Probing Dark Energy and Dark Matter with Weak Lensing

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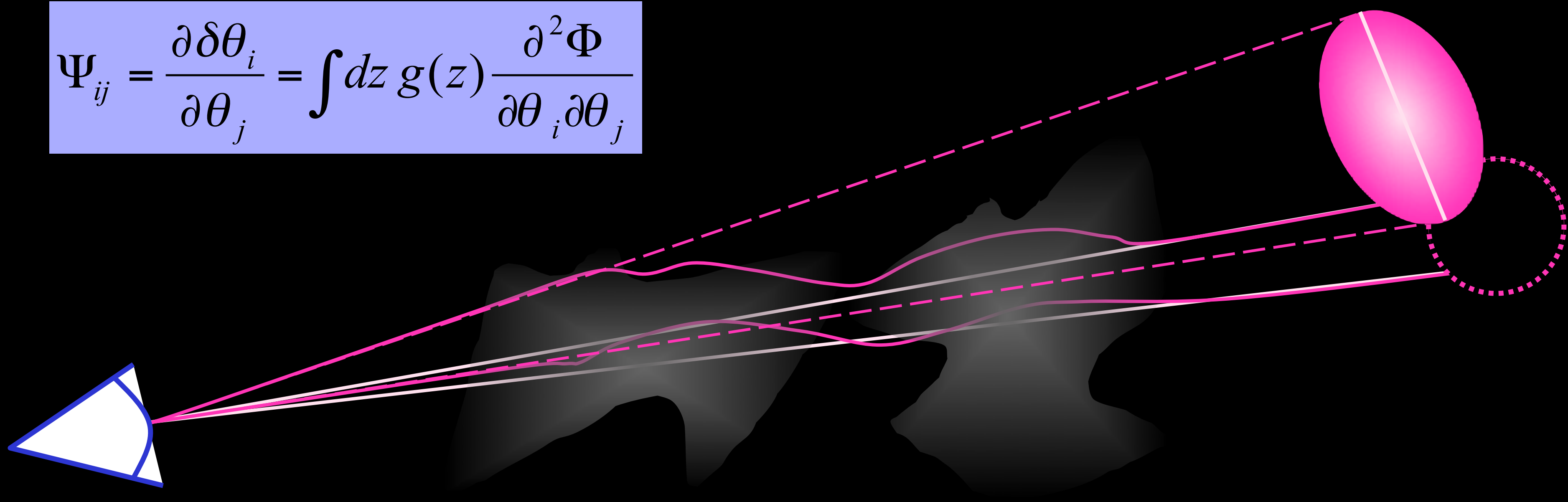
Weak Gravitational Lensing

Distortion matrix:

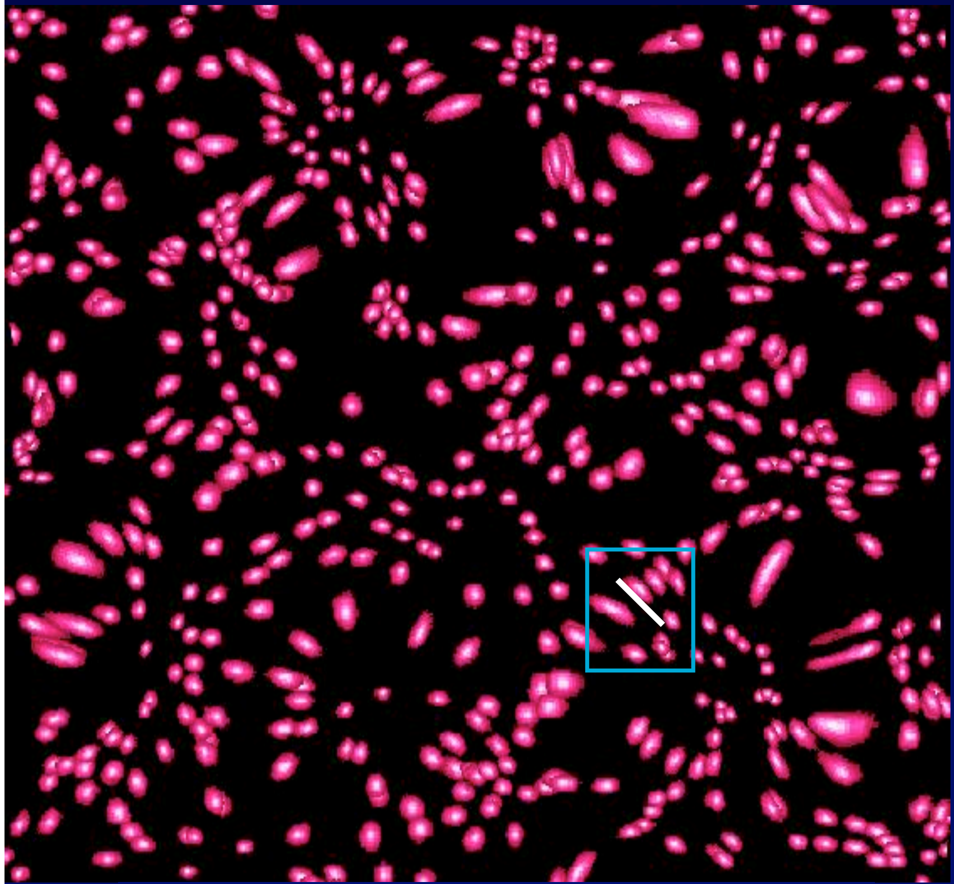
$$\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$$



