Large Scale Structure Surveys

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

SWAPS 2014
Cartigny
13.6.2014

ETH | Cosmology
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ΛCDM Model

Inflation

Radiation

Matter
Baryons (5%)
Dark Matter (24%)

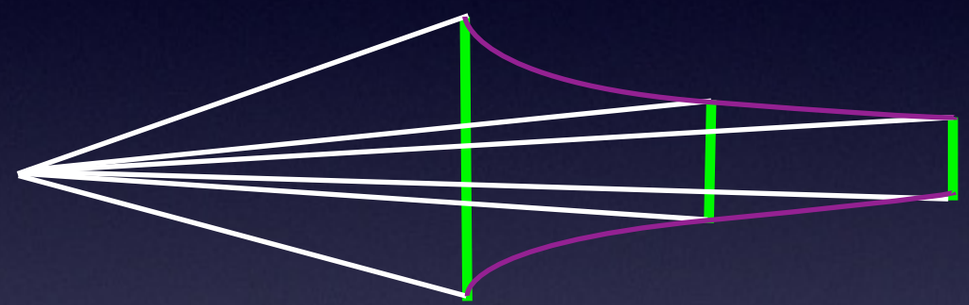
Dark Energy (71%)

Gravity

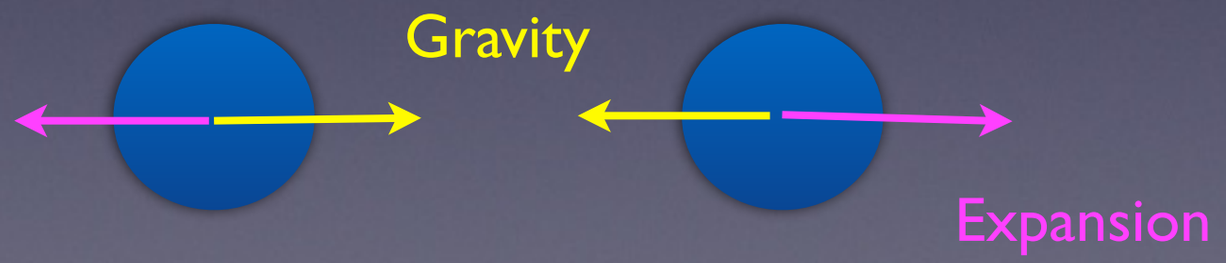
DARK UNIVERSE

Measuring the Dark Universe

- Geometry

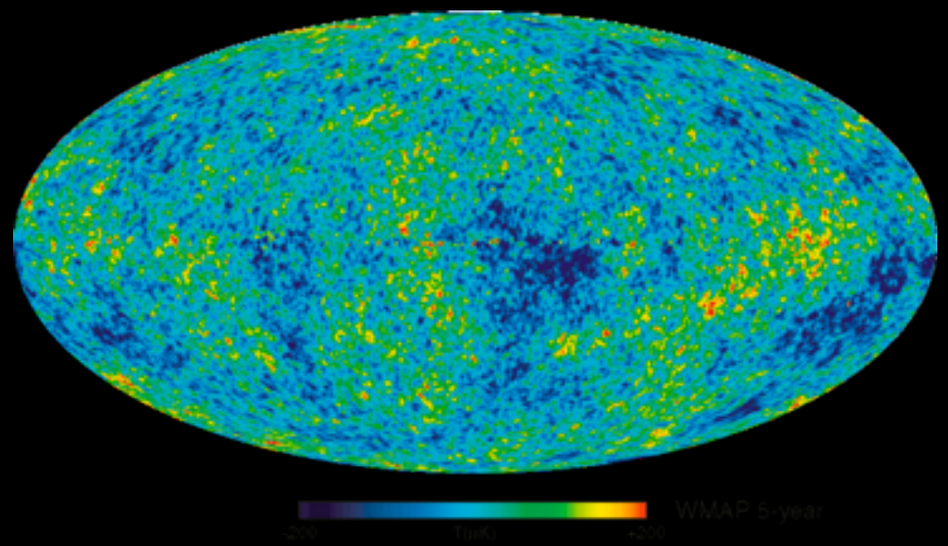


- Growth of structure

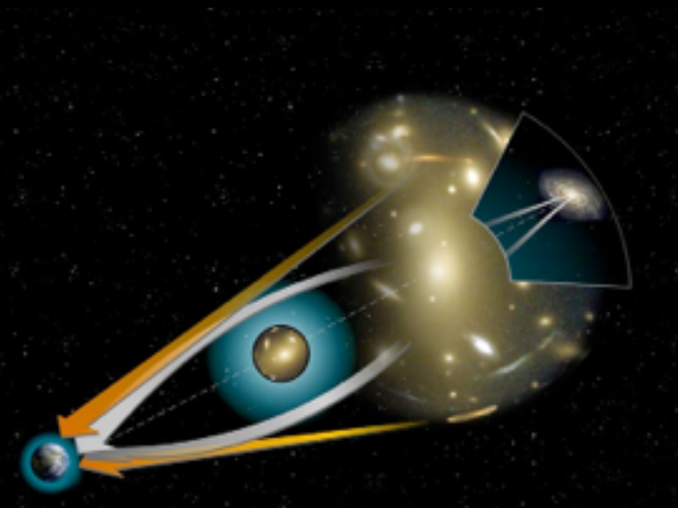


Cosmological Probes

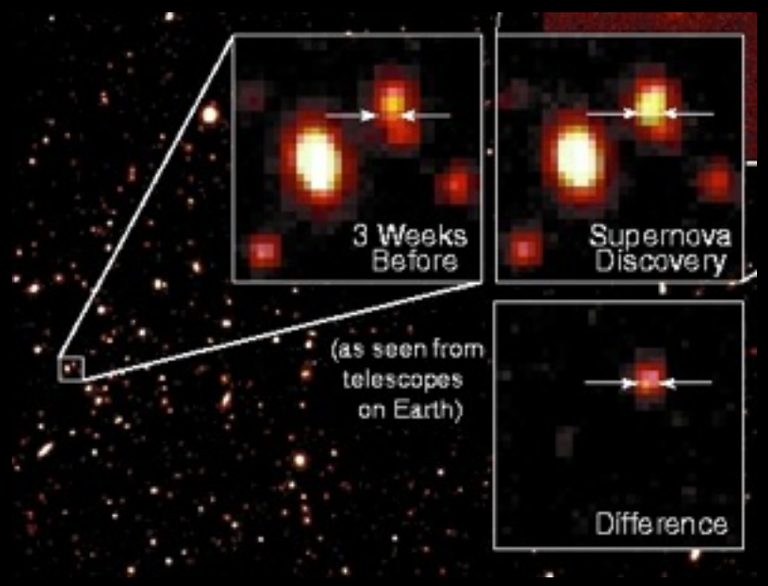
Cosmic Microwave Background



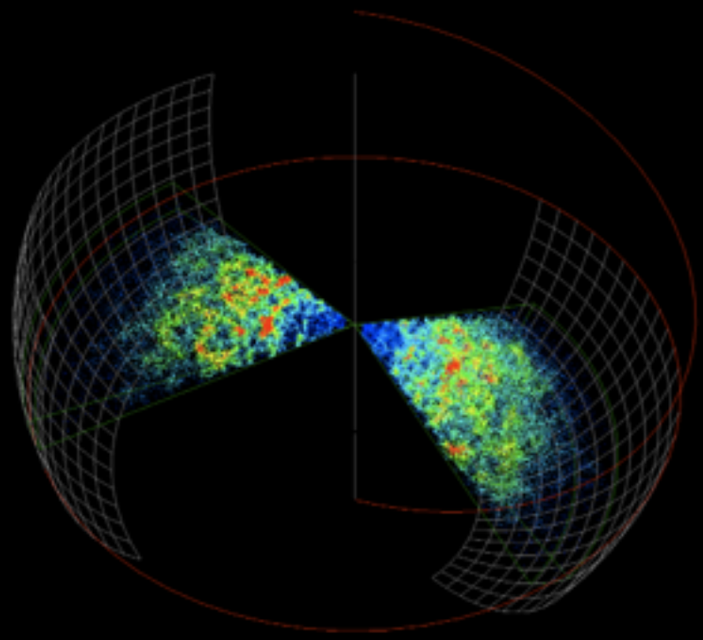
Gravitational Lensing



Supernovae

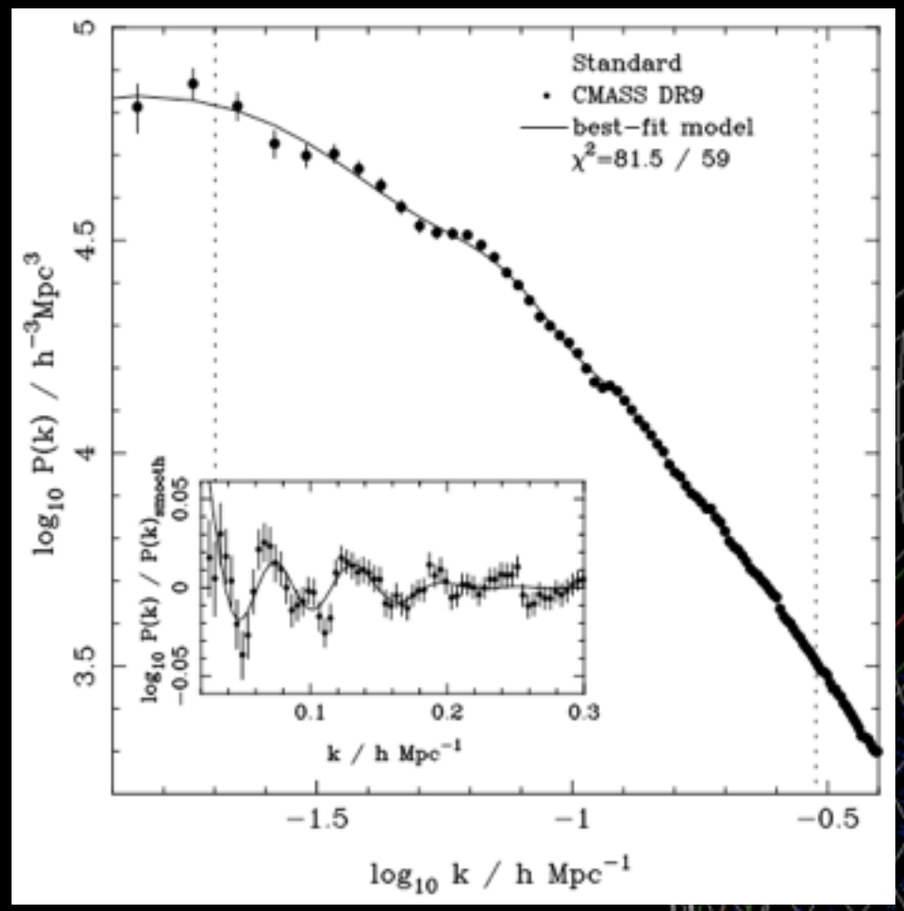


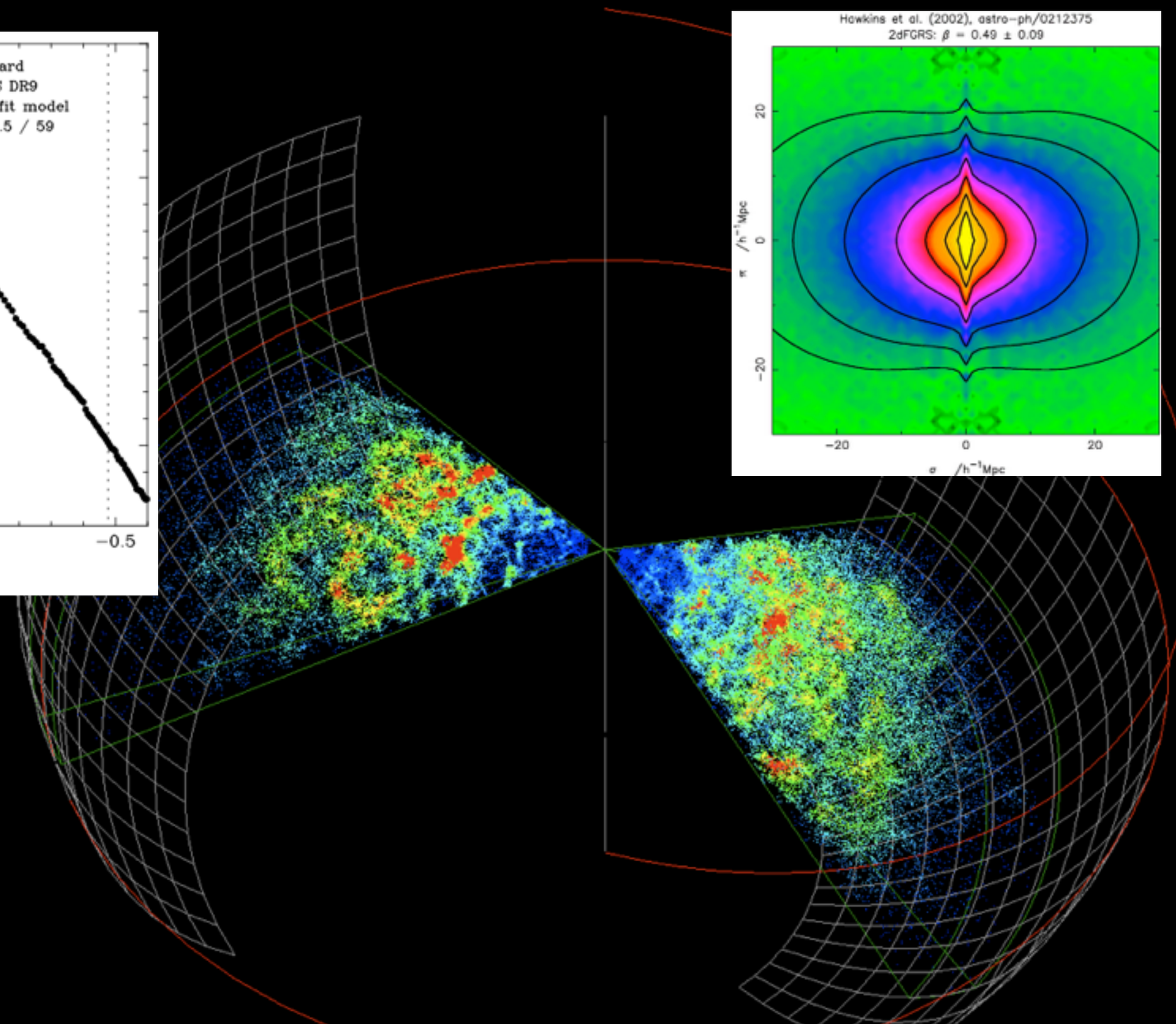
Large Scale Clustering



Galaxy Redshift Surveys

Anderson et al. 2012

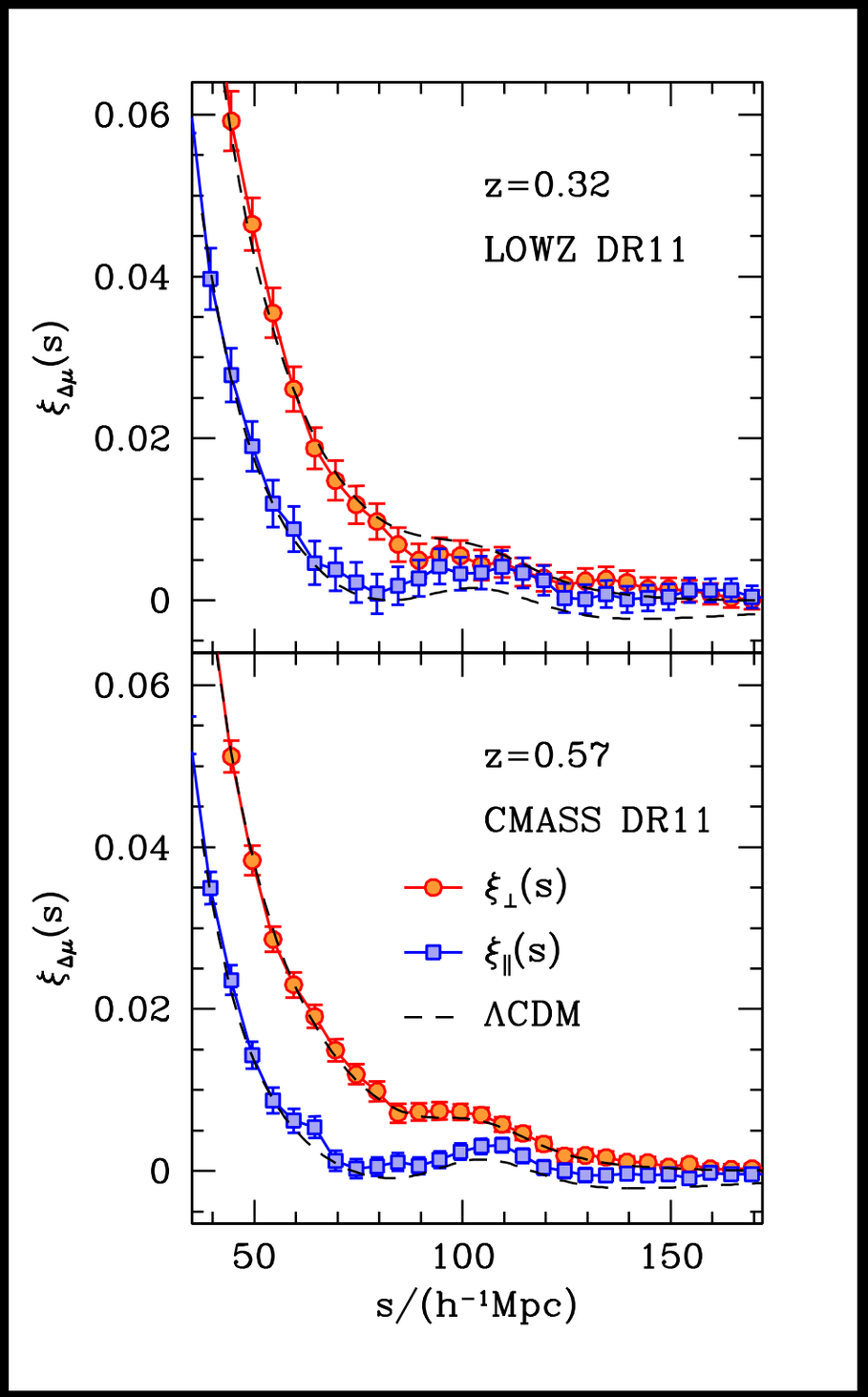




SDSS survey:
Eisenstein et al. 2004
