Cosmological Weak Lensing: Present and Future Surveys

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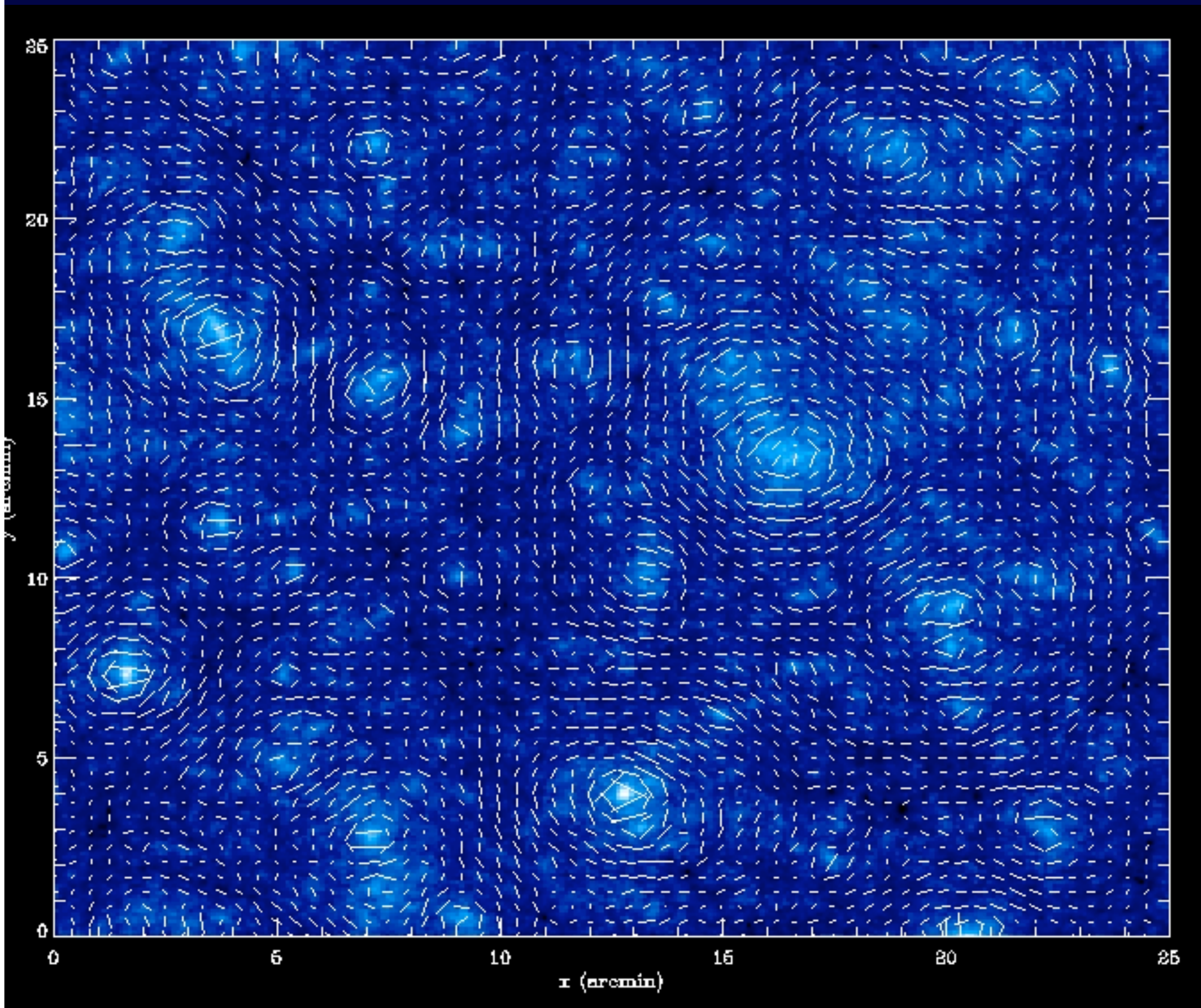
IAS Orsay – Nov 2008

Scientific Promise of Weak Lensing

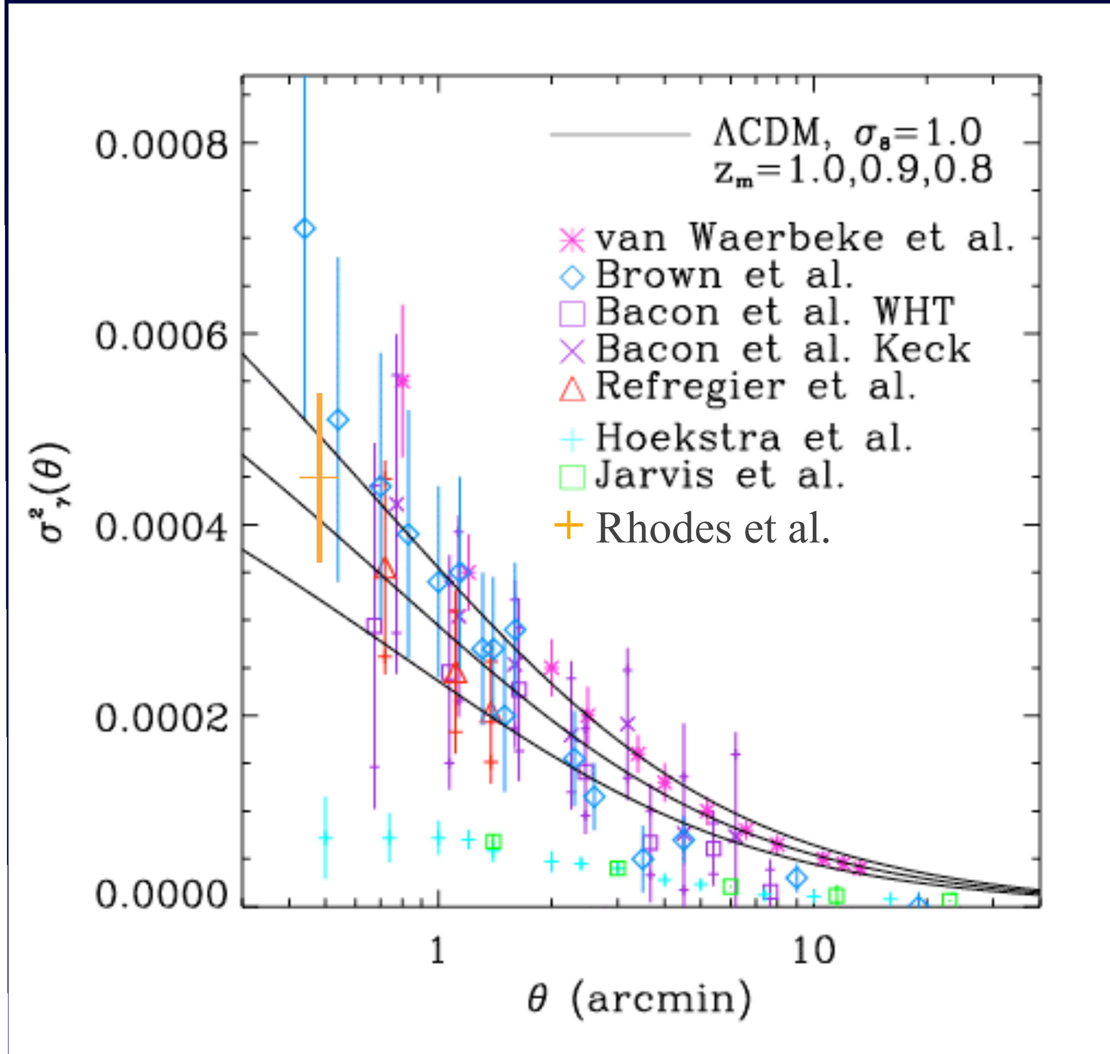
From the statistics of the shear field, weak lensing provides:



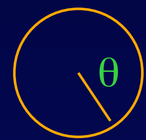
- Mapping of the distribution of Dark Matter on various scales
- Measurement of the evolution of structures
- Measurement of cosmological parameters, breaking degeneracies present in other methods (SNe, CMB)
- Explore models beyond the standard osmological model (ΛCDM)

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

Cosmic Shear Measurements



Shear variance in circular cells:



$\sigma^2_\gamma(\theta)=\langle\gamma^2\rangle$

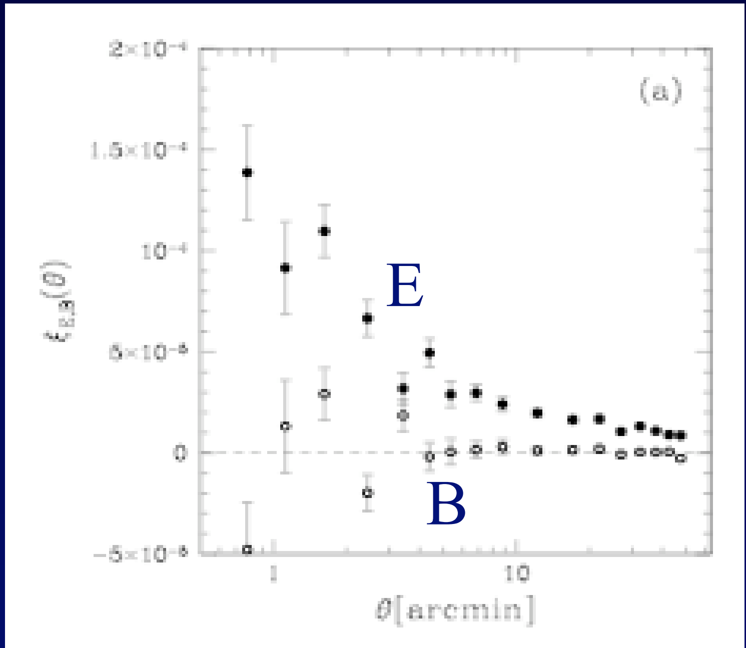
Bacon, Refregier & Ellis 2000*
Bacon, Massey, Refregier, Ellis 2001
Kaiser et al. 2000*
Maoli et al. 2000*
Rhodes, Refregier & Groth 2001*
Refregier, Rhodes & Groth 2002
van Waerbeke et al. 2000*
van Waerbeke et al. 2001
Wittman et al. 2000*
Hammerle et al. 2001*
Hoekstra et al. 2002 *
Brown et al. 2003
Hamana et al. 2003 *
Jarvis et al. 2003
Casertano et al 2003*
Rhodes et al 2004
Massey et al. 2004*

