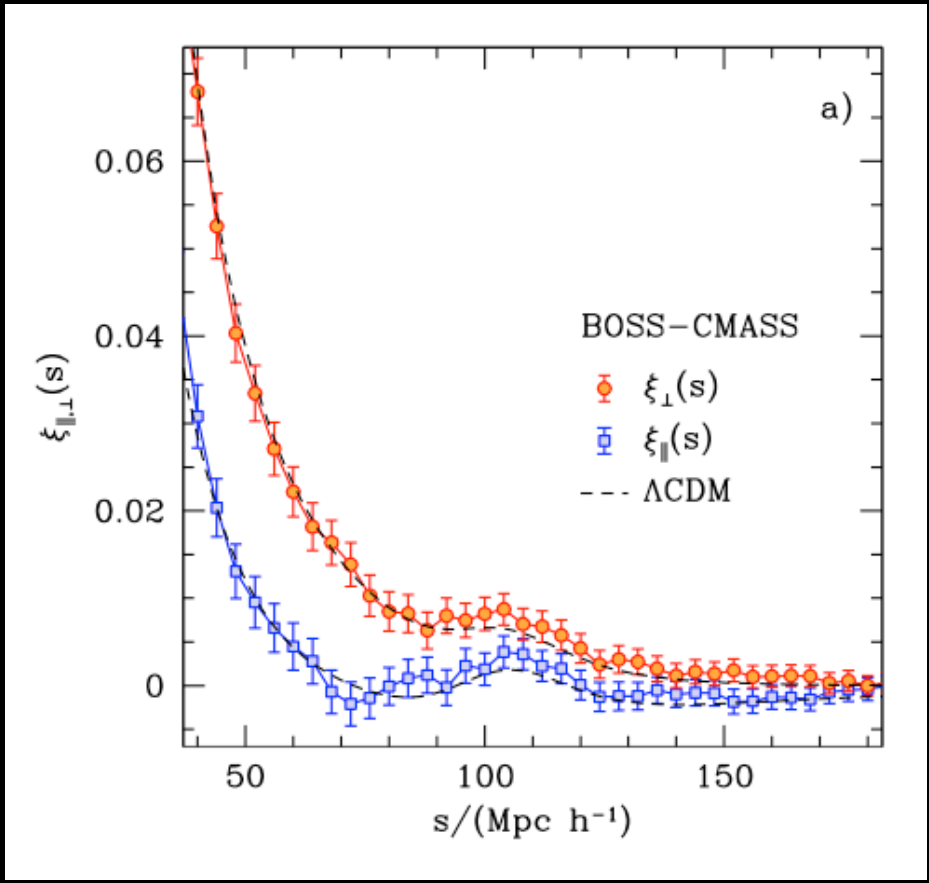


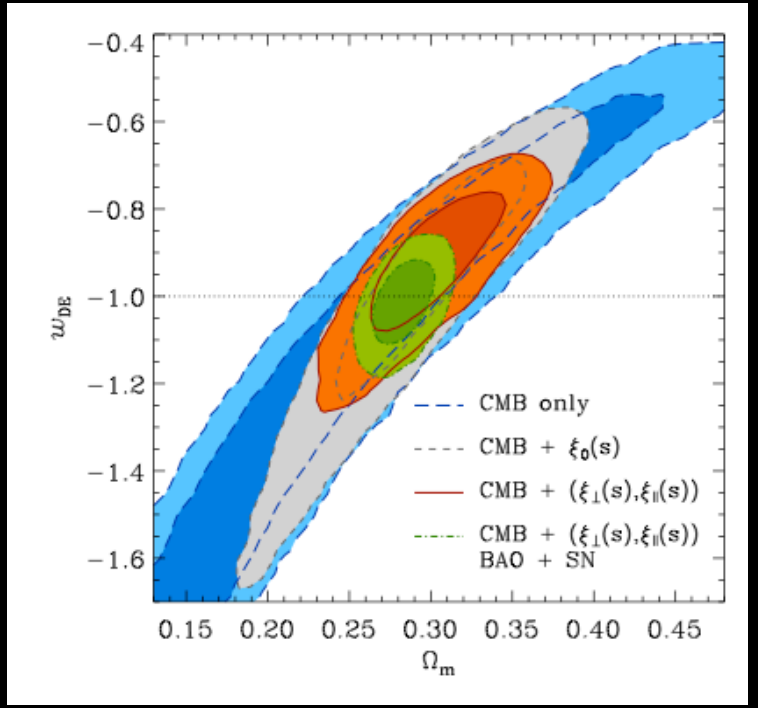


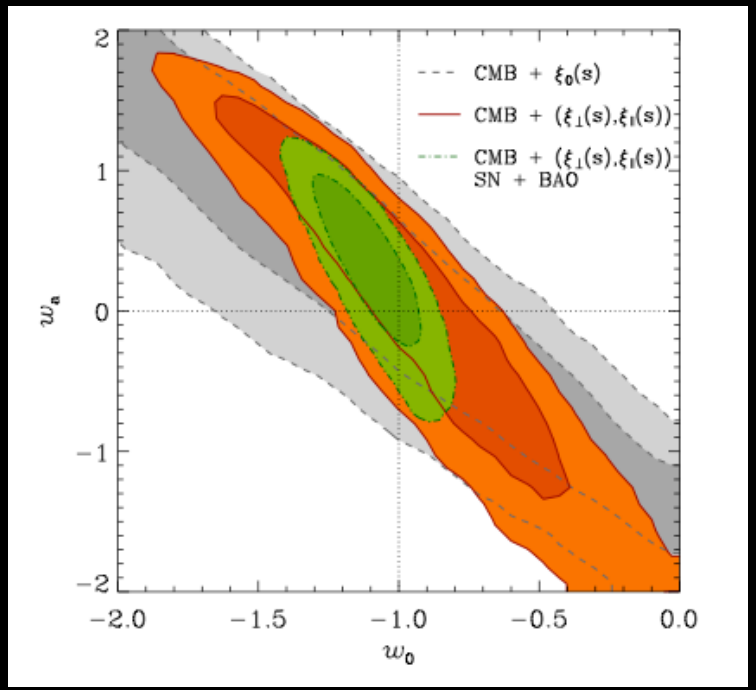
SDSS survey:
Eisenstein et al. 2004
2dF survey:
Percival et al 2004

BOSS

Sánchez et al. 2013





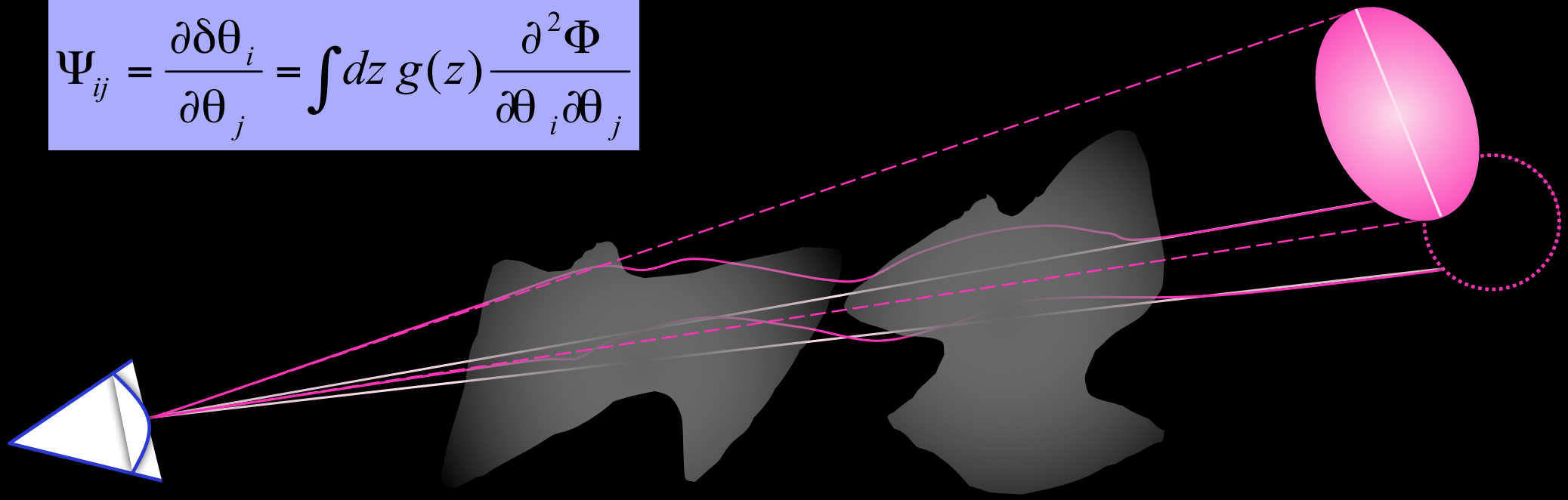


Weak Gravitational Lensing

Massey et al.
review: Refregier 2003

Distortion matrix:

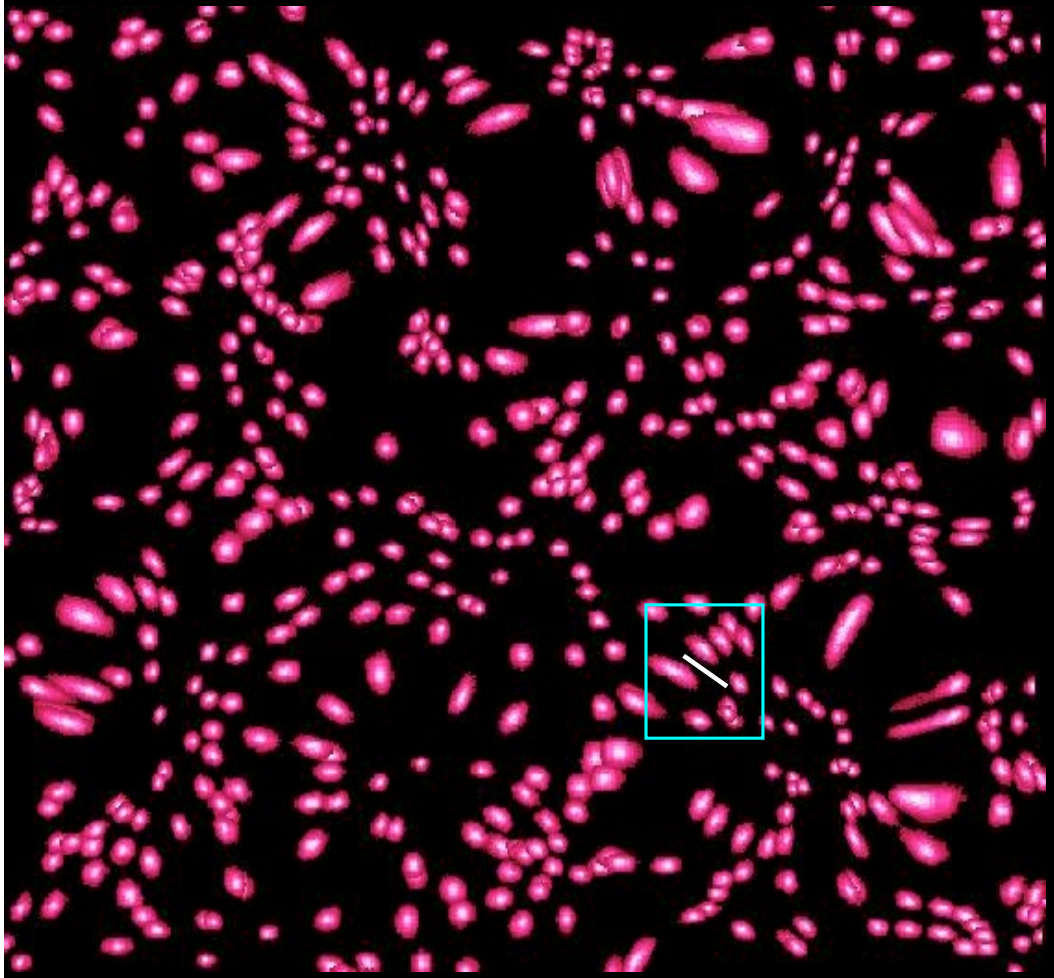
$$\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$$



