Weak Gravitational Lensing by Large-Scale Structure

Alexandre Refregier (Cambridge)

Collaborators:

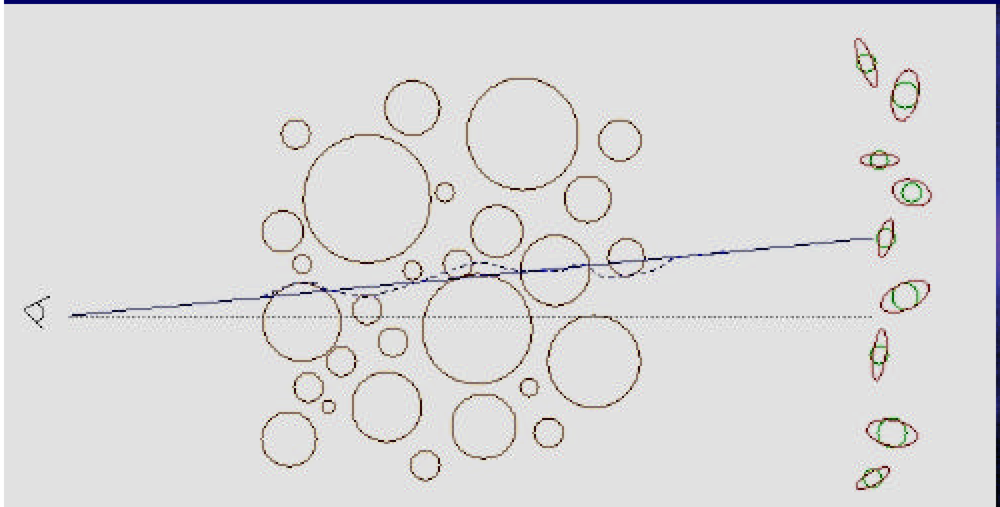
Richard Ellis (Caltech)

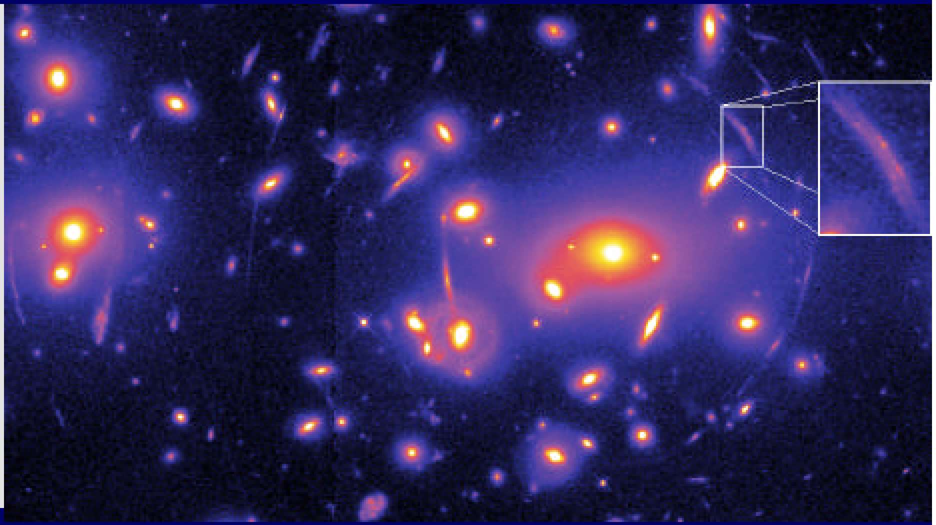
David Bacon (Cambridge)

Richard Massey (Cambridge)

Snowmass 2001 - July 2001

Weak Lensing by Large-Scale Structure





Distortion Matrix:

