Weak Gravitational Lensing

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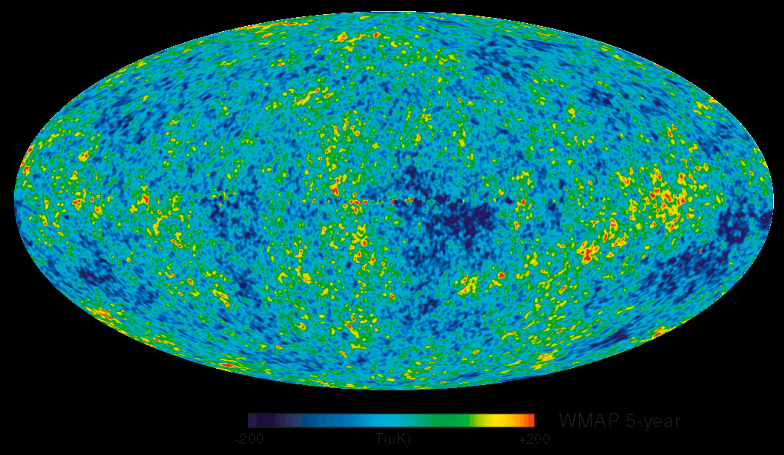
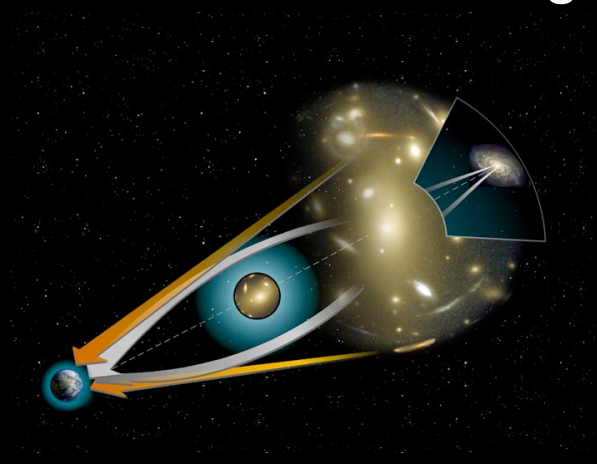
CosmoCruise
4.9.2015

Cosmological Probes

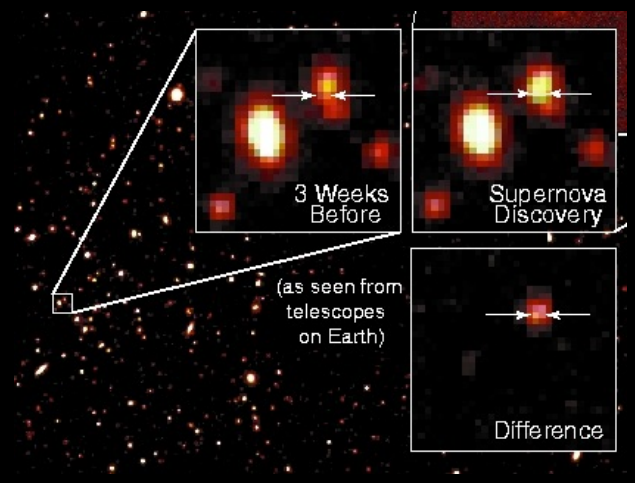
Cosmic Microwave Background



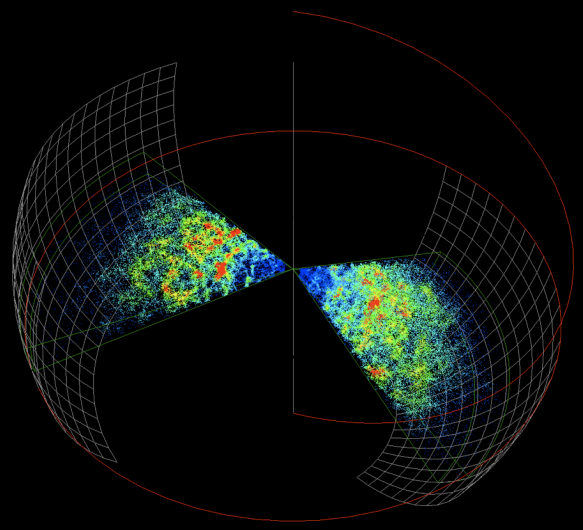
Gravitational Lensing



Supernovae



Galaxy Clustering

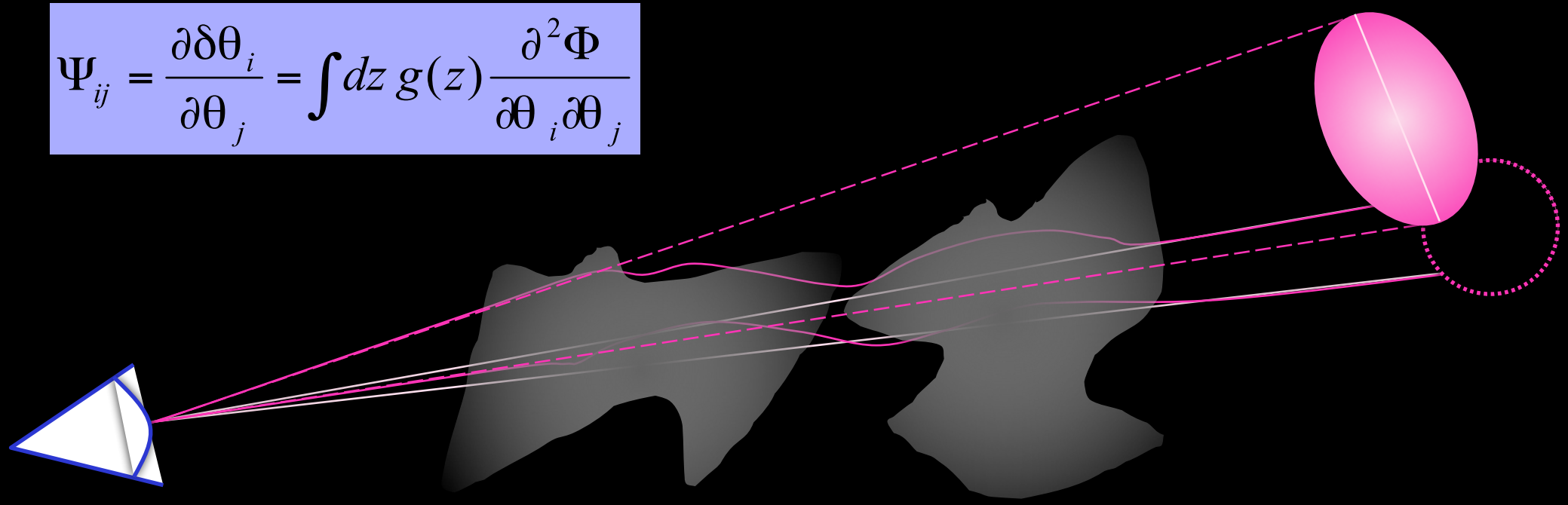


Weak Gravitational Lensing

Massey et al.
review: Refregier 2003

Distortion matrix:

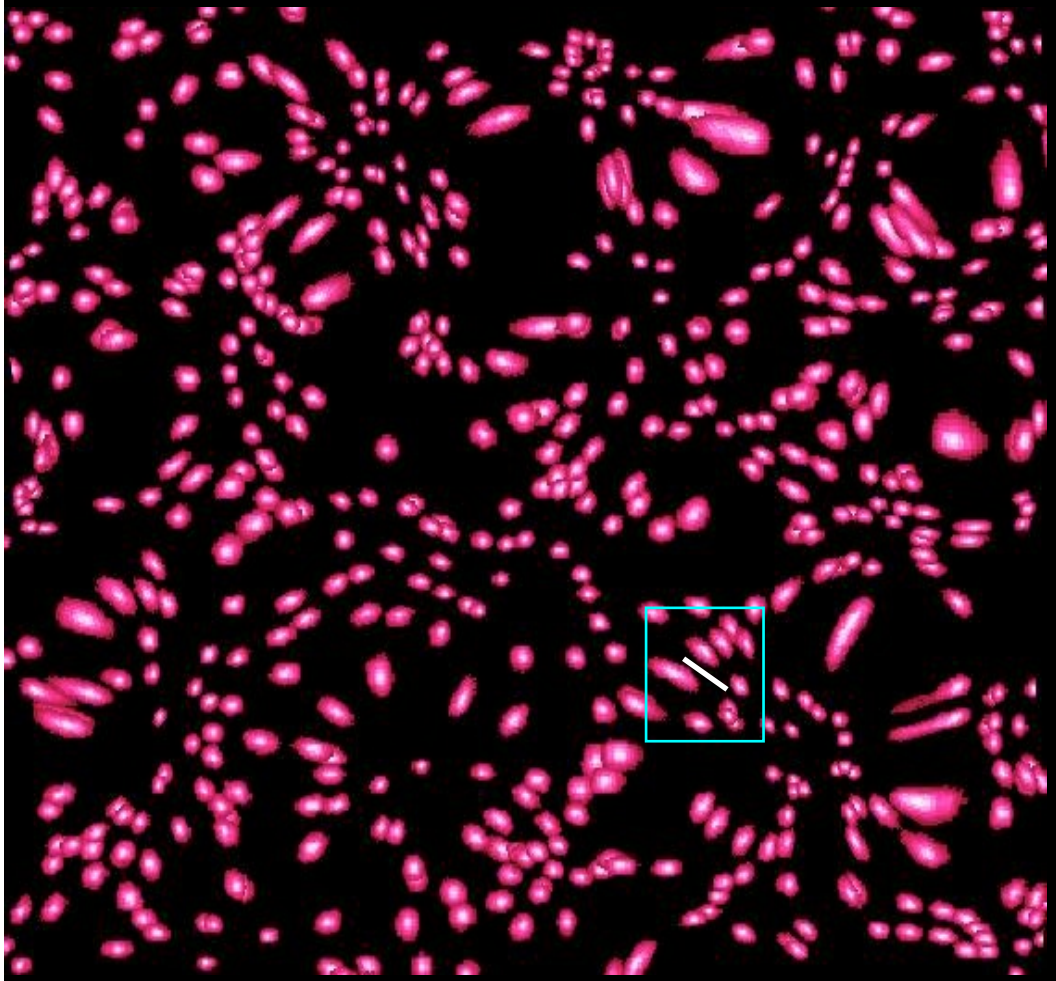
$$\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$$