* not shown

Fu et al. 2008
Benjamin et al. 2006
Hoekstra et al 2005*
Sembolini et al 2005*

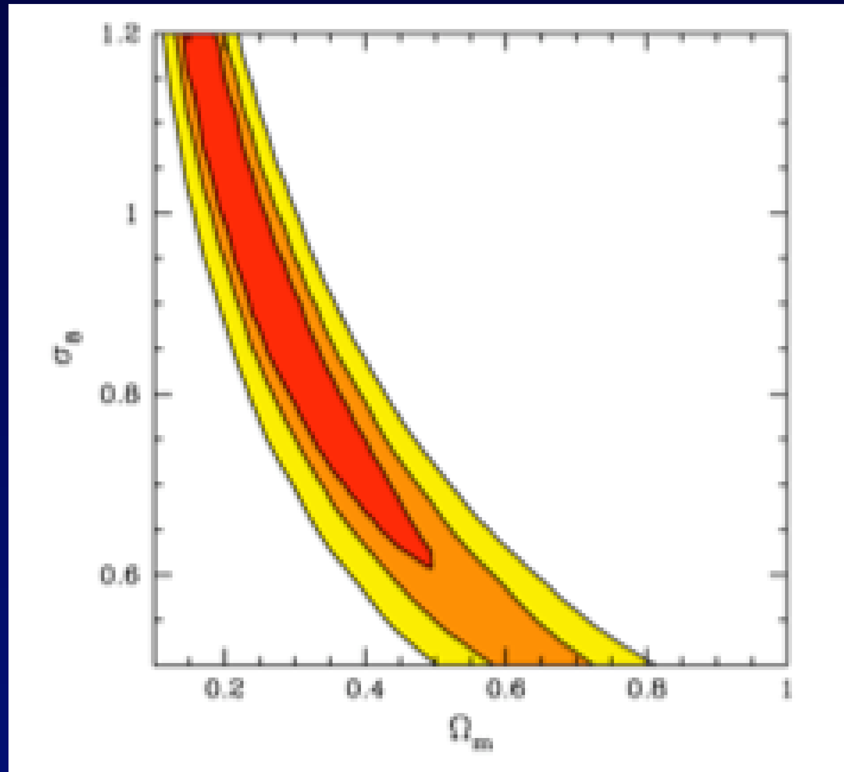
Cosmological Constraints

Shear correlation functions

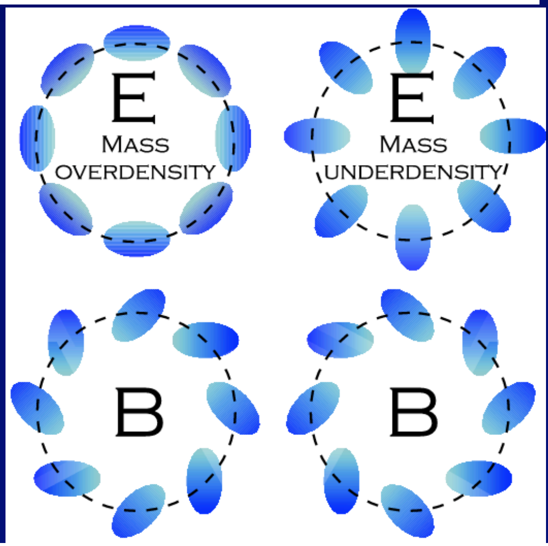


CFHTLS (first 20 deg^2)

Hoekstra et al. 2005, Sembolini et al. 2005



E/B decom-position

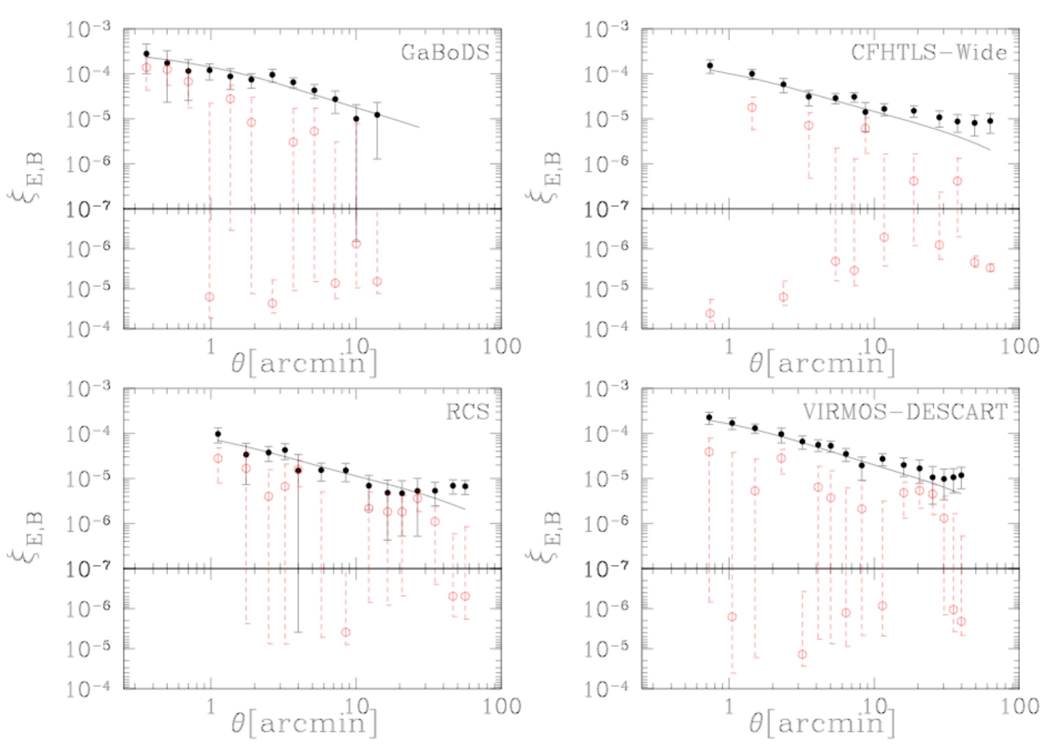


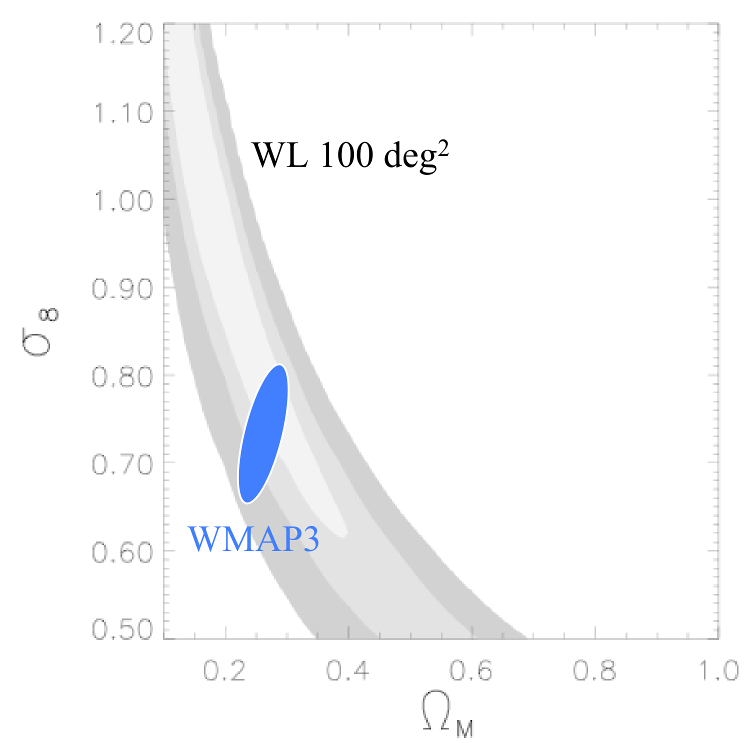
$$\sigma_8 \, (\Omega_m/0.3)^{0.5} = 0.90 \pm 0.04$$

Combined Surveys: 100 deg^2

Benjamin et al 2007

	CFHTLS-Wide	GaBoDS	RCS	VIRMOS-DESCART
Area (deg^2)	22.0	13.0	53	8.5
N_{fields}	2	52	13	4
Magnitude Range	$21.5 < i' < 24.5$	$21.5 < R < 24.5$	$22 < R_C < 24$	$21 < I_{AB} < 24.5$
$< z_{source} >$	0.81	0.78	0.6	0.92
z_{median}	0.71	0.58	0.58	0.84
Previous Analysis	Hoekstra et al. (2006)	Hetterscheidt et al. (2006)	Hoekstra et al. (2002a)	Van Waerbeke et al. (2005)
σ_8 ($\Omega_m = 0.24$)	0.99 ± 0.07	0.92 ± 0.13	0.98 ± 0.16	0.96 ± 0.08
Statistic	$\xi_{E,B}(\theta)$	$\langle M_{ap}^2 \rangle(\theta)$	$\langle M_{ap}^2 \rangle(\theta)$	$\langle \gamma_{E,B}^2 \rangle(\theta)$





great'08

GRavitational lEnsing Accuracy Testing 2008

Challenge submitted to PASCAL network:

Image simulations for shear reconstruction

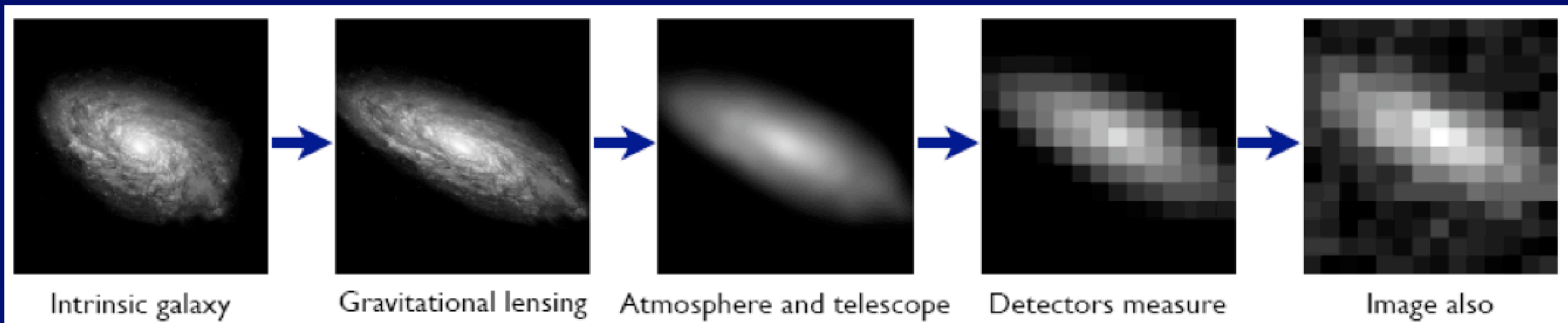
Training sets and blind tests

Live leader board

Aimed at machine learning and signal processing community

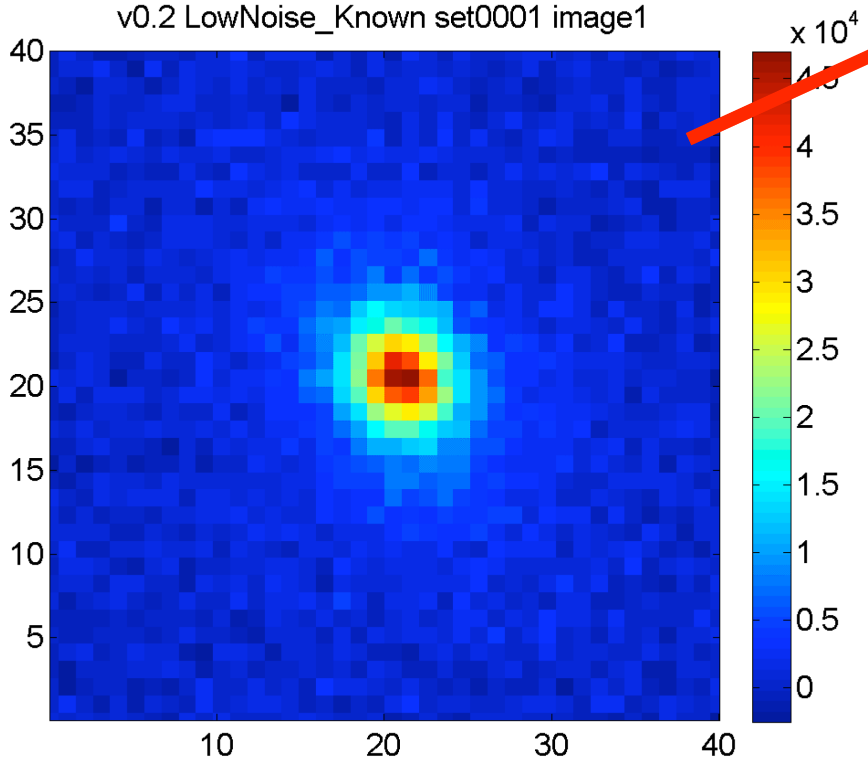
→See Challenge handbook and website by Sarah Bridle et al. 2008

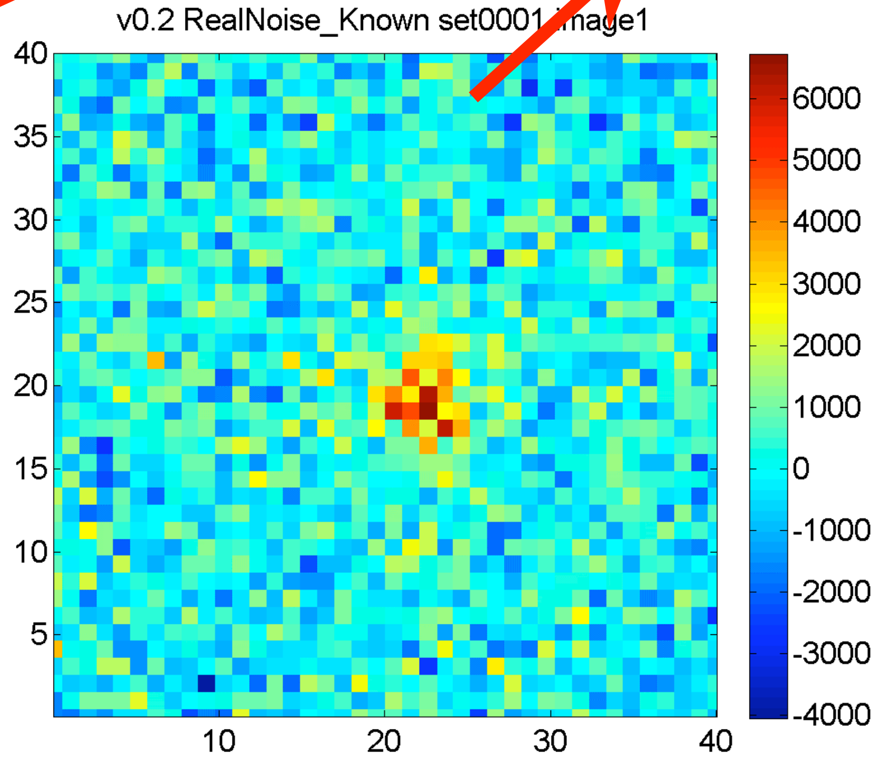
http://www.great08challenge.info/



GREAT08 Data

	True shears provided	Blind competition
Low noise	GREAT08 LowNoise-Known	GREAT08 LowNoise-Blind
Realistic noise	GREAT08 RealNoise-Known	GREAT08 RealNoise-Blind





https://great08.projects.phys.ucl.ac.uk/leaderboard/

e GREAT08 Challenge

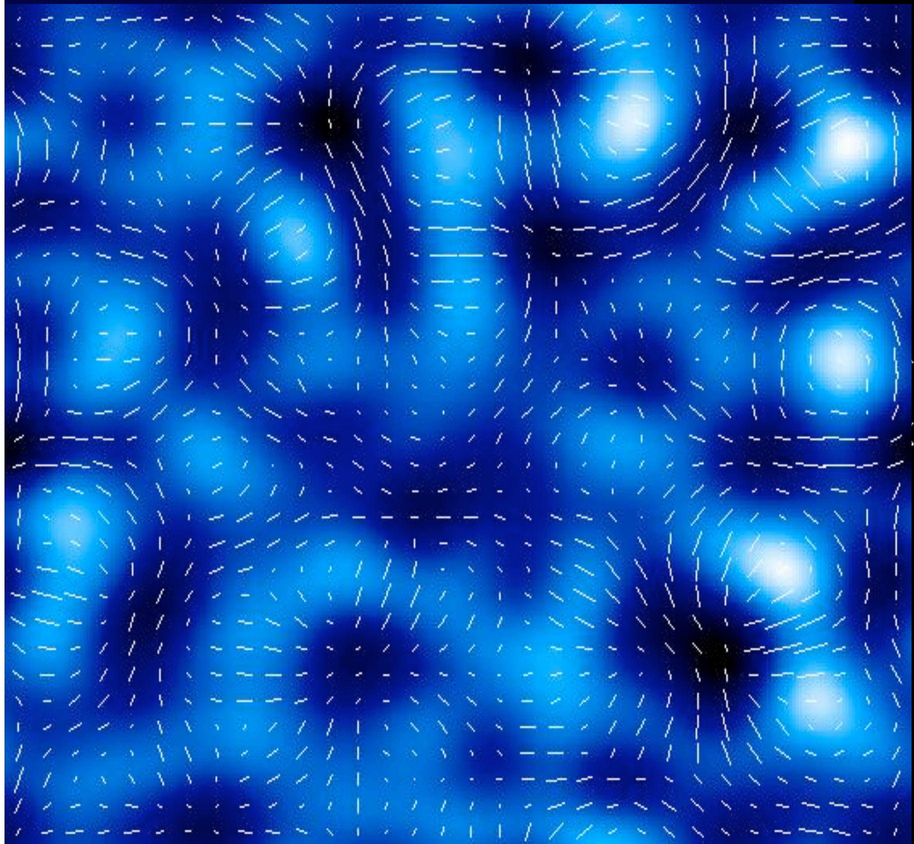
Displaying **GREAT08 RealNoise-Blind** Leader Board. Click here to view the GREAT08 LowNoise-E