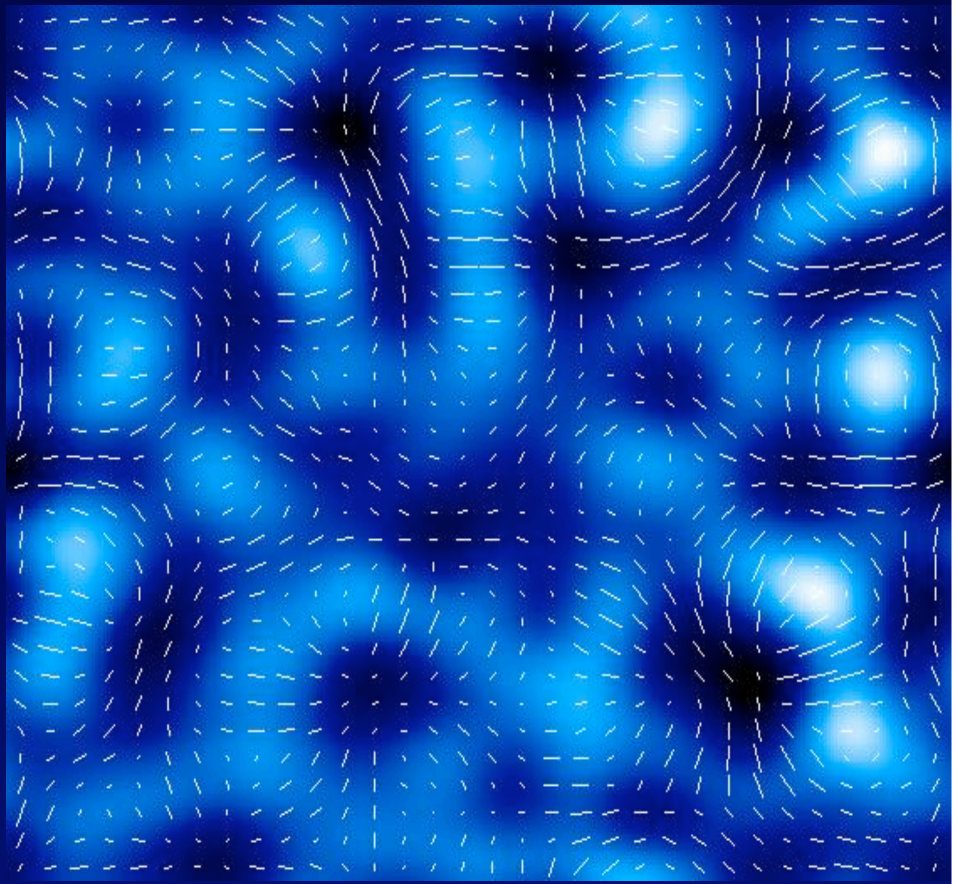
Theory

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

Weak Lensing Shear Measurement



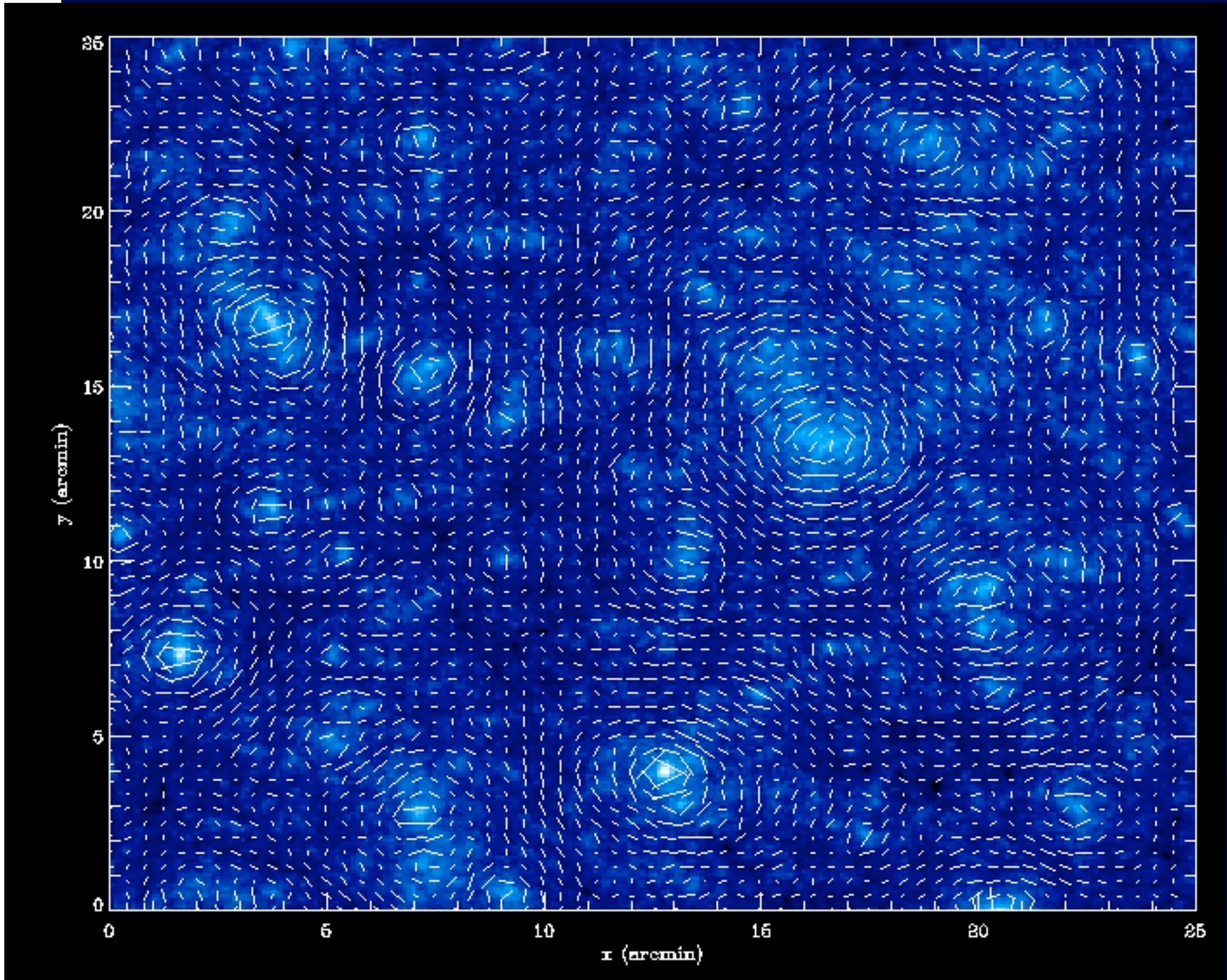
lensed background galaxies



mass and shear distribution

Scientific Promise of Weak Lensing

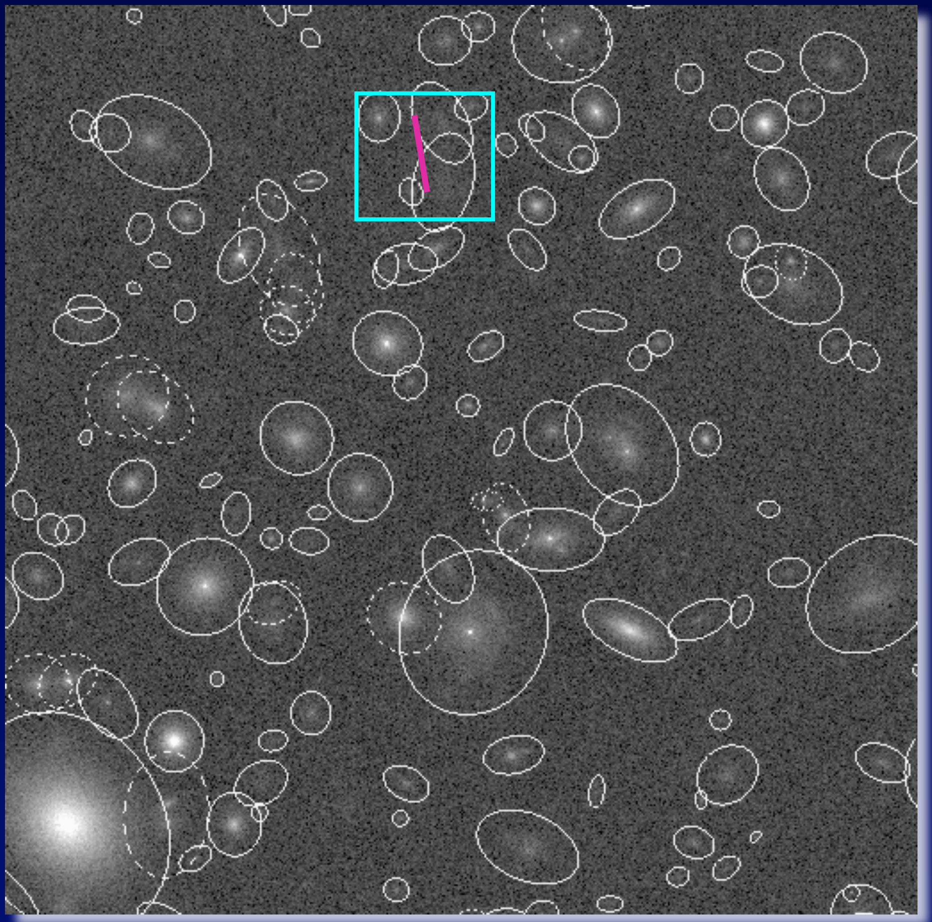
From the statistics of the shear field, weak lensing provides:



- 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

Shear Measurement

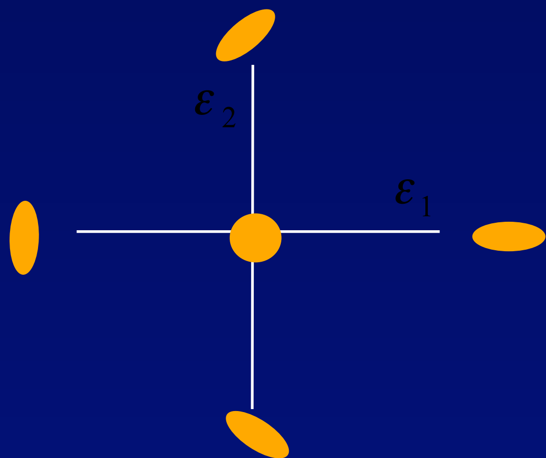


Quadrupole moments: $Q_{ij} = \int d^2x \, x_i x_j w(x) I(x)$

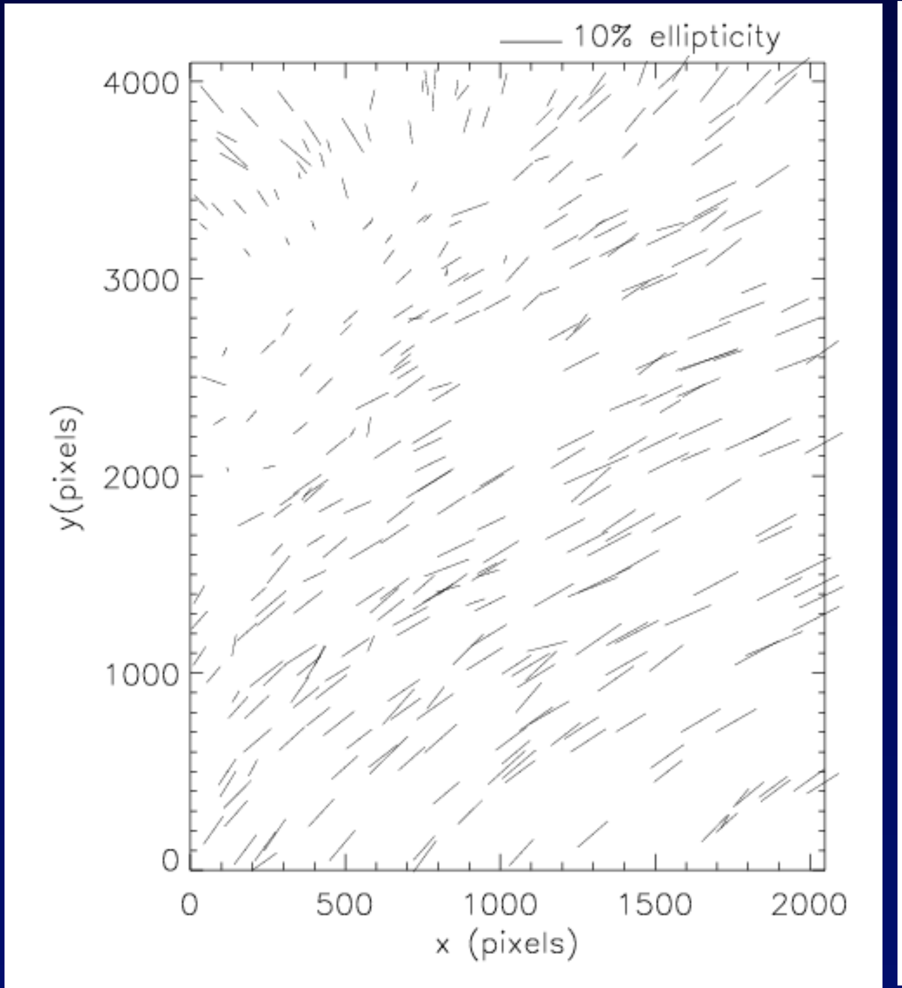
Ellipticity: $\varepsilon_1 = \dfrac{Q_{11} - Q_{22}}{Q_{11} + Q_{22}}, \; \varepsilon_2 = \dfrac{2Q_{12}}{Q_{11} + Q_{22}}$