2dF survey:
Percival et al 2004

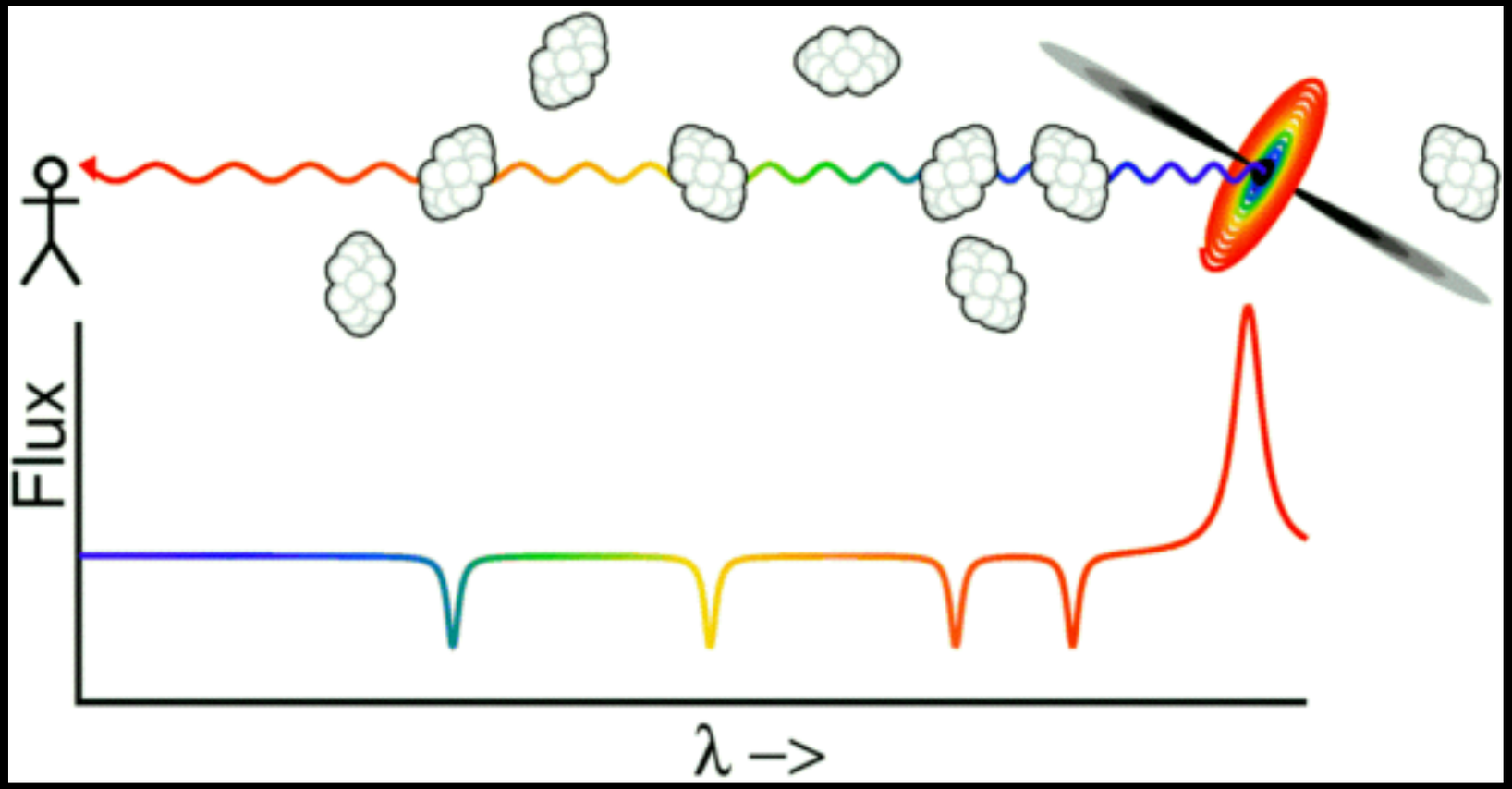
BOSS DR10/11

Sanchez et al. 2013



	ePlanck+BOSS $\xi(s)$	ePlanck+BOSS $\xi_{\Delta_\mu}(s)$	ePlanck + BOSS $\xi_{\Delta\mu}(s)$ +BAO+SN
The ΛCDM model			
h	$0.6824^{+0.0072}_{-0.0072}$	0.6863 ± 0.0075	0.6899 ± 0.0070
$100\Omega_{\rm m}$	$30.22^{+0.94}_{-0.96}$	$29.71^{+0.97}_{-0.96}$	29.24 ± 0.86
Constant dark energy equation of state			
$w_{\rm DE}$	$-1.31^{+0.21}_{-0.16}$	-1.051 ± 0.076	-1.024 ± 0.052
$100\Omega_{\rm m}$	$24.9^{+3.4}_{-2.6}$	28.8 ± 1.6	29.3 ± 1.1
Time-dependent dark energy equation of state			
w_0	$-1.29^{+0.48}_{-0.46}$	$-0.83^{+0.38}_{-0.34}$	-0.95 ± 0.14
w_a	$-0.0^{+1.0}_{-1.1}$	$-0.61^{+0.89}_{-0.96}$	-0.29 ± 0.47
$100\Omega_{\rm m}$	$25.2^{+5.7}_{-6.6}$	$30.9^{+4.1}_{-3.6}$	29.5 ± 1.3
Non-flat models			
$100\Omega_k$	0.07 ± 0.31	0.10 ± 0.29	0.15 ± 0.29
$100\Omega_{\rm m}$	30.18 ± 0.96	$29.60^{+0.99}_{-0.97}$	29.11 ± 0.91