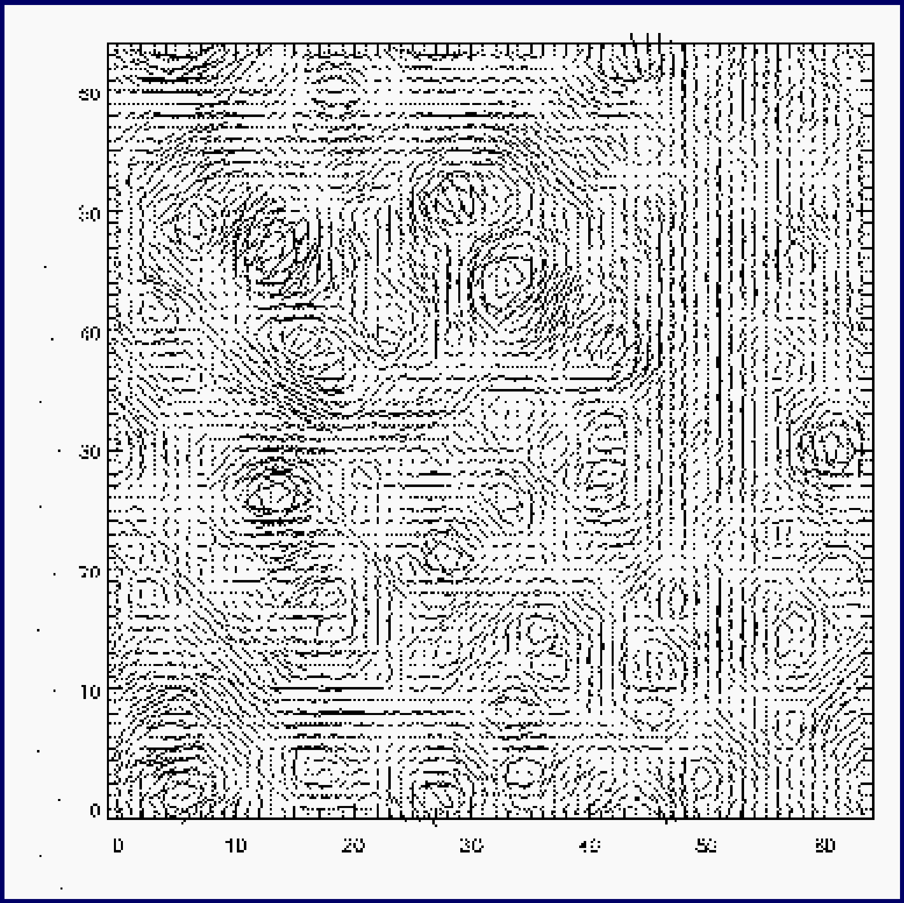
$$\Psi_{ij} = \frac{\partial dq_i}{\partial q_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial q_i \partial q_j}$$

Theory

→ Direct measure of the distribution of mass in the universe, as opposed to the distribution of light, as in other methods (eg. Galaxy surveys)

Scientific Promise of Weak Lensing

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



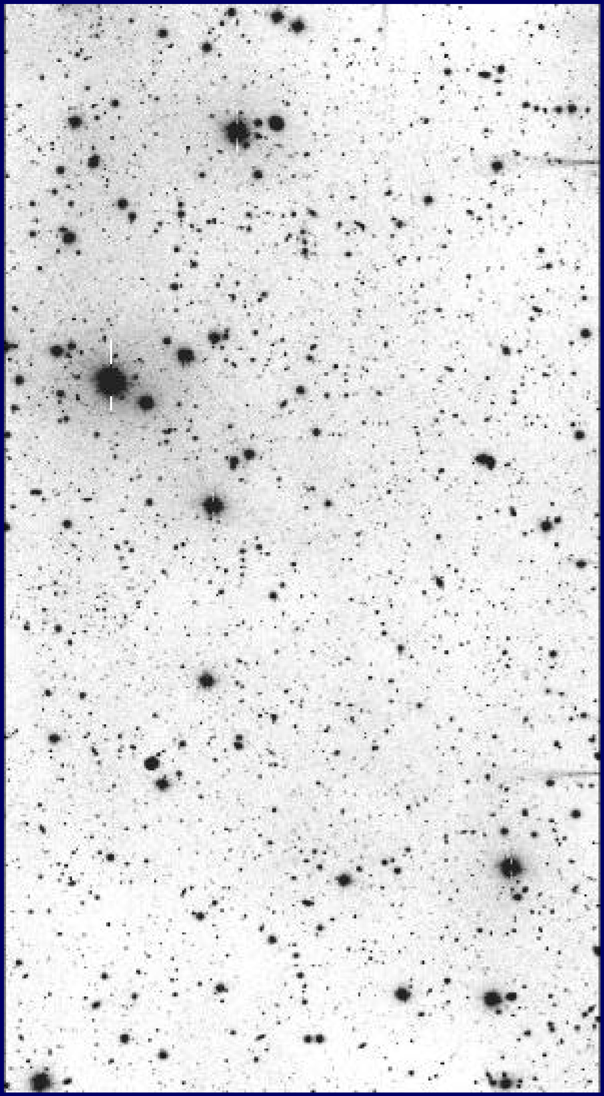
- Mapping of the distribution of Dark Matter on various scales
- Measurement of cosmological parameters, breaking degeneracies present in other methods (SNe, CMB)
- Measurement of the evolution of structures
- Test of gravitational instability paradigm
- Test of General Relativity in the weak field regime
- a mass-selected cluster catalog