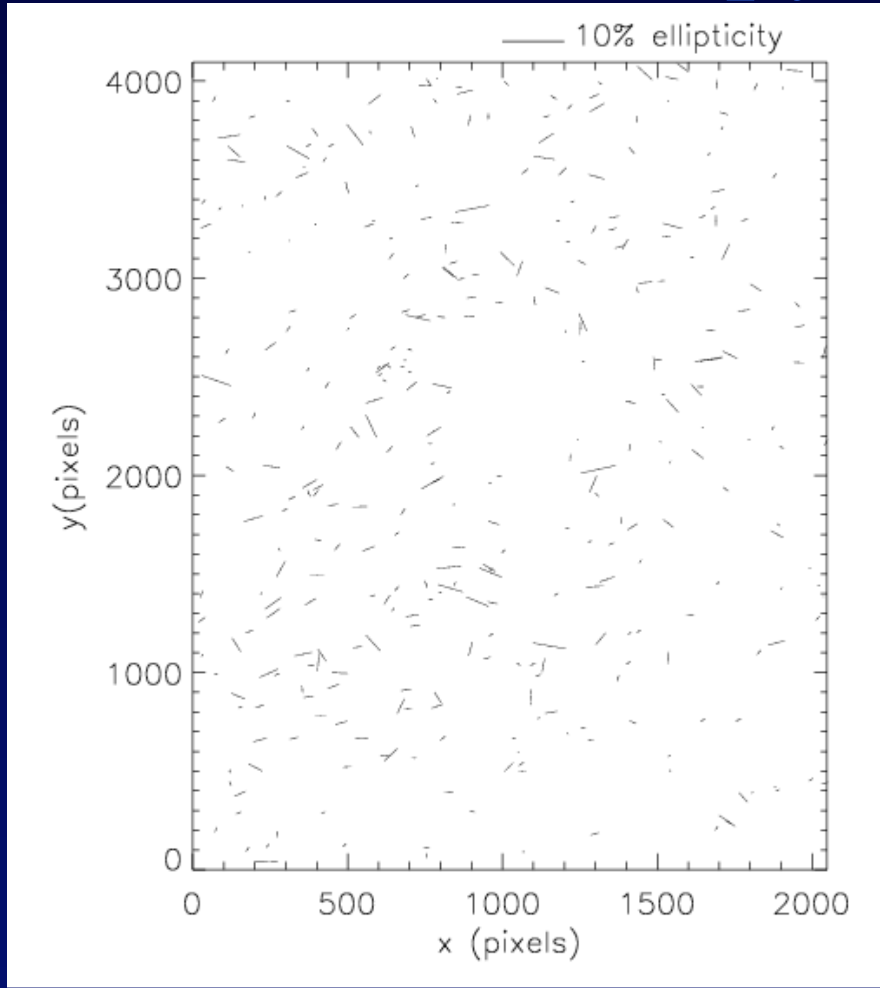
Shear: $\Psi_{ij} = \begin{pmatrix} 1 - \kappa - \gamma_1 & \gamma_2 \\ \gamma_2 & 1 - \kappa + \gamma_1 \end{pmatrix}$

Relation: $\langle \varepsilon_i \rangle = P^{\gamma} \gamma_i$



Systematic Effects: PSF anisotropy

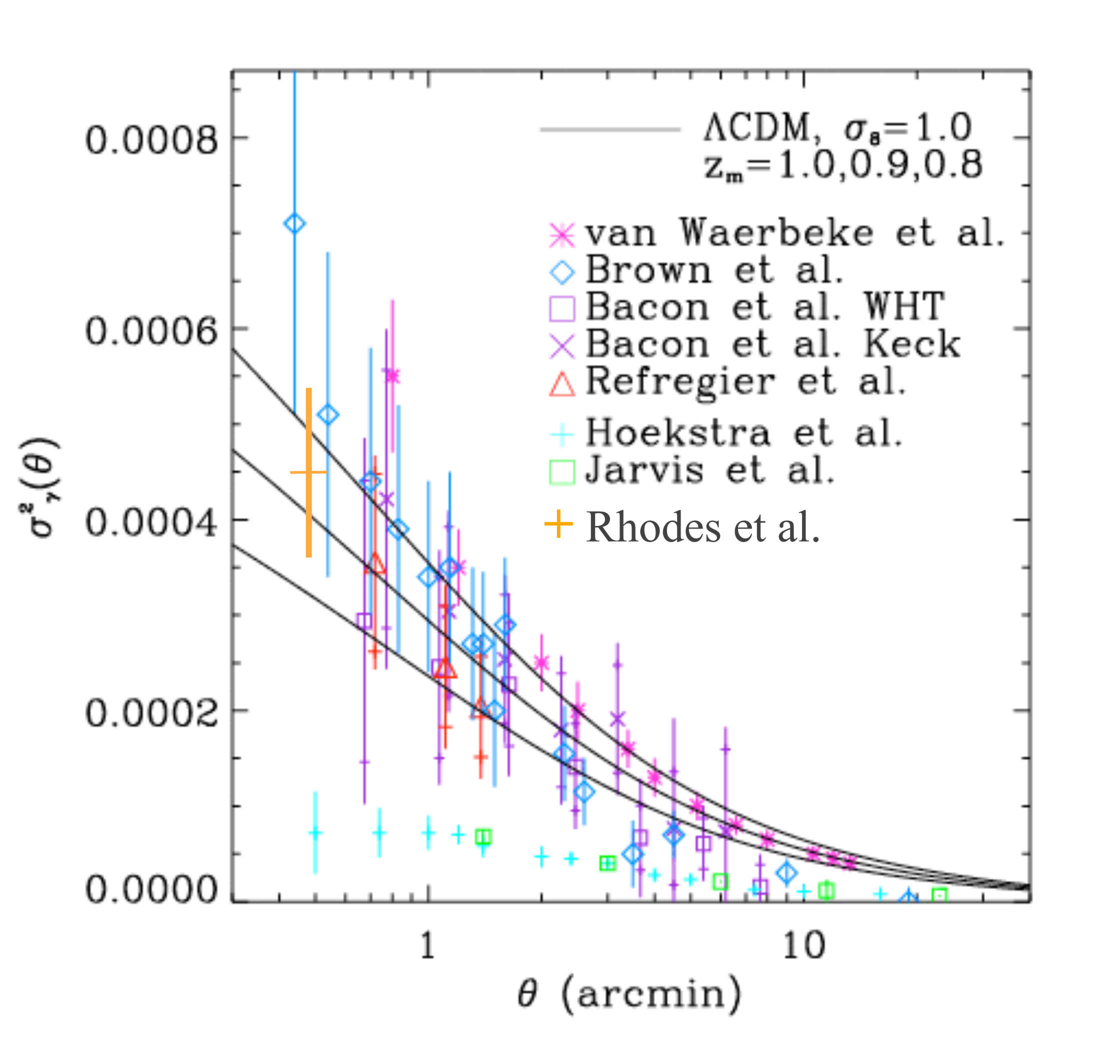




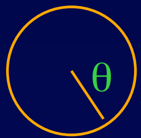
Methods: Bonnet & Mellier (1995), Kaiser, Squires & Broadhust (1995), Kuijken (1999), Kaiser (1999), Rhodes, Refregier & Groth (2000), Refregier & Bacon (2001), Bernstein & Jarvis (2001), Hirata & Seljak (2002), Kitching et al. 2007

Comparison Challenges: STEP, GREAT08, GREAT10

Cosmic Shear Measurements



Shear variance in circular cells:



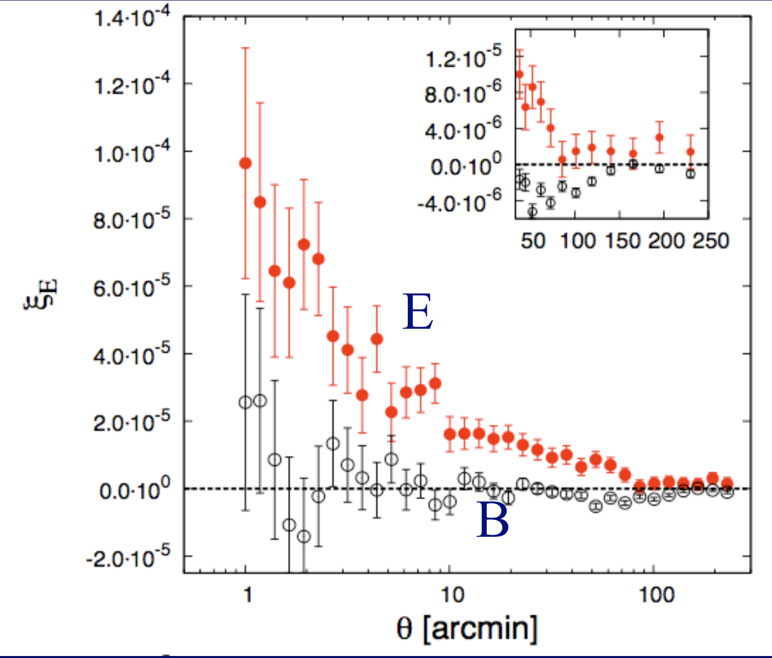
$\sigma^2_\gamma(\theta)=<\gamma^2>$

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

* not shown

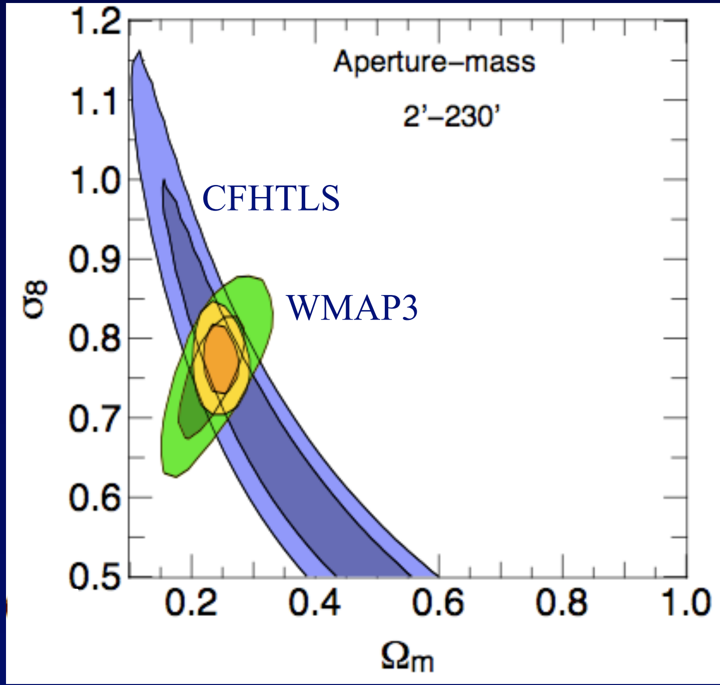
Cosmological Constraints

Shear correlation functions

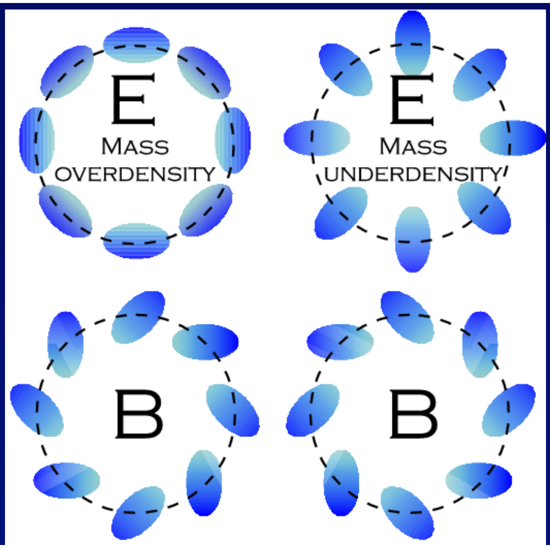


CFHTLS (first 57 deg^2)