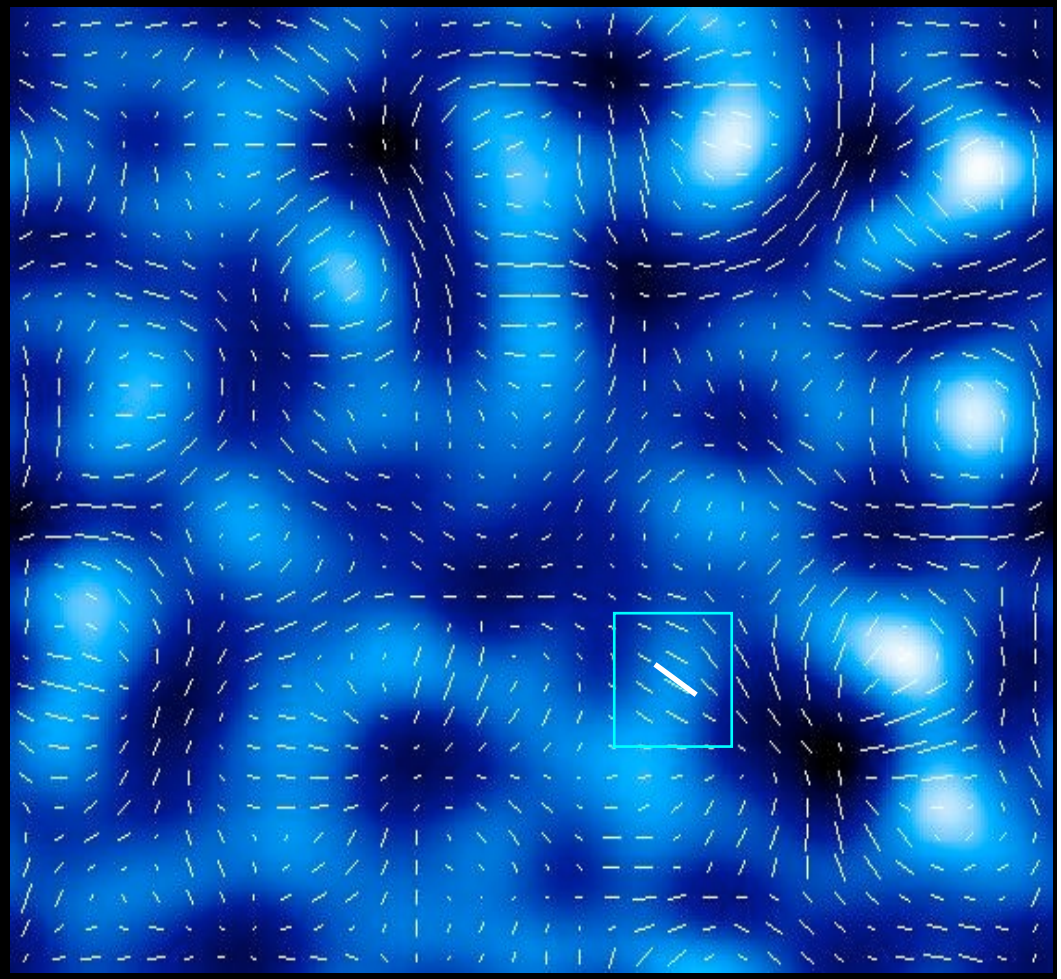
Theory

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

Weak Lensing Shear Measurement



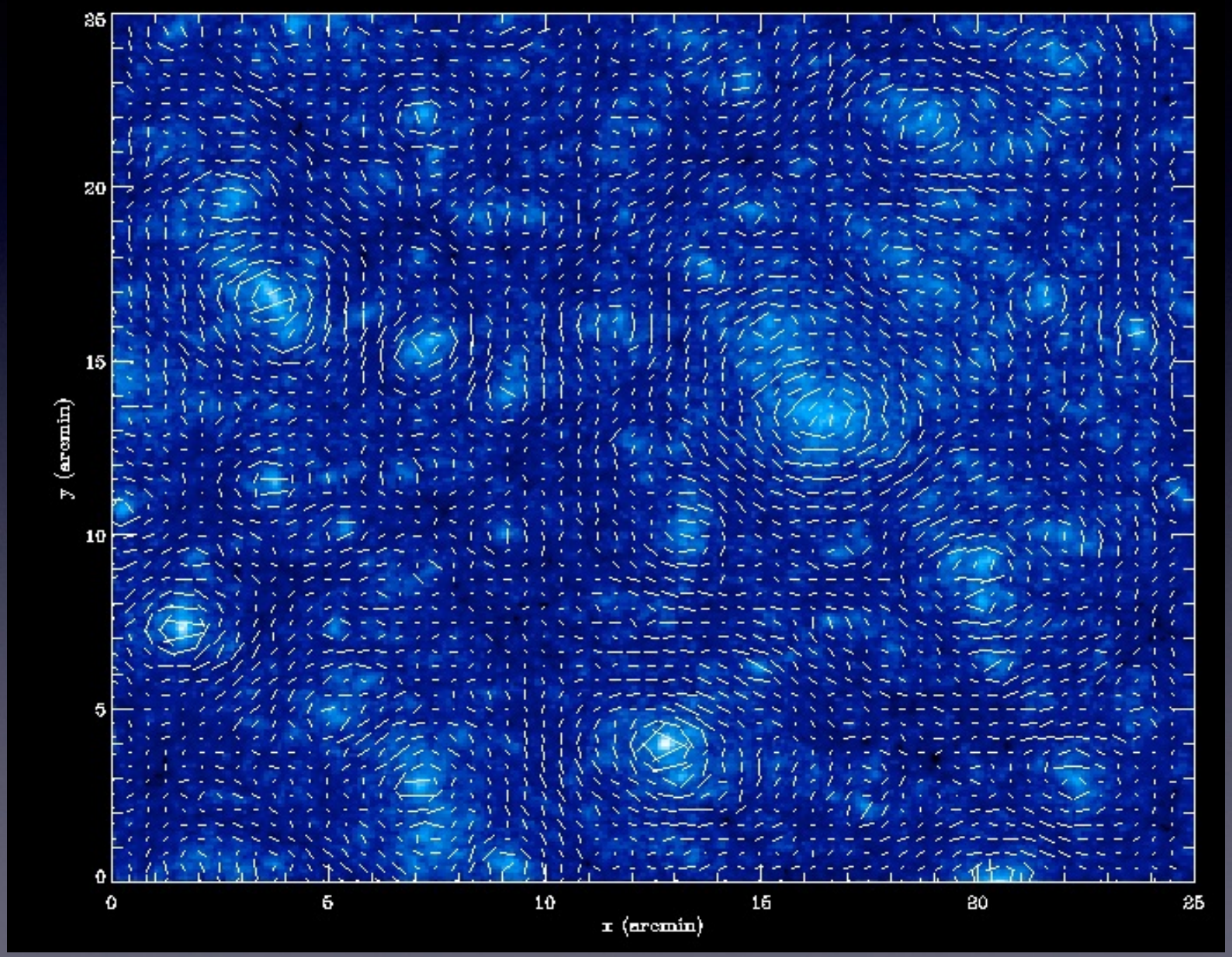
lensed background galaxies



mass and shear distribution

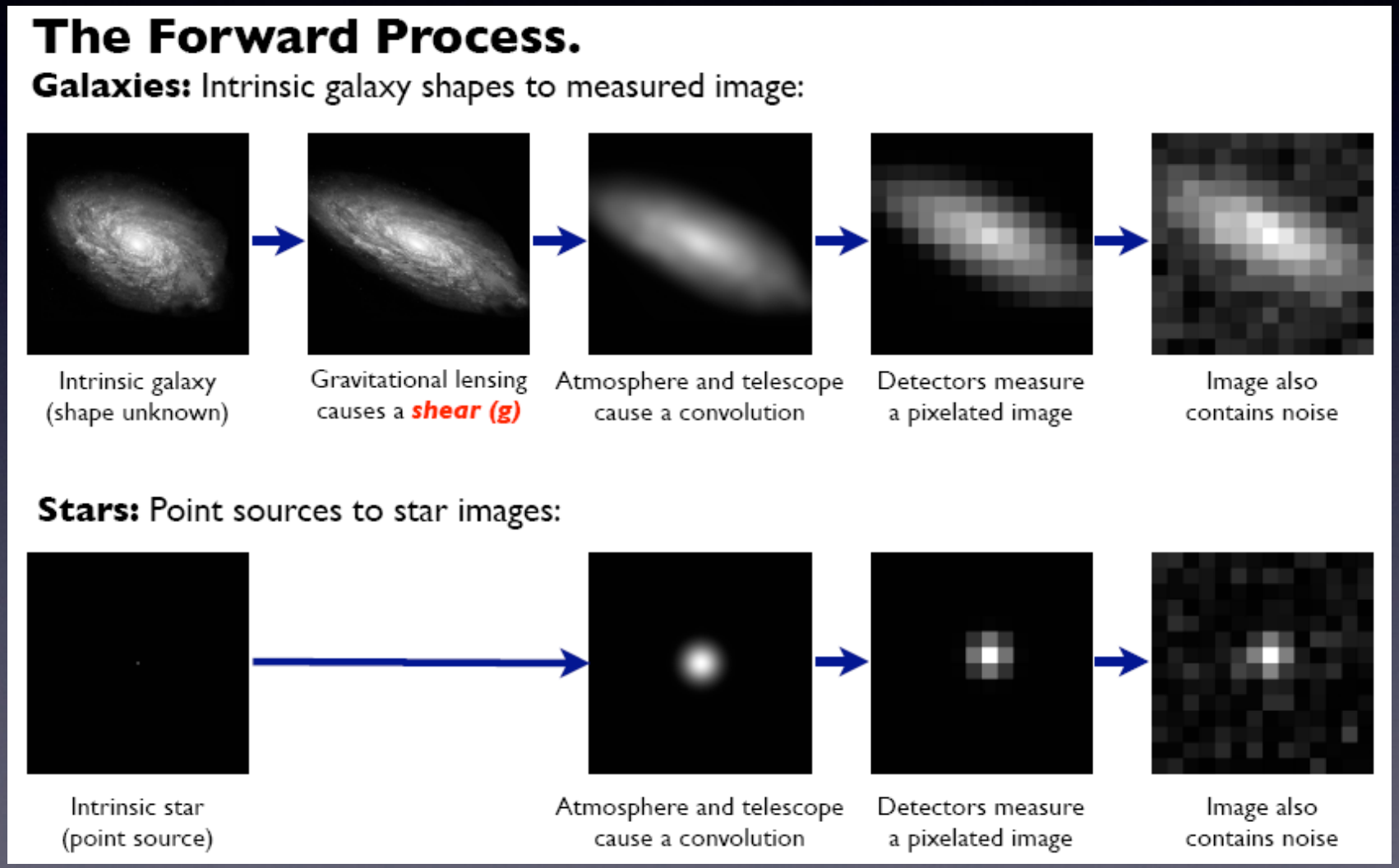
Simulated Shear Map

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

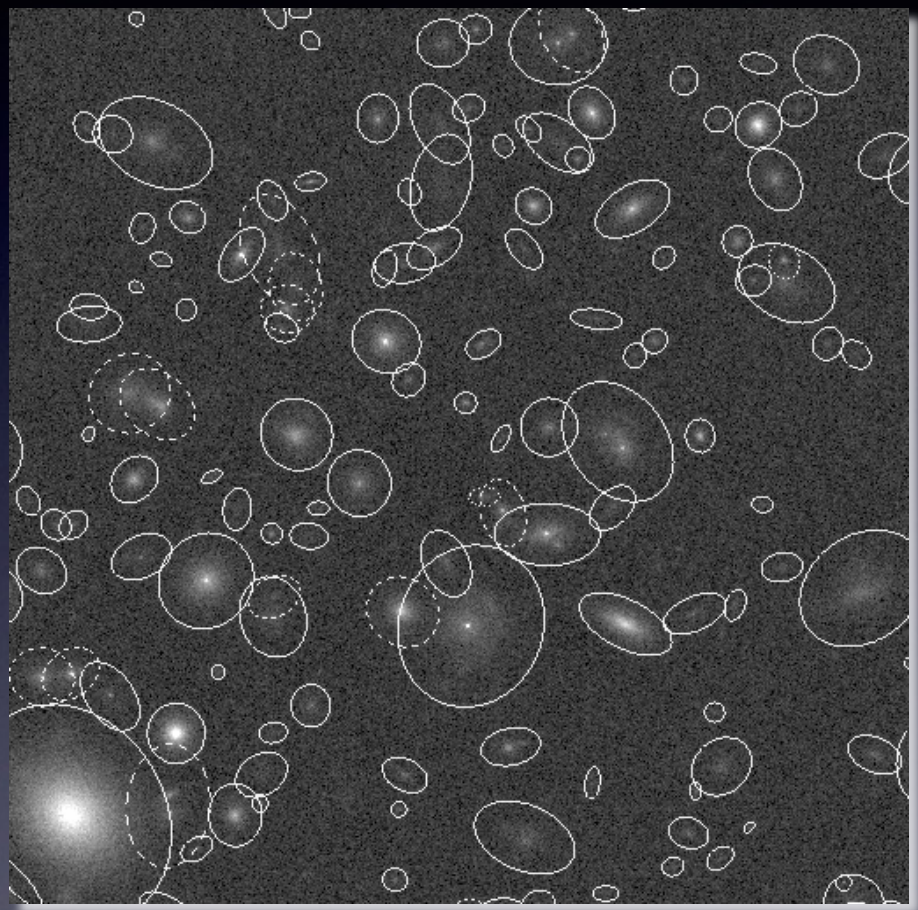


Shear Measurement Problem

GREAT08 handbook, Bridle et al 08



Shear Measurement Methods



Moment based methods: Kaiser et al 95, Rhodes et al. 99, Bernstein 10, Bernstein & Armstrong 2014, Bernstein et al. 2014

Shape fitting methods: Kuijken 99, Refregier & Bacon 2003, Bernstein & Jarvis 02, Bridle et al. 02, Nakijima & Bernstein 07, Miller et al. 07, Peng et al. 02, Gentile et al. 2012, Kacprazk et al. 2013, Zuntz et al. 2014

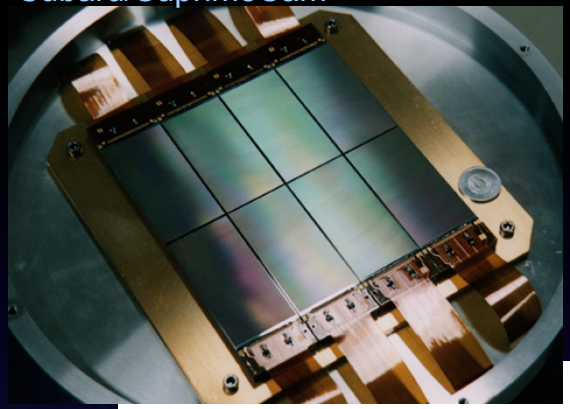
Stacking methods: Lewis 09, Hosseini & Bethge 09