Rank	Name	Method	Q	Error Flag	Submissi
1	T Kitching*	Lensfit	116.8	-	Sun, 26 Oct 2008
2	C Heymans*	KSBf90	52.3	-	Thu, 23 Oct 2008
3	K Kuijken*	KKshapelets	23.0	-	Tue, 30 Sep 2008
4	S Bridle*	im2shape	20.1	-	Fri, 17 Oct 2008 :
5	M Jarvis*	B&J deconvolved shapelets	9.8	-	Mon, 13 Oct 2008
6	S Bridle*	Unweighted stacked quadrupole moments	1.2	-	Tue, 23 Sep 2008

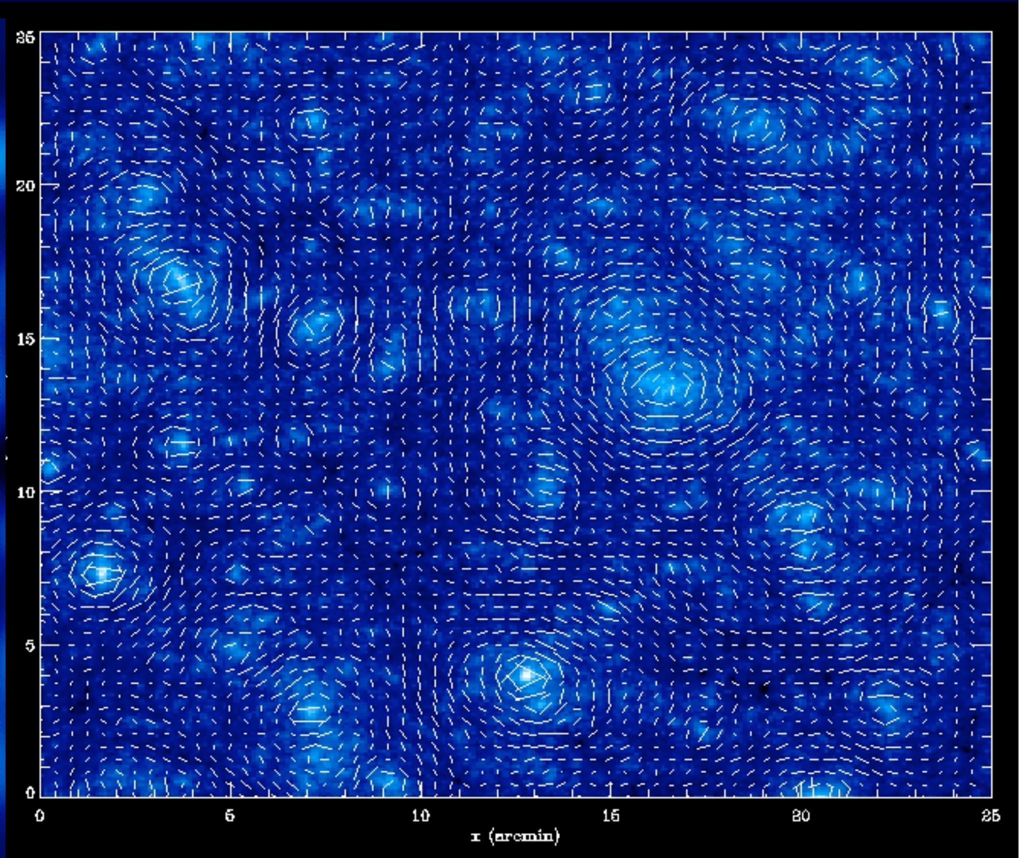
e end of a name indicates GREAT08 Team and/or STEP Team members. These participants have acc GREAT08 Challenge Simulations. However they have not consciously used this information in their

ıere to return to the login page.

Cosmic Shear Field is Non-Gaussian



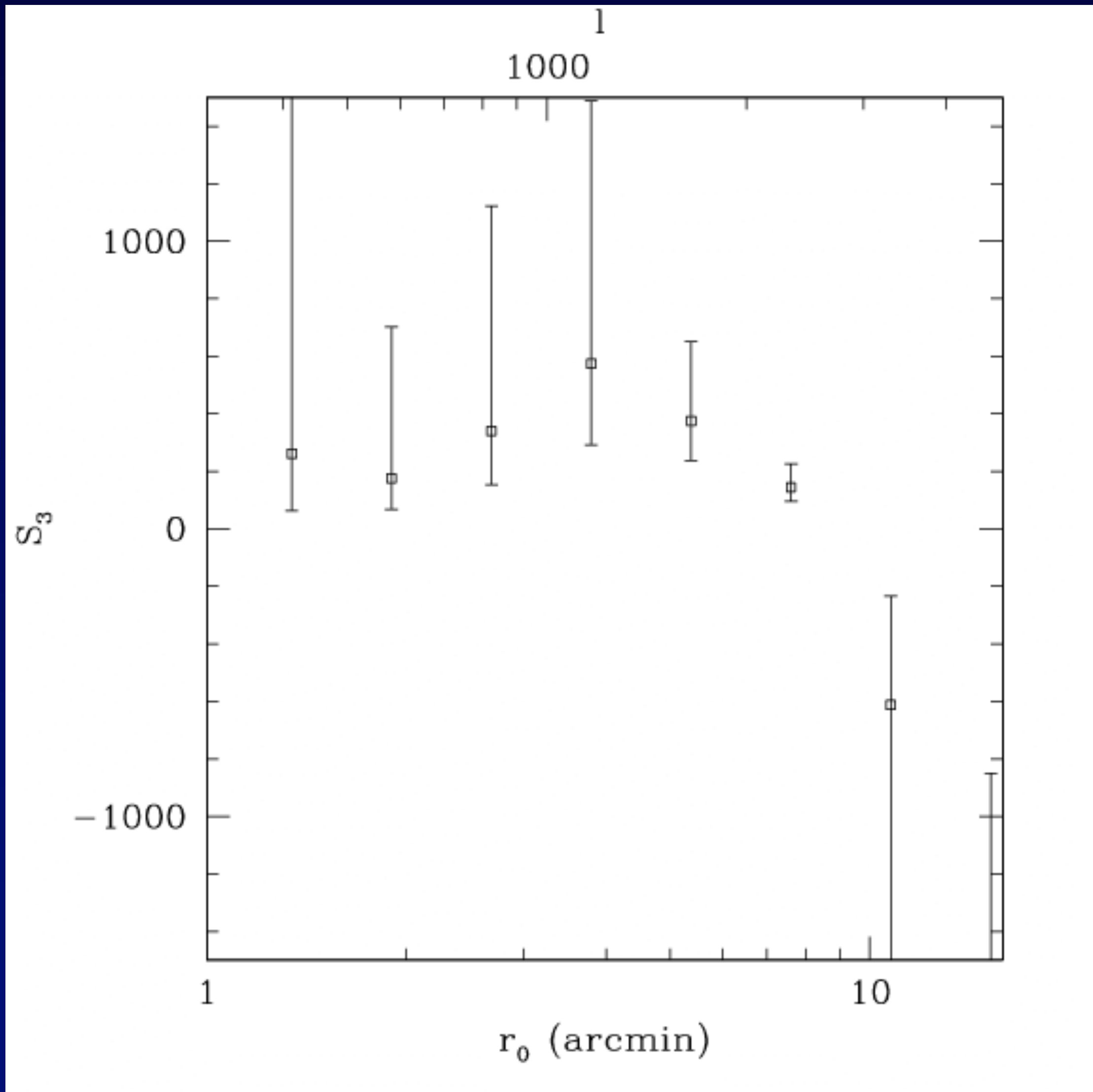
Gaussian field



Simulated Mass Map

→ There is information beyond 2-point functions

Skewness



Pen et al. 2003

Cf. Bernardeau et al. 1997, Bernardeau et al. 2002, Zhang, Pen, Zhang & Dubinsky 2003

Variance: $\langle \kappa^2 \rangle$

Skewness:

$$S_3 = \langle !^3 \rangle / \langle !^2 \rangle^2$$

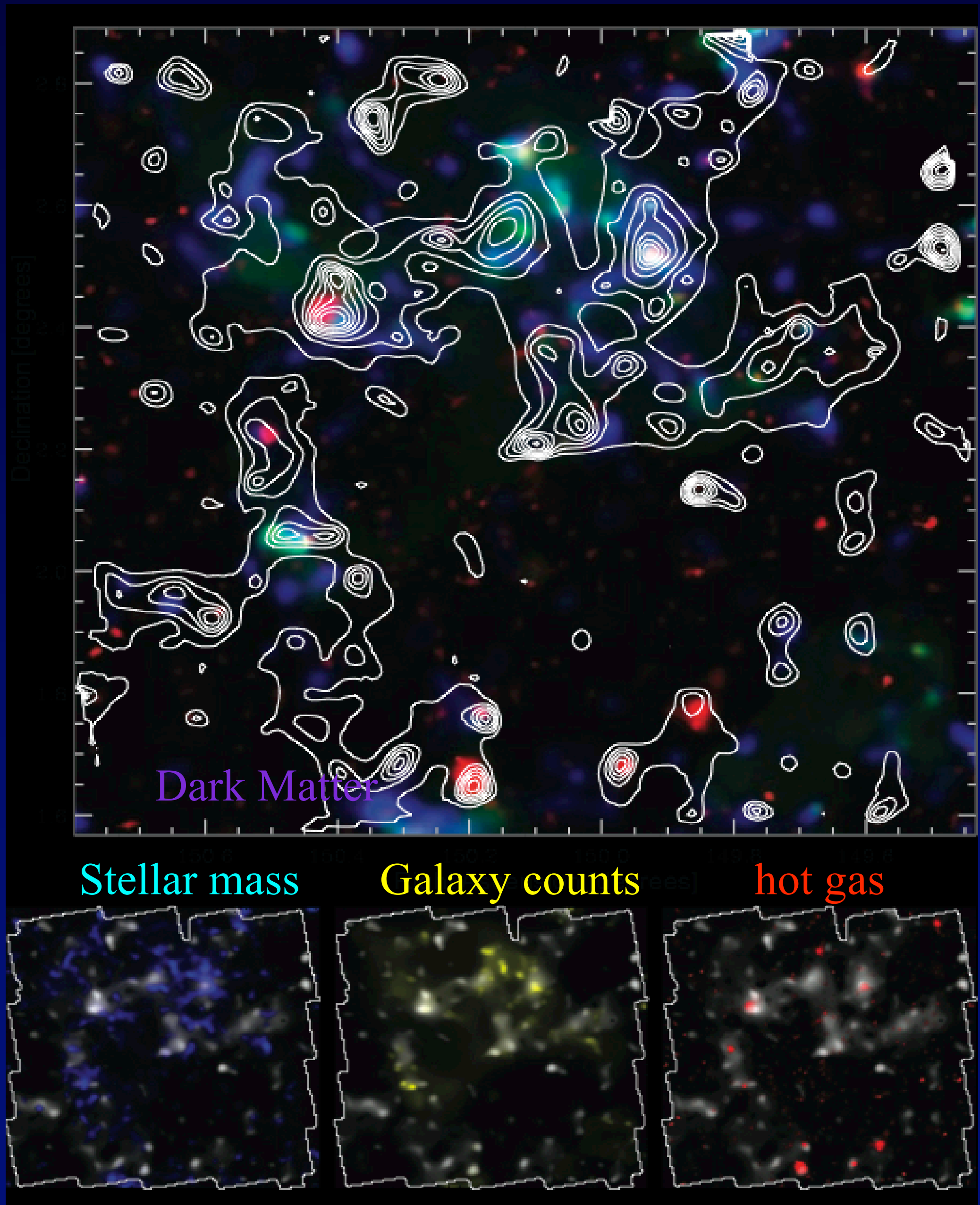
→ Skewness depends only weakly on σ_8 and h

→ break degeneracies

→ Pen et al. find Ω_m<0.5 (90%CL)

→ Zhang et al. predict $\Delta\Omega_m/\Omega m \approx 10\%$ for CFHTLS at 2.5’

Dark Matter Mapping



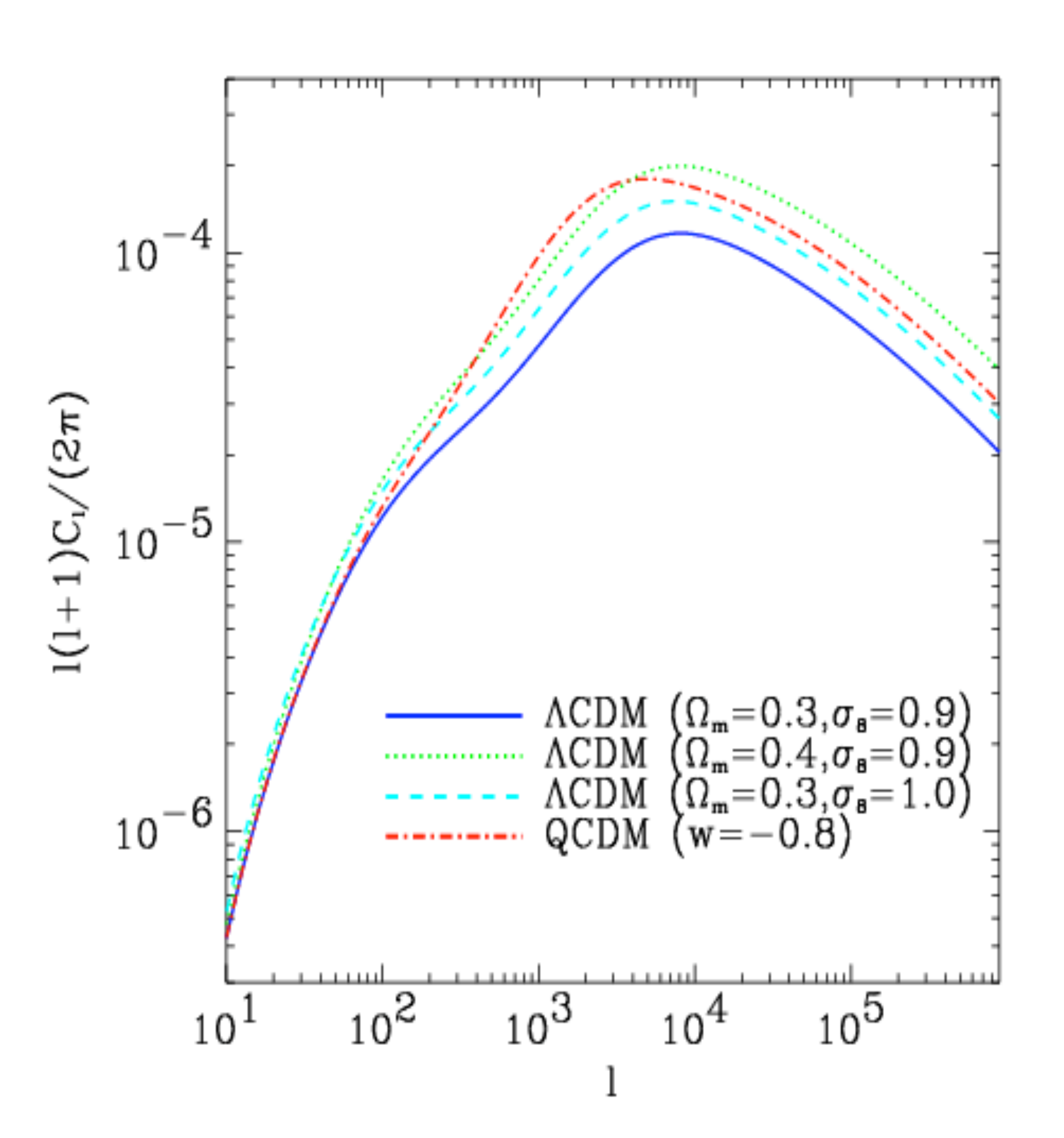
COSMOS HST ACS survey in one band, with ground-based photometry and spectroscopy, 2 deg^2
Massey et al. 2006, Nature cover

Mass inversion using multi-Resolution techniques
Starck, Pires, Refregier 2005; Pires et al. 2008

Future Instruments

Survey	Diameter (m)	FOV (deg^2)	Area (deg^2)	start
CFHTLS	3.6	1	172	2003
KIDS (VST)	2.6	1	1700	2008
DES (NOAO)	4	2	5000	2011
HSC (Subaru)	8	2	2000?	2011
Pan-STARRS	1.8(x4)	4(! 4)	20000	2007(12)
LSST	8.4	7	20000	2014
Euclid	1.2 space	1.0	20000	2017
JDEM	~1.4space	?	?	2015

Dark Energy and Weak Lensing



Dark Energy equation of state:

$w=p/\rho$ (w=-1 for Λ)

modifies:

- angular-diameter distance
- growth rate of structure

a(t)

- power spectrum on large scales

(Ma, Caldwell, Bode & Wang 1999)

→ w can be measured from the lensing power spectrum

→ But, there are degeneracies between w, Ω_M ,σ_8 and Γ

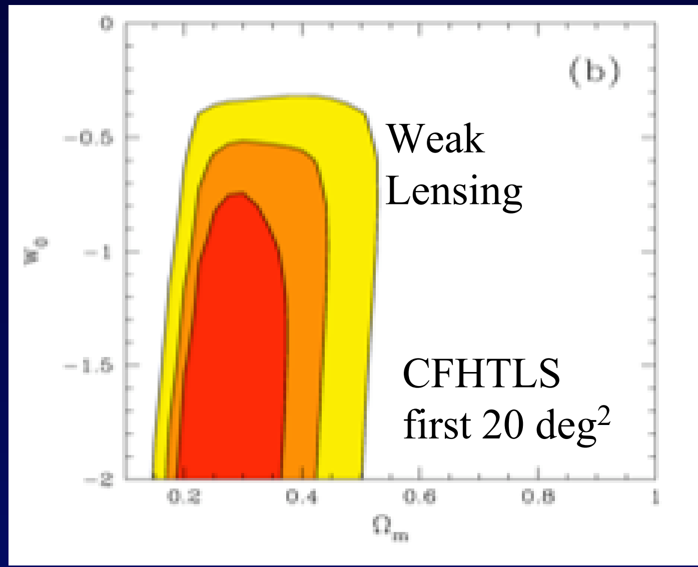
Cf. Hui 1999, Benabed & Bernardeau 2001, Huterer 2001, Hu 2000, Munshi & Wang 2002

Current DE Constraints

Current constraints: 10-20% on constant w

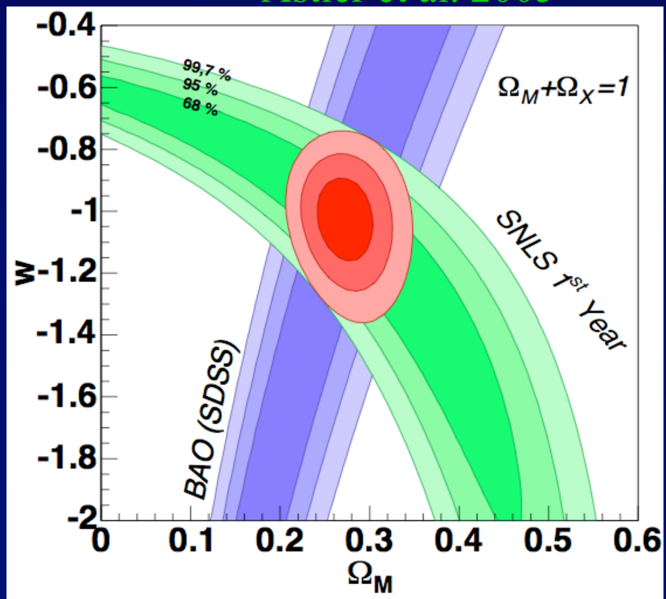
For definite answers on DE: need to reach a precision of 1% on (varying) w and 10% on w'