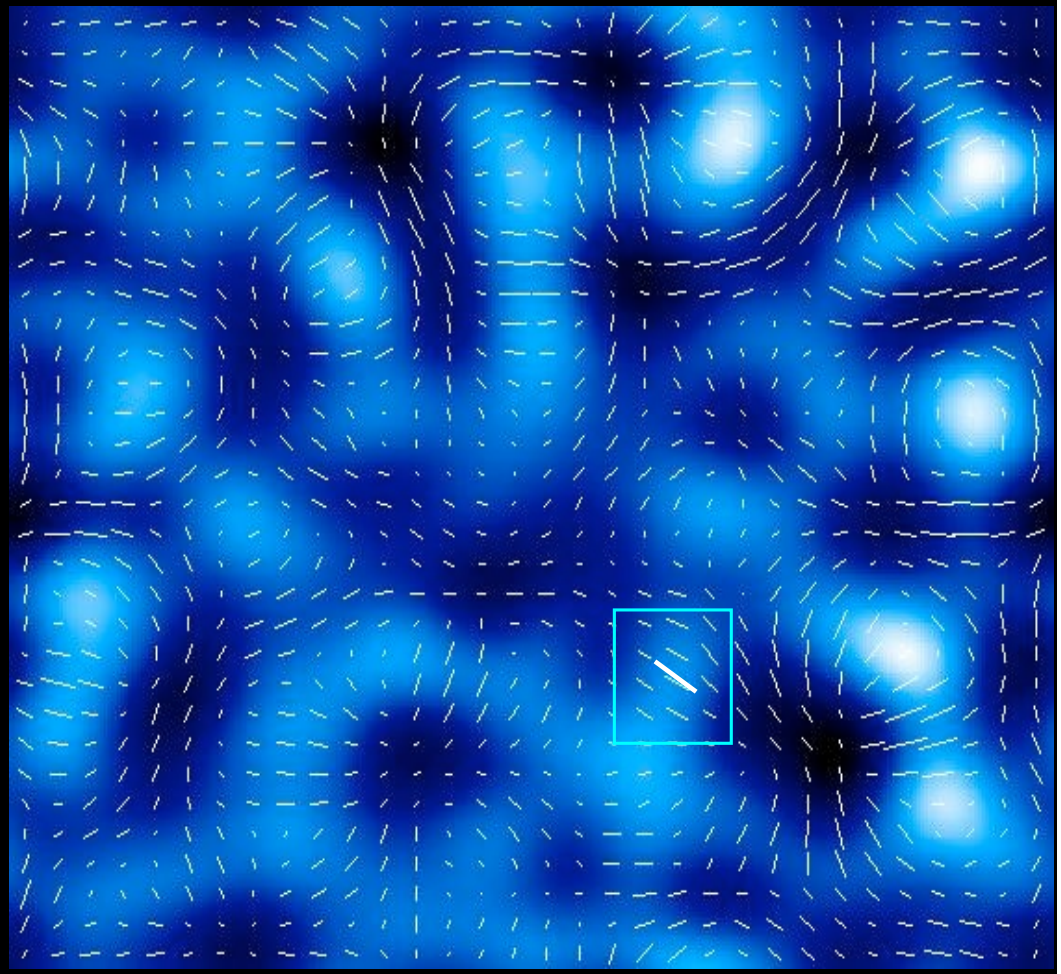
Theory

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

Weak Lensing Shear Measurement



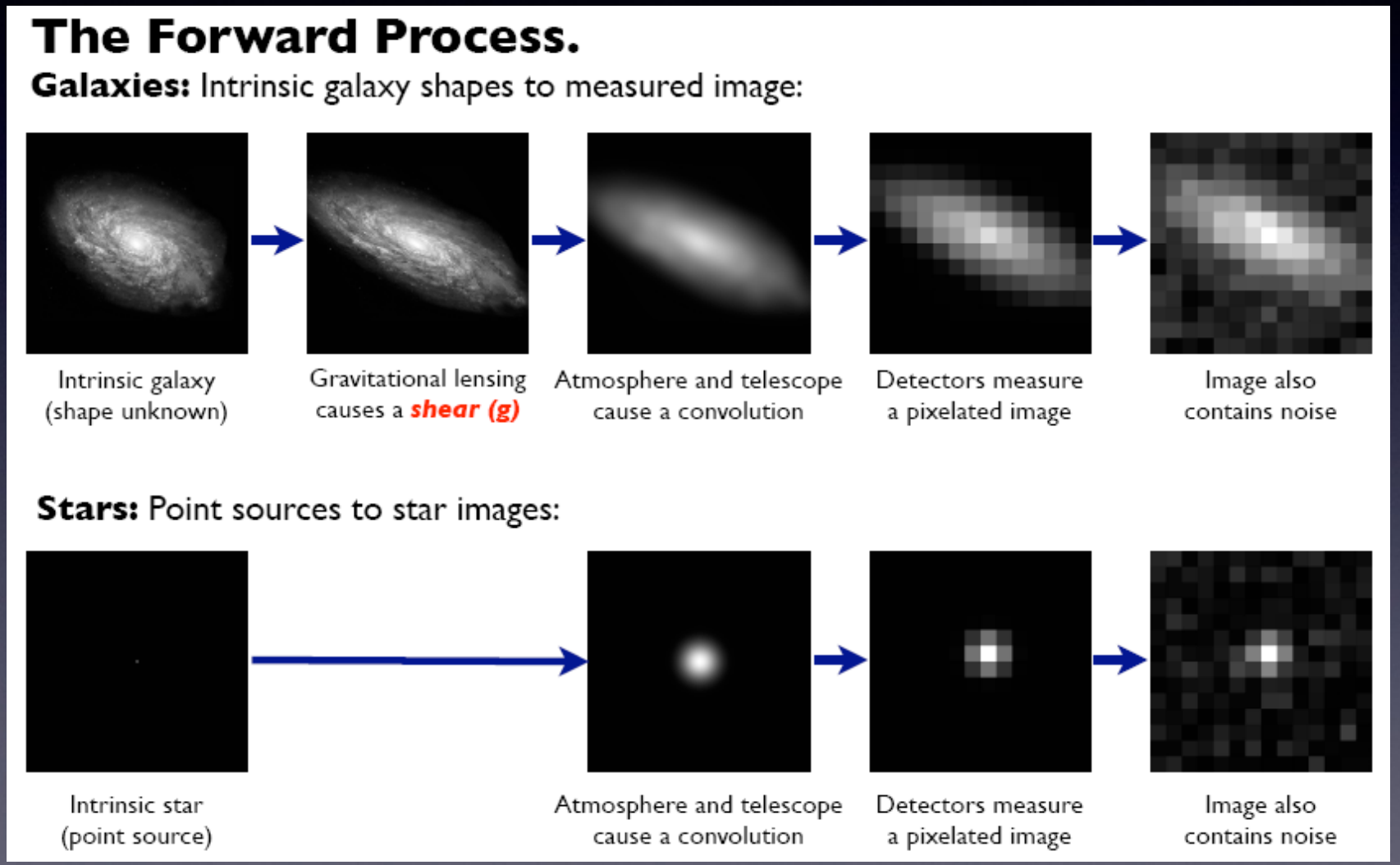
lensed background galaxies



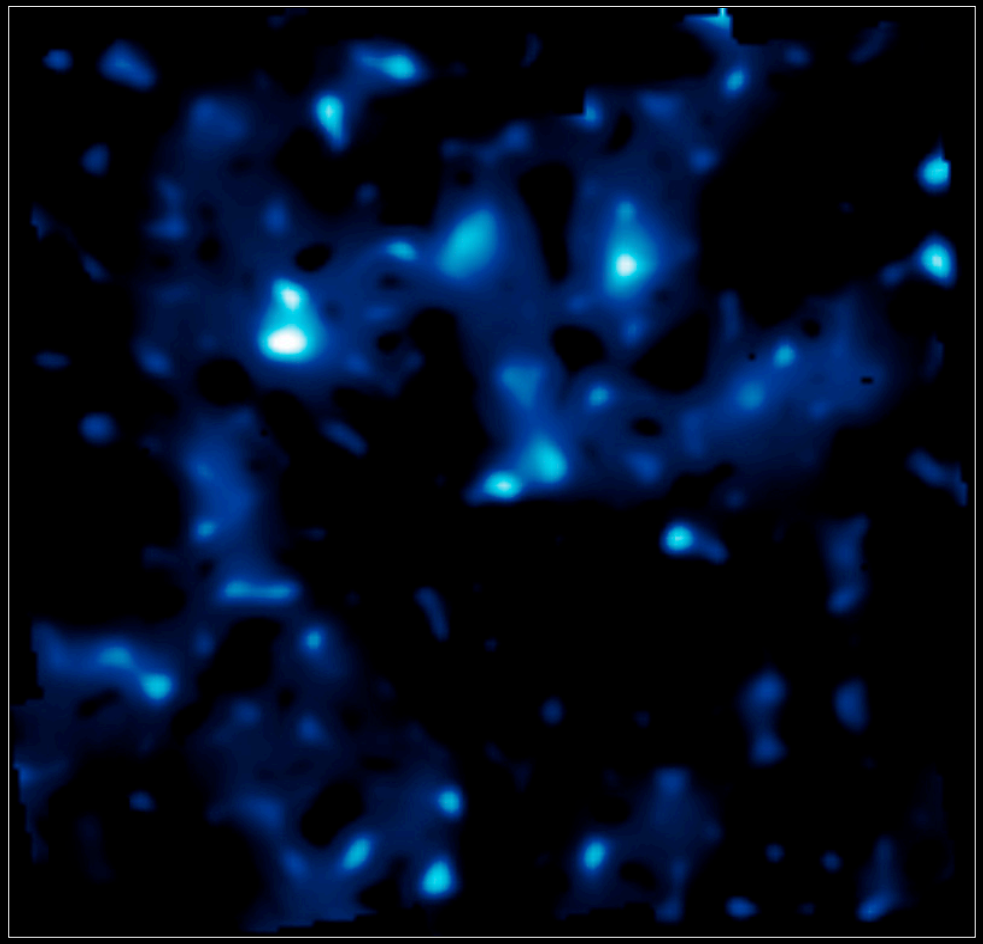
mass and shear distribution

Shear Measurement Problem

GREAT08 handbook, Bridle et al 08



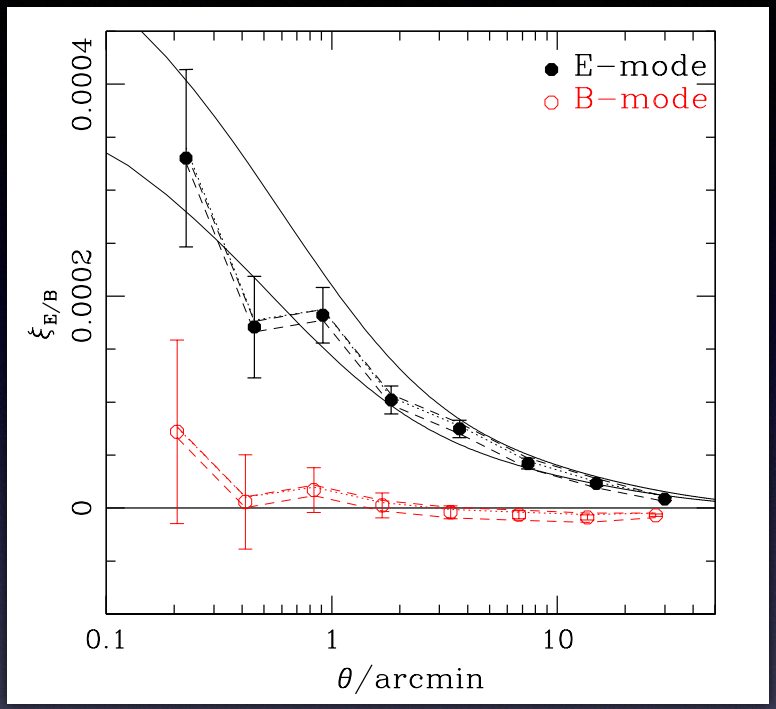
COSMOS Dark Matter Map

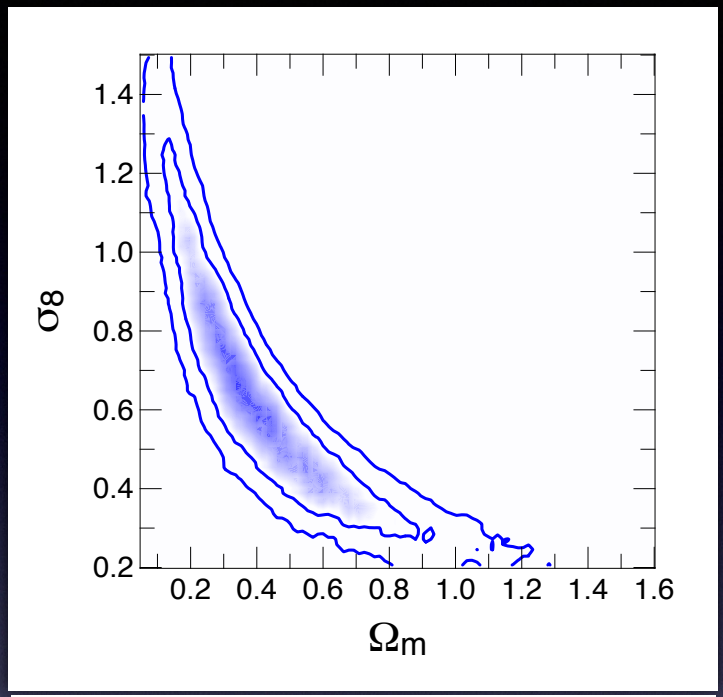


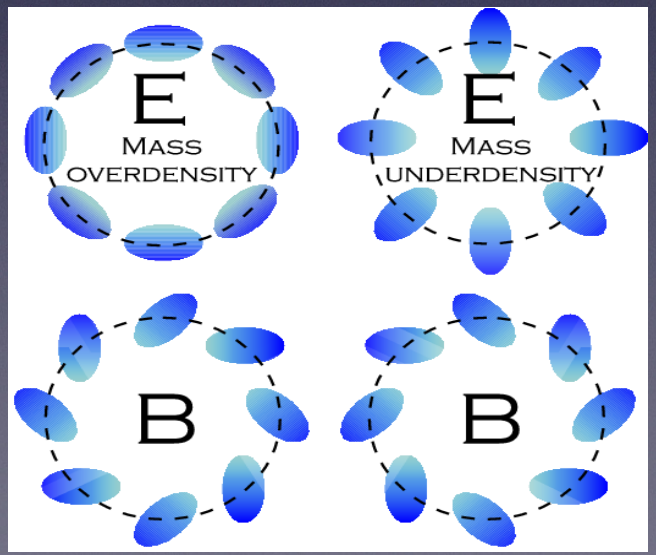
COSMOS HST
ACS survey
2 deg^2
Massey et al.
2006, Nature