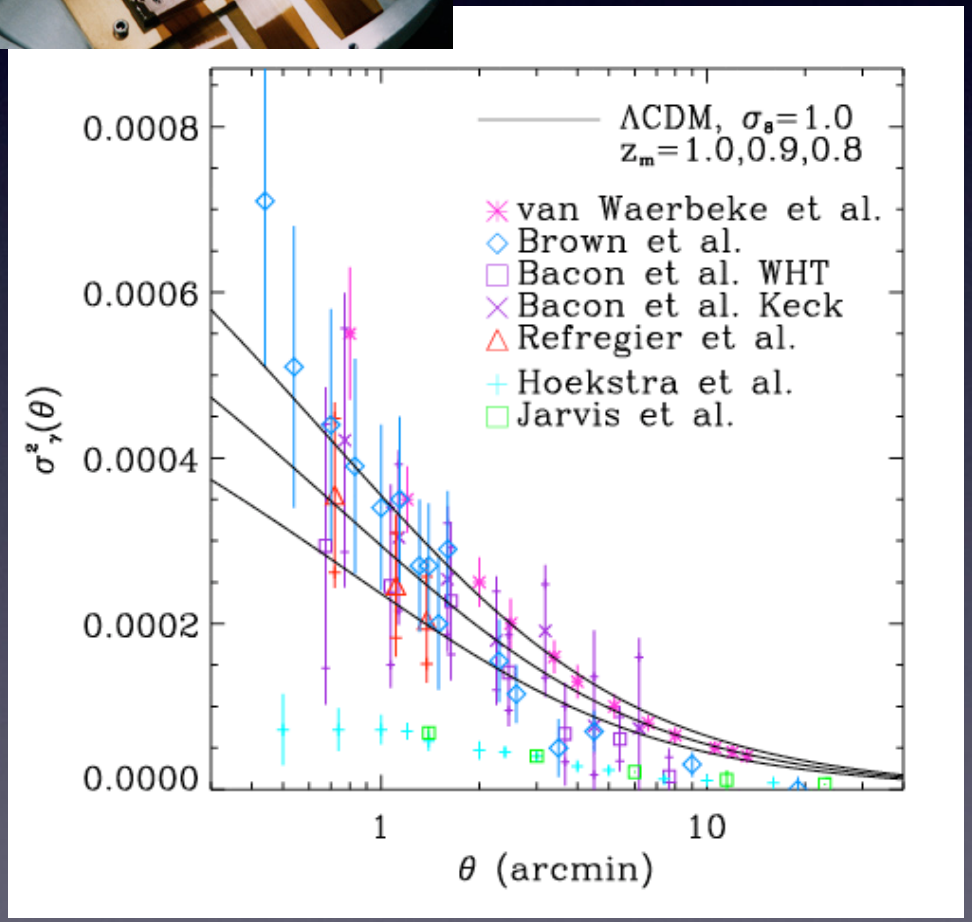
Forward Modelling methods: Berge et al. 2012, Refregier & Amara 2014, Bruderer et al. 2015

→ Data challenges: STEP (Heymans et al. 2005, Massey et al 2006); GREAT 08 (Bridle et al. 08); GREAT3 (Rowes et al. 2014)

Cosmic Shear Measurements

Subaru/SuprimeCam





First detections

Wittman et al. 2000
Bacon, Refregier & Ellis 2000
Kaiser et al. 2000
Maoli et al. 2000
van Waerbeke et al. 2000*

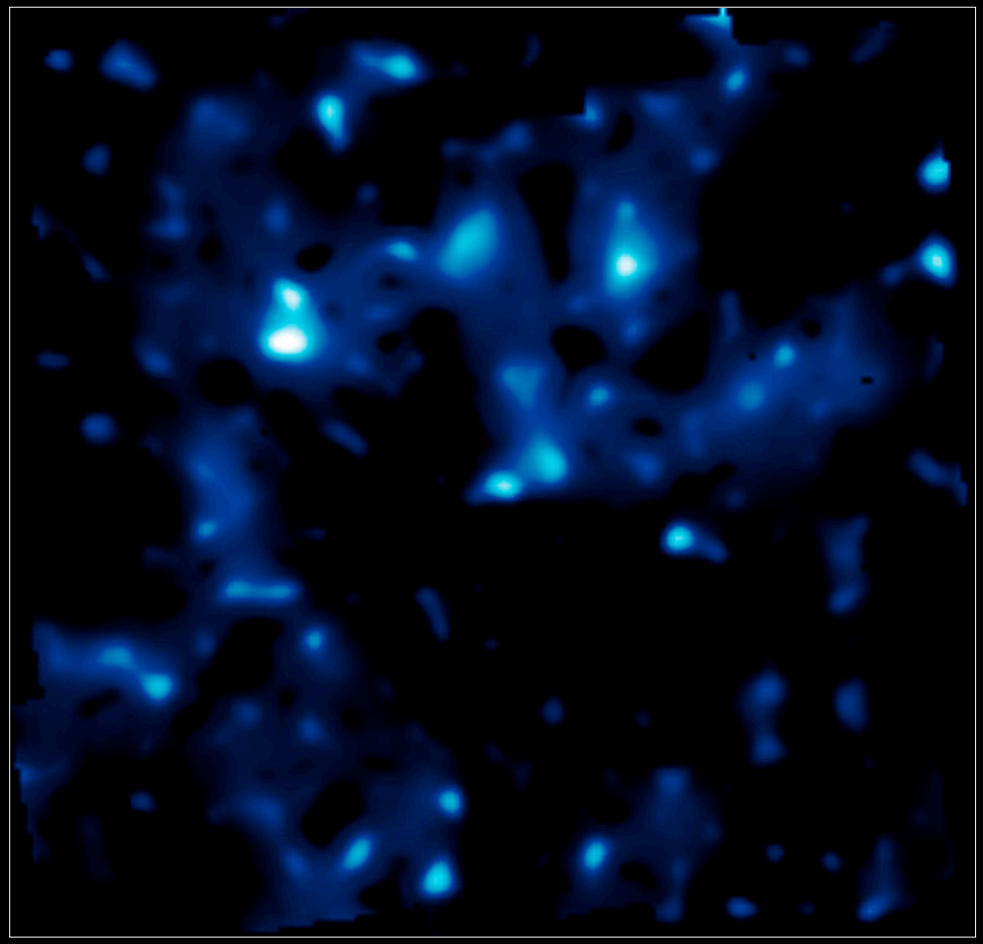
space

Bacon, Massey, Refregier, Ellis 2001
Rhodes, Refregier & Groth 2001
van Waerbeke et al. 2001
Hammerle et al. 2001
Refregier, Rhodes & Groth 2002
Hoekstra et al. 2002
Brown et al. 2003
Hamana et al. 2003
Jarvis et al. 2003
Casertano et al 2003
Rhodes et al 2004

radio

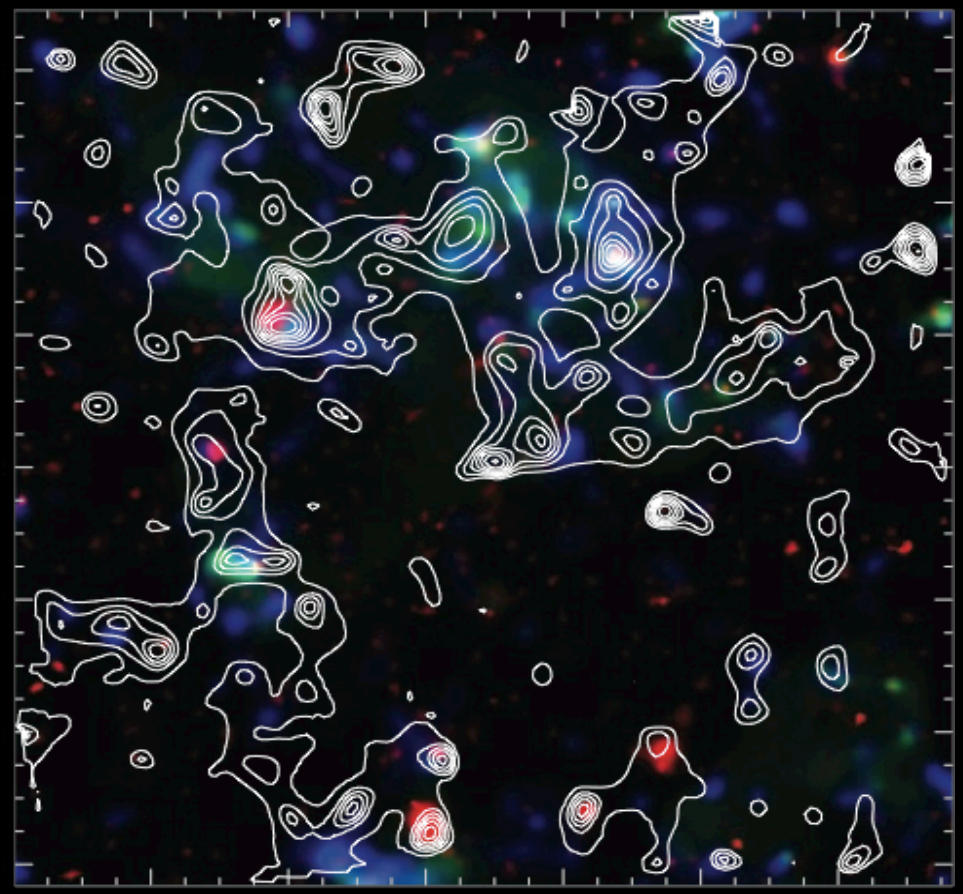
Chang, Refregier & Helfand 2004
Massey et al. 2004
Sembolini et al 2005
Hoekstra et al 2005
Benjamin et al. 2006
Fu et al. 2008
Schrabback et al. 2009
Lin et al. 2011
Heymans et al. 2013+
Jee et al. 2013
Kuijken et al. 2015
DES collaboration 2015