Curvature and dark energy			
$w_{\rm DE}$	$-1.53^{+0.24}_{-0.28}$	-1.05 ± 0.11	$-1.009^{+0.062}_{-0.060}$
$100\Omega_k$	$-0.38^{+0.24}_{-0.28}$	0.02 ± 0.43	-0.14 ± 0.33
$100\Omega_{\rm m}$	$22.0^{+3.2}_{-4.9}$	28.9 ± 2.0	29.4 ± 1.2
Massive neutrinos			
$\sum m_\nu$	$< 0.23\,$eV (95% CL)	$< 0.24\,$eV (95% CL)	$< 0.23\,$eV (95% CL)
f_ν	< 0.017 (95% CL)	< 0.019 (95% CL)	< 0.017 (95% CL)
Massive neutrinos and dark energy			
$\sum m_\nu$	$< 0.49\,$eV (95% CL)	$< 0.47\,$eV (95% CL)	$< 0.33\,$eV (95% CL)
$w_{\rm DE}$	$-1.49^{+0.24}_{-0.30}$	-1.13 ± 0.12	-1.046 ± 0.063
Additional relativistic degrees of freedom			
$N_{\rm eff}$	3.35 ± 0.27	3.31 ± 0.27	3.30 ± 0.27
$100\Omega_{\rm m}$	29.7 ± 1.0	29.2 ± 1.1	29.1 ± 1.0
Deviations from general relativity			
γ	-	0.69 ± 0.15	0.69 ± 0.15
$100\Omega_{\rm m}$	-	$29.76^{+0.93}_{-0.90}$	29.62 ± 0.89
Dark energy and modified gravity			
γ	-	0.88 ± 0.22	0.75 ± 0.17
$w_{\rm DE}$	-	-1.15 ± 0.11	-1.055 ± 0.057