Fu et al. 2008

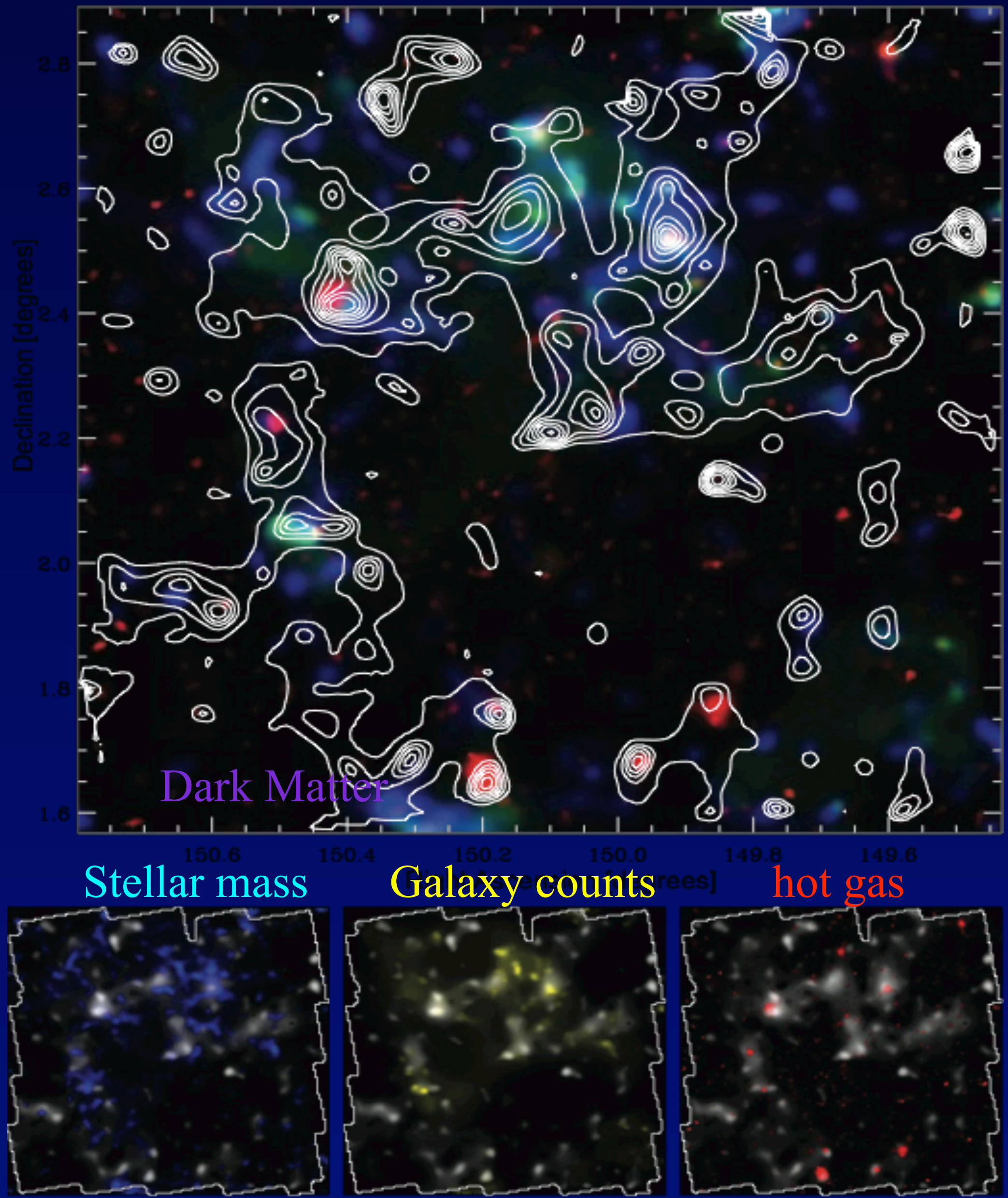


E/B decom-position



$$\sigma_8 \,(\Omega_m/0.25)^{0.64} = 0.78 \pm 0.04$$

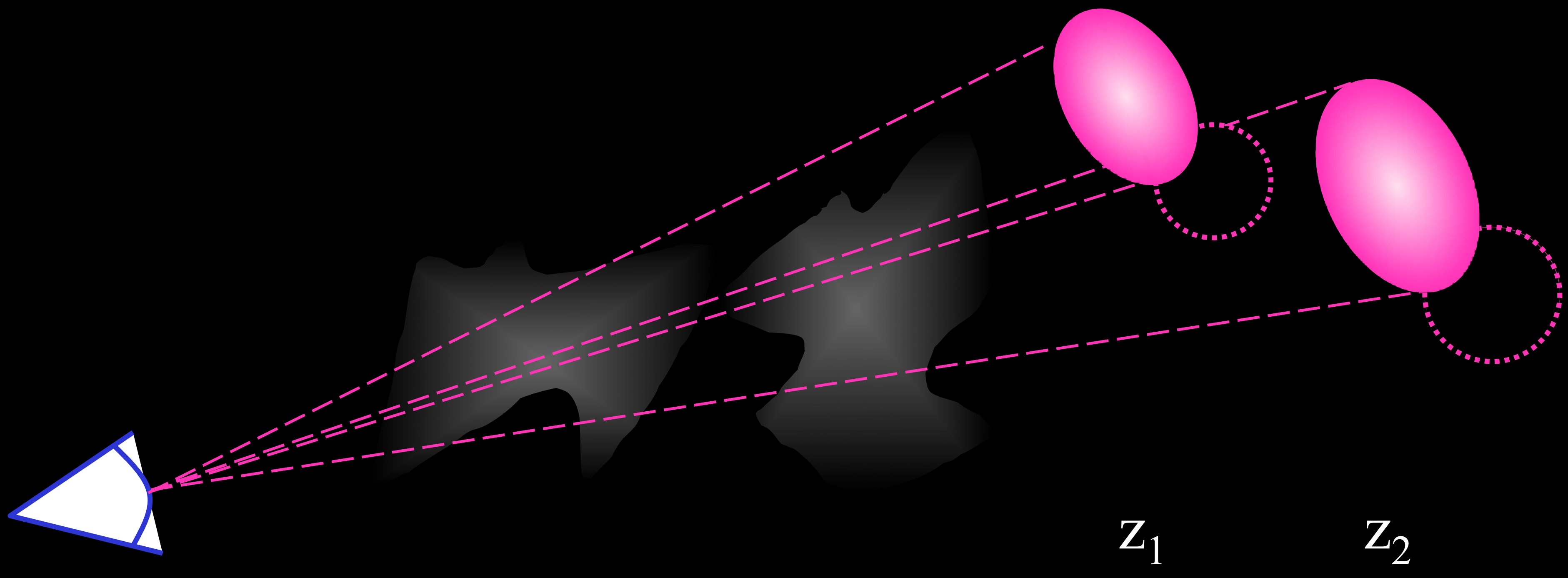
Dark Matter Mapping



COSMOS HST ACS survey in one band, with ground-based photometry and spectroscopy, 2 deg^2