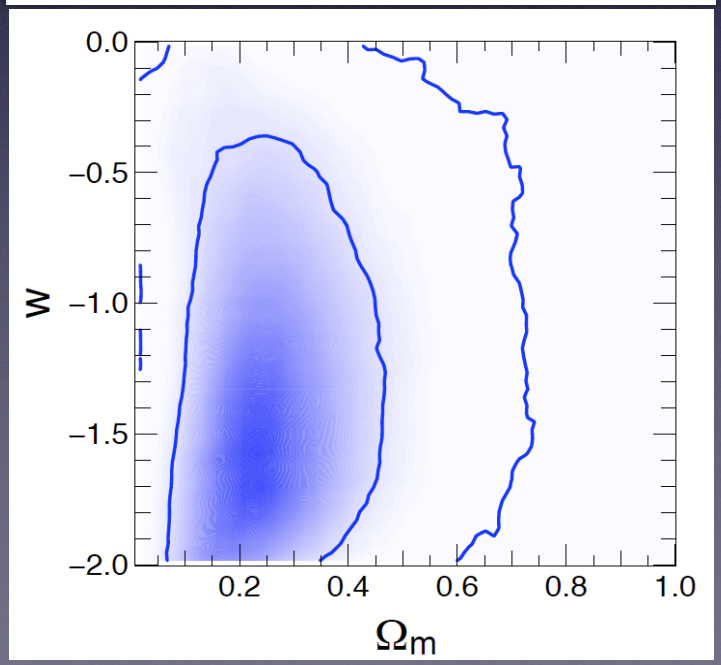
COSMOS

Schrabback et al. 2010



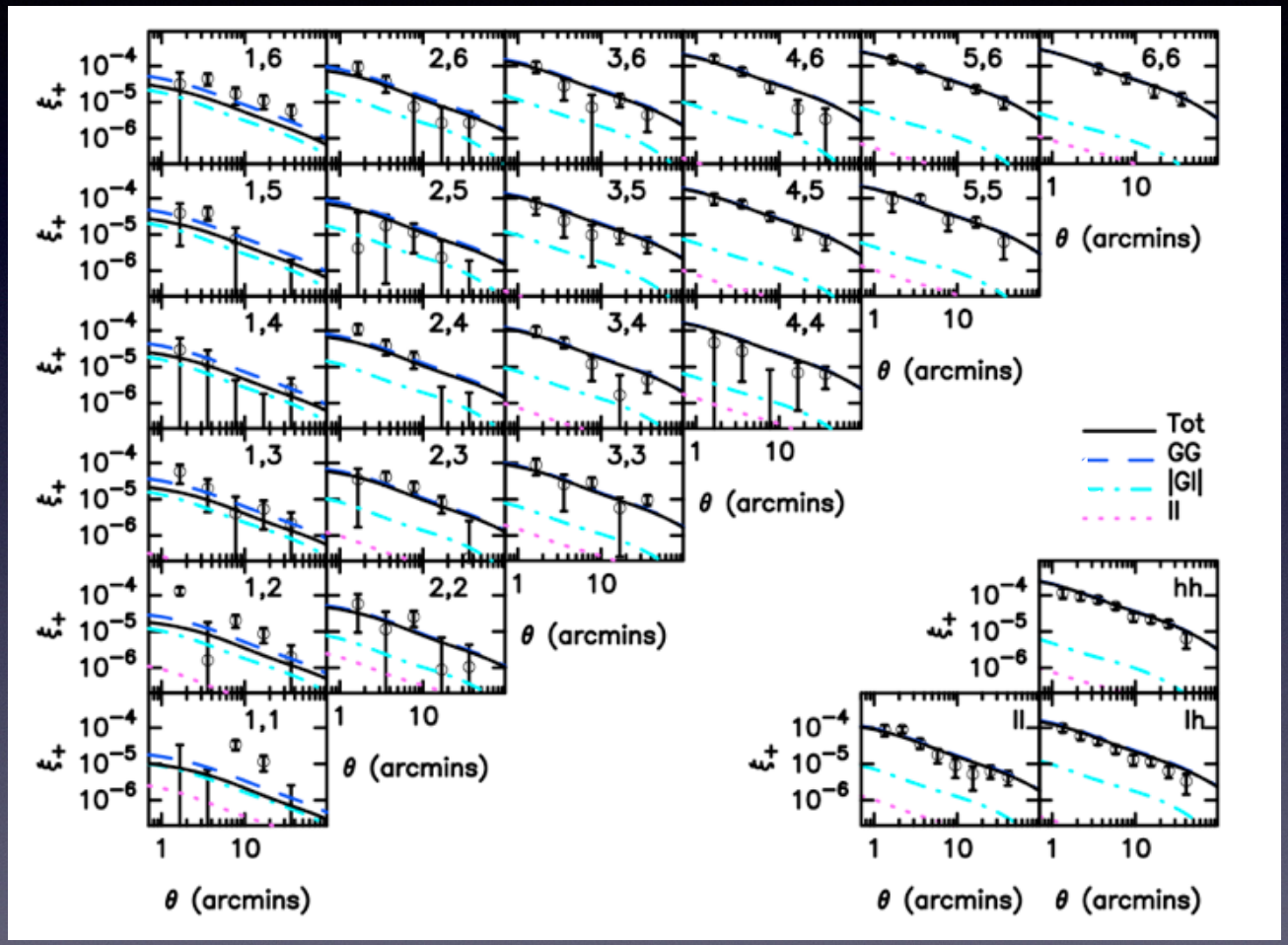


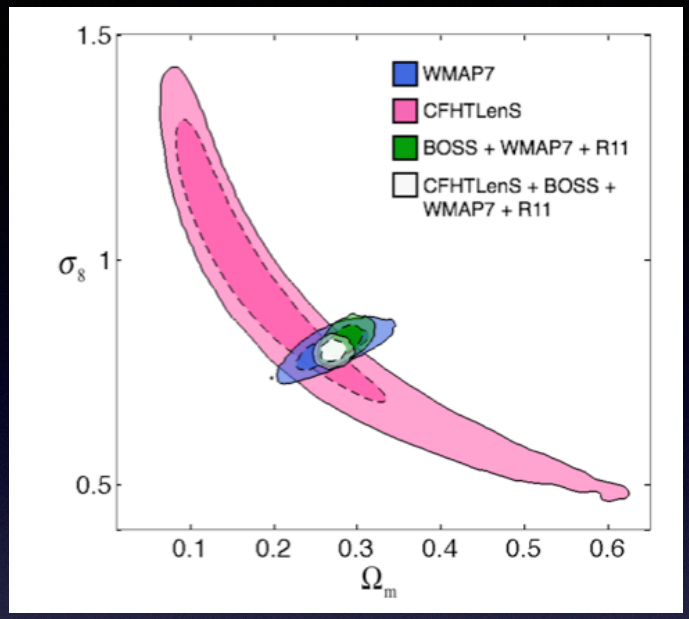


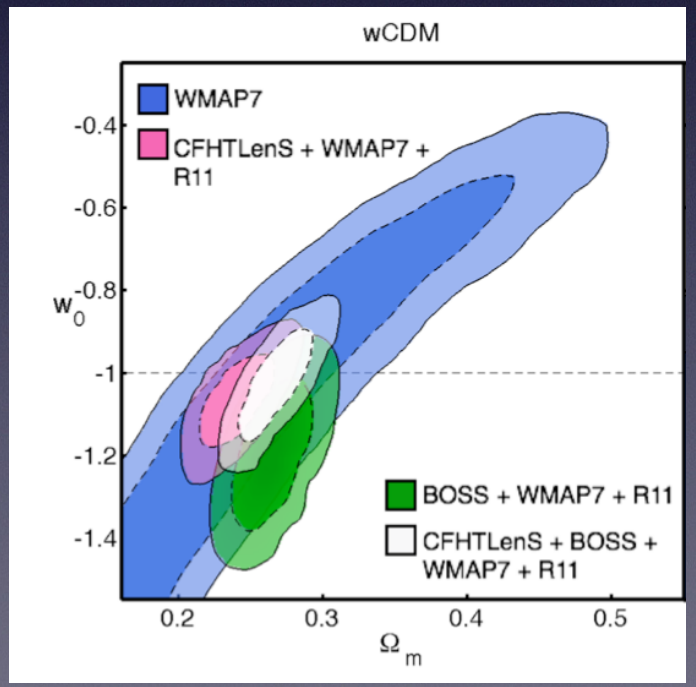


CFHTLenS

Heymans et al. 2013



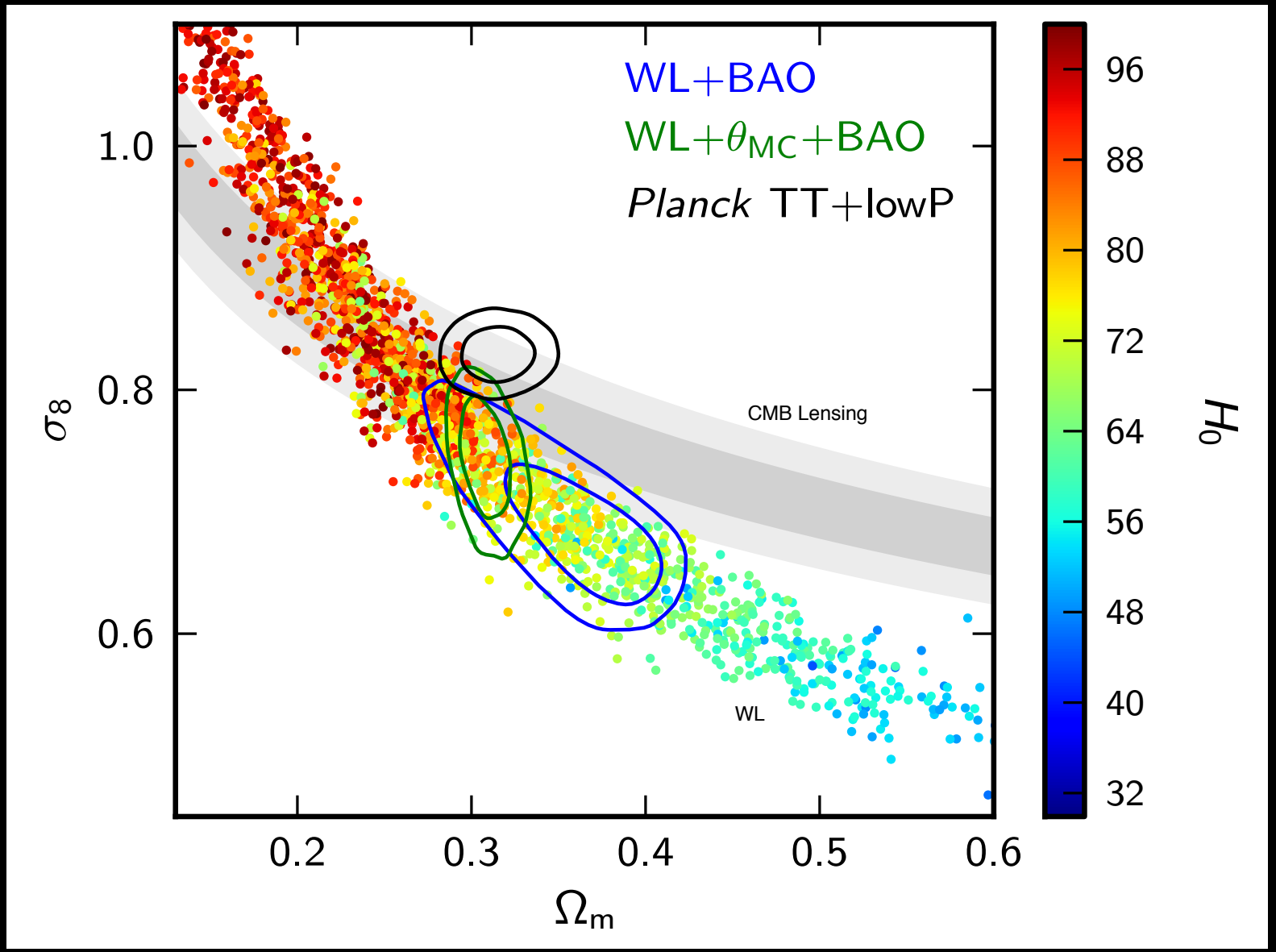




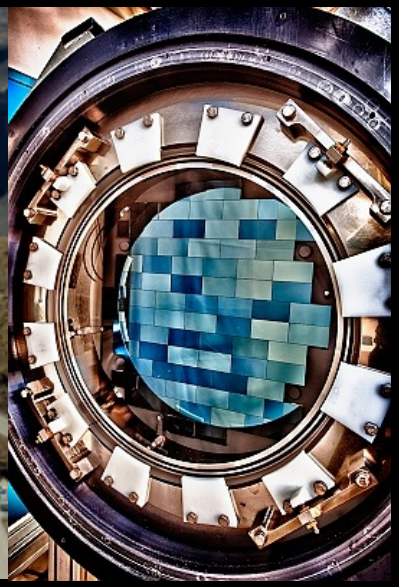
154 sq. deg., median z~0.7

Power Spectrum Amplitude

Planck XIII 2015

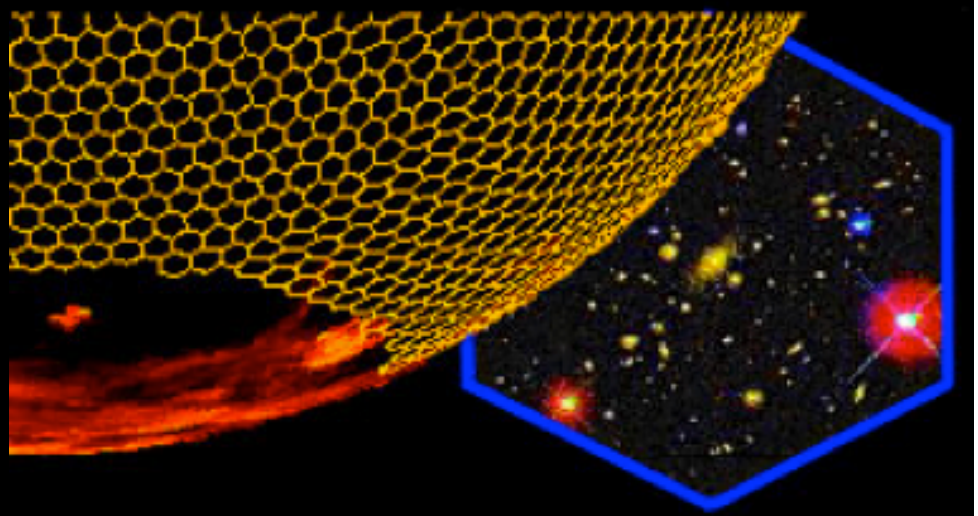


Dark Energy Survey