COSMOS Dark Matter Map



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

COSMOS Dark Matter Map



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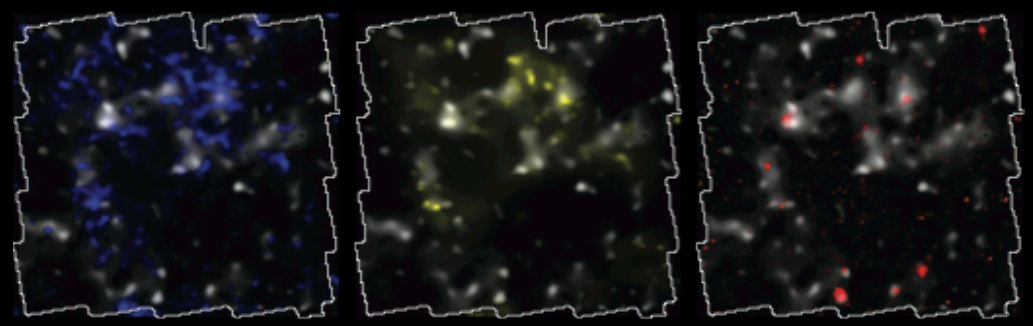
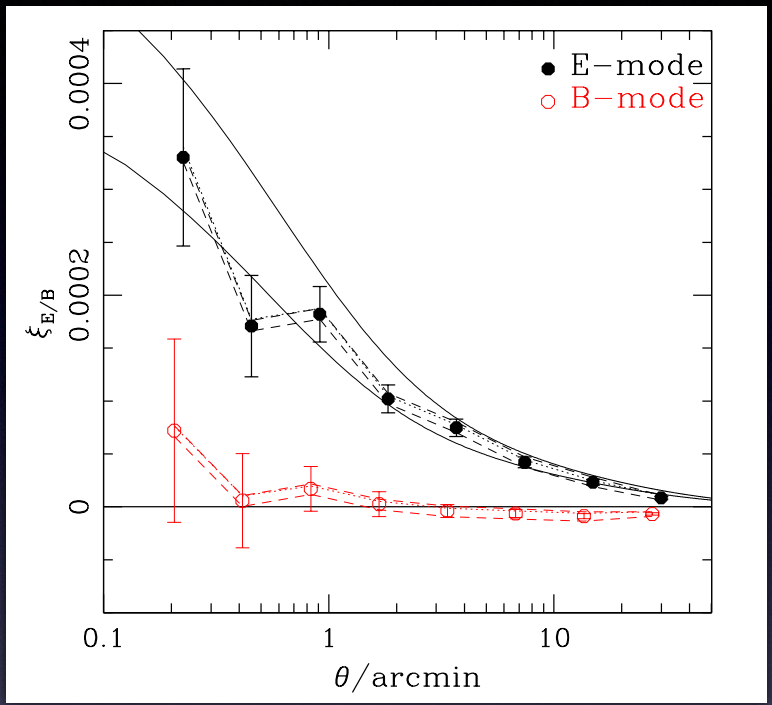
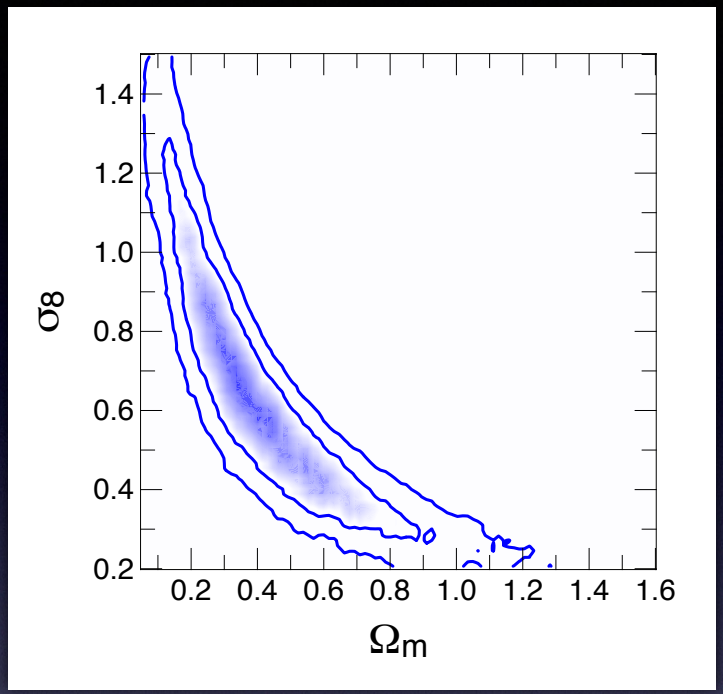
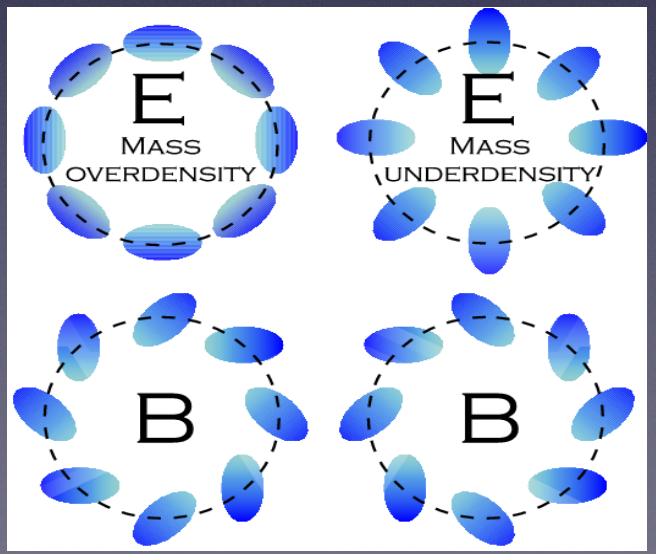