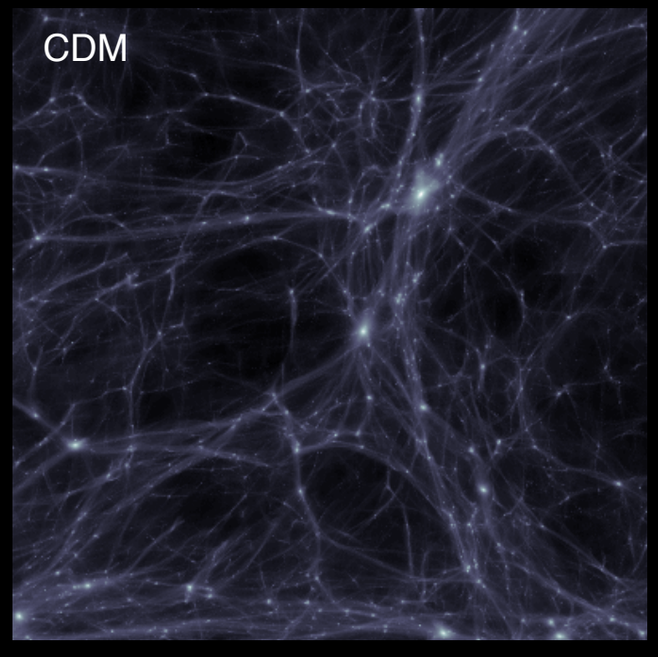
Lyα Forest

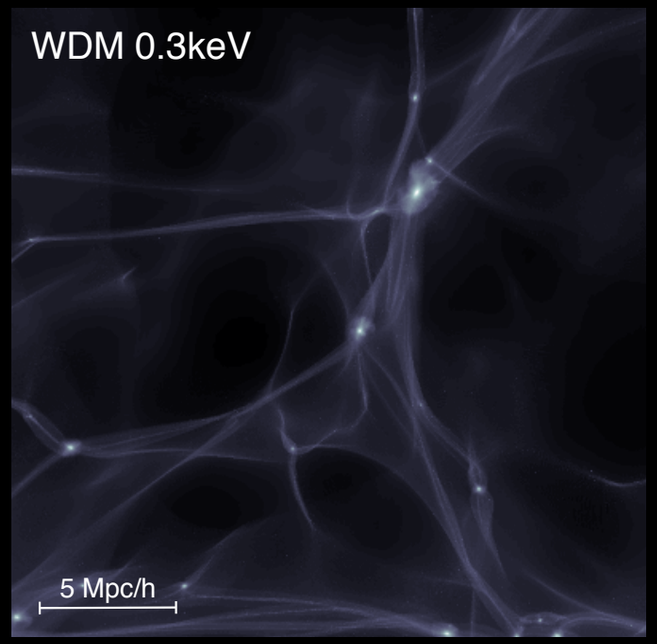


credit: N. Wright, B. Keel

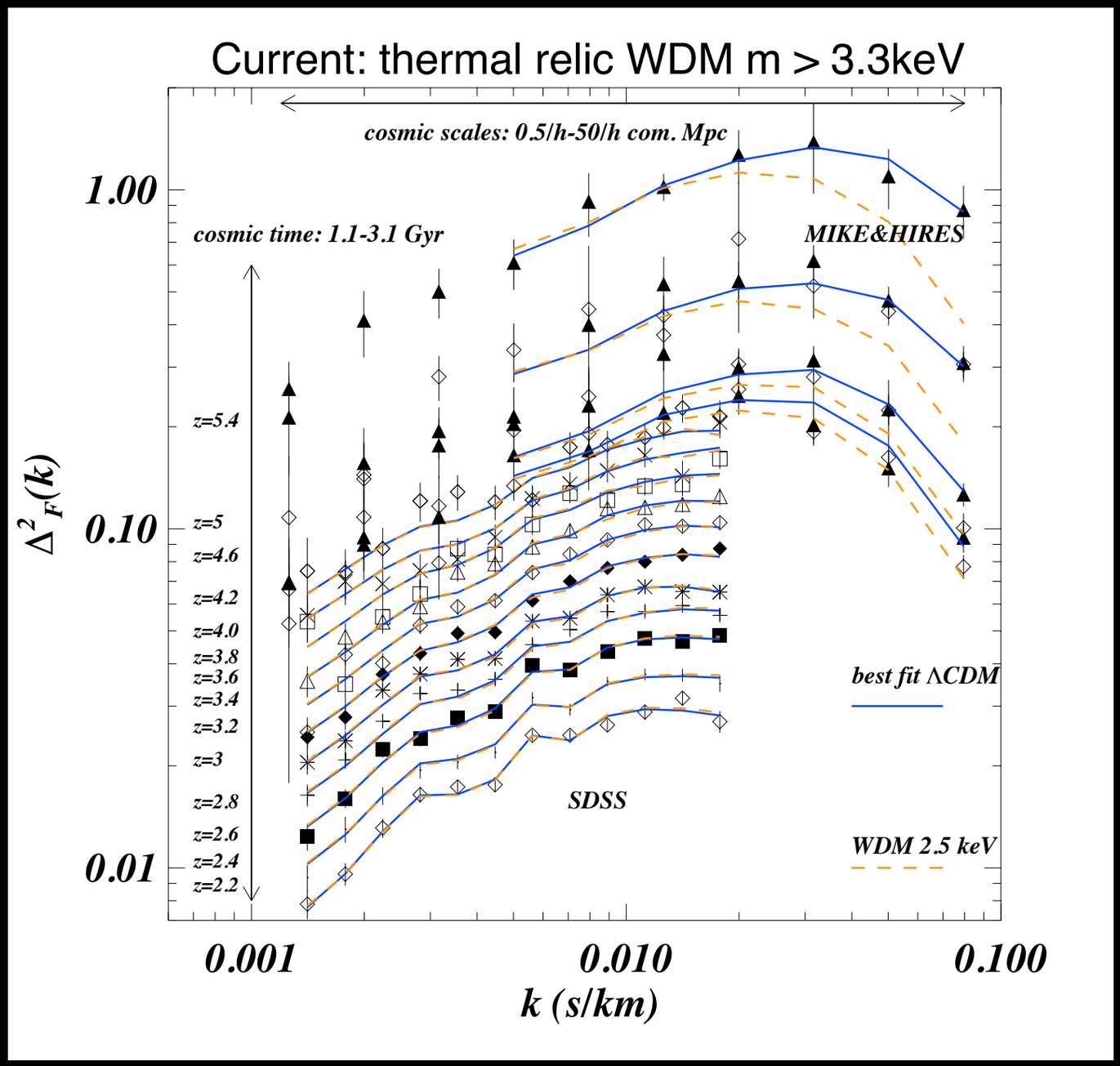
Warm Dark Matter

Hahn 2013





Markovic & Viel 2014