Hoekstra et al. 2005

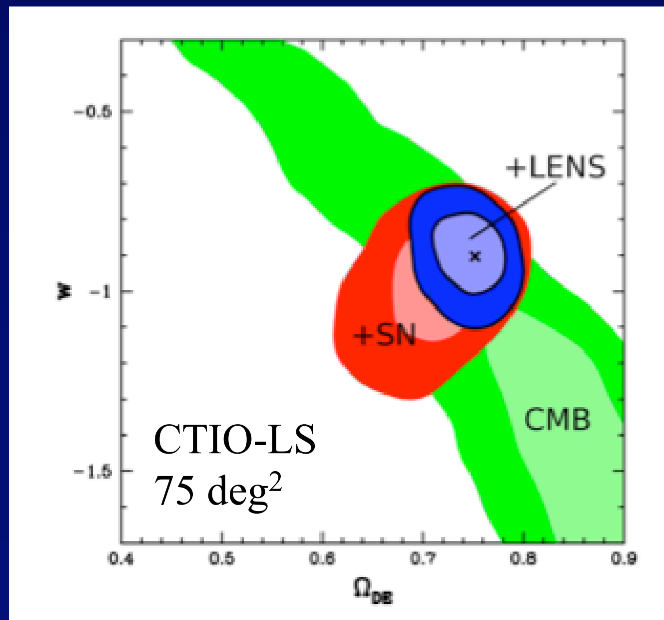


Comparison with Other Probes

Astier et al. 2005



Jarvis et al. 2006

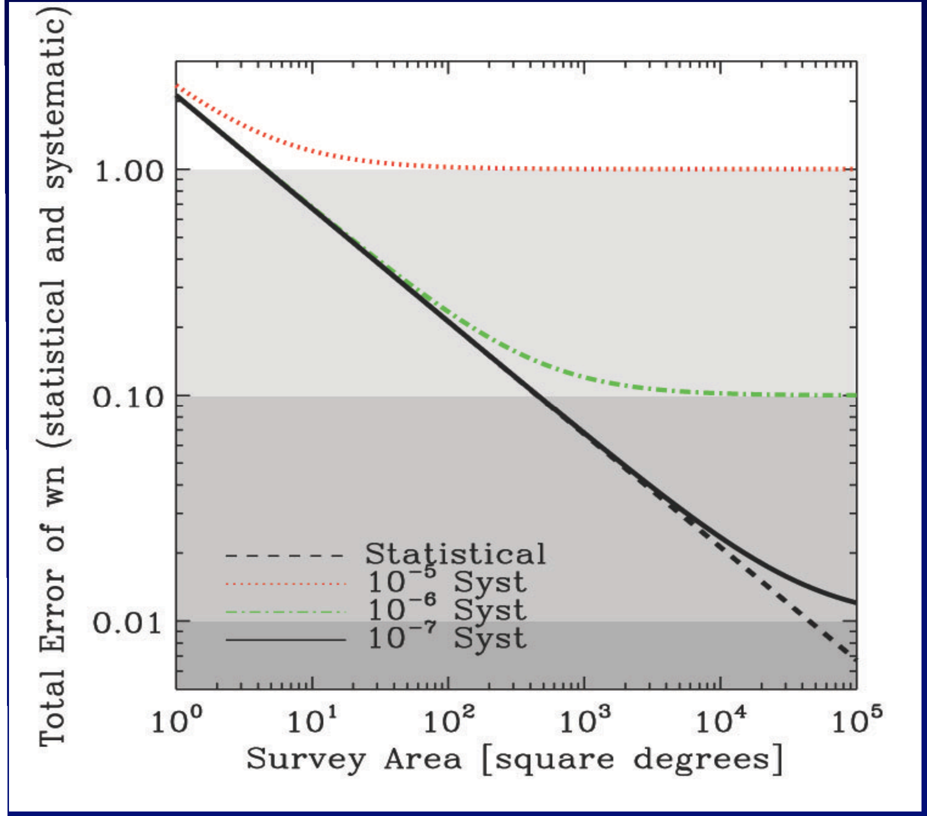


Requirements for Weak Lensing

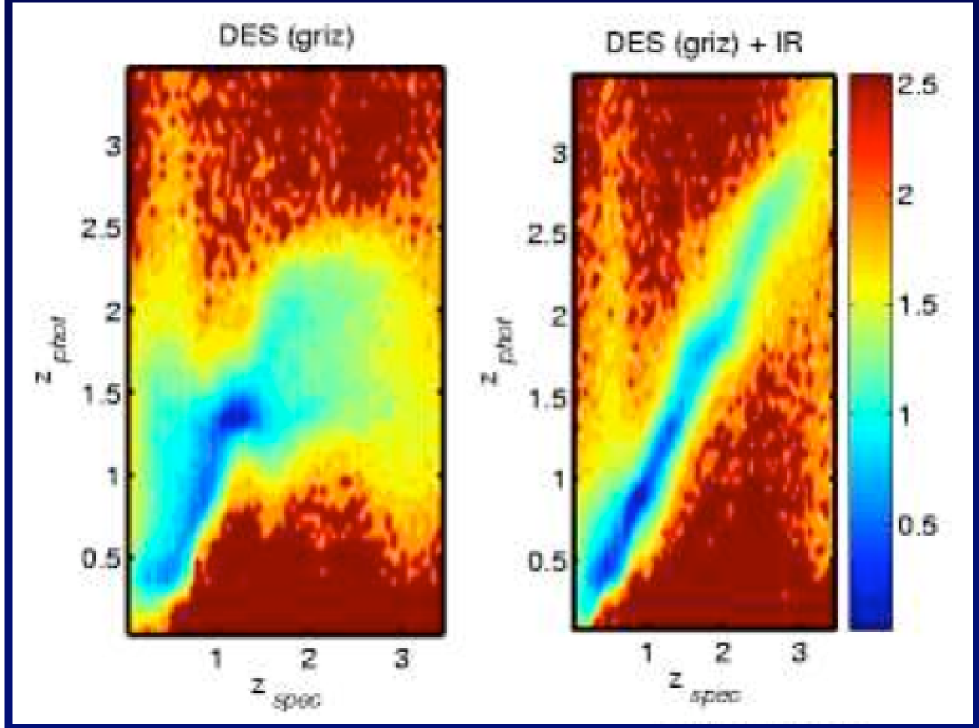
Statistics: optimal survey geometry: wide rather than deep for a fixed survey time, → need 20,000 deg^2 to reach ~1% precision on w

Redshift bins: need good photo-z to make redshift bins and to correct for intrinsic alignements → need IR

Systematics: Need to gain 2 orders of magnitude in systematic residual variance → need about 50 bright stars to calibrate PSF



Amara & Refregier 2007, 2008



Abdalla et al. 2007

Cosmological Probes

EUCLID

Primary probes:

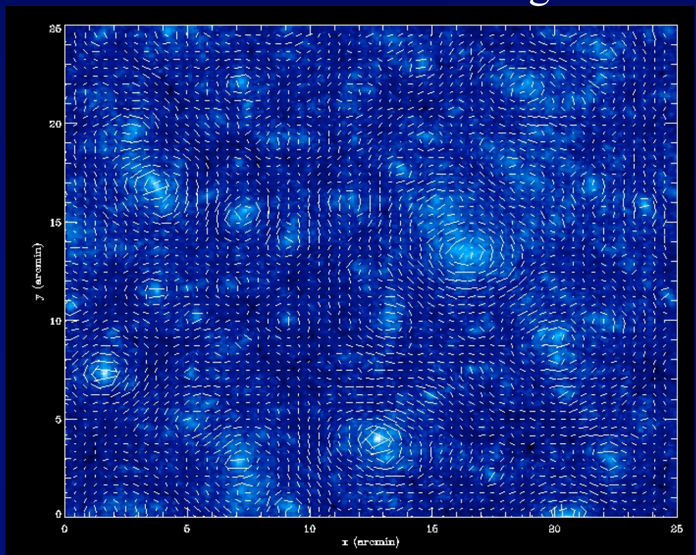
with all-sky Vis+NIR imaging and spectroscopic survey

- Weak Lensing
- Baryonic Accoustic Oscillations

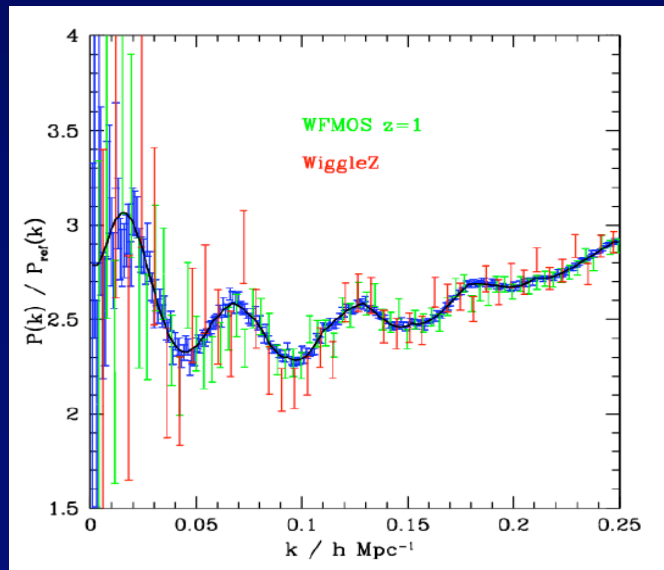
Additional Probes:

- Clusters Counts
- Galaxy clustering (full P(k))
- Redshift space distortions
- Integrated Sachs-Wolfe Effect (correlation with CMB)

Weak Lensing



BAO

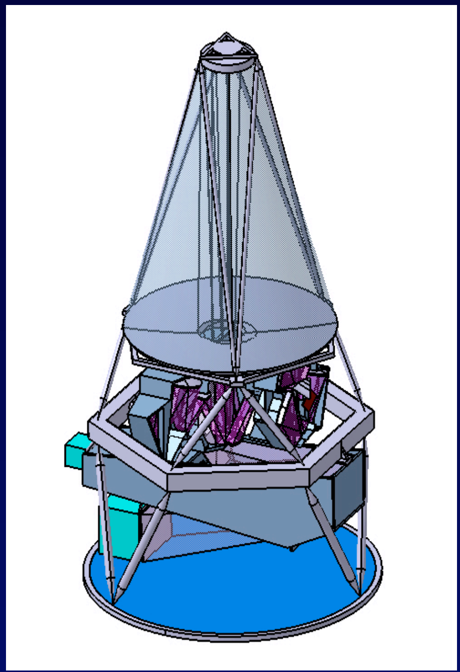


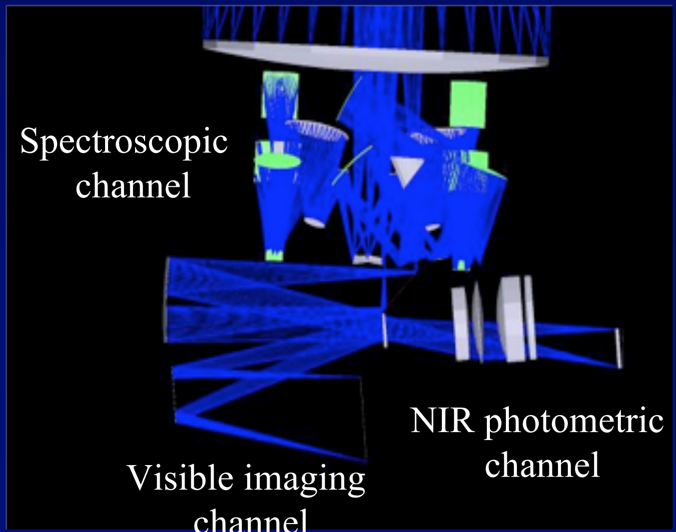
Euclid Mission Implementation

EUCLID

Mission elements:

- L2 Orbit
- 4-5 year mission
- Data rate Max 700 Gbits/day (compressed)
- Telescope: three mirror assembly (TMA) with 1.2 m primary
- Instruments:
- – Visible imaging channel: 0.5 deg^2, 0.10'' pixels, 0.23'' PSF FWHM, broad band R+I+Z (0.55-0.92mu), CCD detectors, galaxy shapes
- – NIR photometry channel: 0.25-0.5 deg^2, 0.3'' pixels, 3 bands Y,J,H (1.0-1.7mu), HgCdTe detectors, Photo-z's
- – NIR Spectroscopic channel: 0.25-0.5 deg^2, R=400, 0.9-1.7mu, slits with DMD (backup: slitless), redshifts





Euclid Surveys

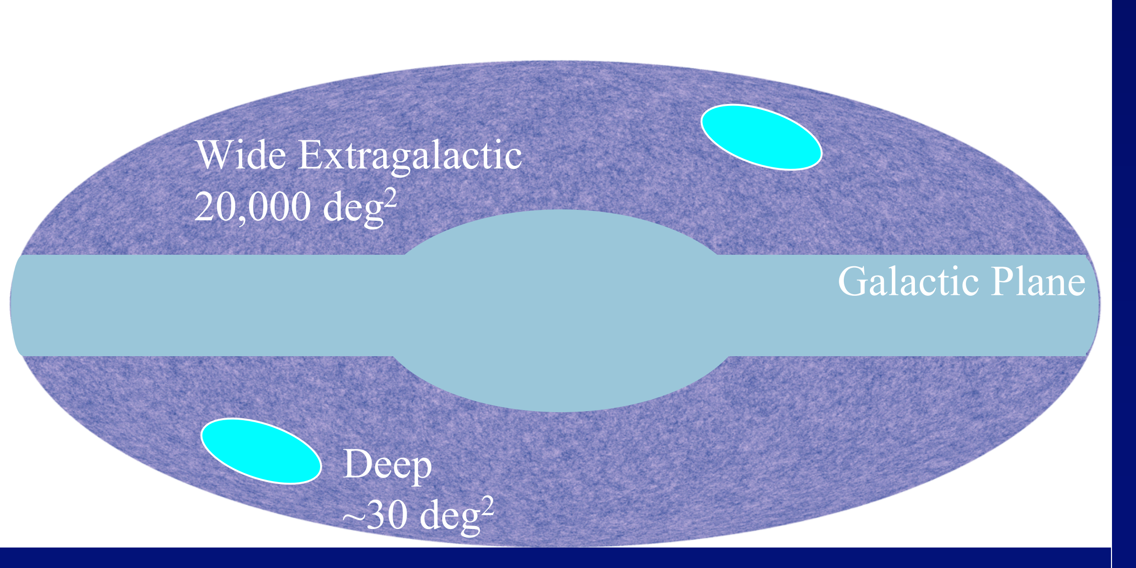
EUCLID

Wide Survey: entire extra-galactic sky (20 000 deg^2)

- Imaging for Weak lensing:
  - Visible: Galaxy shape measurements in R+I+Z<24.5 (AB,10σ), 40 resolved galaxies/$amin^2$, median resdshift of 0.9
  - NIR photometry: Y,J,H<24 (AB, 5σ PS), photometric redshifts rms 003-0.05(1+z) with ground based complement
- Spectroscopy for BAO:
  - Spectroscopic redshifts for 33% of all galaxies with H(AB)<22 mag, σ_z<0.001

Deep Survey: ~30 deg^2, visible/infrared imaging to H(AB)=26 mag and spectroscopy to H(AB)=24 mag

Galactic surveys: Galactic plane and microlensing extra-solar planet surveys under discussion



Horizon Project Simulations, Teyssier et al.

Weak Lensing Tomography

Wide Survey: 20,000 deg^2, 40 galaxies/amin^2, z_m=0.9, ground-based complement for photo-z's