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

First light Sept 2012

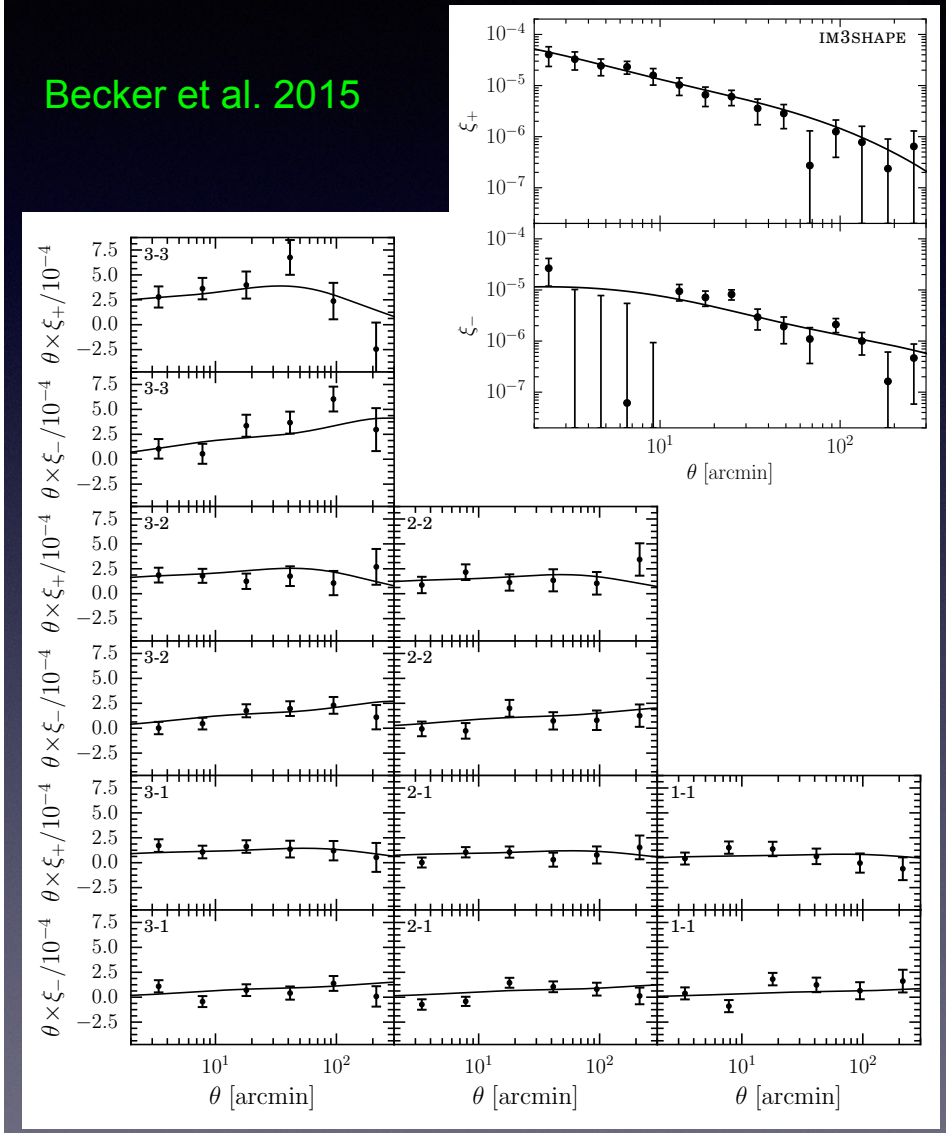


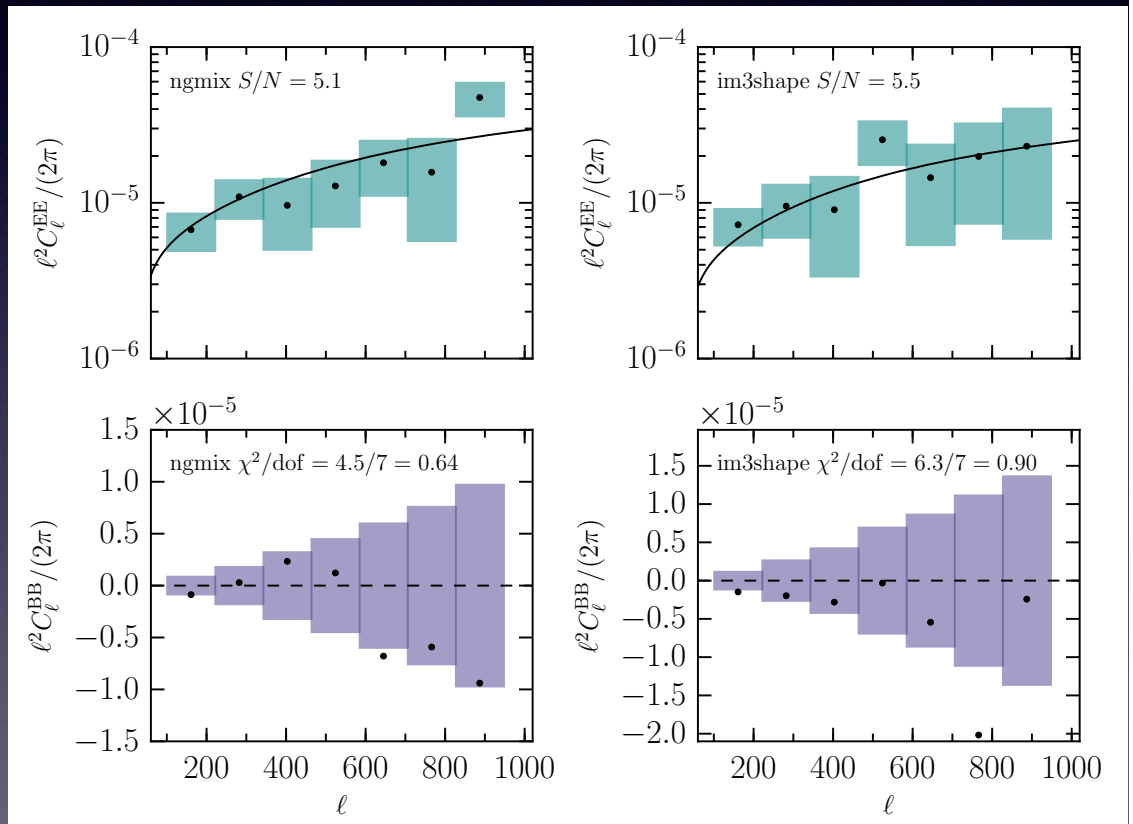
DES SV Results

Jarvis et al. 2015
Bonnet et al. 2015
Becker et al. 2015
DES Collab 2015

DES SV: first 170 deg^2, grizy, mag<24, z_m~0.7, seeing~0.9”

Becker et al. 2015

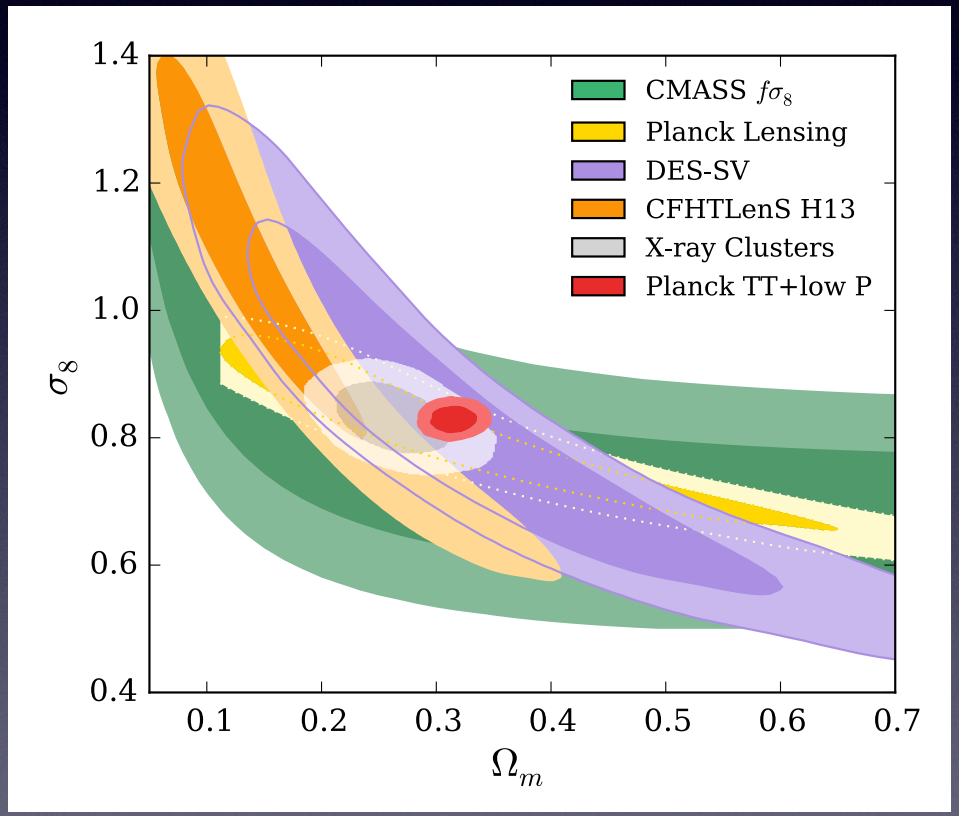


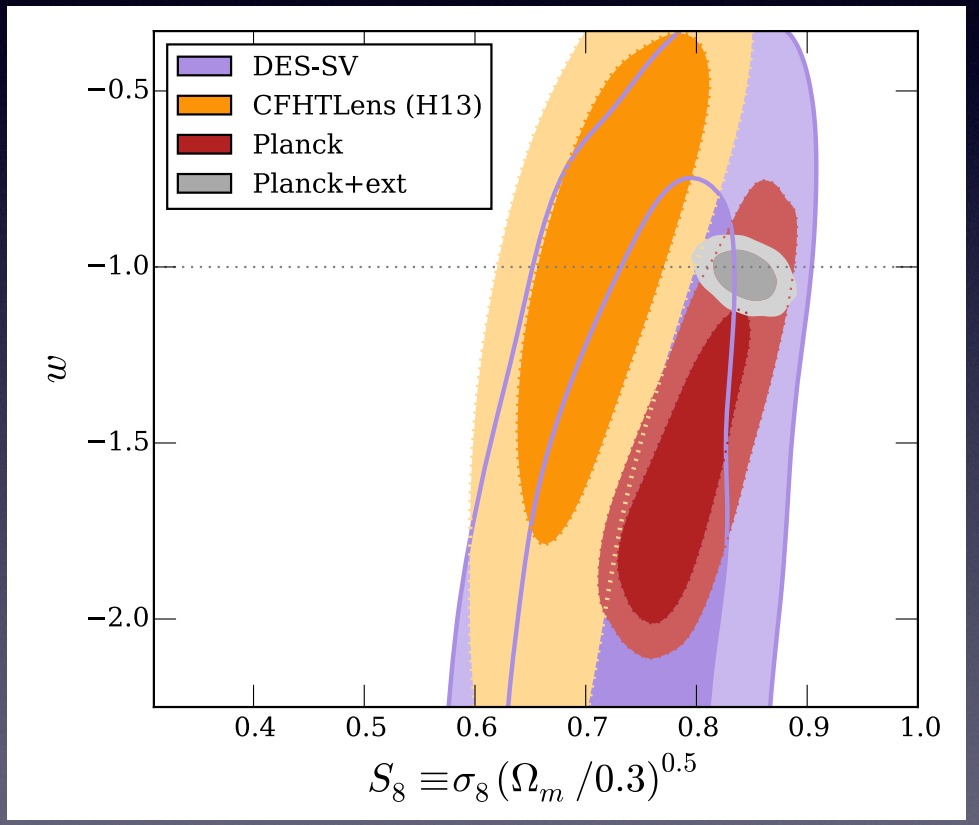


DES SV Results

DES SV: first 170 deg^2, grizy, mag<24, z_m~0.7, seeing~0.9”