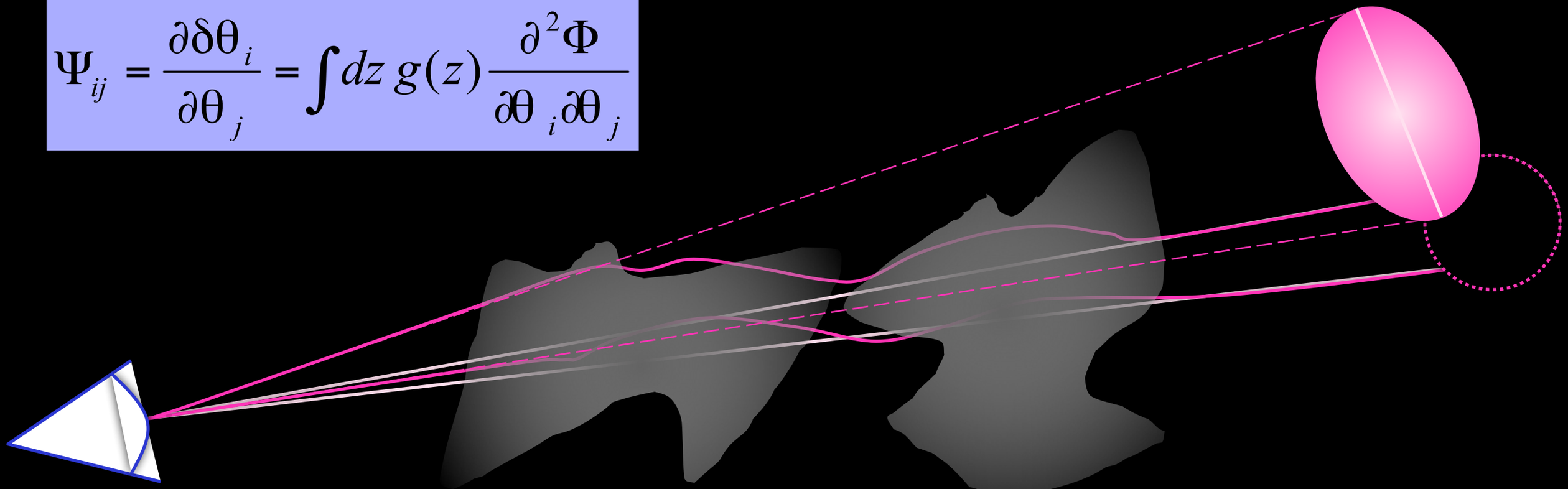


Weak Gravitational Lensing

Massey et al.
review: Refregier 2003

Distortion matrix:

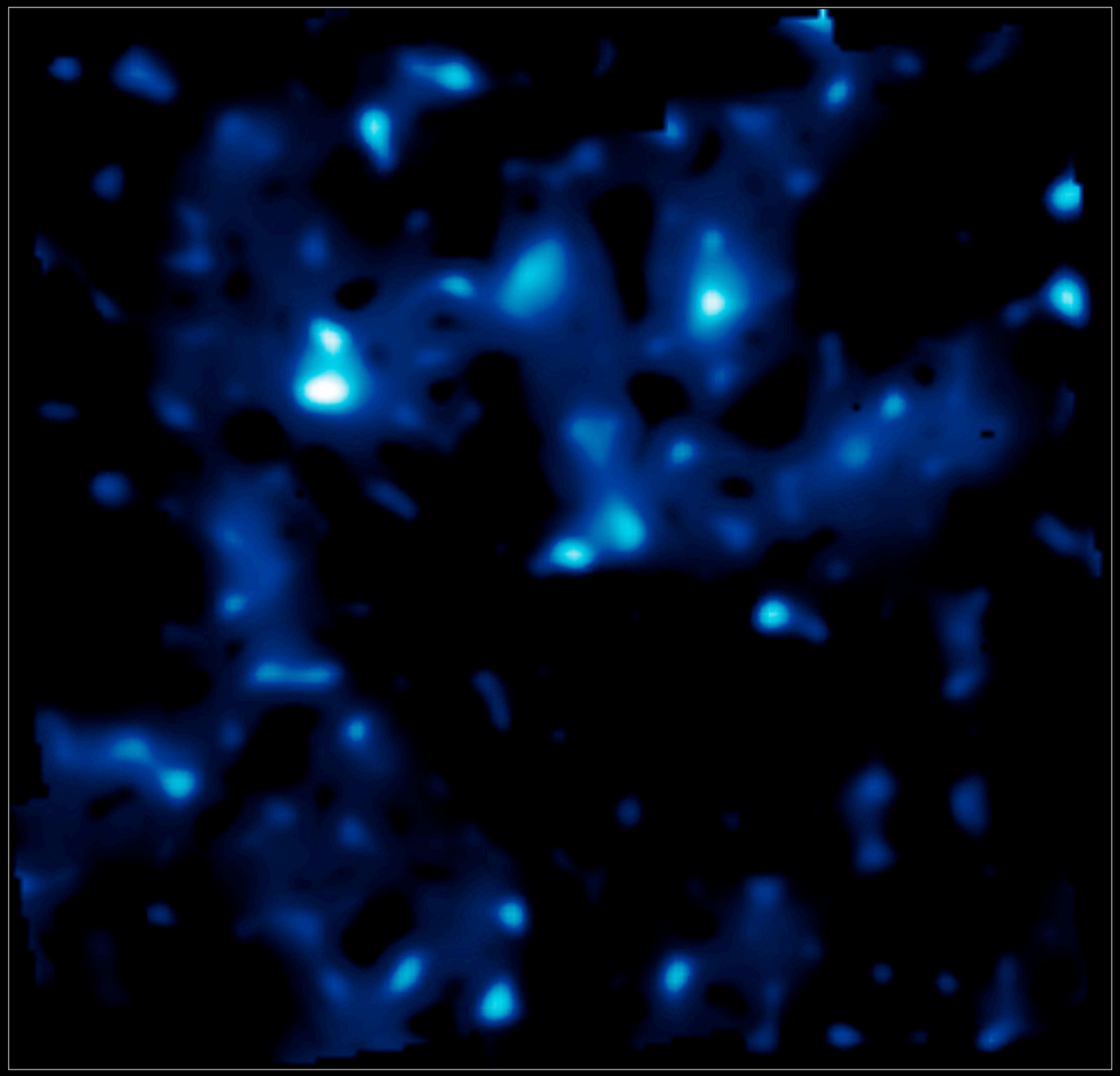
$$\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$$