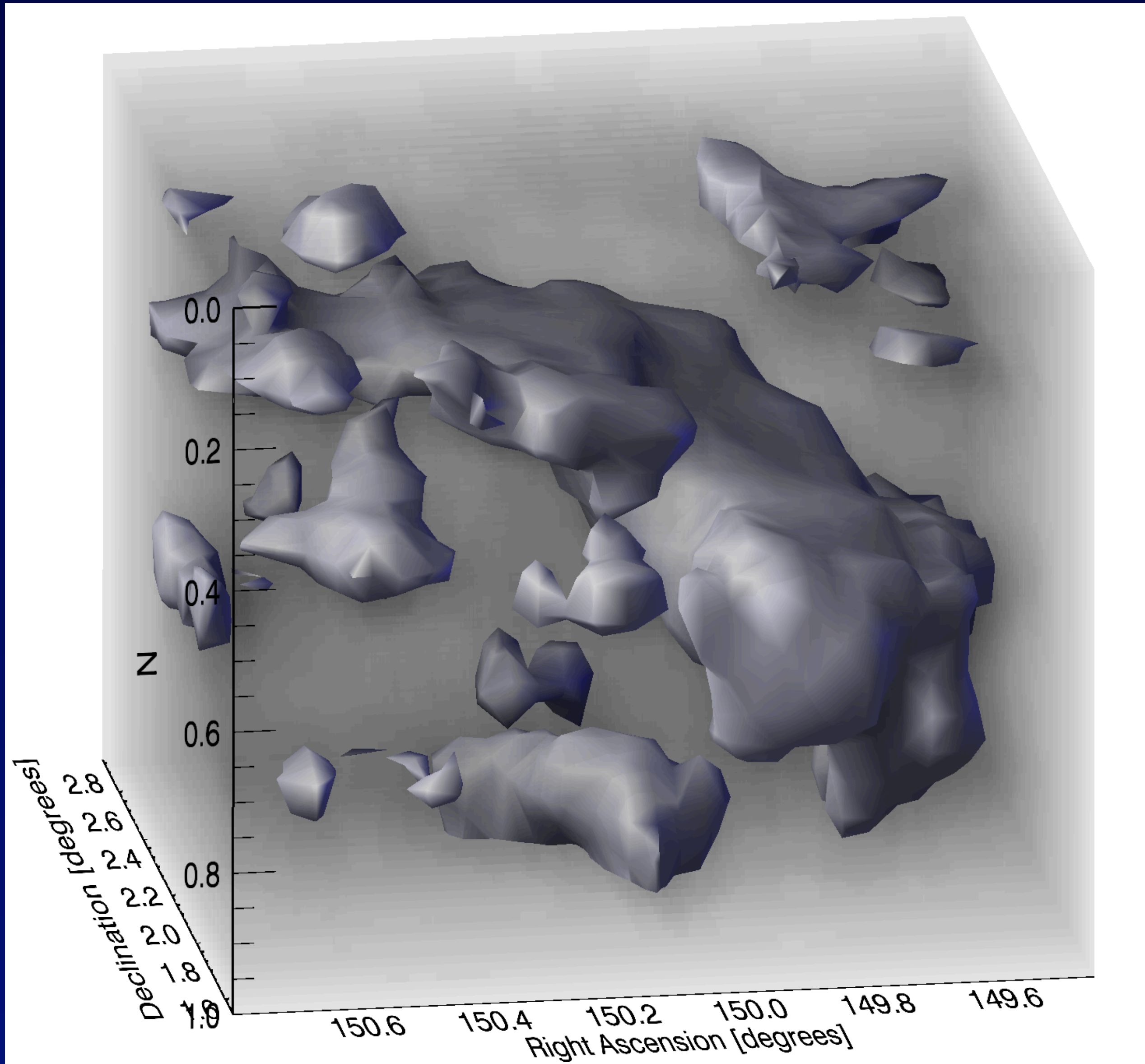
Massey et al. 2006, Nature

Weak Lensing Tomography



→ Measure the redshift dependence of the weak lensing signal

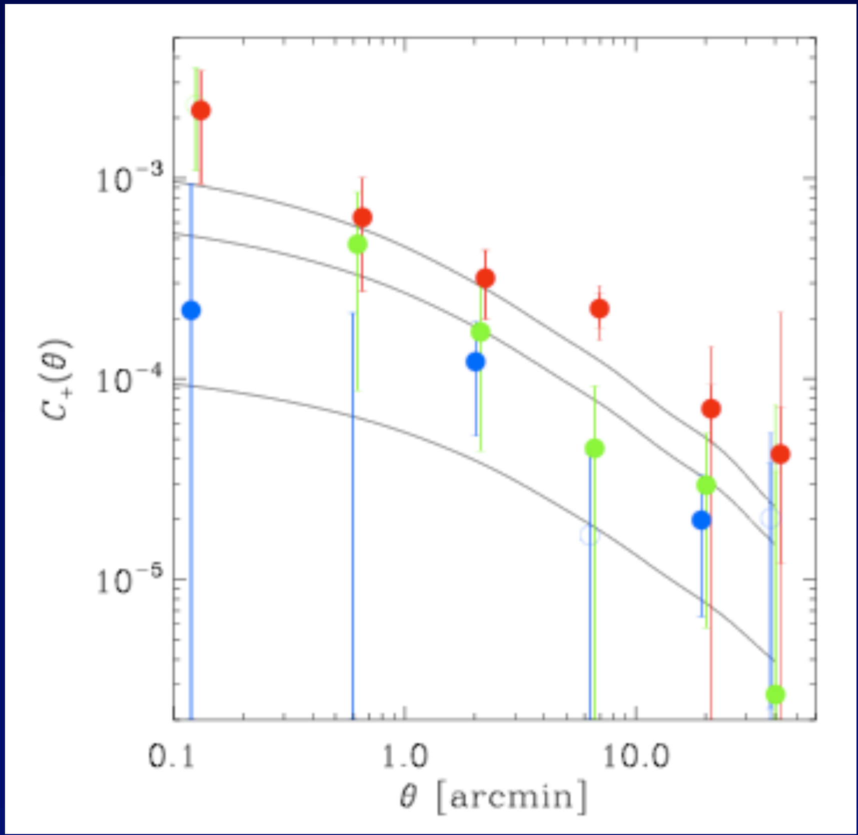
3D Mass Reconstruction with COSMOS

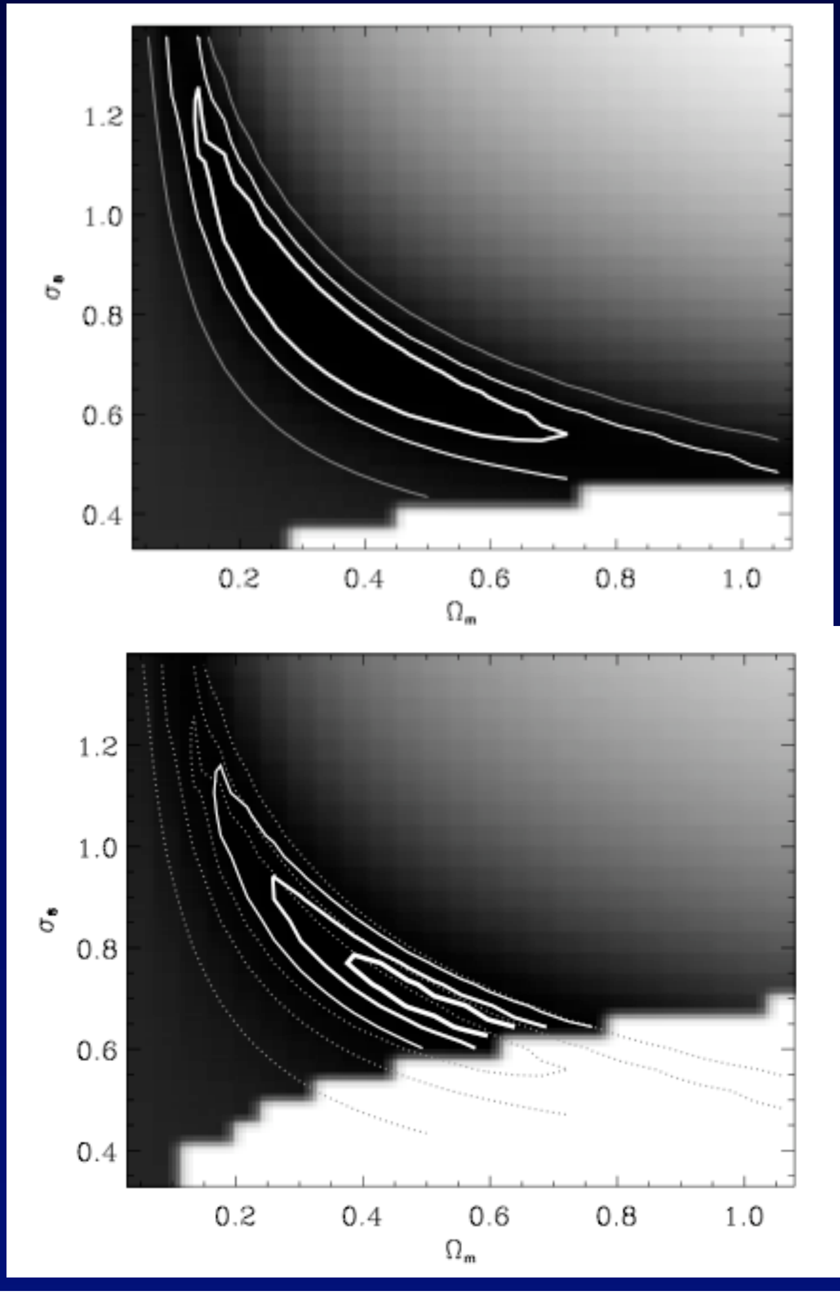


Massey et al. 2006

Weak Lensing Tomography with COSMOS

Massey et al. 2007



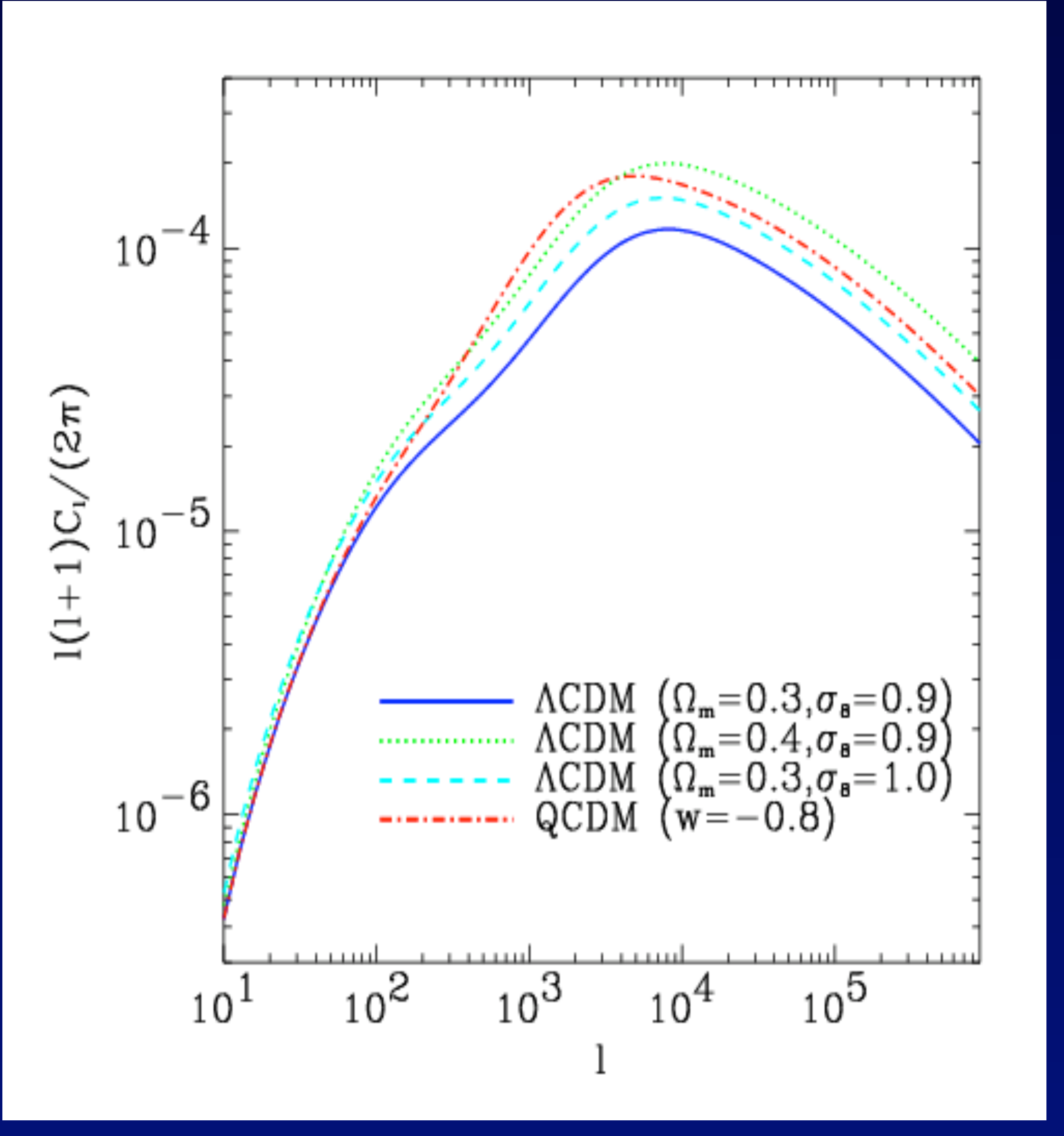


Wide-Field Imaging: Future Instruments

Survey	Diameter (m)	FOV[a] (deg^2)	Area[b] (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	5000(?)	2011
Pan-STARRS	1.8(x4)	4(x4)	20000	2009(2014)
LSST	8	7	20000	2014
Euclid	1.2 space	1	20000	2017
JDEM	1.5 space	1(?)	20000(?)	2015-2018