DES Collab 2015

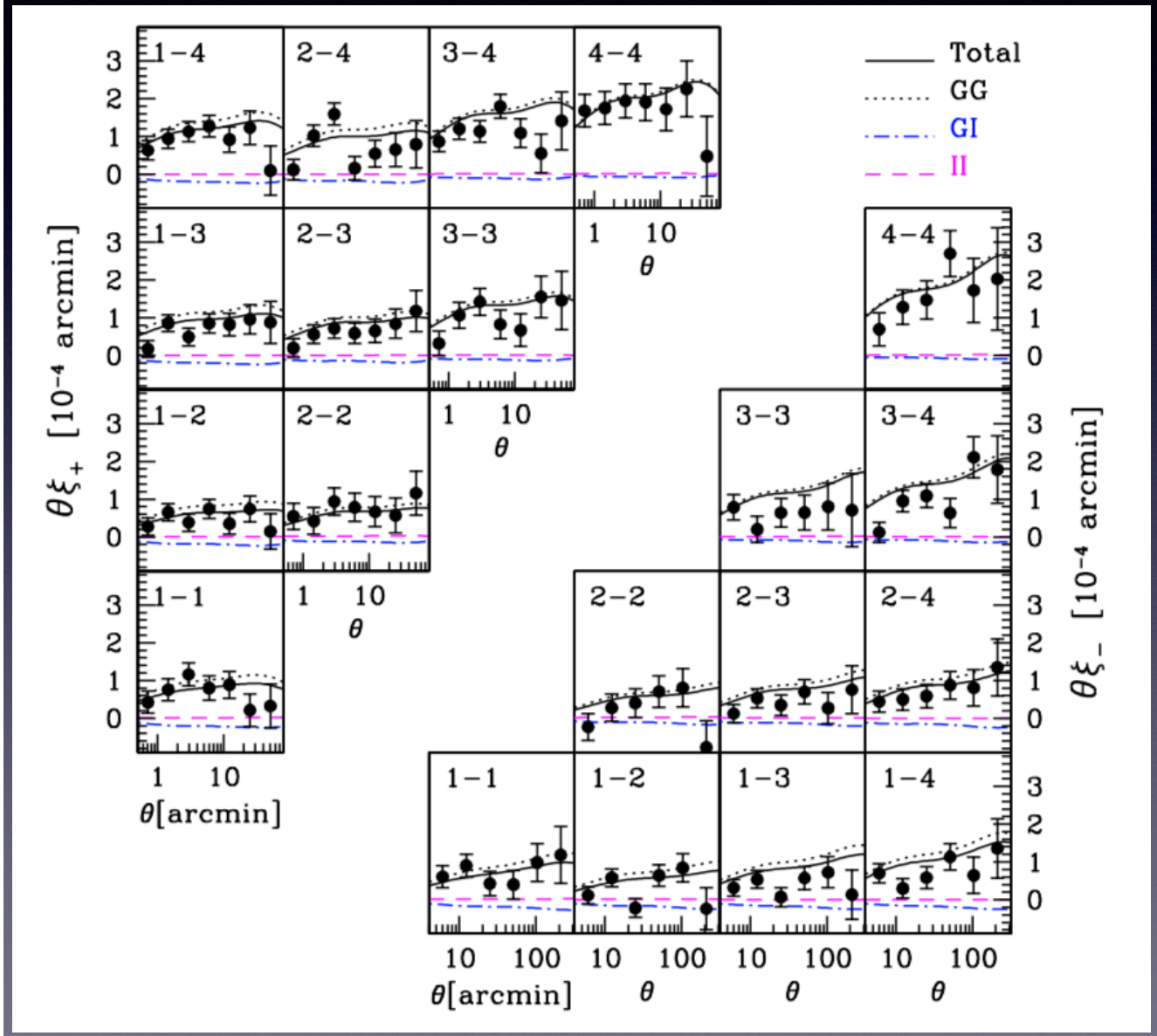


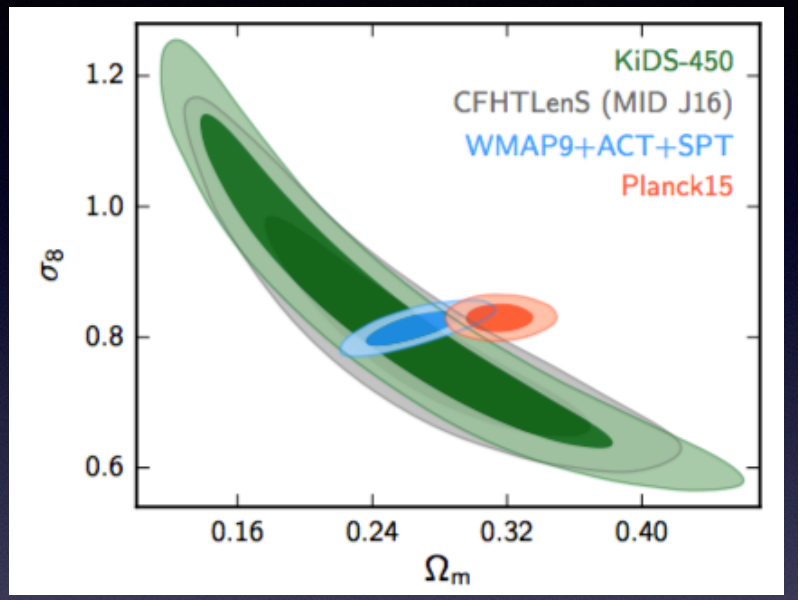


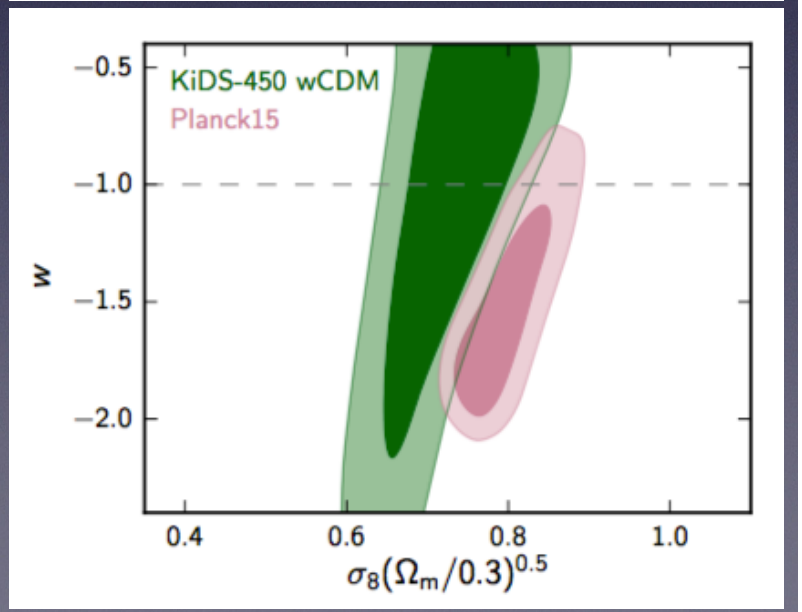
KiDS 450

Hildebrandt et al. 2016

VST, first 450 deg^2, ugri, r band: mag<24.9(5σ), z_m~0.5, seeing~0.7”

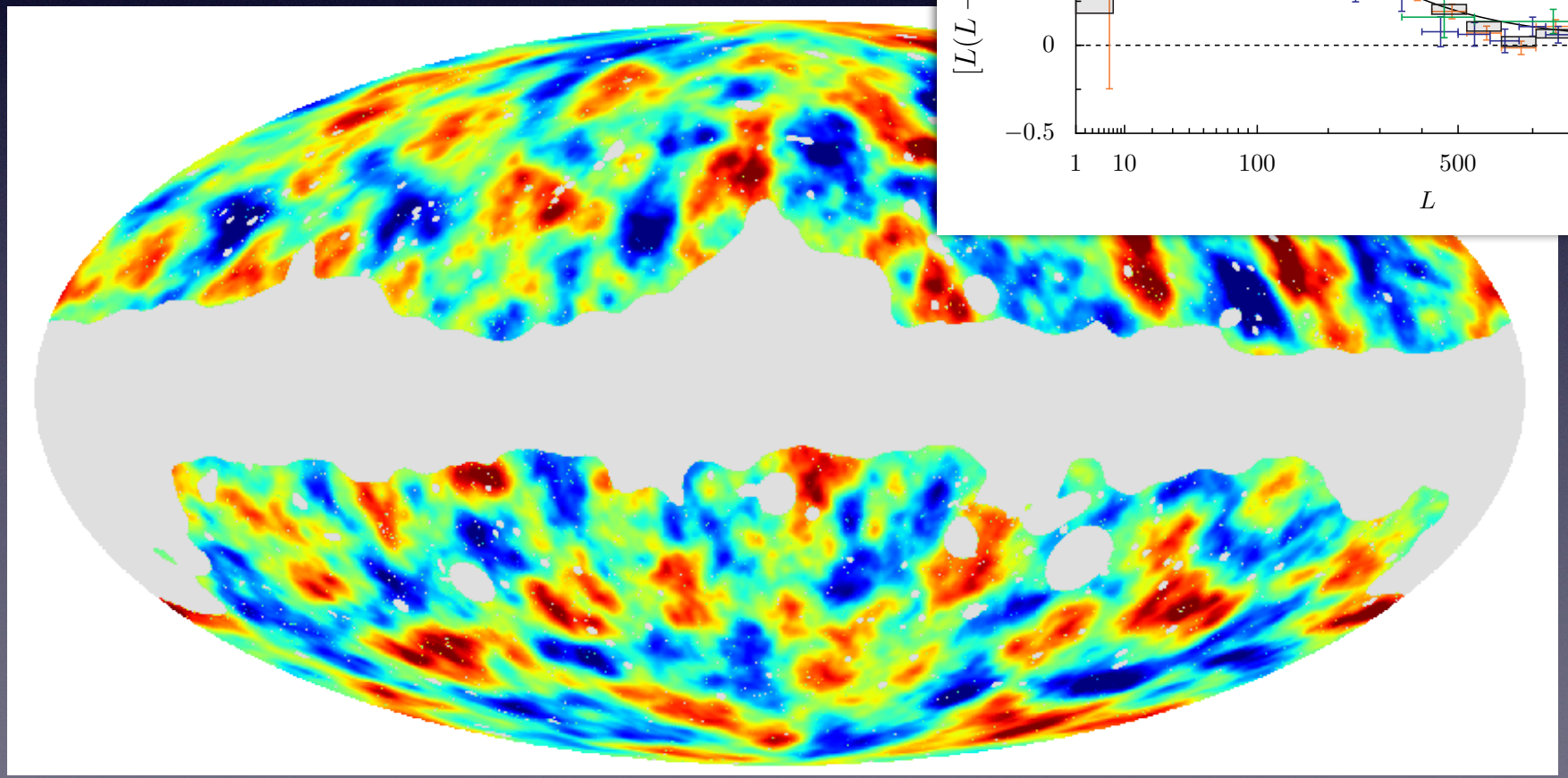


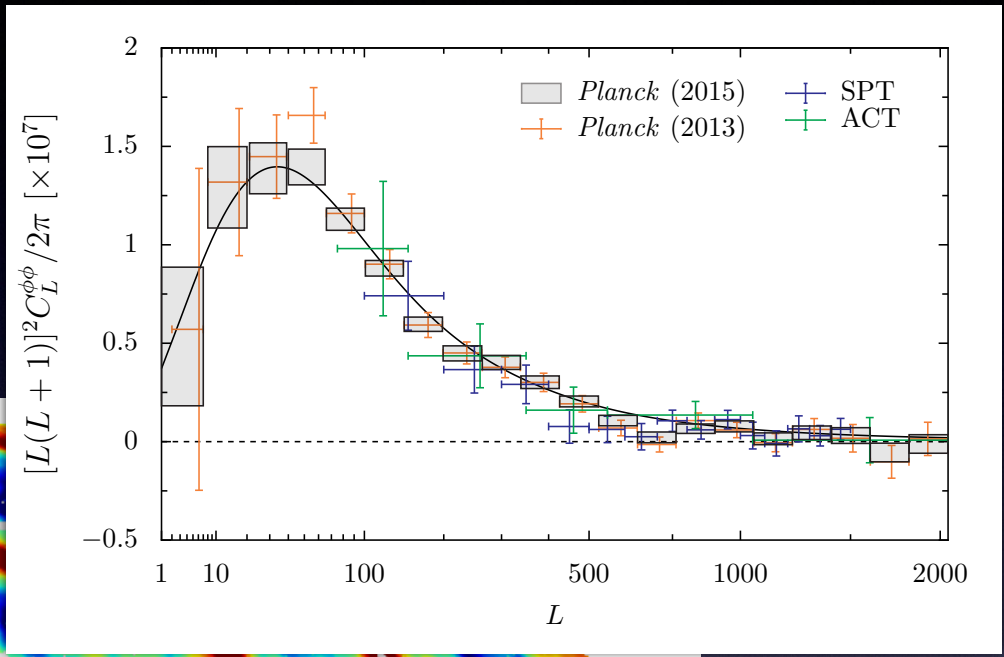




CMB Lensing

Planck XV, 2015



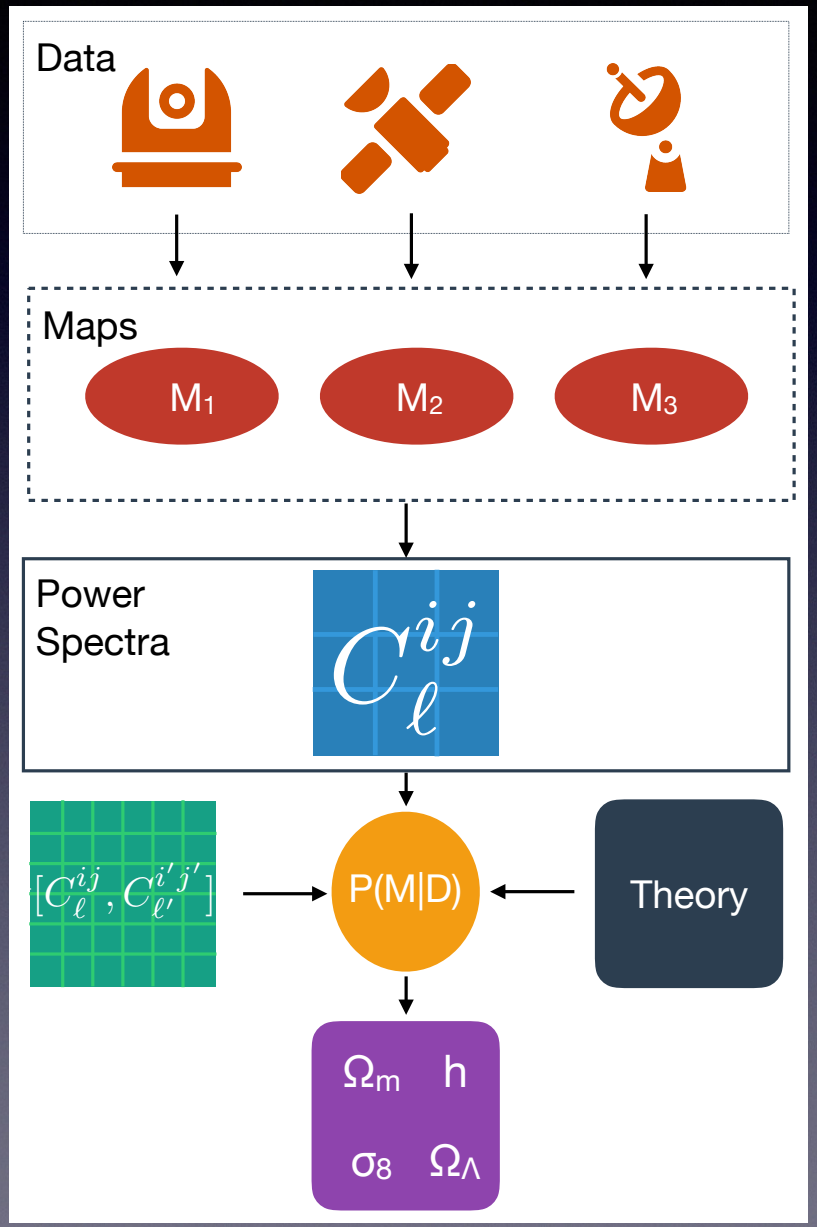


Integrated Probes

Nicola, Refregier & Amara, 2016a,b

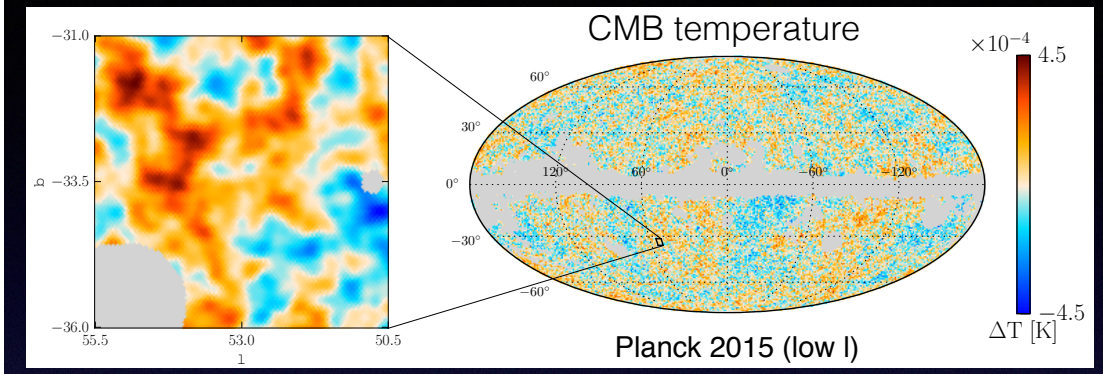
Probe Combination:
Usually done at last stage of analysis by combining likelihoods assuming they are independent