Theory

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

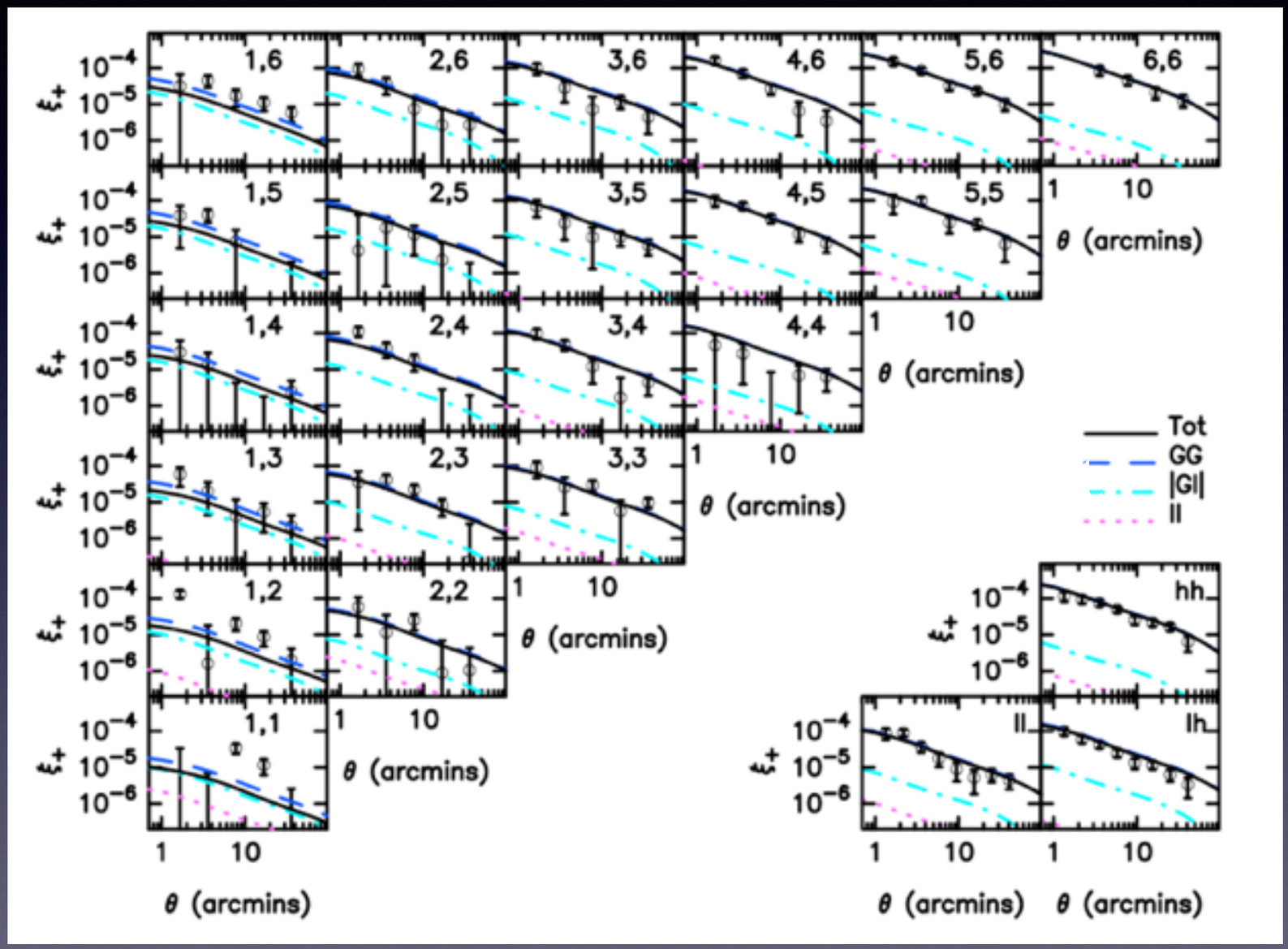
COSMOS Dark Matter Map

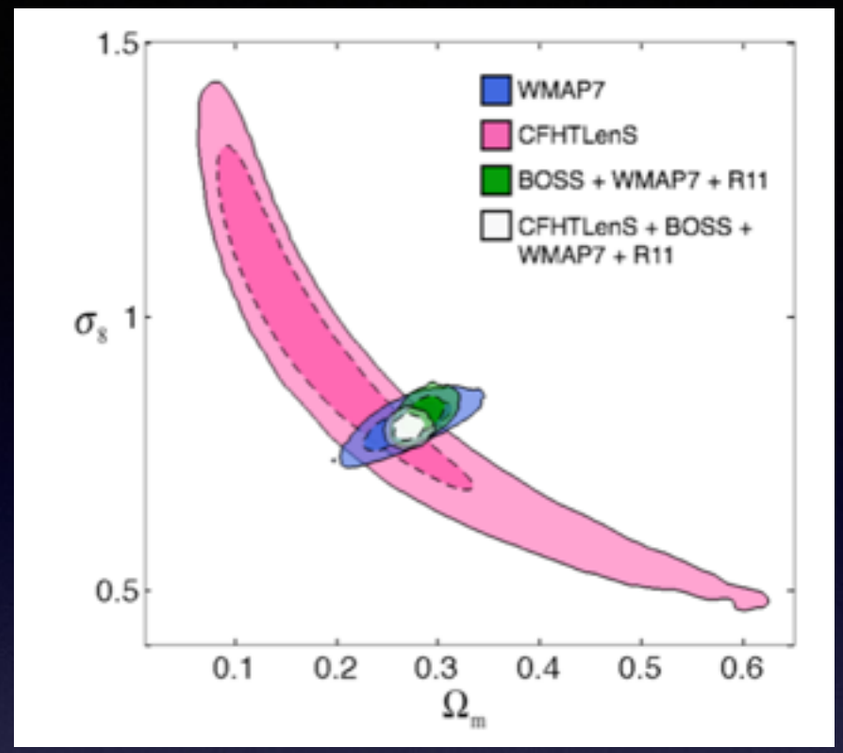


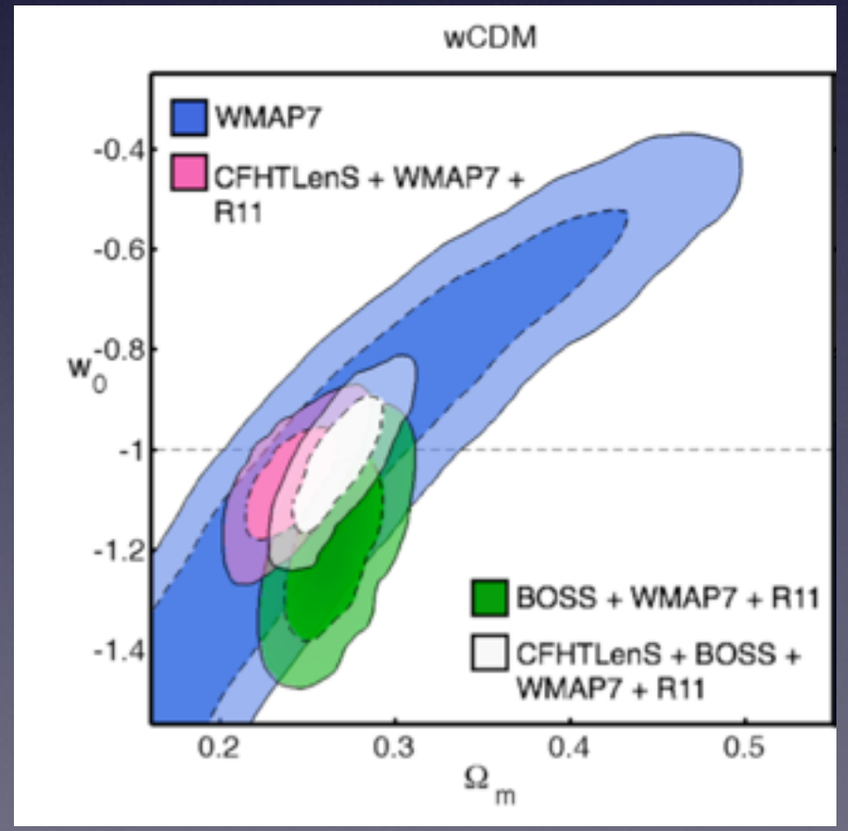
COSMOS HST
ACS survey
2 deg^2
Massey et al.
2006, Nature

CFHTLenS

Heymans et al. 2013



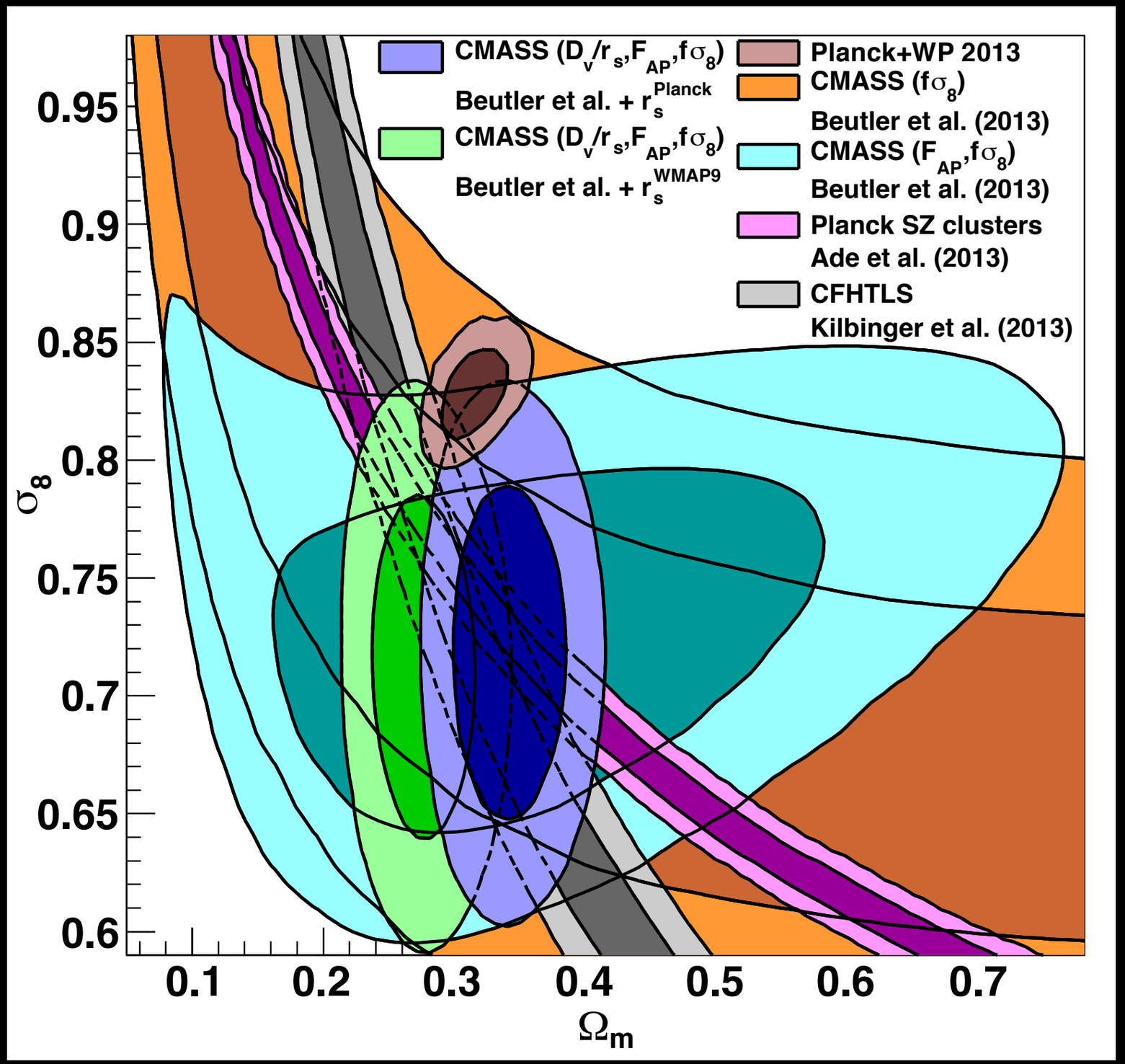