WL power spectrum for each z-bin

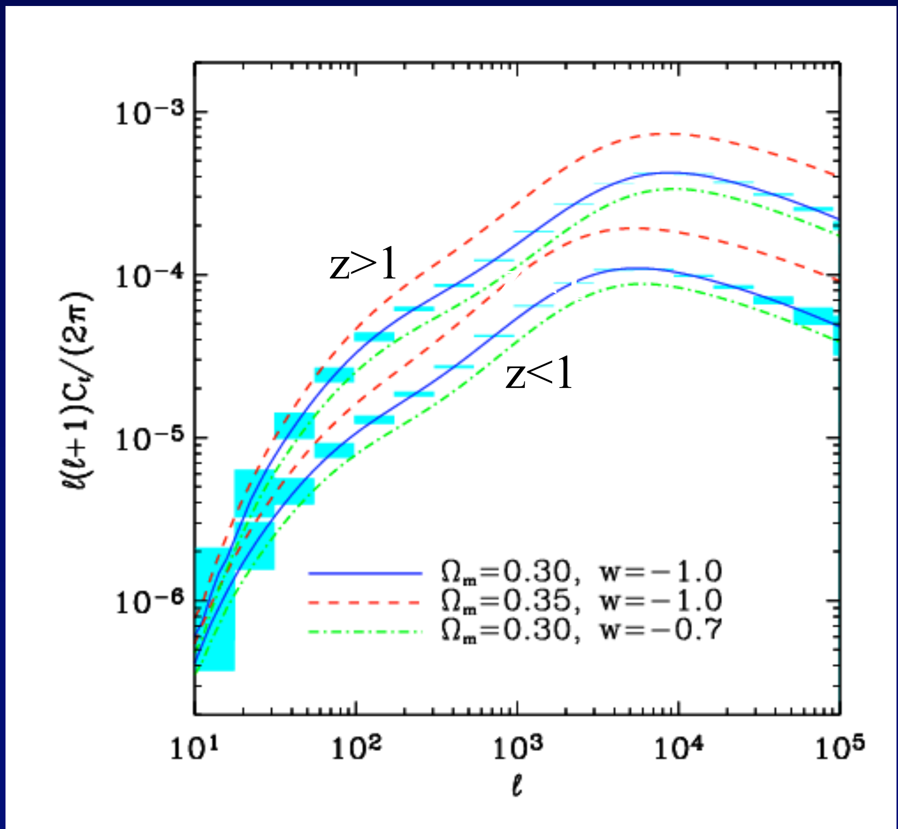
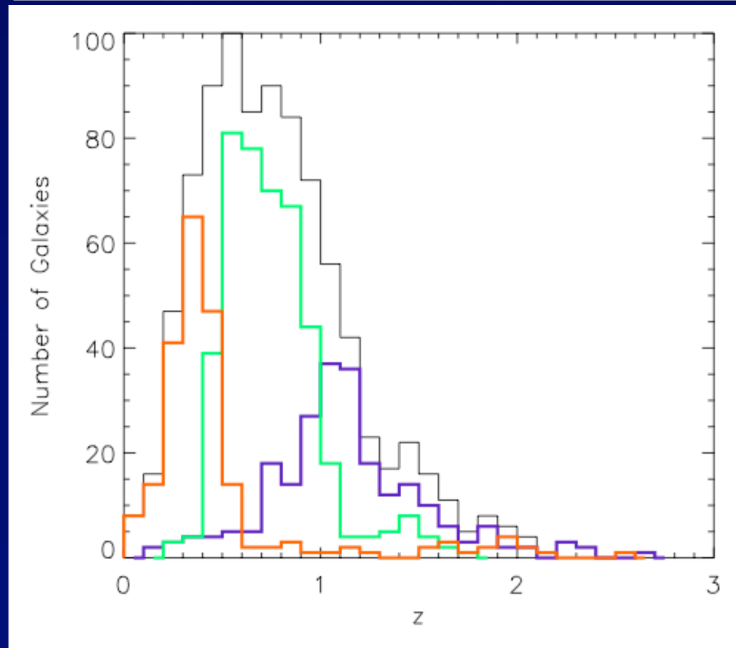
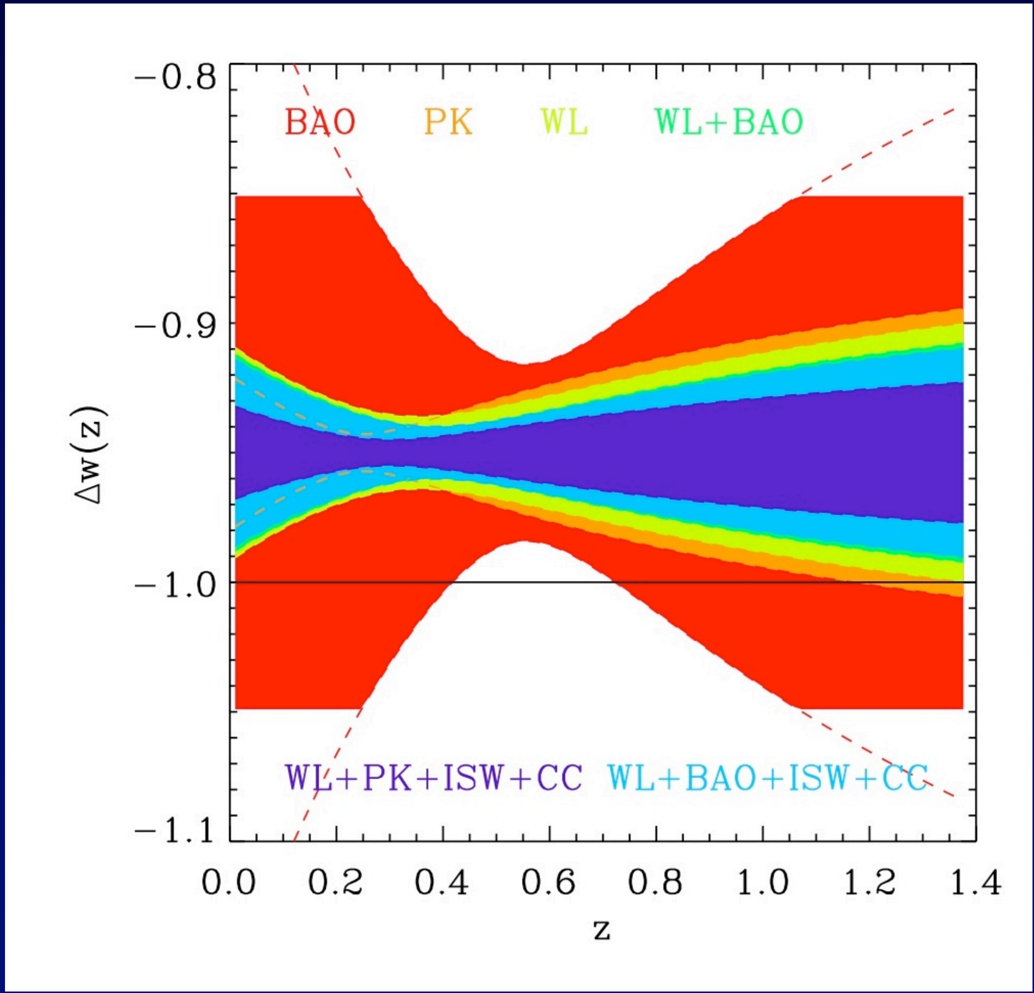


Image simulations from 3 groups
(incl.: Magneville, Palanque, Bertin et al.)



Cosmology and Legacy science

EUCLID



Euclid Cosmology WG

Cosmology:

Measurement of cosmological parameters with unprecedented accuracy

Control of systematics with independent cosmoligical probes

→Measurement of Dark Energy equation of state parameter w and its evolution w' with 1% and 10% accuracy respectively

Legacy:

- Visible/NIR imaging survey: morphologies and vis/NIR colors for billions of galaxies out to z~2, 3D dark matter map
- Spectroscopic survey: 3D map of the luminous matter distribution, spectra of ~200 million galaxies to z~2
- Deep survey: infrared imaging to H(AB)=26 and spectroscopy to H(AB)=24, galaxies with 2<z<7. Objects at z>7 and up to z~10 can be colour-selected from the Y,J,H colours

→ Impossible to reach from the ground

Overall Impact on Cosmology

	DE FoM	Dark Energy			Matter Content		Initial Conditions	
		Δw_n	Δw_a	$\Delta\Omega_v$	$\Delta\Omega_m$	$\Delta\Omega_b$	$\Delta\sigma_8$	Δn_s
WMAP 6	0.13	0.6	13	0.07	0.06	0.008	0.14	0.03
Planck	12	0.03	2.5	0.0036	0.006	0.0009	0.031	0.0037
DUNE	400	0.02	0.12	0.007	0.004	0.1	0.006	0.011
DUNE + Planck	1600	0.011	0.056	0.0018	0.002	0.0006	0.0020	0.0031

DUNE will challenge all the sectors of the Cosmological model:

- Dark Energy: w_n and w_a with an error of 2% and 10% respectively
- Dark Matter properties: test of CDM paradigm, precision of 0.04eV on sum of neutrino masses (with Planck)
- Initial Conditions: constrain amplitude, slope and higher order parameters of primordial power spectrum, constrain primordial non-gaussianity
- Gravity: Distinguish GR from simplest modified Gravity theories by reaching a precision of 2% on the growth exponent γ ($d\ln\delta_m/d\ln a \propto \Omega_m^{\gamma}$)

→ Goal: uncover new physics

iCosmo

A. Amara
T. Kitching
A. Rassat
A. Refregier

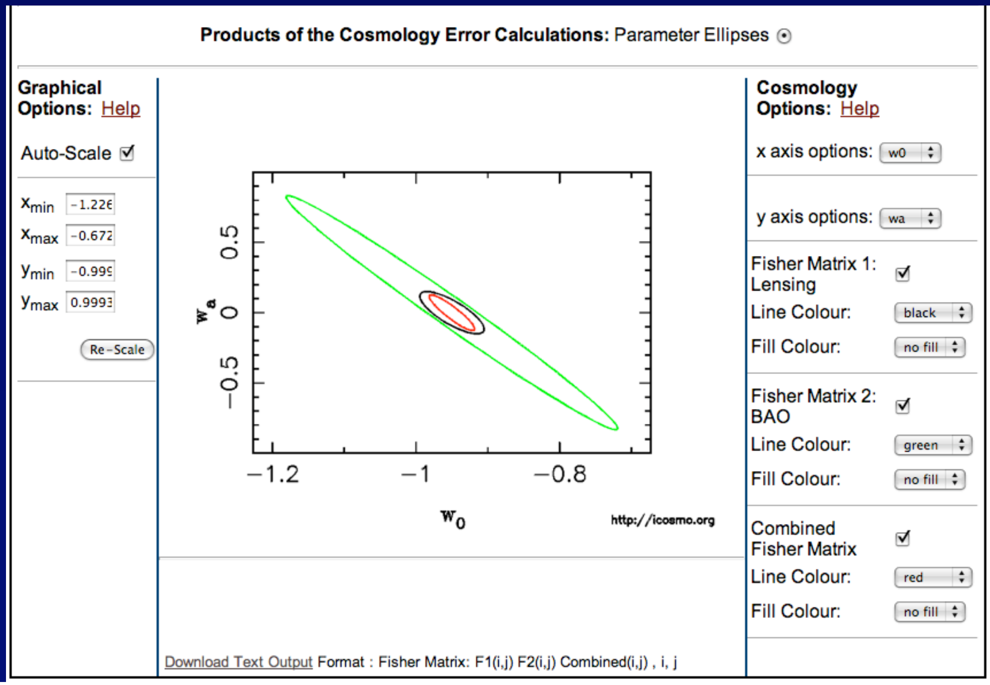
Interactive package for cosmology:

- Freely available interactive IDL code (development platform)
- Interactive web interface
- Web based tutorials and teaching resources

Features:

- Basic quantities: distance scales, growth factor, P(k)
- Observables: BAO, WL, Sne observables
- Parameter constraints: Fisher matrices

→ Can be used to analyse and optimise future surveys



www.icosmo.org

Contributions welcome!

Conclusions

- Weak Lensing provides a measurement of density fluctuations at low redshifts, complementary to CMB but different: 10^{-2} signal, gaussian and non-gaussian, linear and non-linear regime, 3-dimensional

- Current Weak Lensing surveys now together cover ~100 deg^2 and provide a measure of σ_8 with a precision of 5-10% and of other cosmological parameters

- Future missions such as Euclid will provide a 3-dimensional all-sky map of the dark and visible matter in the Universe, set tight constraints on Dark energy (~1% precision on w and ~10% on dw/da) and other cosmological parameters, and producs a wealth of secondary science