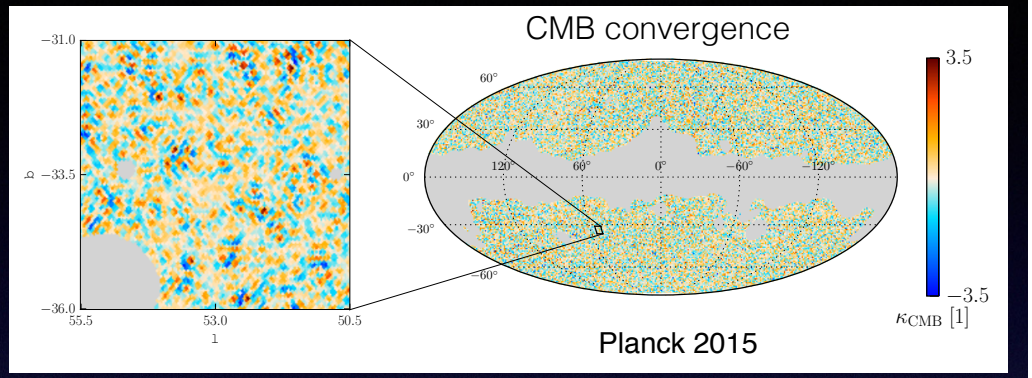
Integrated Approach:
Combine probes at early stage in common framework at the map level
Takes full account of correlation between probes
Provides test of systematics and of model