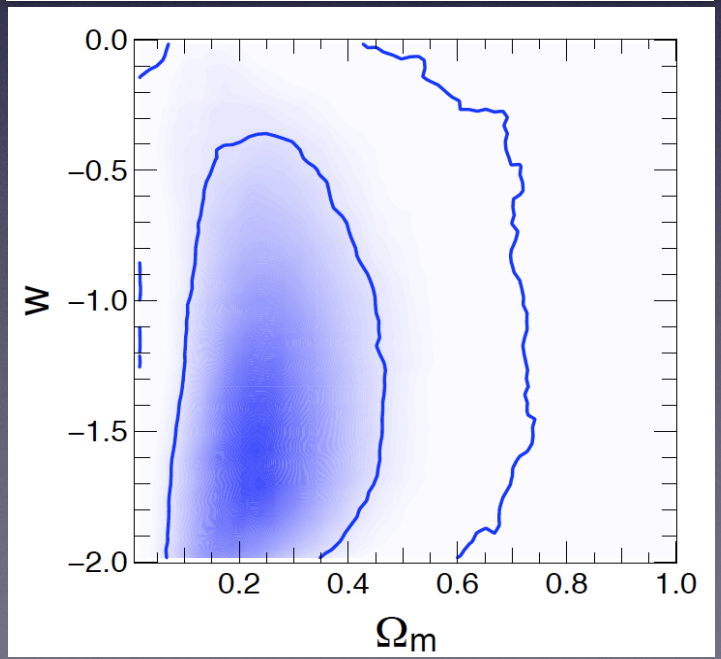
COSMOS

Schrabback et al. 2010



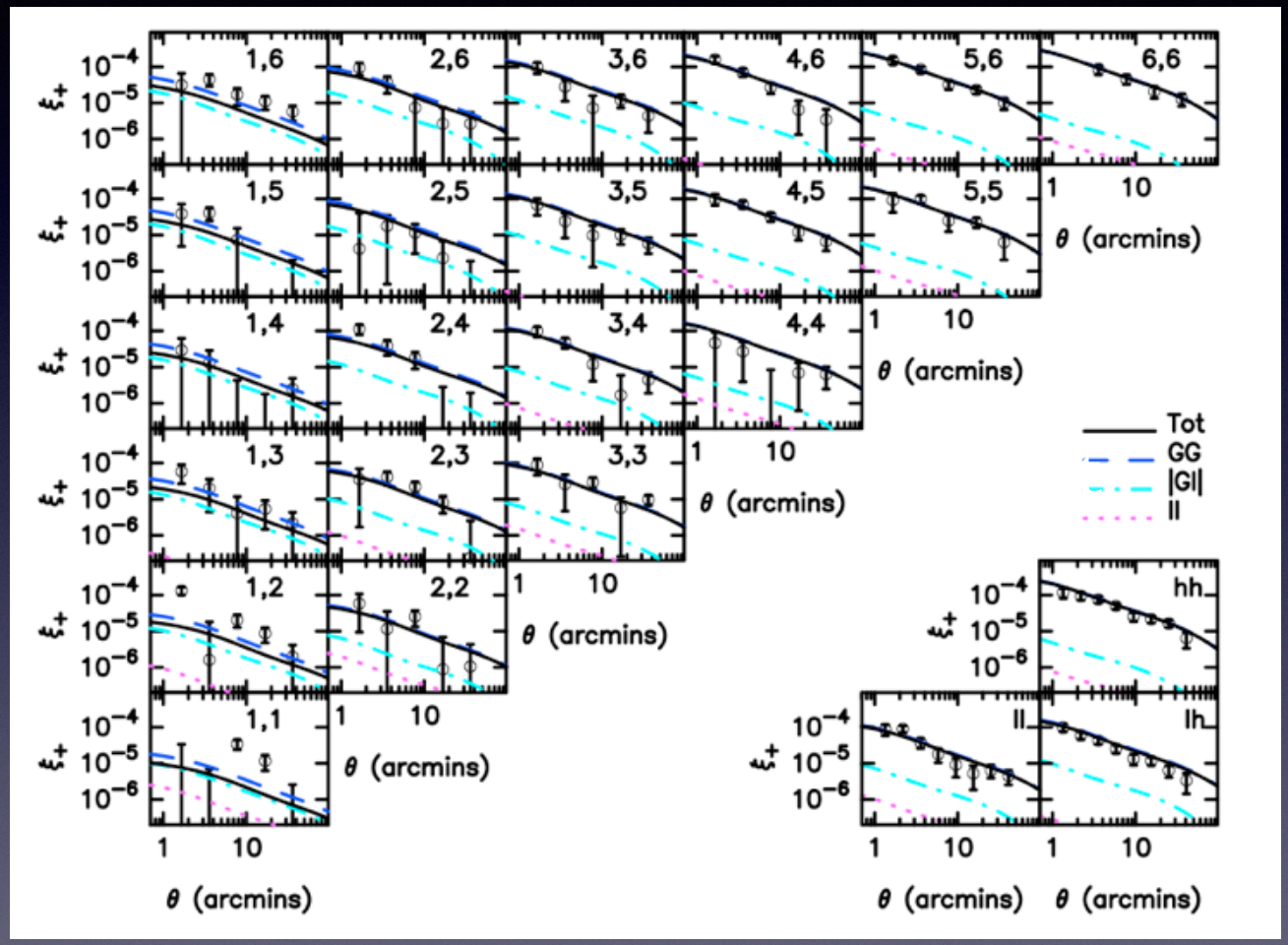


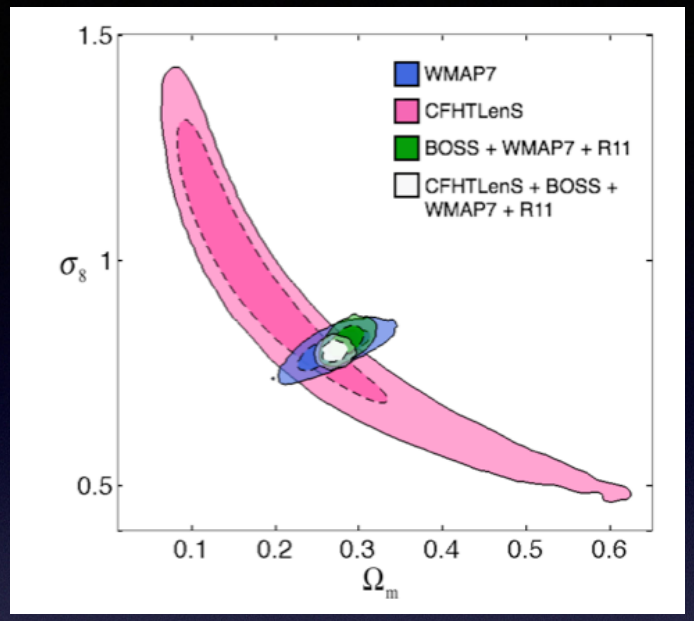


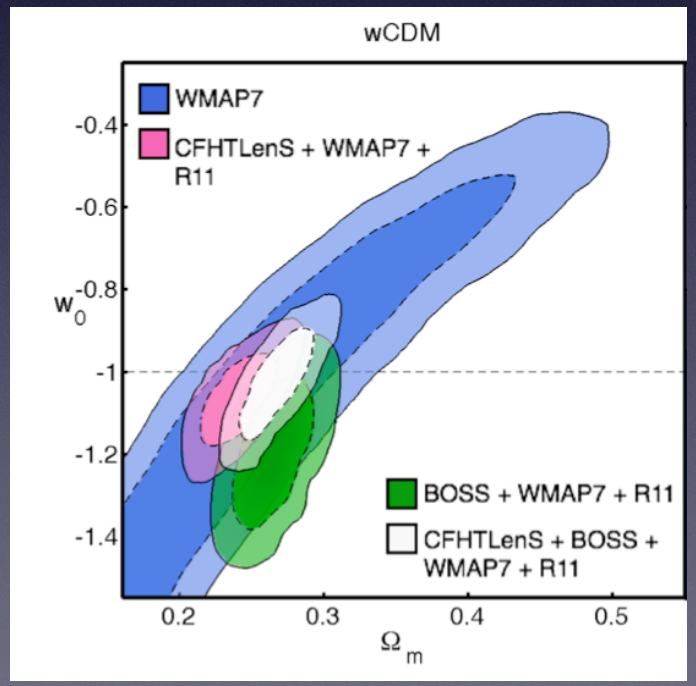


CFHTLenS

Heymans et al. 2013



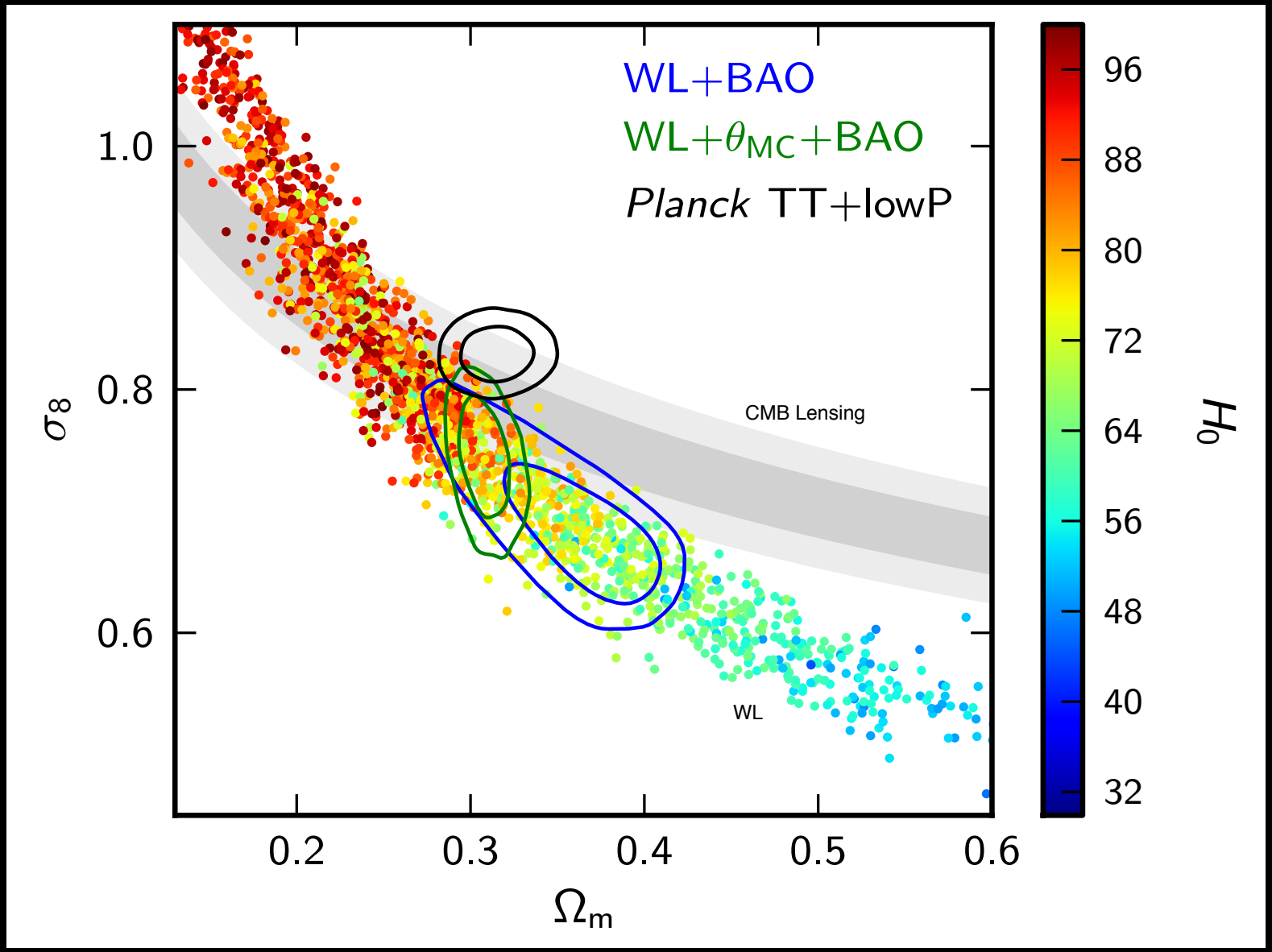




154 sq. deg., median z~0.7

Power Spectrum Amplitude

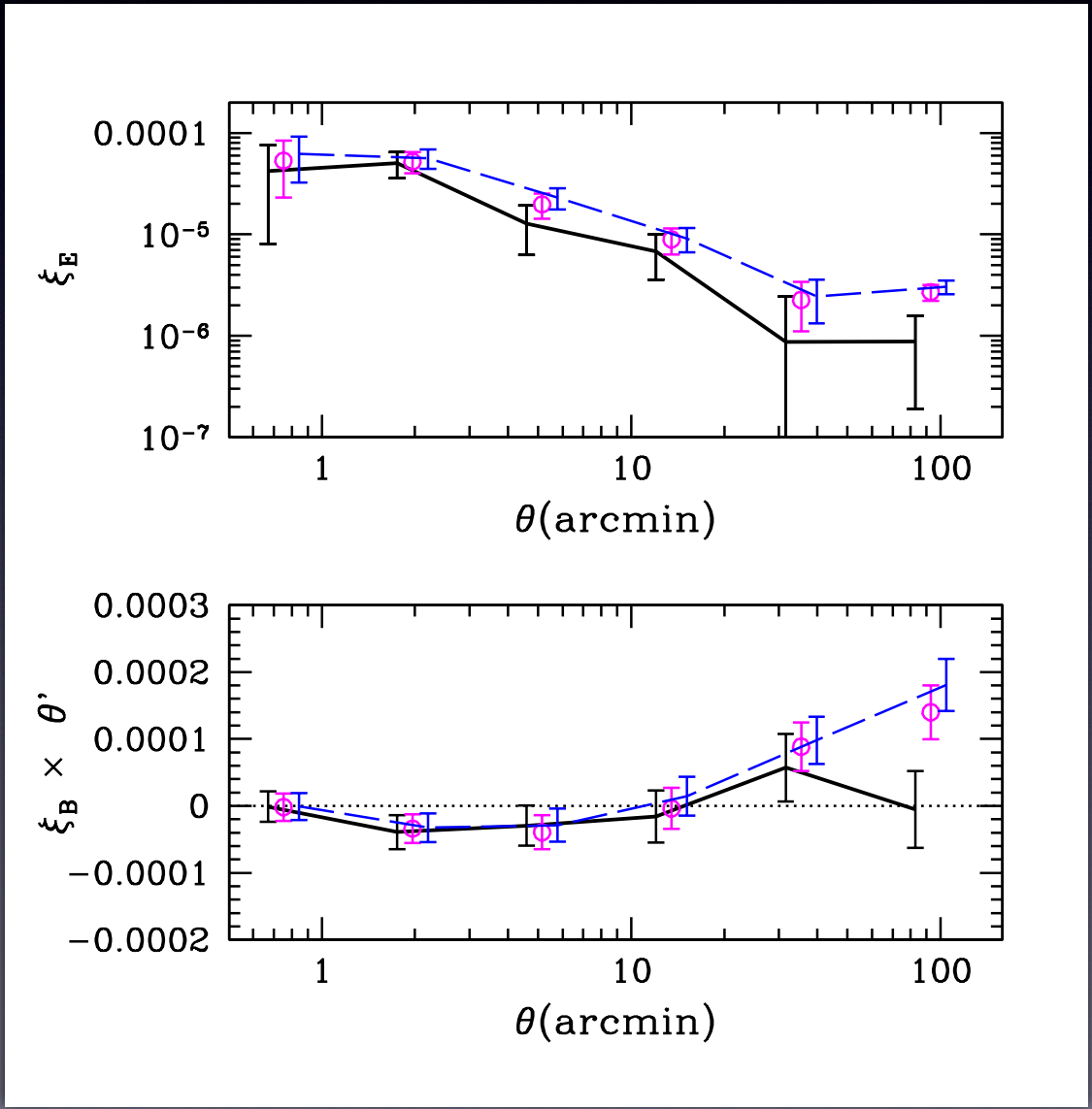
Planck XIII 2015



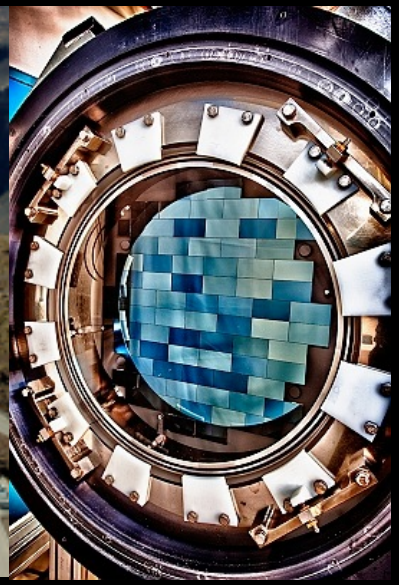
KiDS First Results

VST, first 101 deg^2, ugri, r band: mag<24.9(AB,5σ), z_m~0.53, seeing~0.7”