a) Imaging
b) Extragalactic

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

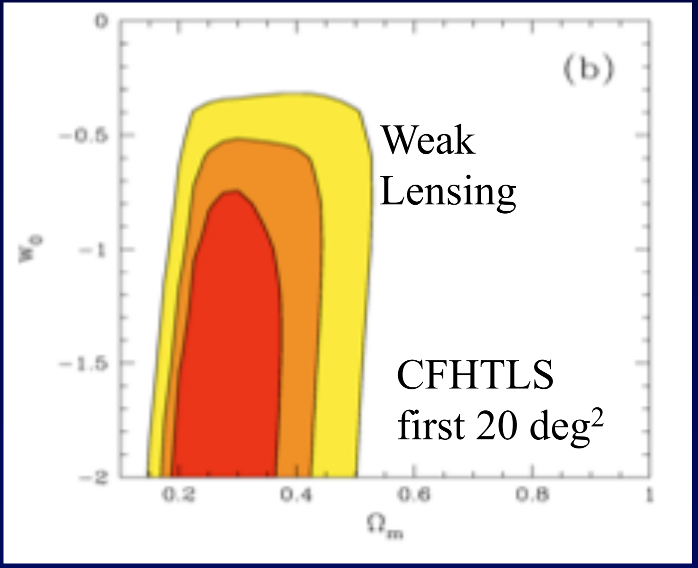
Cf. Hui 1999, Benabed & Bernardeau 2001, Huterer 2001, Hu 2000, Munshi & Wang 2002

Current DE Constraints

Current constraints: 10-20% on constant w

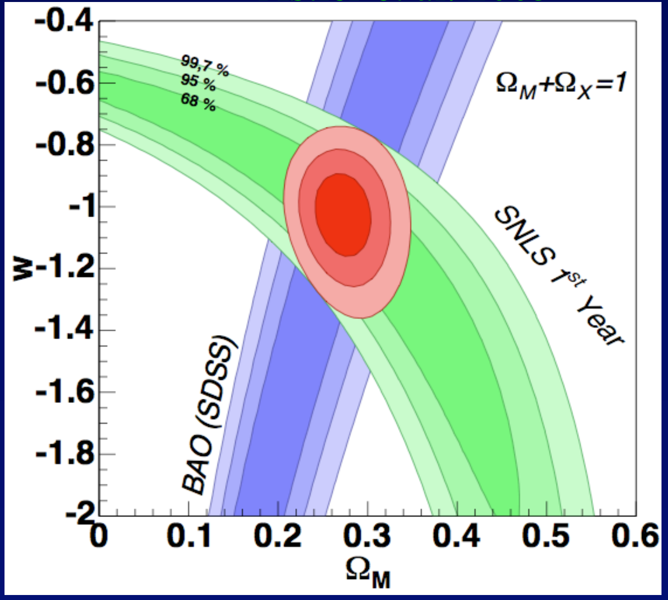
For definite answers on DE: need to reach a precision of 1% on (varying) w and 10% on w'

Hoekstra et al. 2005

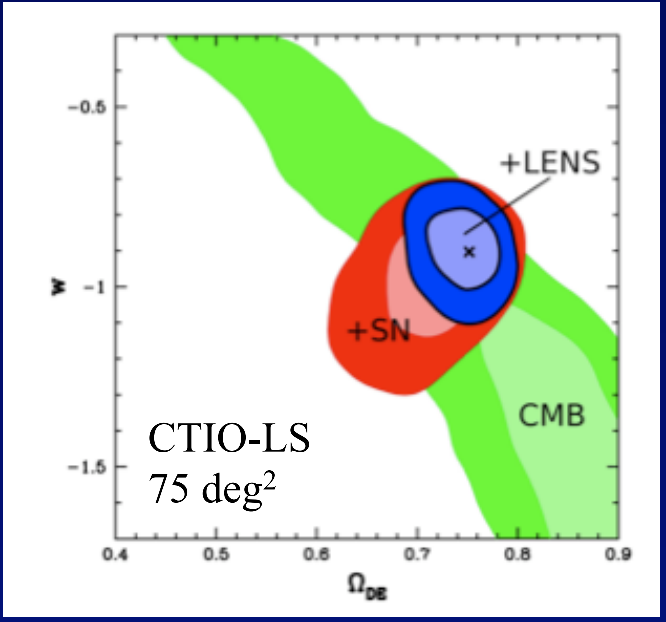


Astier et al. 2005

Comparison with Other Probes



Jarvis et al. 2006

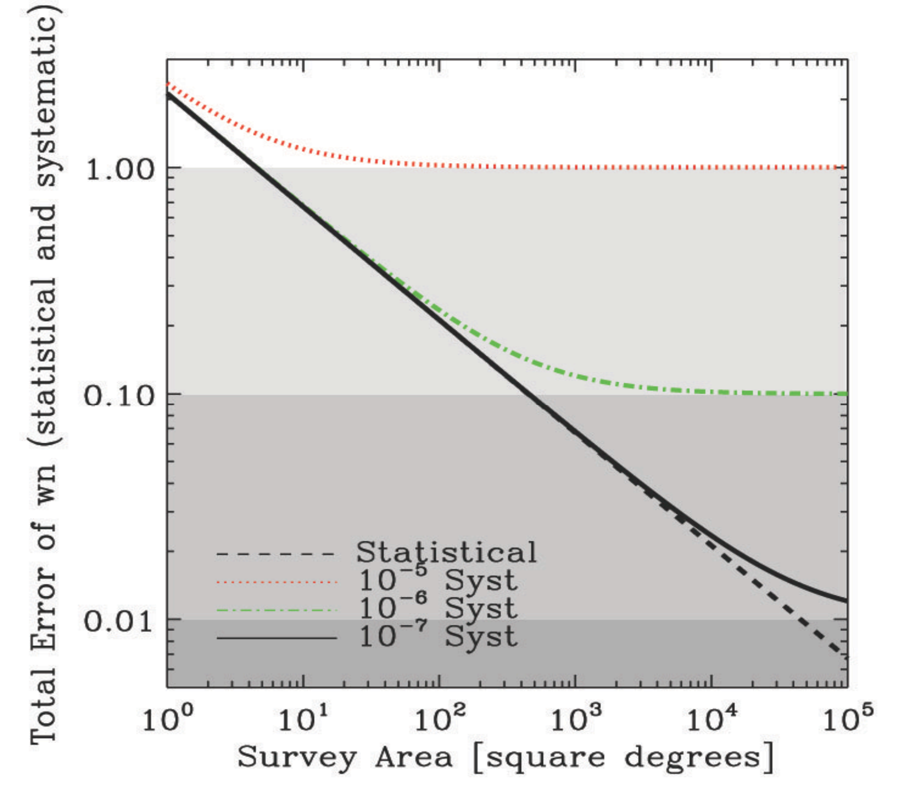


Requirements for Weak Lensing

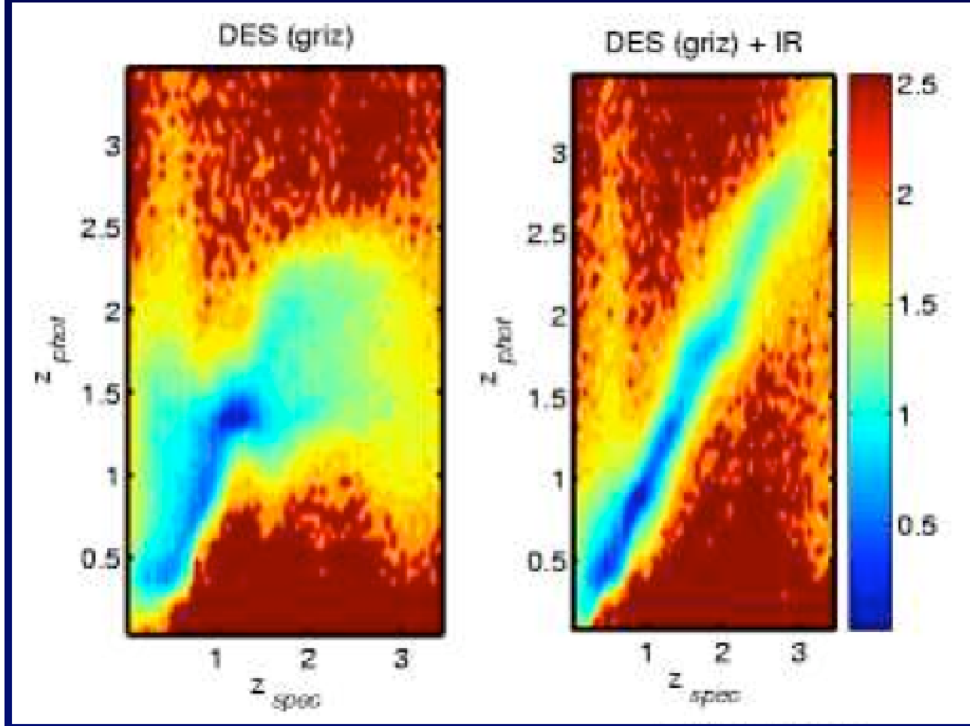
Statistics: optimal survey geometry: wide rather than deep for a fixed survey time, → need 20,000 deg^2 to reach ~1% precision on w