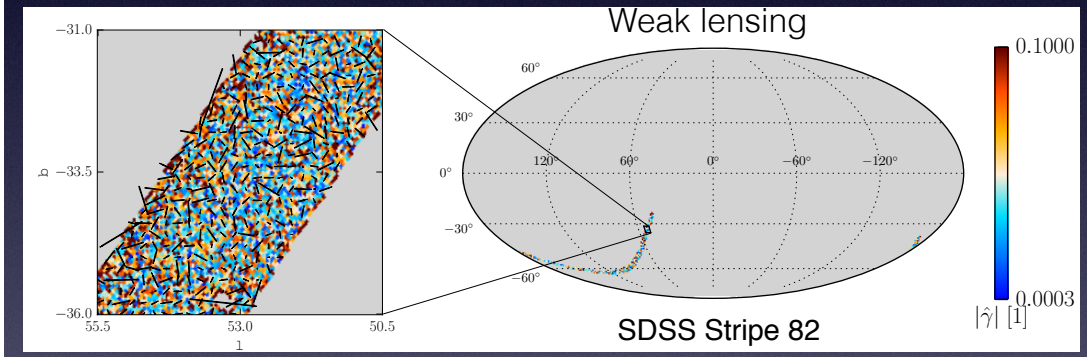


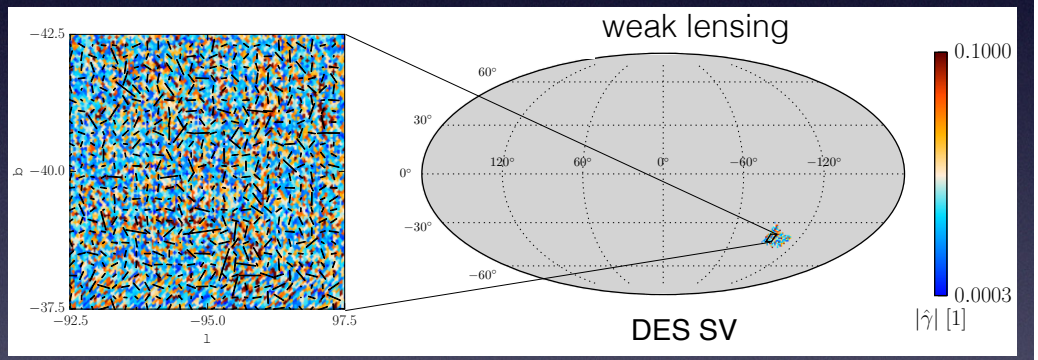
Implementation

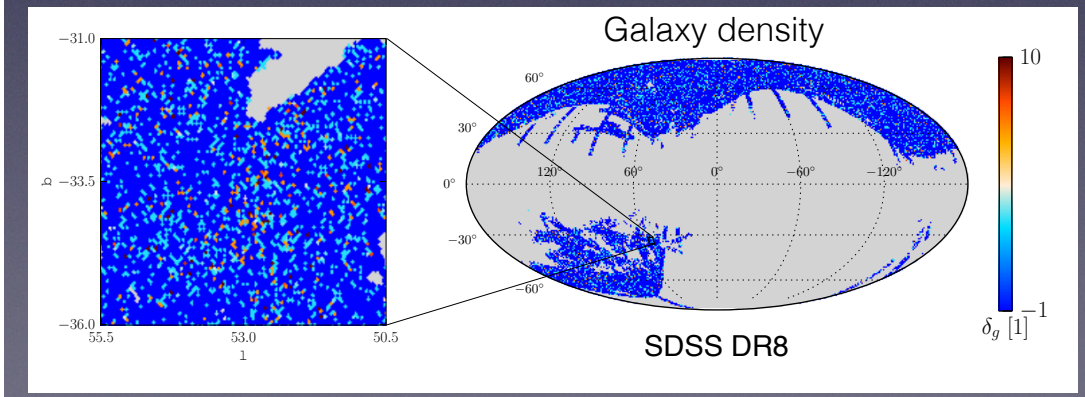
Nicola, Refregier & Amara, 2016a,b

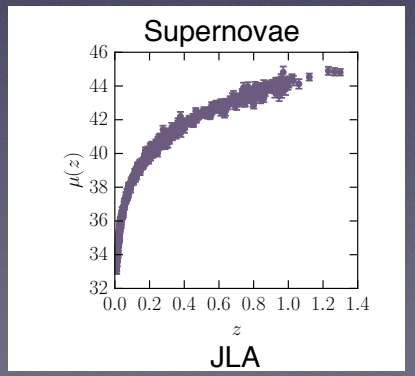


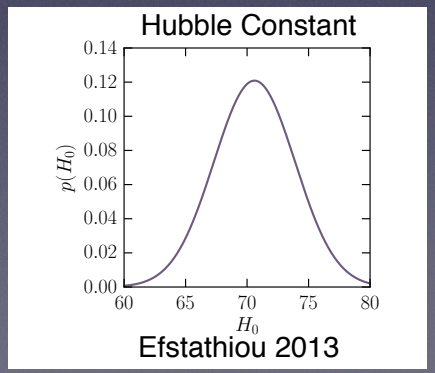




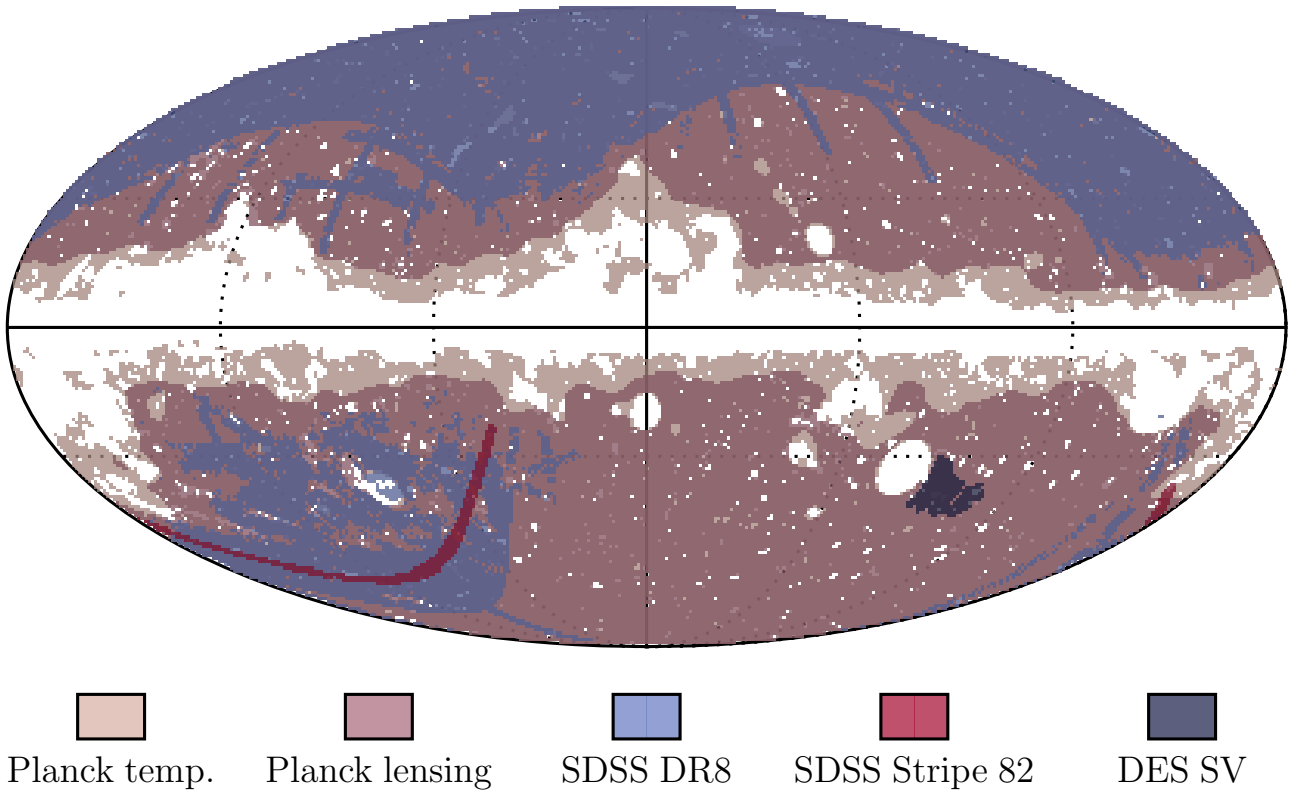


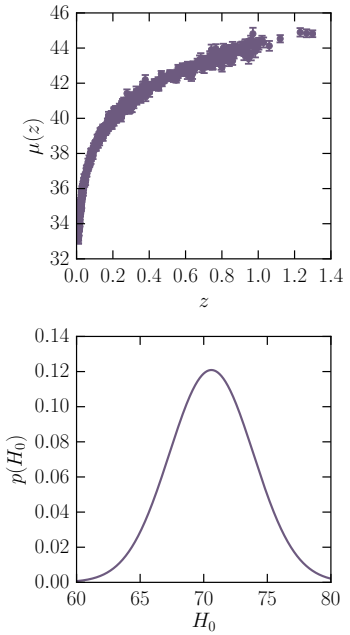






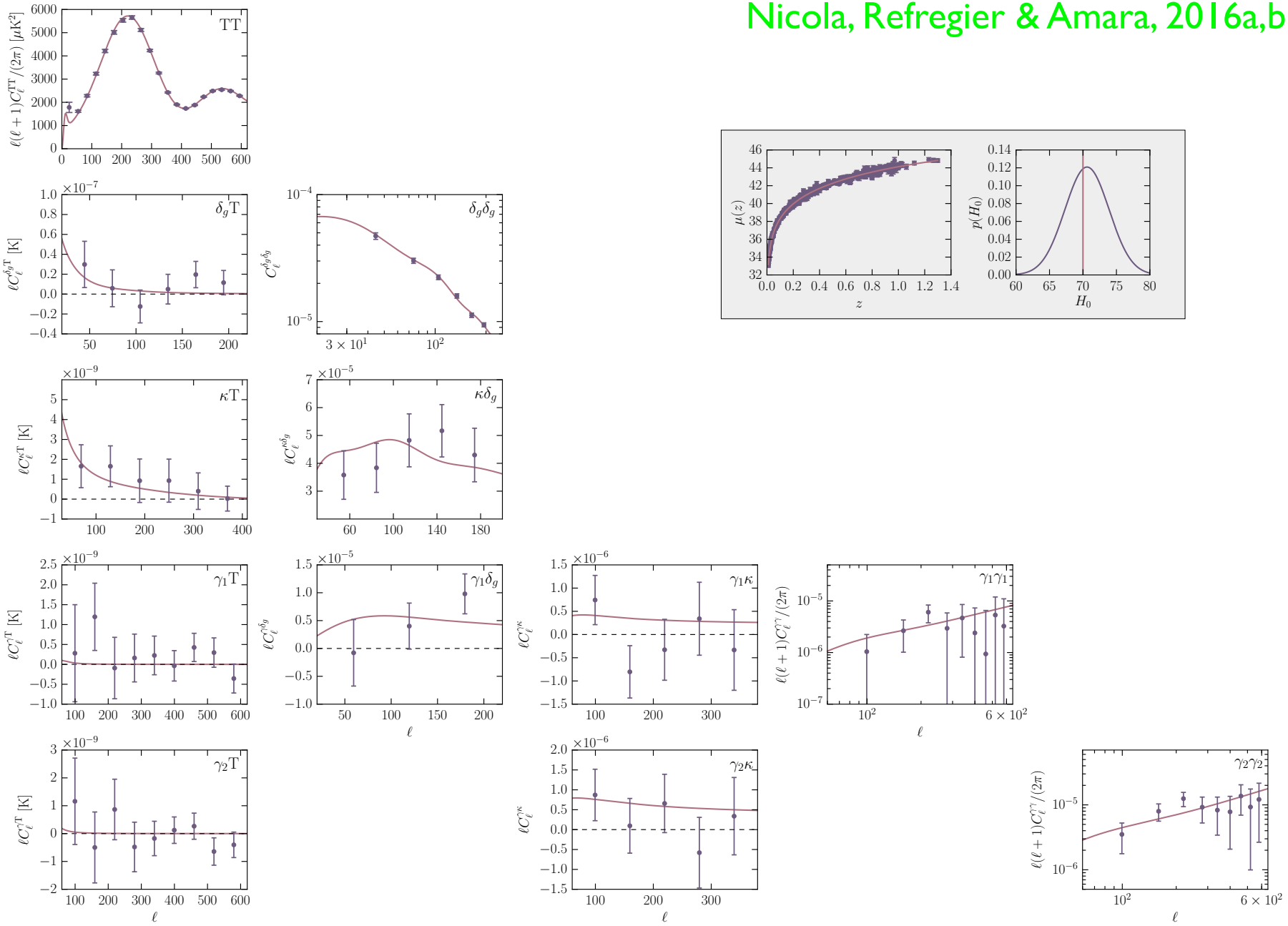
Survey Areas



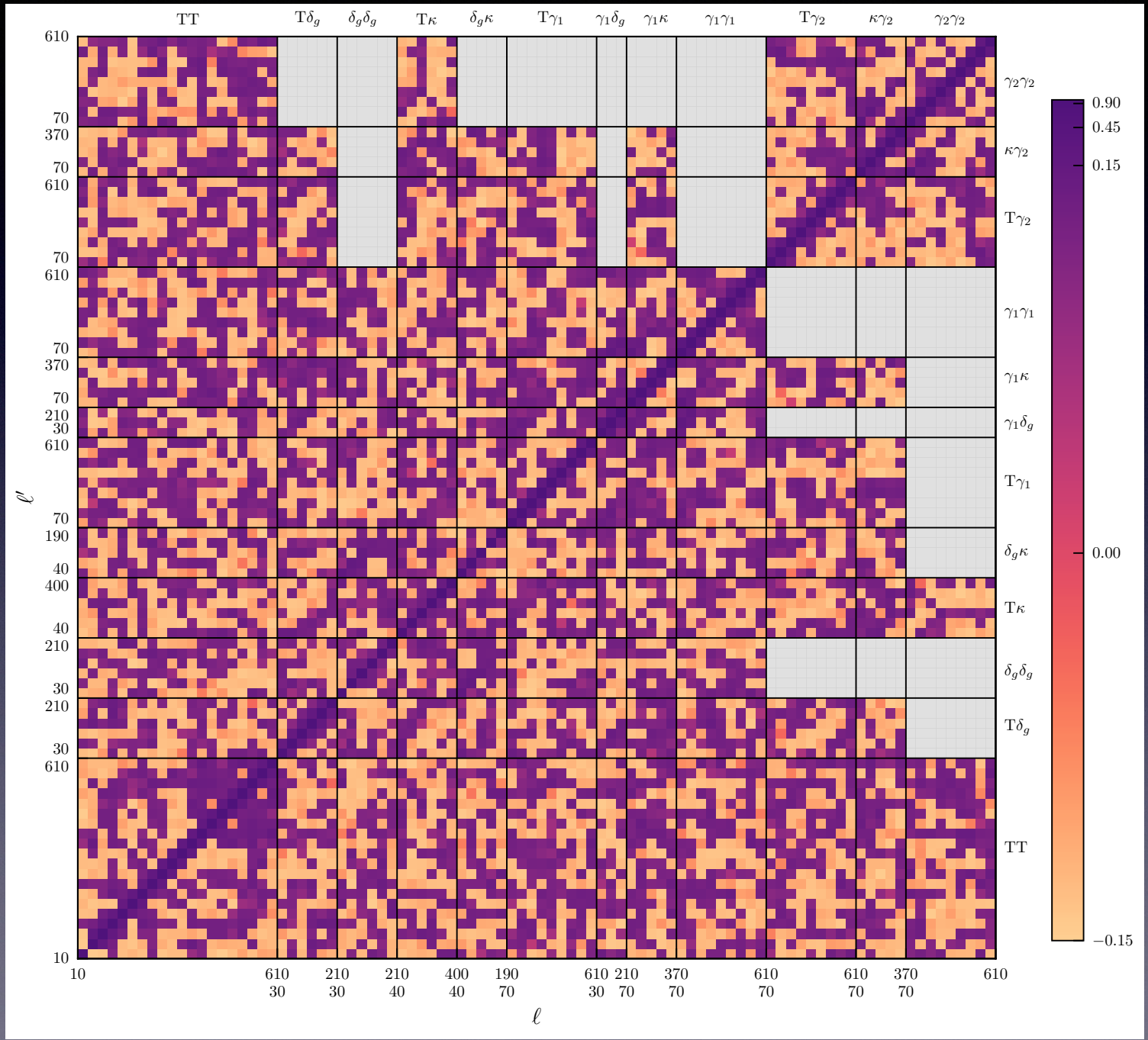


Power Spectra

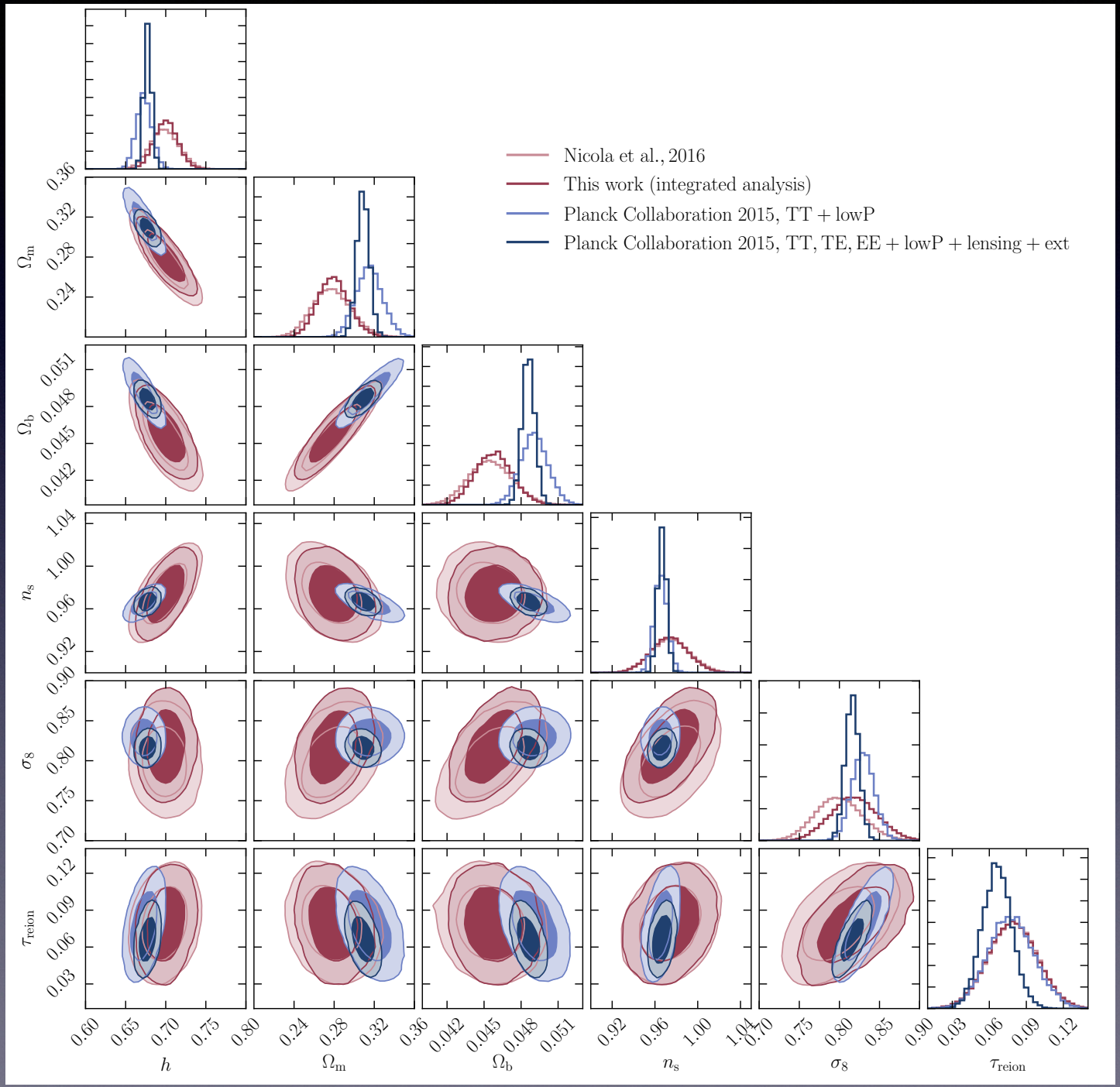
Nicola, Refregier & Amara, 2016a,b



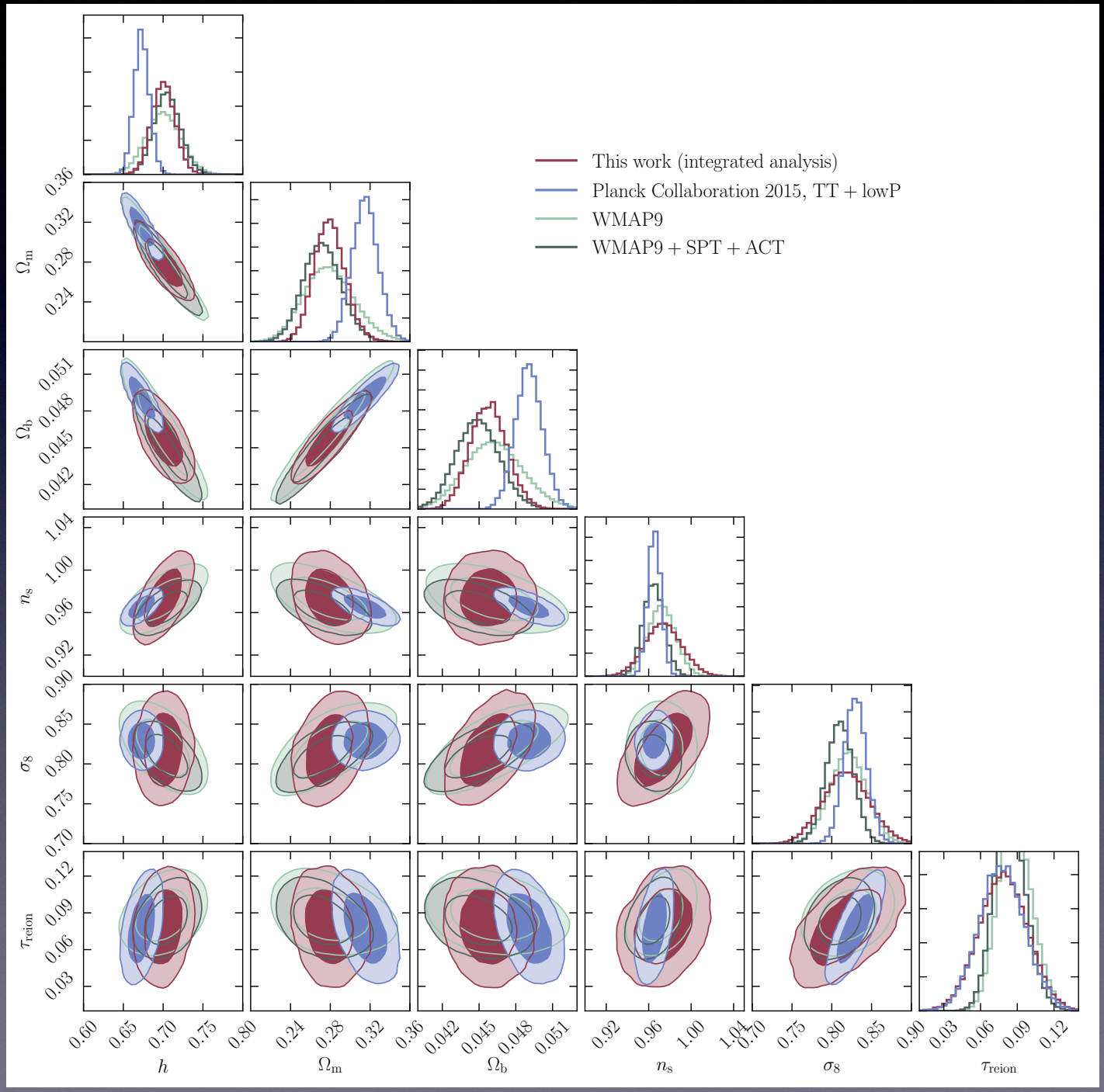
Covariance Matrix



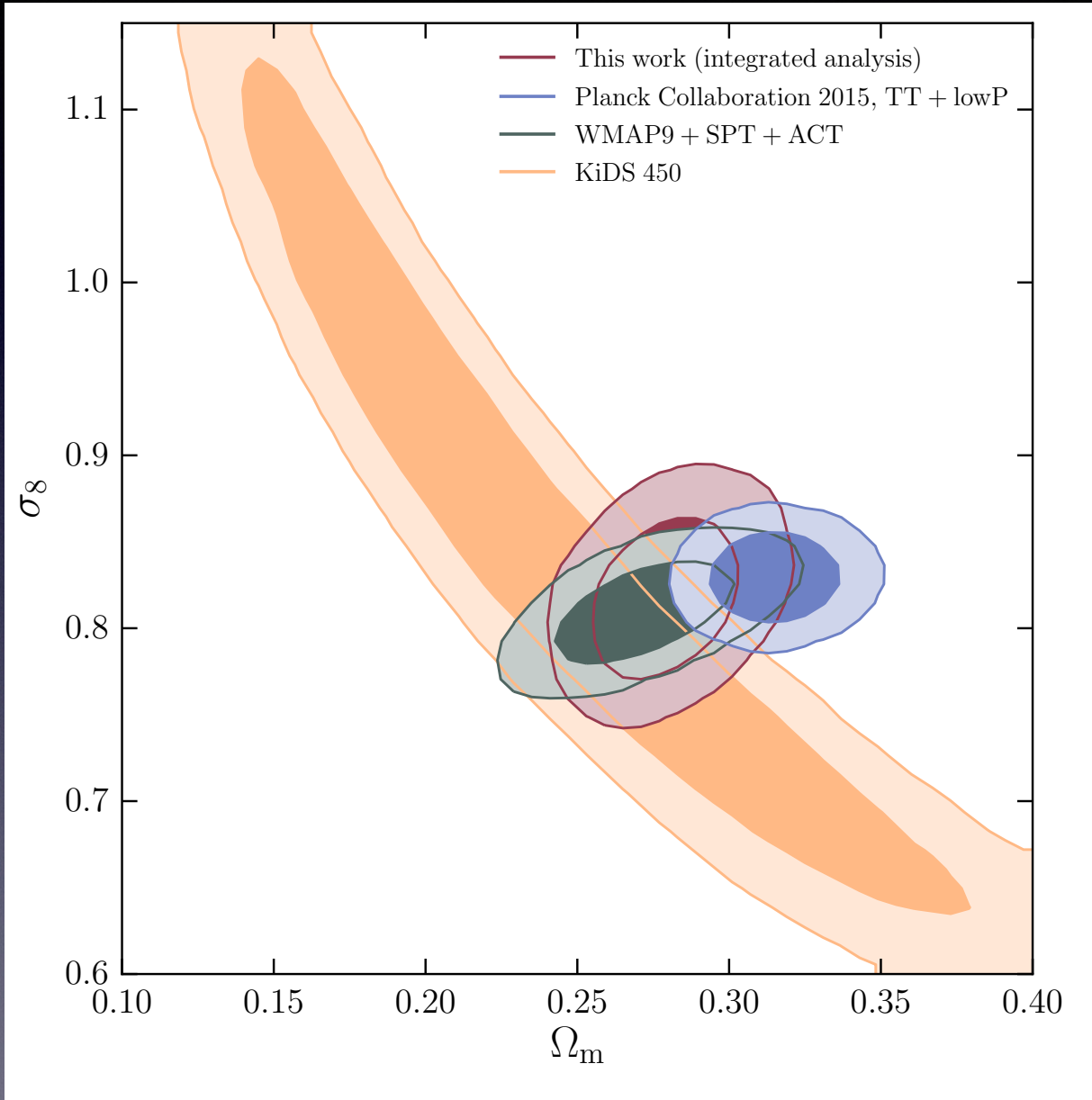
Cosmological Constraints



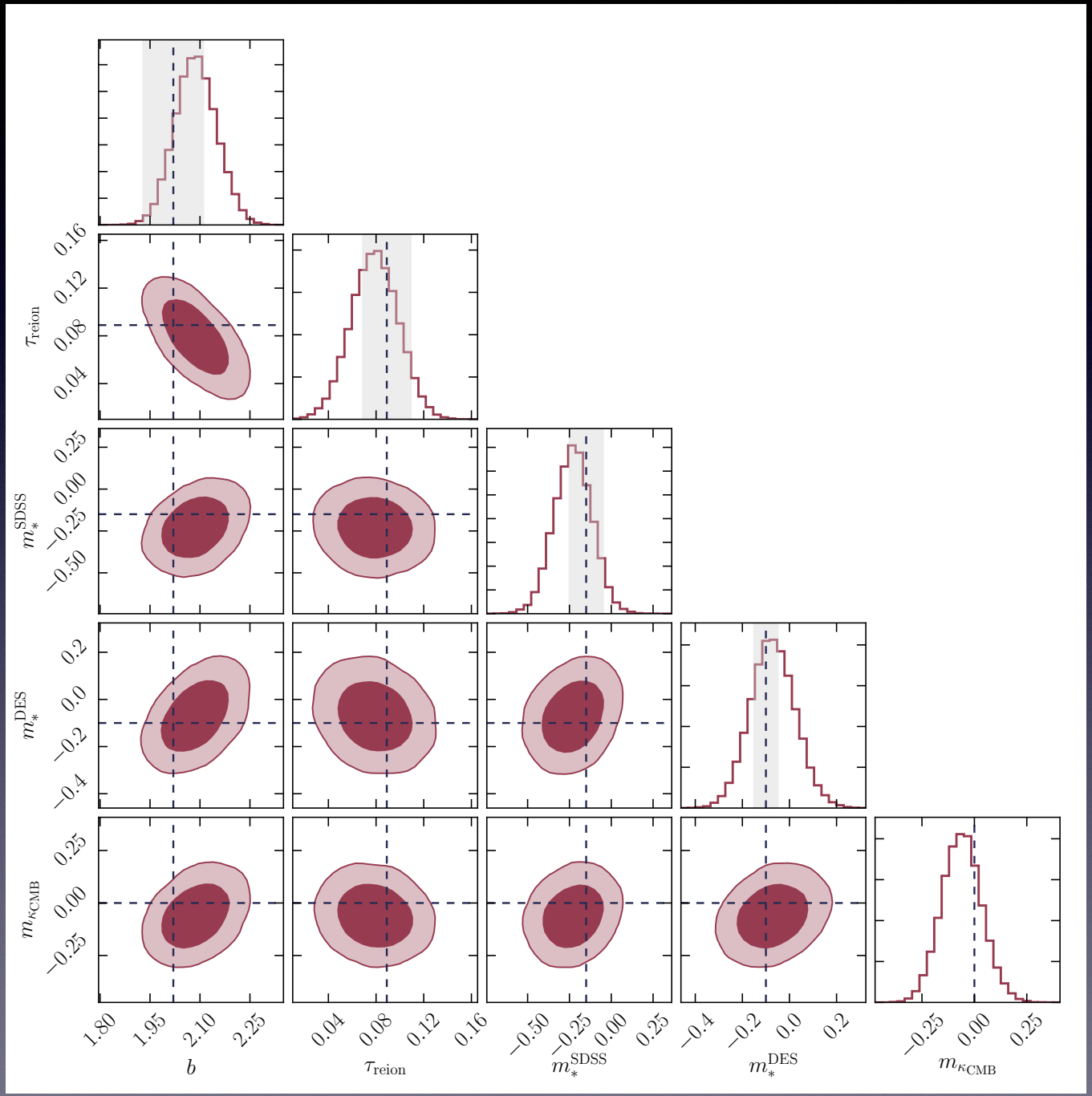
Cosmological Constraints



Power Spectrum Amplitude



Probe Calibrations



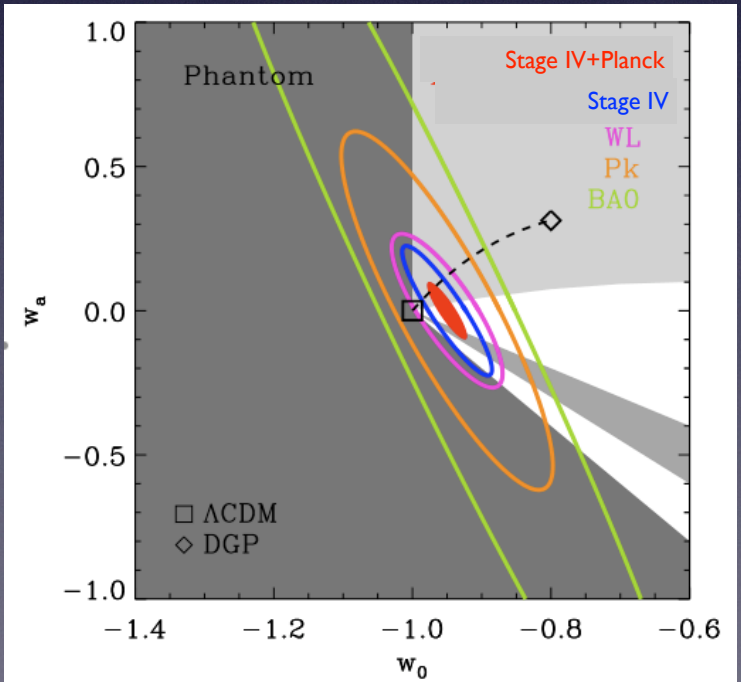
Wide-Field Instruments

CMB		Planck, SPT, ACT, Keck
VIS/NIR	Imaging	VST, DES, Pann-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