Kuijken et al. 2015

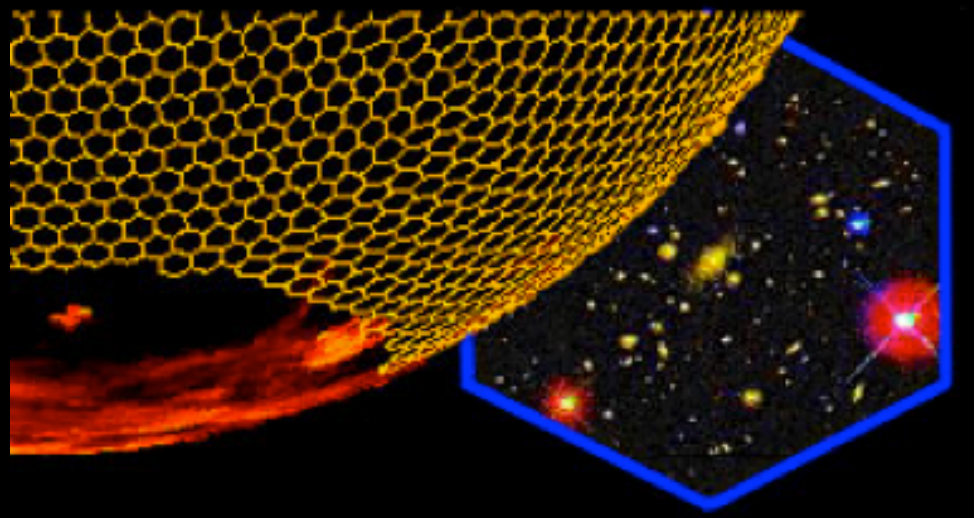


Dark Energy Survey



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

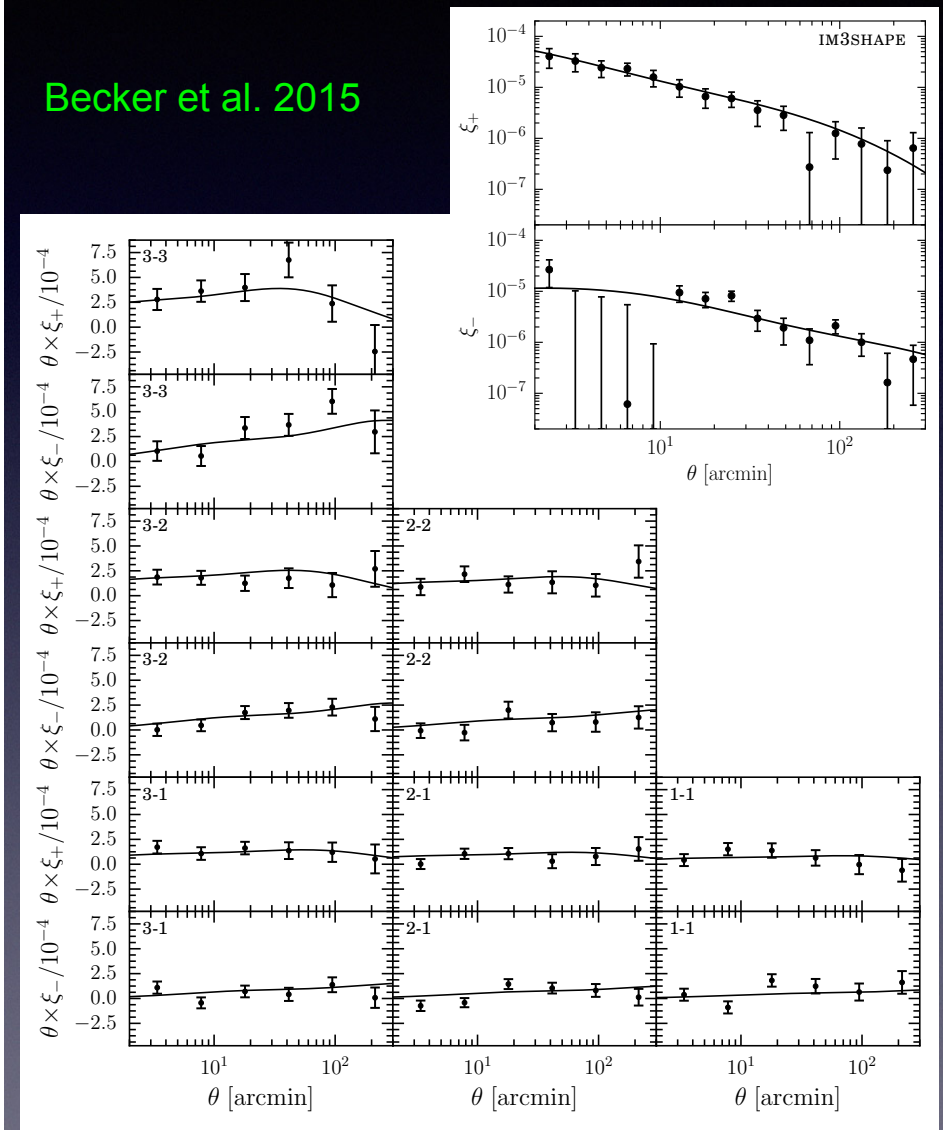


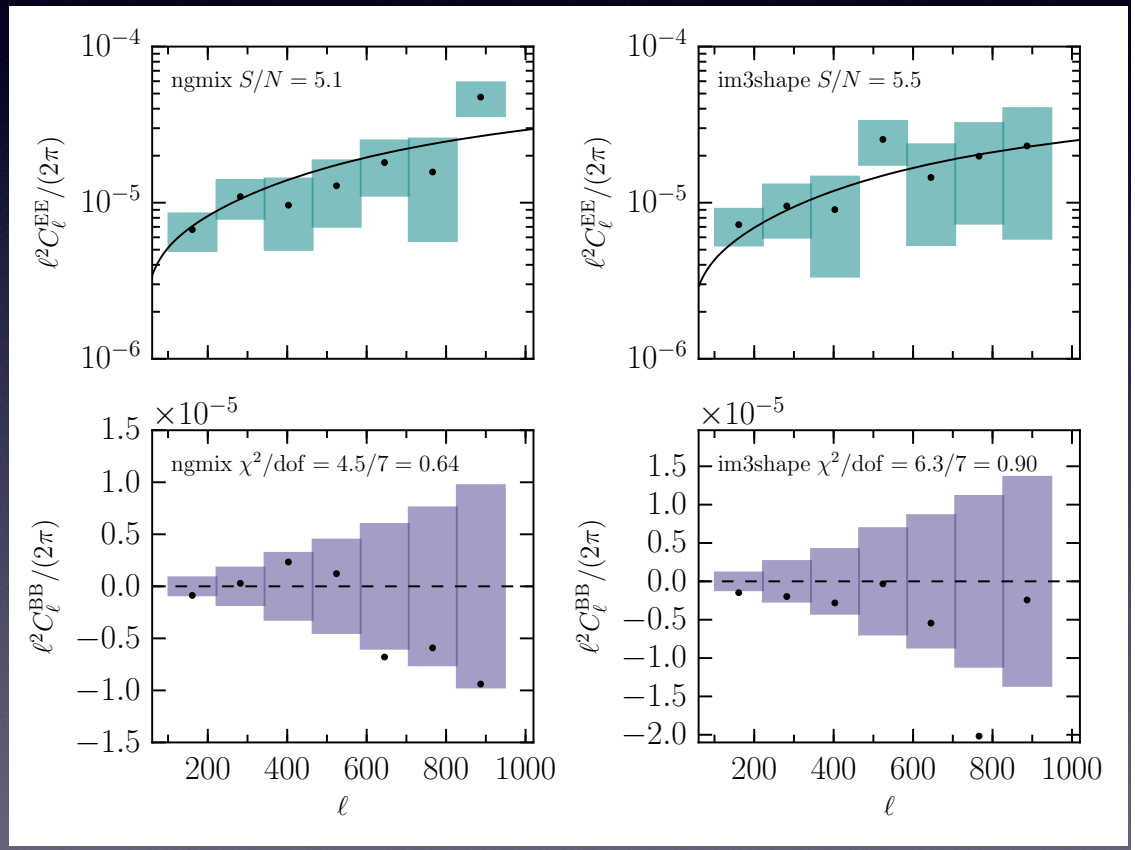
DES SV Results

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

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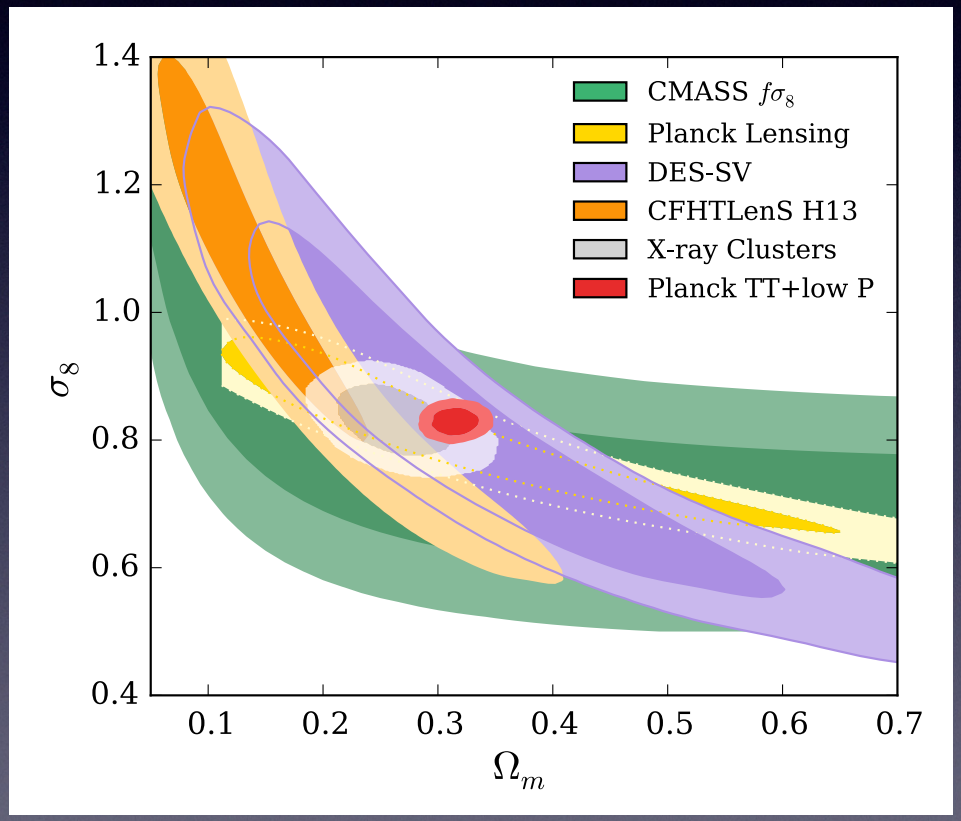
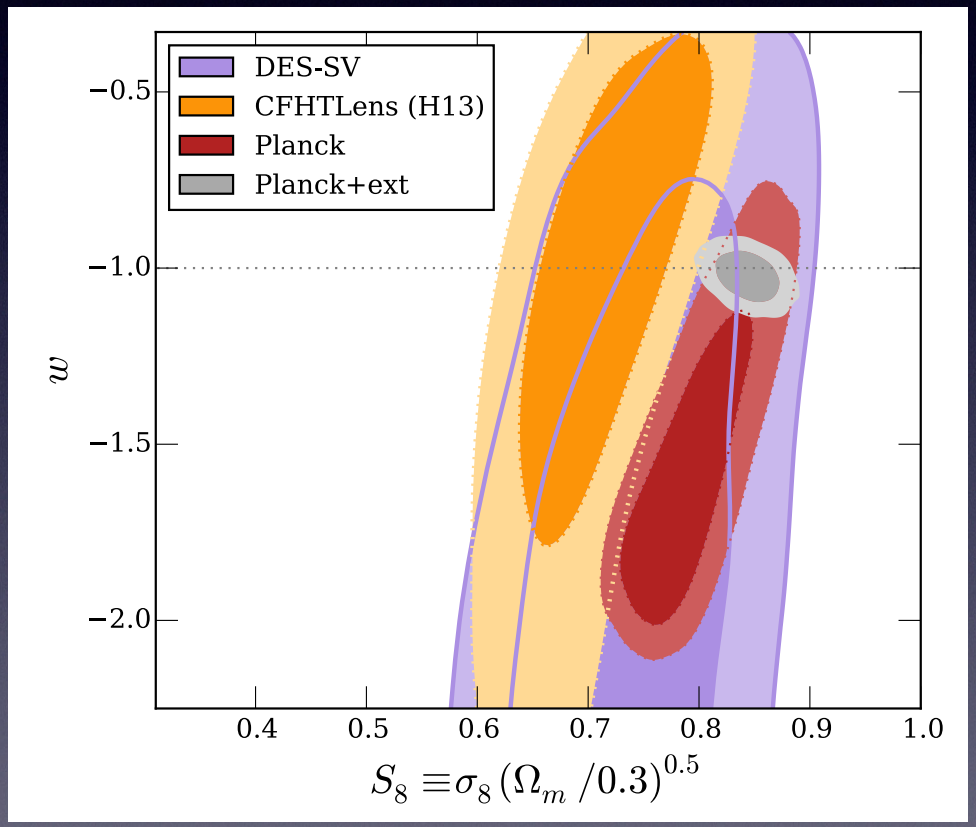
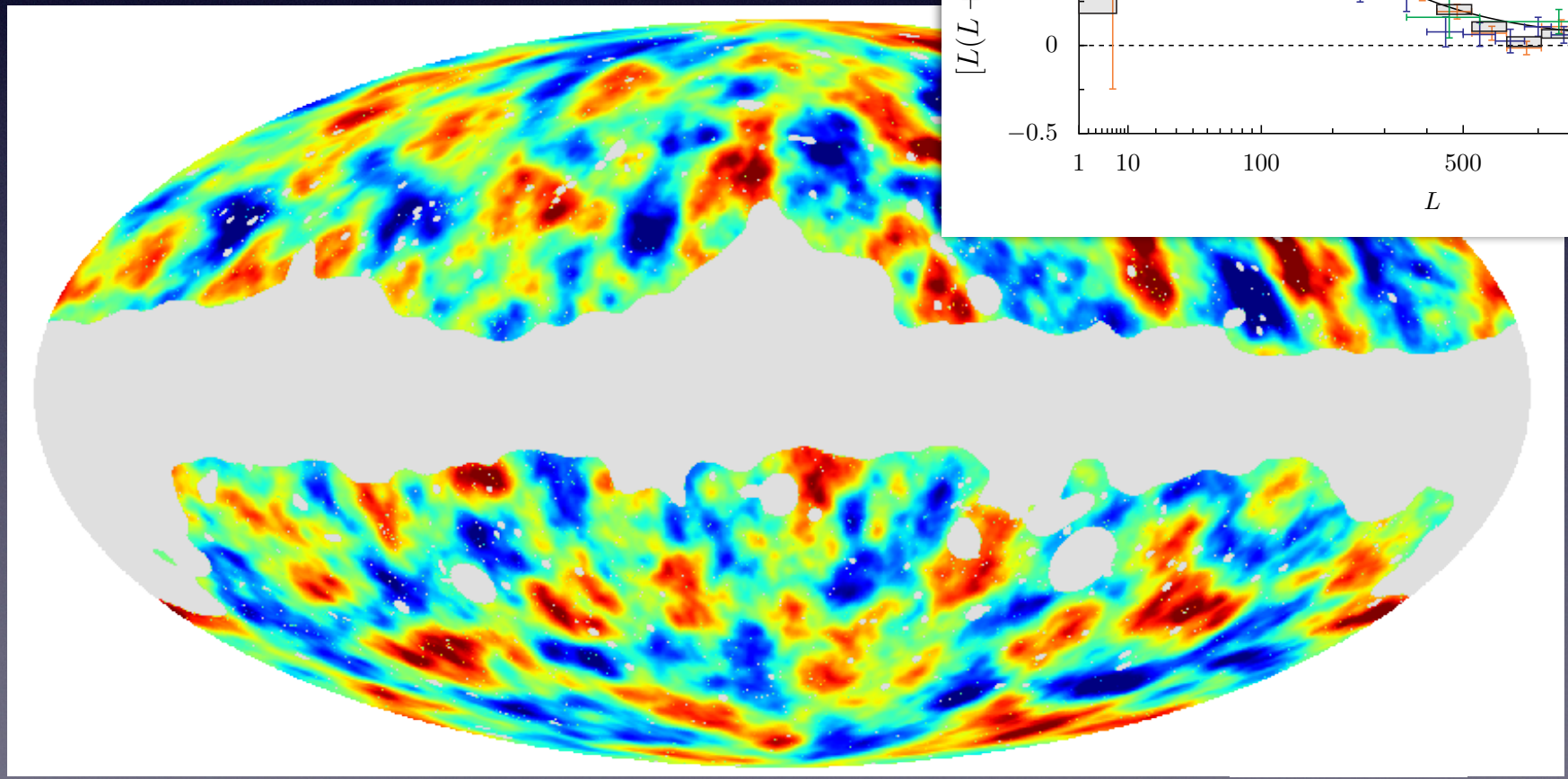
DES Collab 2015