154 sq. deg., median z~0.7

Power Spectrum Amplitude

Beutler et al. 2014



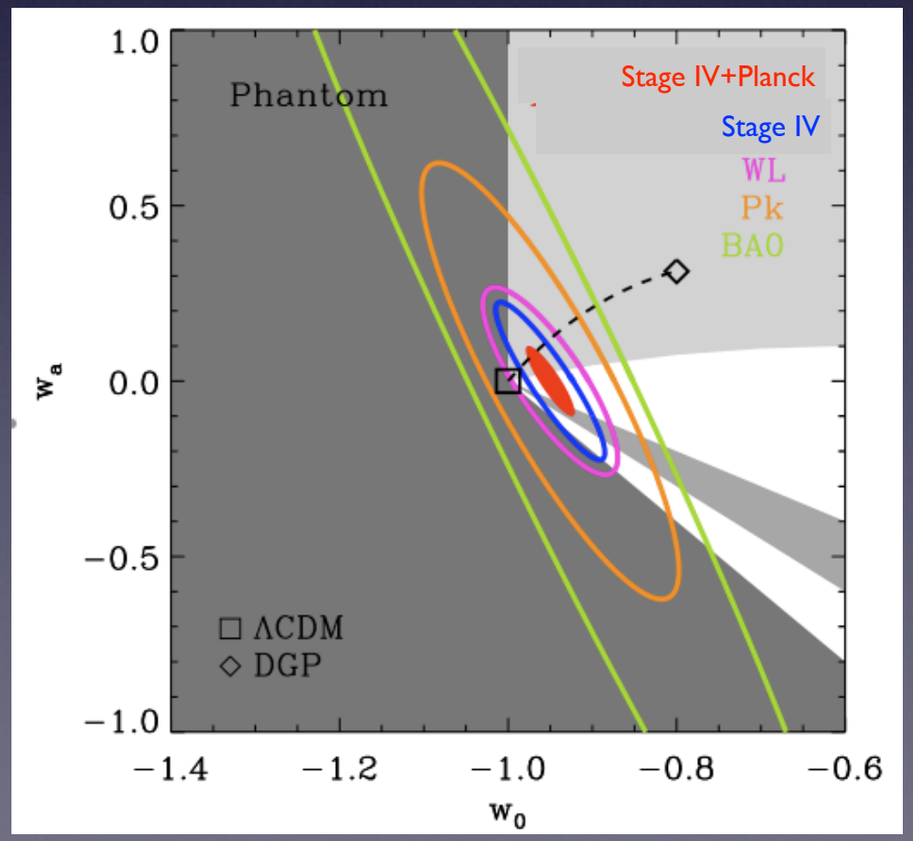
Wide-Field Instruments

CMB		Planck, SPT, ACT, BICEP2, Keck
VIS/NIR	Imaging	VST, DES, Pann-STARRS, LSST Euclid, WFIRST, Subaru Boss, Wigglez, DESI, HETDEX
	Spectro	
Radio		LOFAR, GBT, Chimes, BINGO, 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:

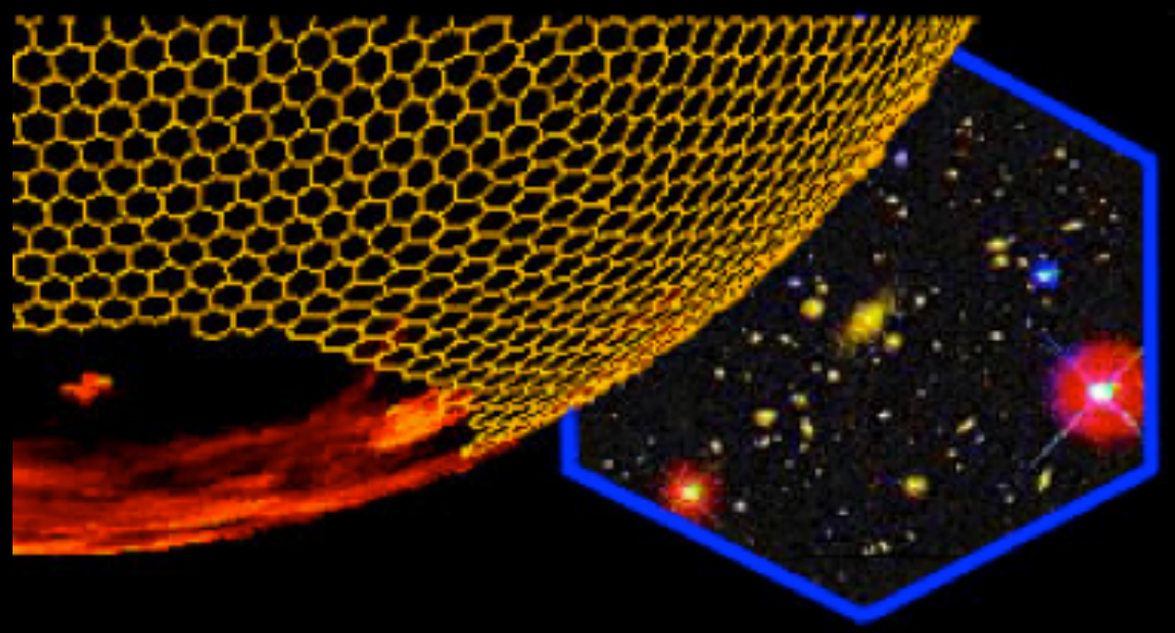
- Dark Energy: w_p and w_a with an error of 2% and 13% respectively (no prior)
- Dark Matter: test of CDM paradigm, precision of 0.04eV on sum of neutrino masses (with Planck)
- Initial Conditions: constrain shape of primordial power spectrum, primordial non-gaussianity
- Gravity: test GR by reaching 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

Dark Energy Survey

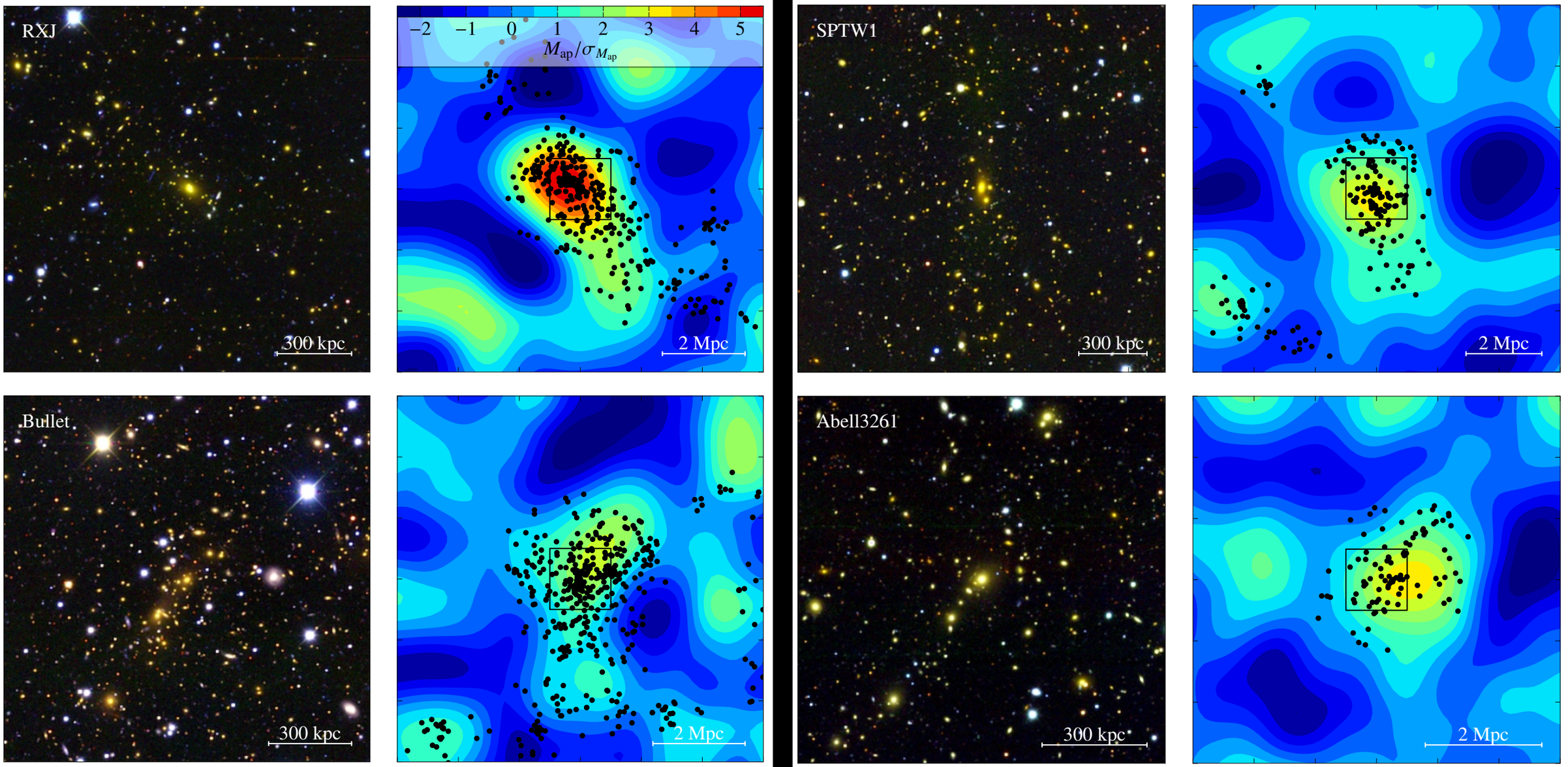
Blanco 4m at CTIO
74 2k×4k CCDs, 0.27”/pix
2.2 deg^2 FOV
5000 deg^2 survey (+SNe survey)
g,r,i,z,y to mag 24
200M galaxies

First light Sept 2012



DES Early Results

Melchior et al. 2014



Conclusions

- Concordance LCDM model in good agreement with LSS surveys (although some tensions are present)

- Current surveys already place constraints on Dark Energy, Neutrinos, Dark Matter and Gravity

- Great prospects for upcoming and future surveys