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

Euclid Mission: Cosmological Probes

EUCLID

Primary probes:

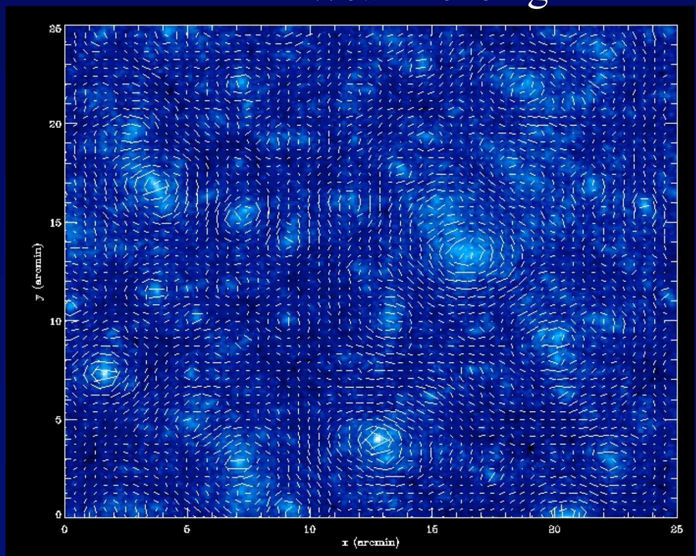
with all-sky Vis+NIR imaging and spectroscopic survey

- Weak Lensing
- Baryonic Accoustic Oscillations

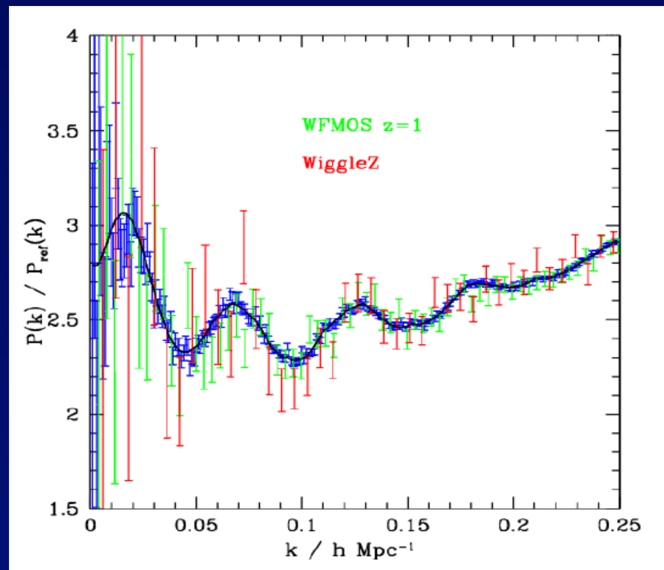
Additional Probes:

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

Weak Lensing



BAO

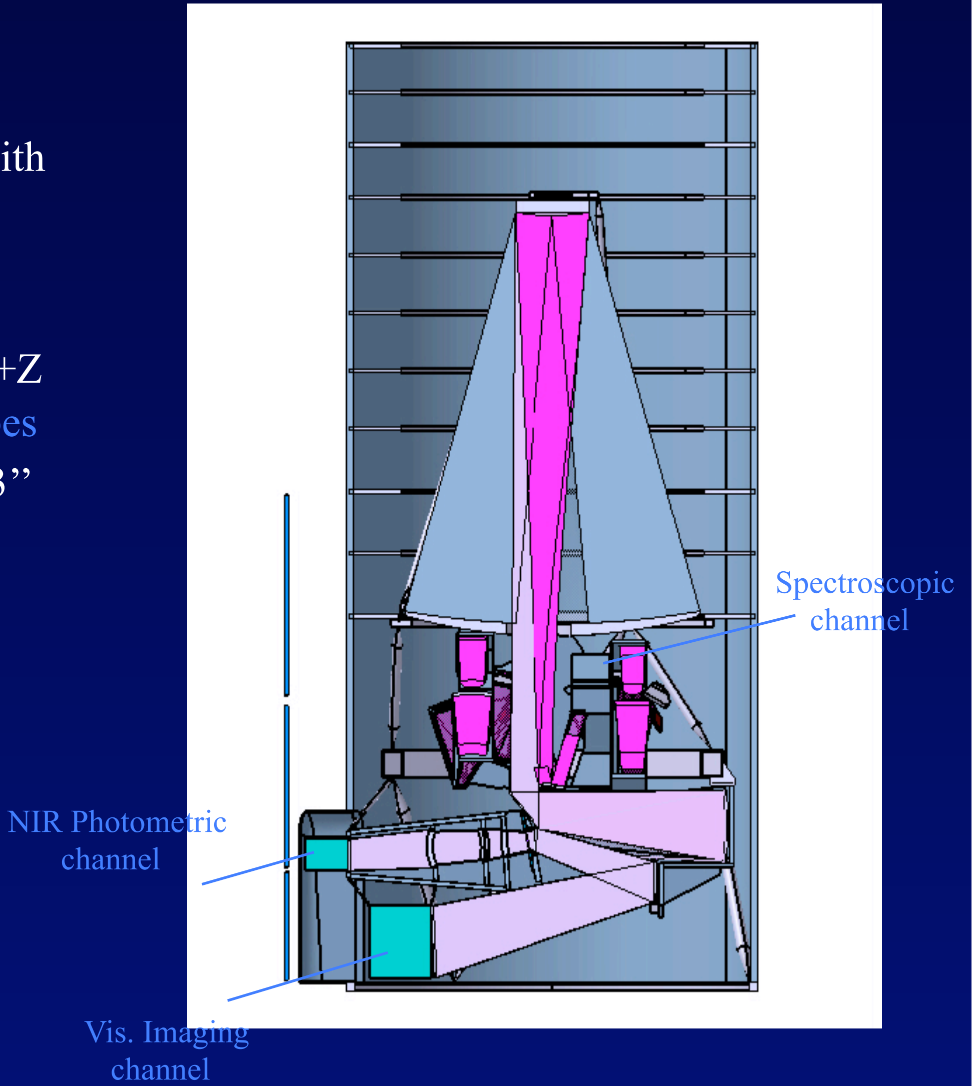


Euclid Mission

EUCLID

Mission baseline:

- L2 Orbit
- 4-5 year mission
- Telescope: three mirror assembly (TMA) with 1.2 m primary
- Instruments:
- – Visible imaging channel: 0.5 deg^2, 0.10'' pixels, 0.18'' 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: 0.5 deg^2, R=200-600, 0.9-1.7mu, baseline: slitless, option: slits with DMD, redshifts



Instrument consortia:

- Imaging: France, Germany, Italy, Spain, Switzerland, UK, USA
- Spectroscopy: Italy, France, UK, Germany, Netherlands, Spain, Norway, Austria, Switzerland, Romania, USA

Euclid Surveys

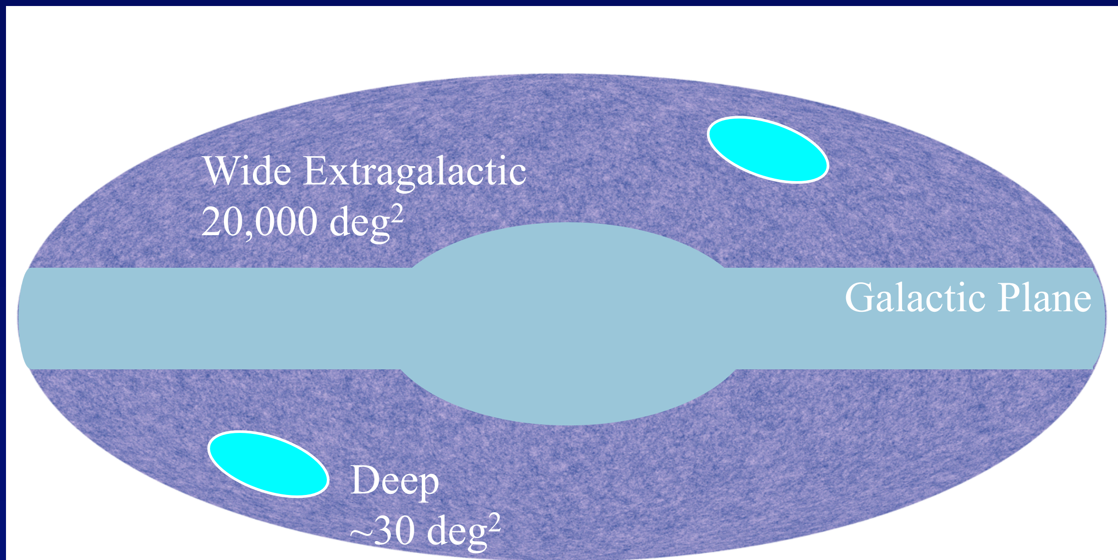
EUCLID

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: galaxy emission line fluxes >4.10^{-16} ergs/cm^2/s (slitless), and 1/3 of H(AB)<22 mag galaxies (DMD), 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



Weak Lensing Tomography

Wide Survey: 20,000 deg^2, 35 galaxies/amin^2, z_m=0.9, ground -based complement for photo-z's