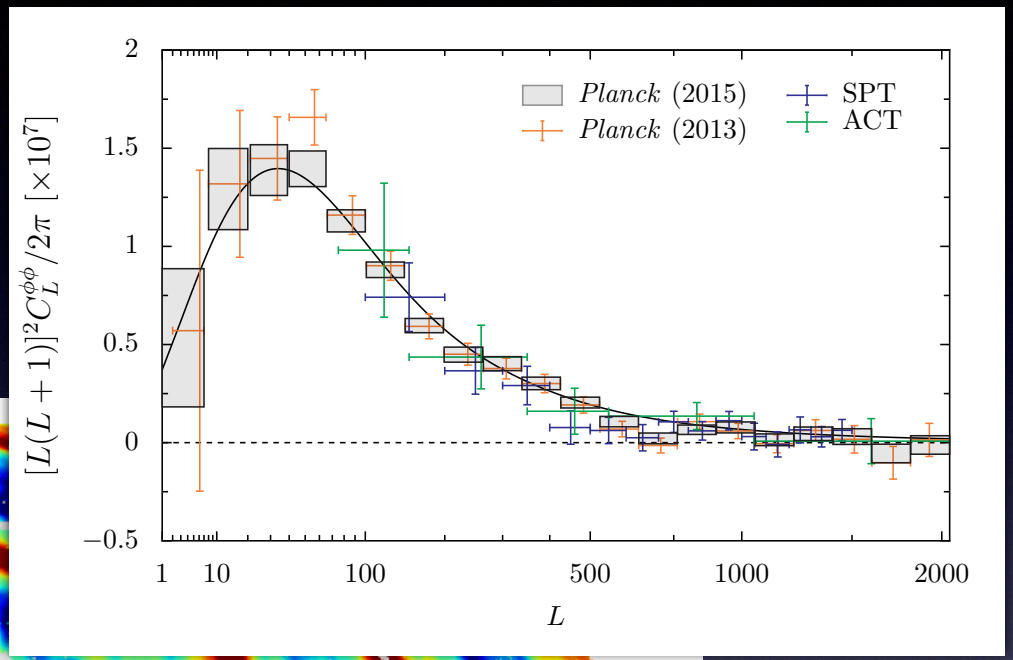




CMB Lensing

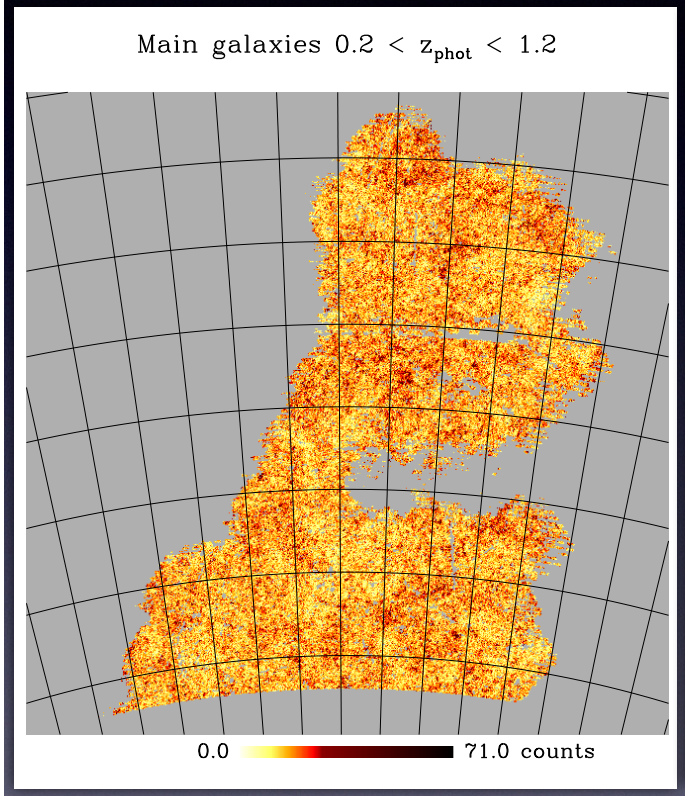
Planck XV, 2015

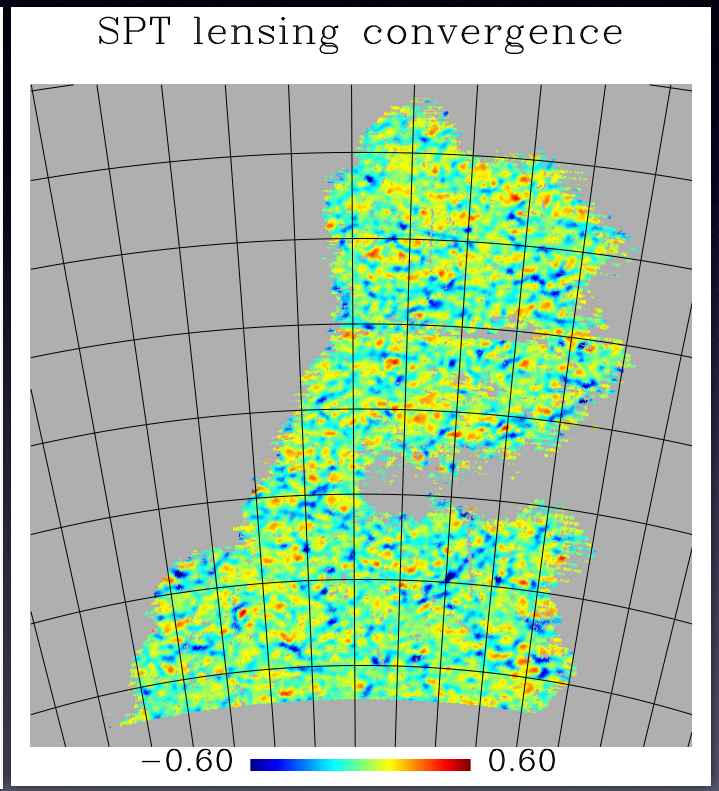


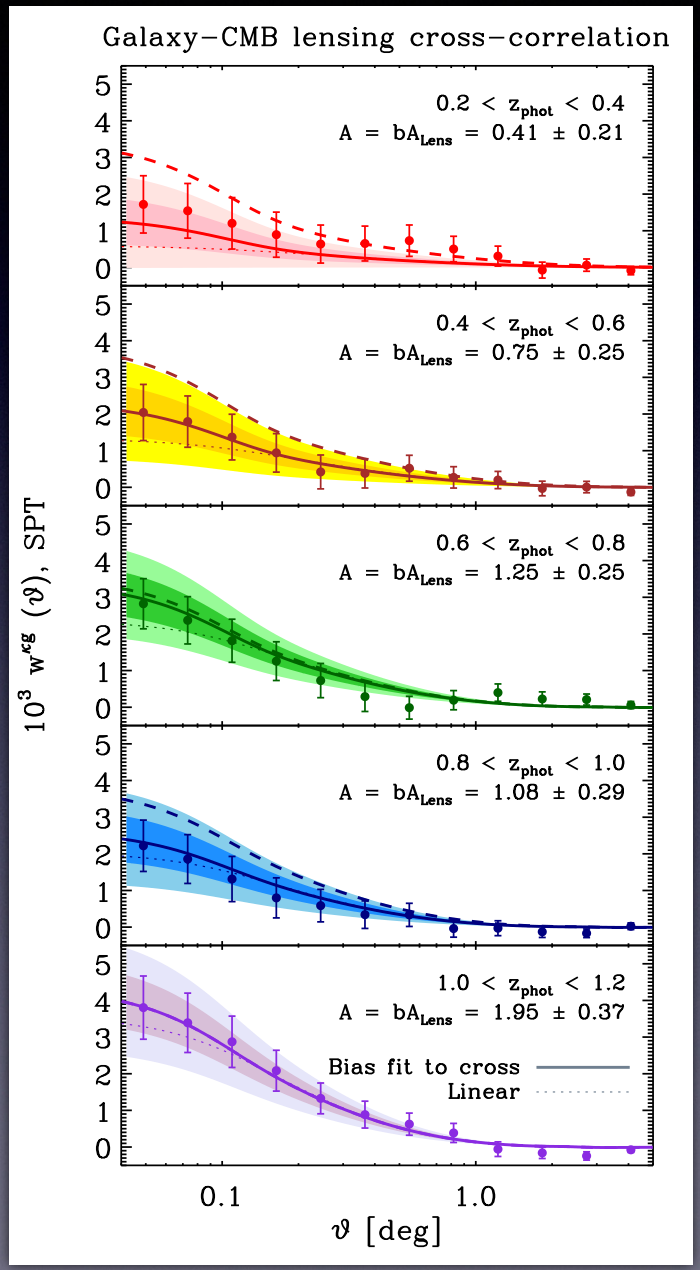


DES/SPT

Giannantonio et al. 2015







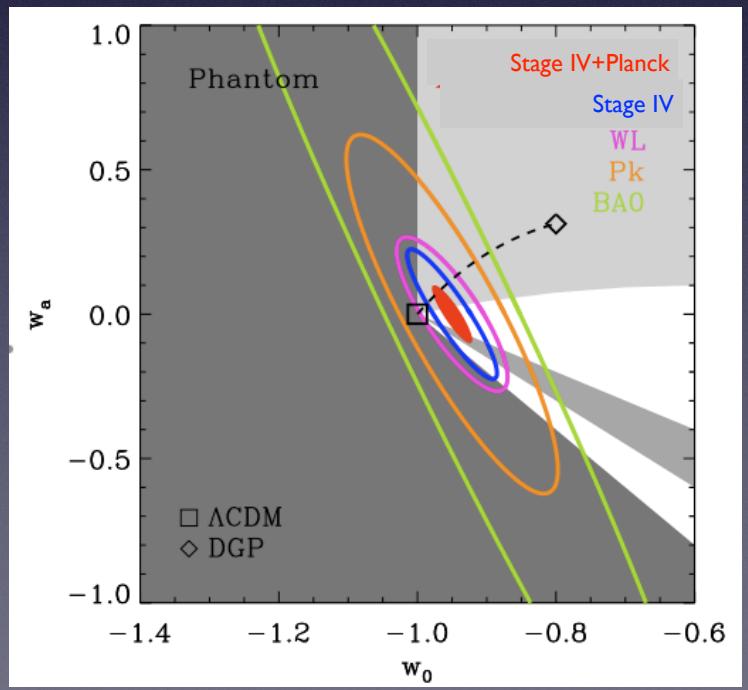
Wide-Field Instruments

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



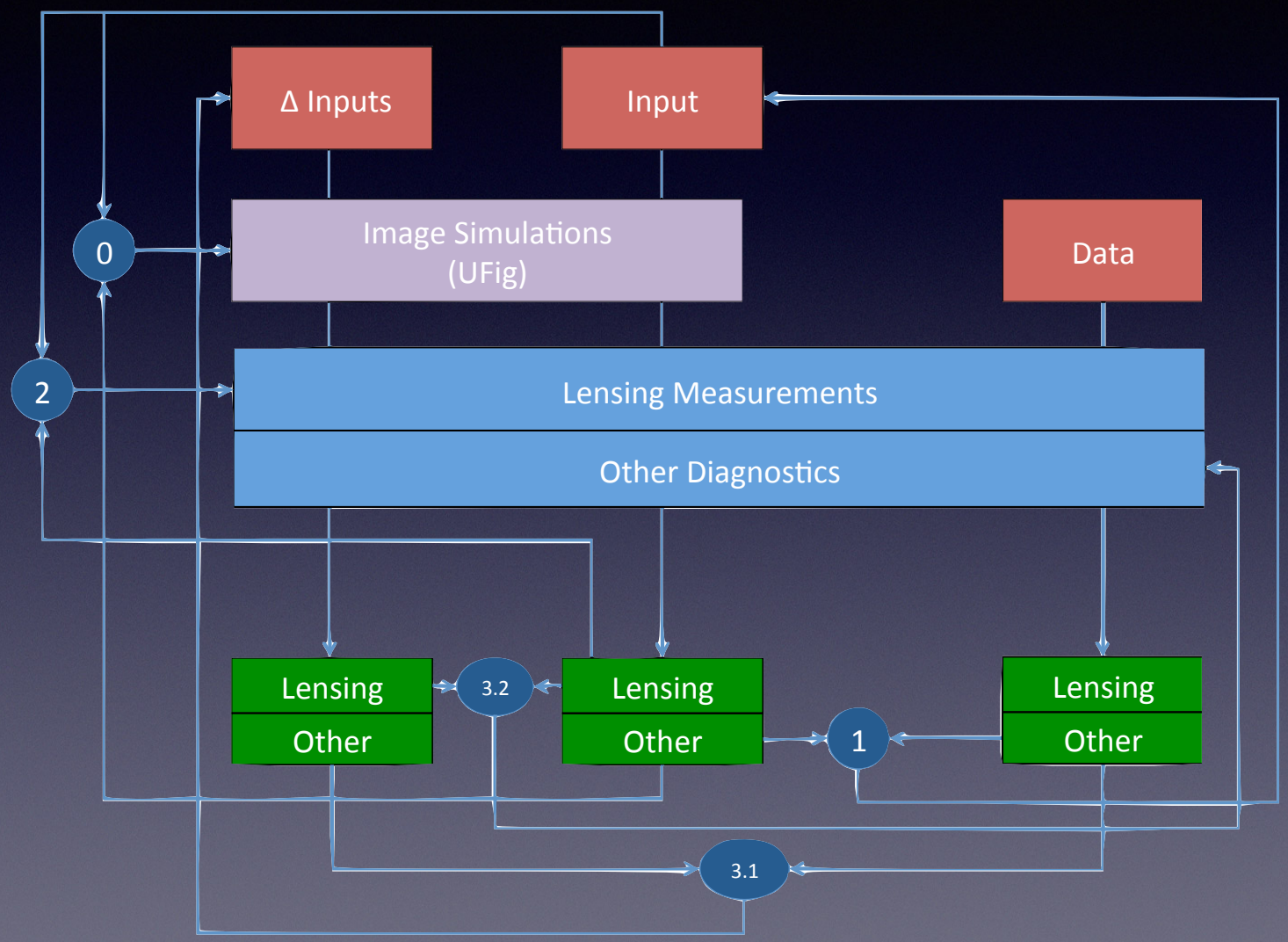
Stage IV Surveys will challenge all sectors of the cosmological model:

- 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

Monte-Carlo Control Loops

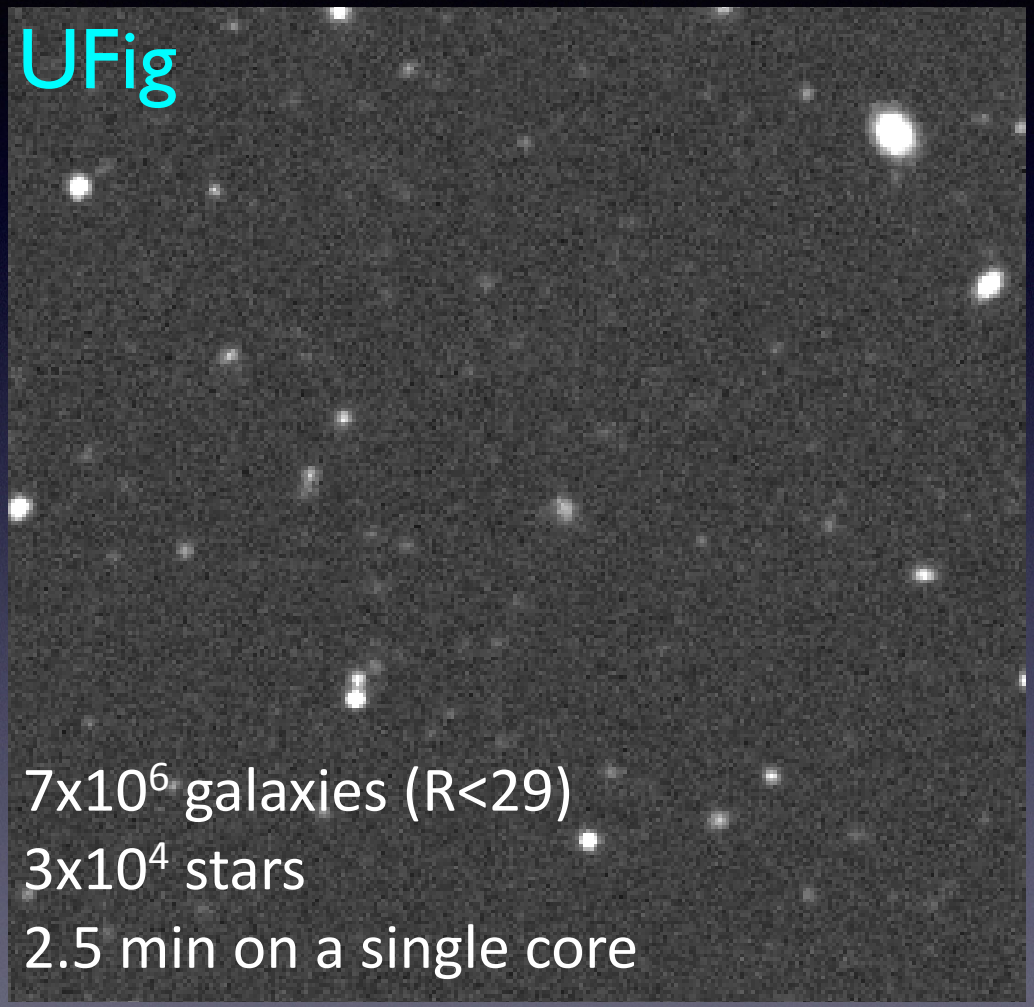
Refregier & Amara 2013



ETH zürich

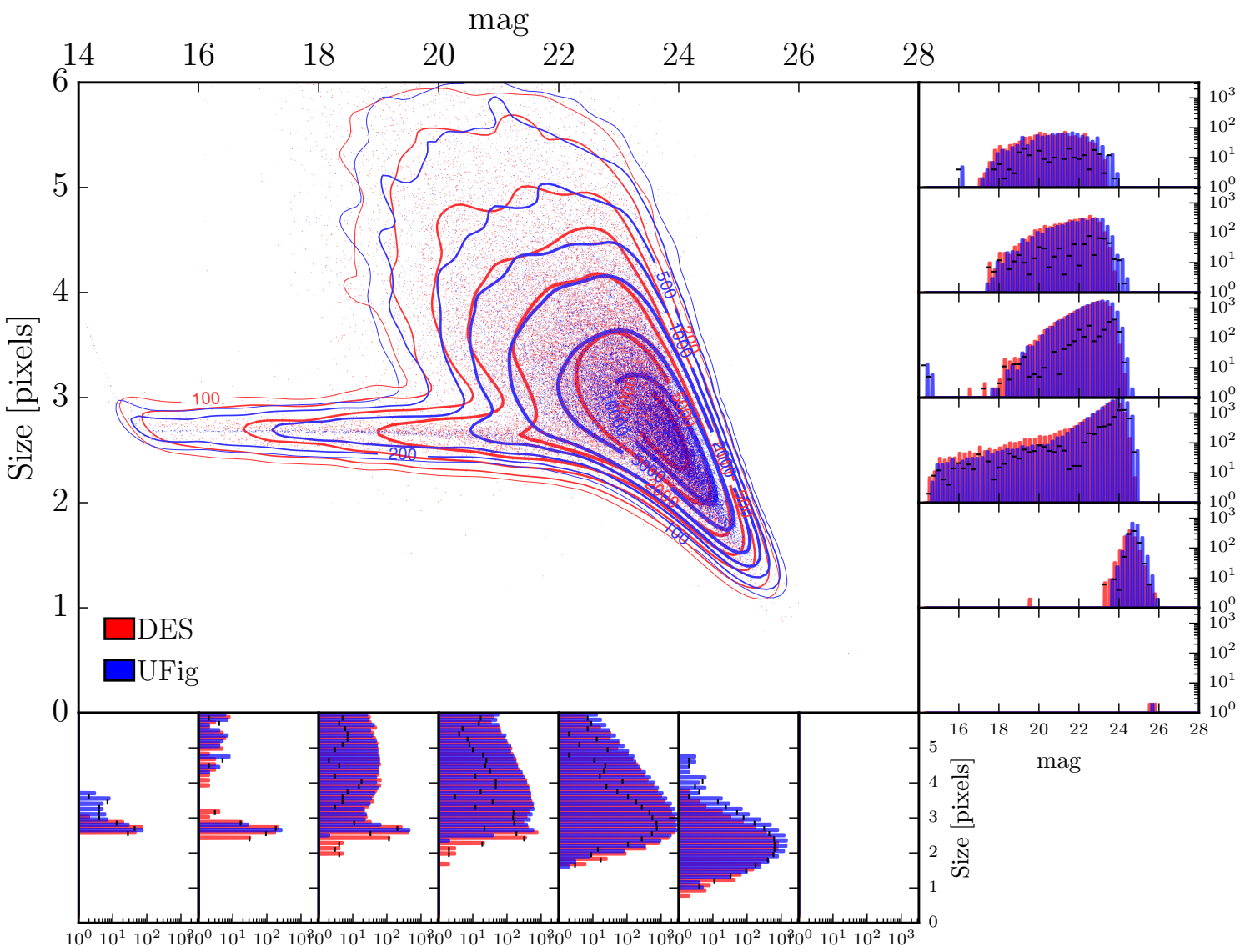
UFig Ultra Fast Image Generator

Bergé et al. 2013; Bruderer et al. 2015



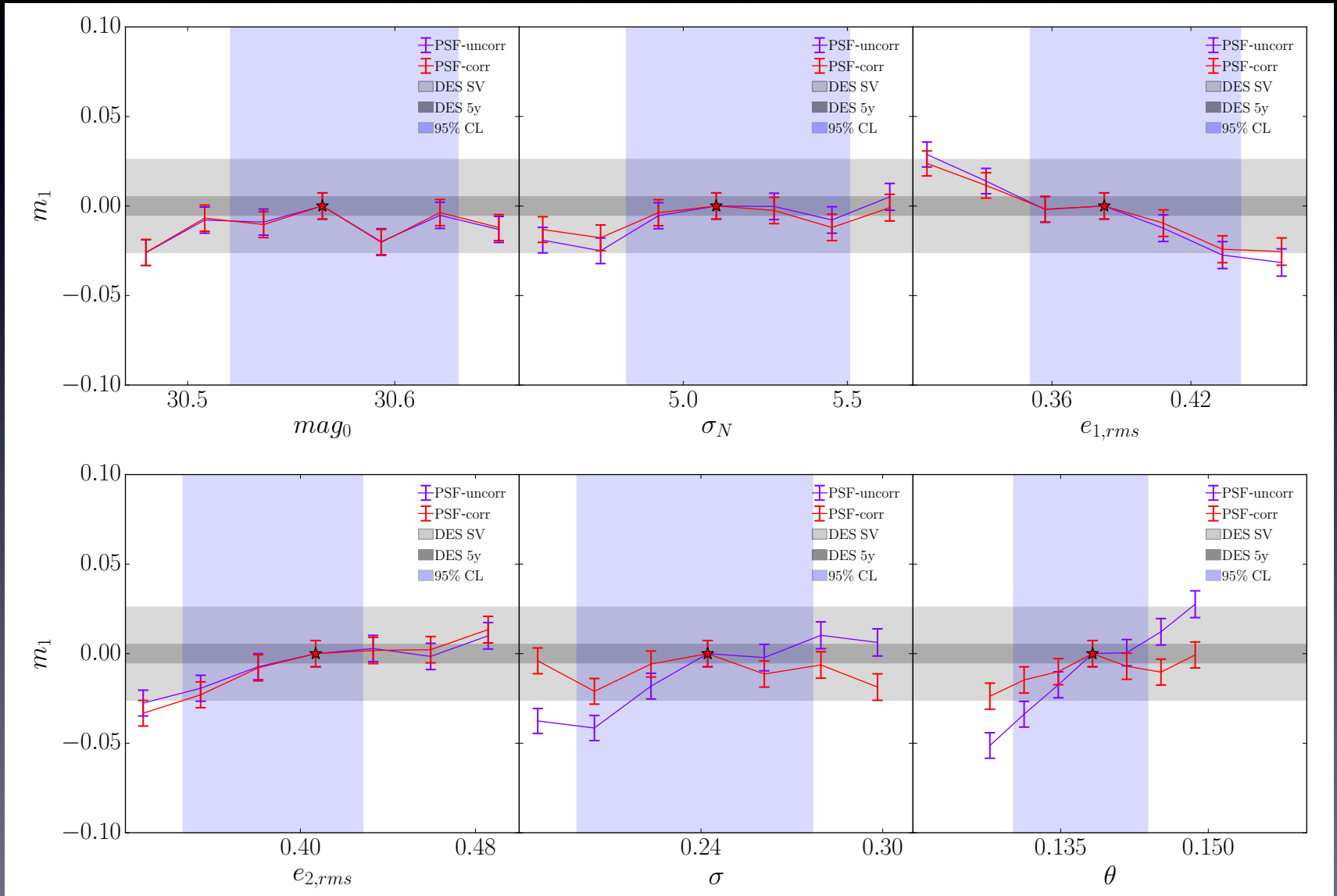
MCCL: First Implementation

Bruderer et al. 2015



Tolerance Analysis

Bruderer et al. 2015



Conclusions

- Gravitational Lensing is a special probe of the dark universe: purely gravitational, direct probe of mass, strong statistical power

- Many wide field lensing surveys coming online or being planned: require new level of data analysis

- DES Science Verification results tend to alleviate tension on power spectrum amplitude

- Synergy between Weak Lensing, CMB and galaxy clustering