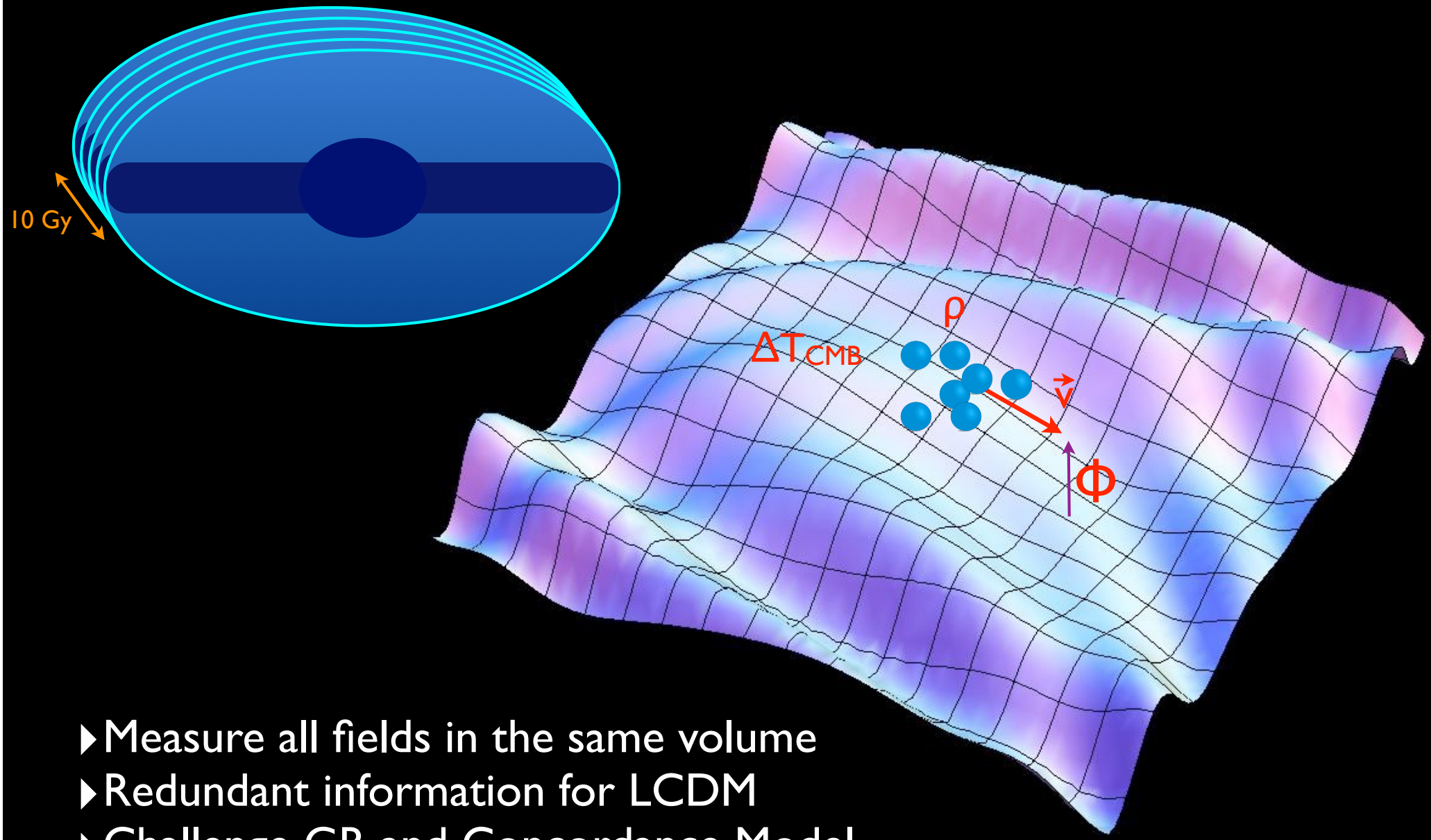


Stage IV Surveys will challenge all sectors of the cosmological model:

- 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 ($d\ln_m/d\ln a_m$)

→ Uncover new physics and map LSS at 0<z<2: Low redshift counterpart to CMB surveys

Integrated Probe Analysis



- Measure all fields in the same volume
- Redundant information for LCDM
- Challenge GR and Concordance Model

Conclusions

- Integrated Cosmological probe approach takes full account of probe correlations and provides a stringent test of systematics and of cosmological model

- An implementation combining CMB temperature (low l), CMB lensing, weak lensing, galaxy clustering, supernovae and H_0, reveals:
  - No tension between these data sets and a good agreement with LCDM
  - Indication of a tension between Planck-high l and the other probes
  - Probe calibration parameters in agreement with expectations

- Further extensions to include smaller scales and baryonic effects in the context of future surveys