WL power spectrum for each z-bin

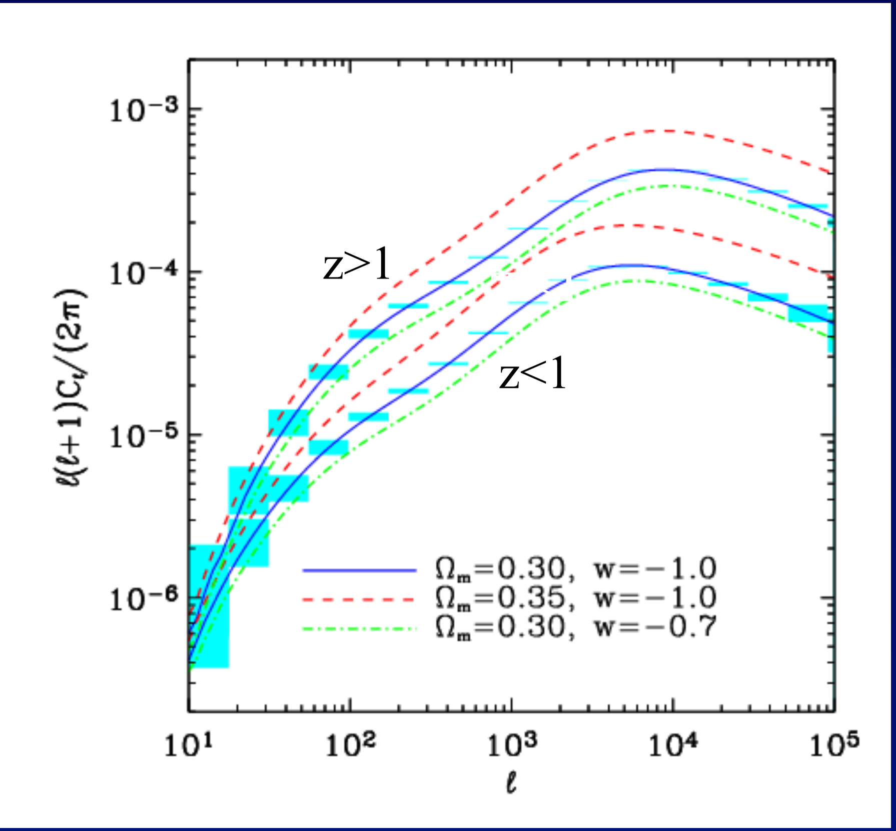
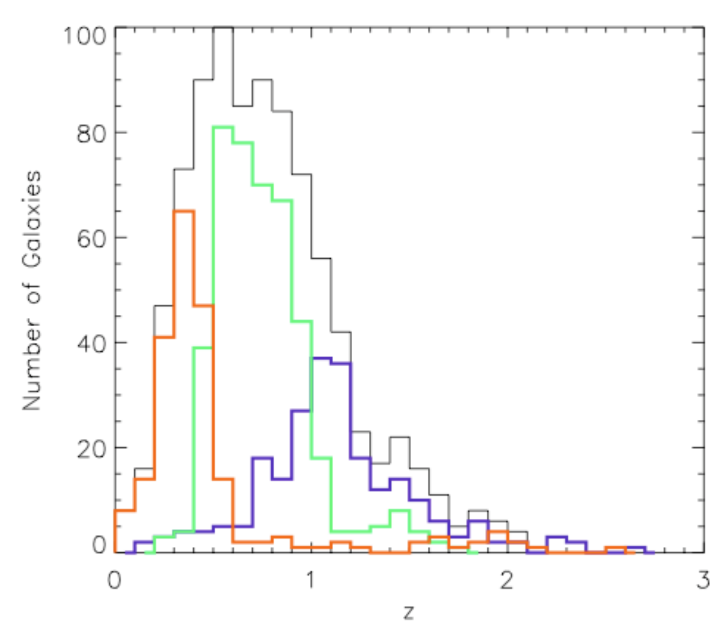
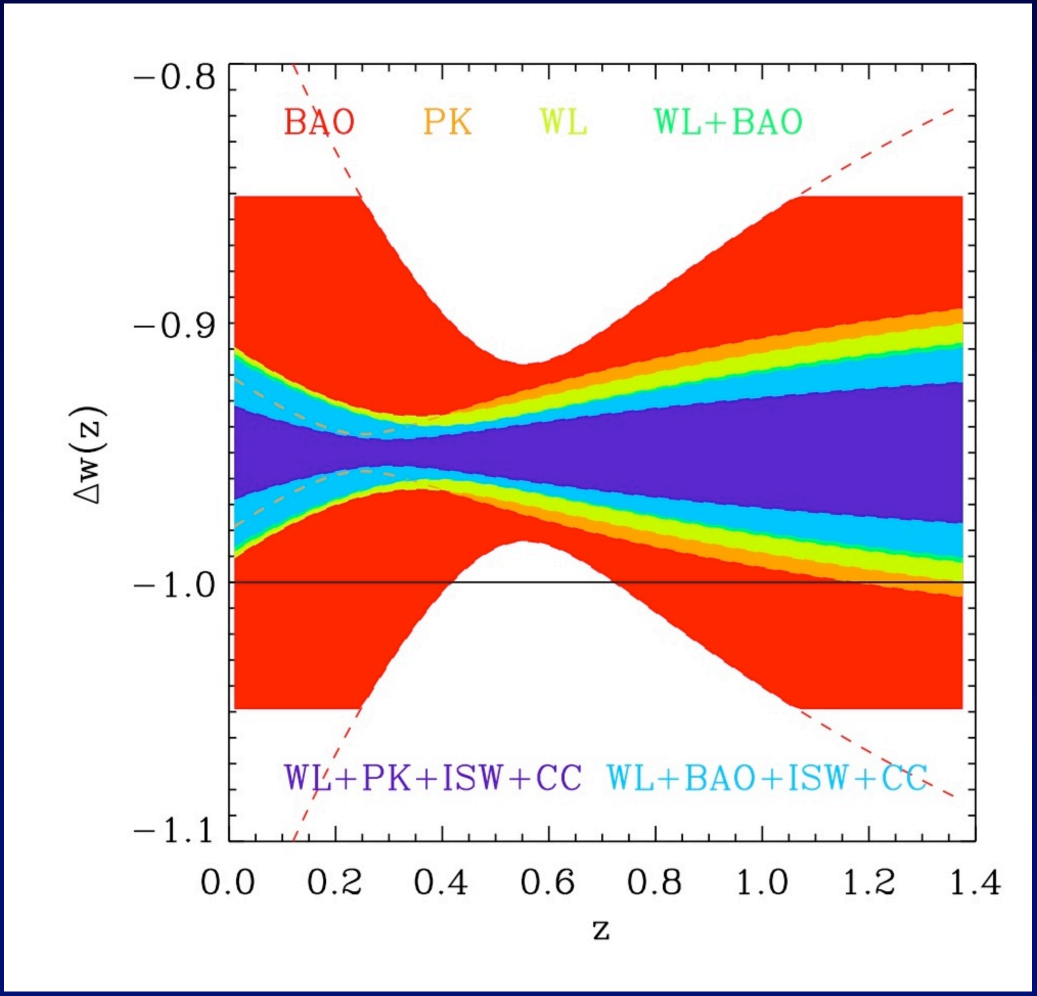


Image simulations



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

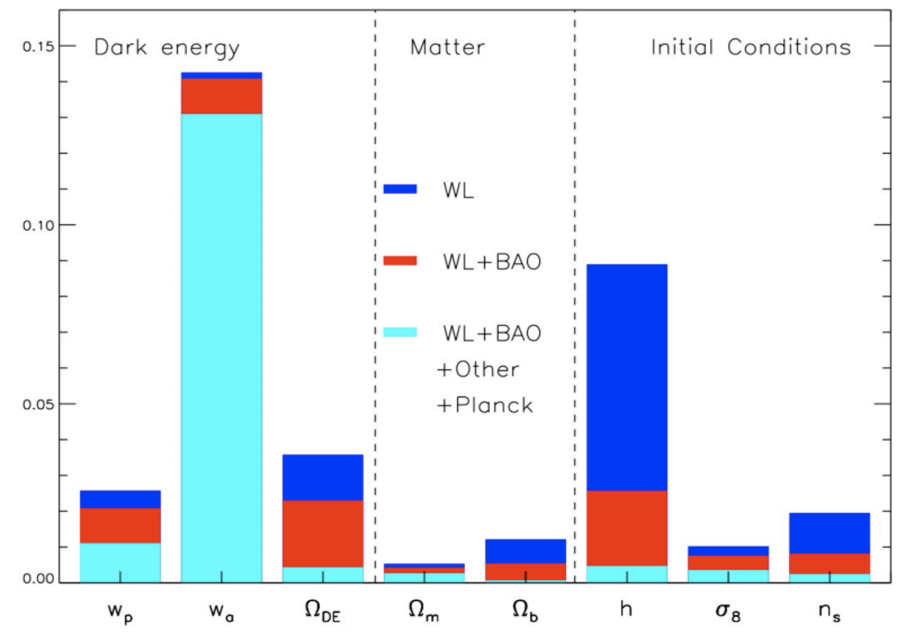
Legacy:

- 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

EUCLID



Euclid will challenge all the sectors of the Cosmological model:

- Dark Energy: w_n and w_a with an error of 2% and 13% respectively (no priors)
- 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 ($d\ln\delta_m/d\ln a \propto \Omega_m^{\gamma}$)

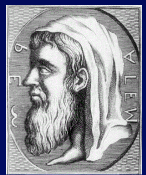
→ Uncover new physics

→ Map the LSS at 0<z<2: low redshift counterpart of CMB measurements

EUCLID

Project Status

- 2004: Wide-field Dark Universe Mission proposed as a *Theme* to ESA's Cosmic Vision programme
- June 2007: DUNE and SPACE proposed to ESA's Cosmic Vision AO as M-class missions
- Oct 2007: DUNE and SPACE jointly selected for an ESA Assessment Phase
- Jan-May 2008: Formation and activities of the Concept Advisory Team (CAT) to define a common mission concept



- May 2008: Validation of the merged concept *Euclid* by the ESA AWG
- May 2008: Formation of the Euclid Science Study team (ESST) to replace CAT
- May-June 2008: Technical study by ESA's Concurrent Design Facility (CDF)
- Sept 2008-Sept 2009: Industrial and Instrumental Assessment study phase (ESA/NASA discussions →)
- 2010-2011: Definition phase (if selected)
- 2012-2017: Implementation phase (if further selected)
- 2017: ESA launch of the first Cosmic Vision M-class mission

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 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 all sectors of the cosmological model (in particular on DE:~1% precision on w and ~10% on dw/da) and produce a wealth of secondary science