Jain et al. 1997, 1x1 deg

Deep Optical Images

William Herschel Telescope
La Palma, Canaries

16'x8'
R<25.5
30 (15) gals/sq. arcmin



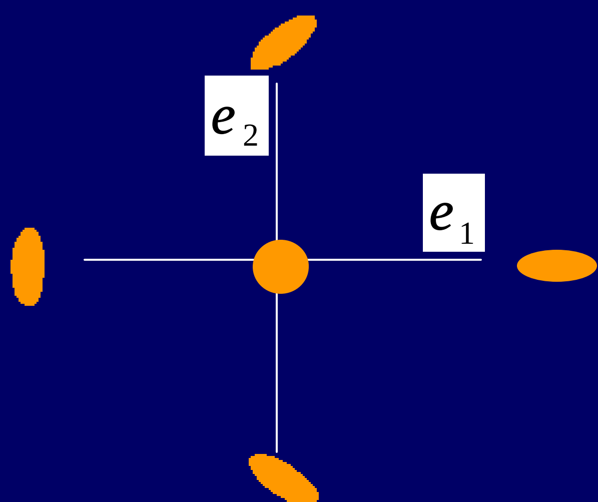
Procedure

Quadrupole moments:

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

Ellipticity:

$$e_1 = \frac{Q_{11} - Q_{22}}{Q_{11} + Q_{22}}, e_2 = \frac{2Q_{12}}{Q_{11} + Q_{22}}$$



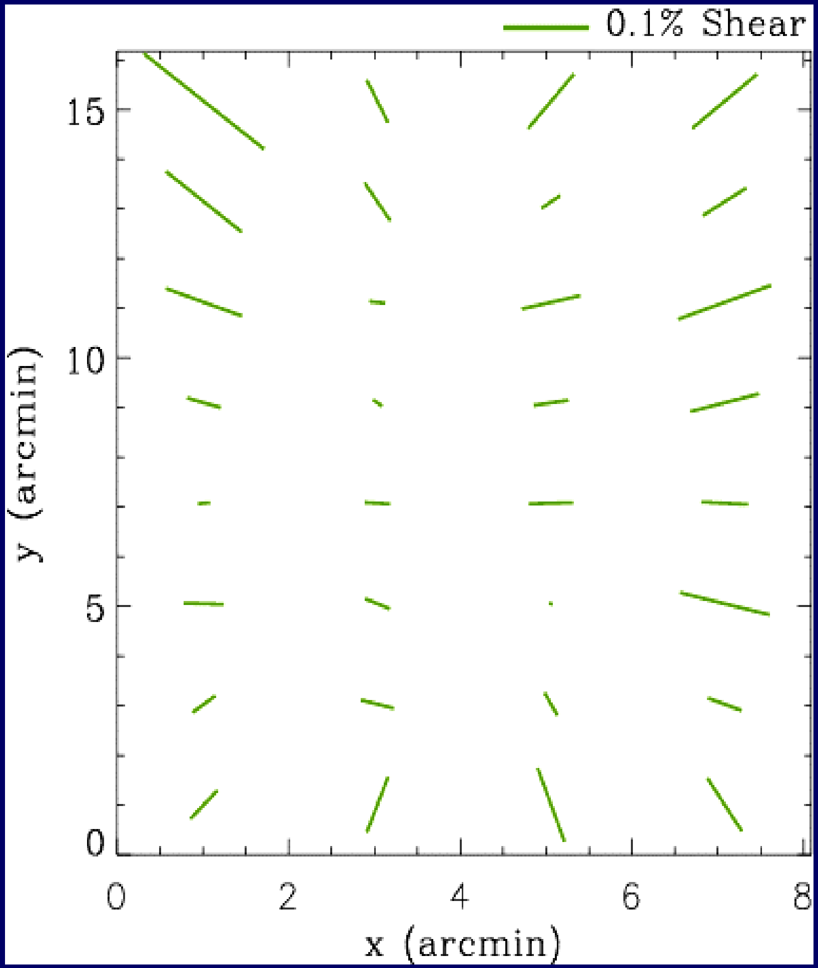
Shear:

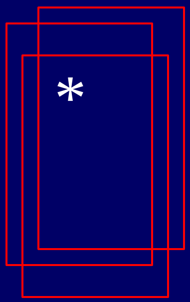
$$\Psi_{ij} = \begin{pmatrix} 1-k-g_1 & g_2 \\ g_2 & 1-k+g_1 \end{pmatrix}$$

Relation:

$$\langle e_i \rangle = P^g g_i$$

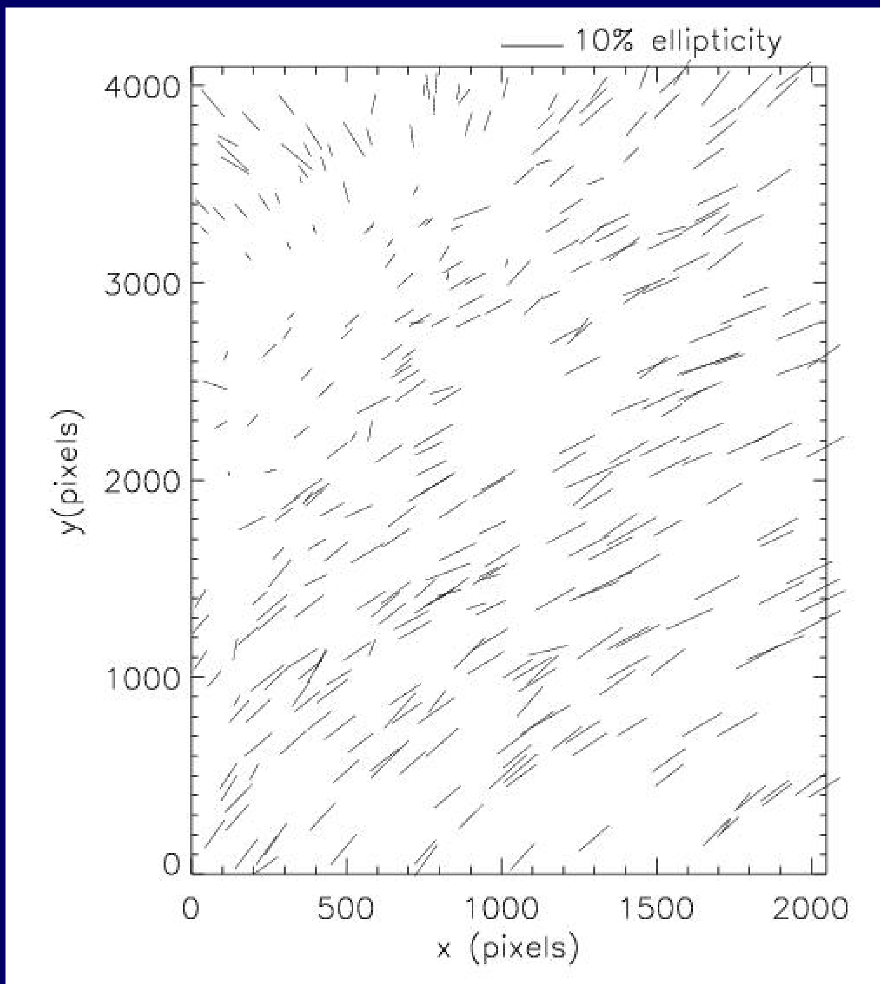
Instrumental Distortion

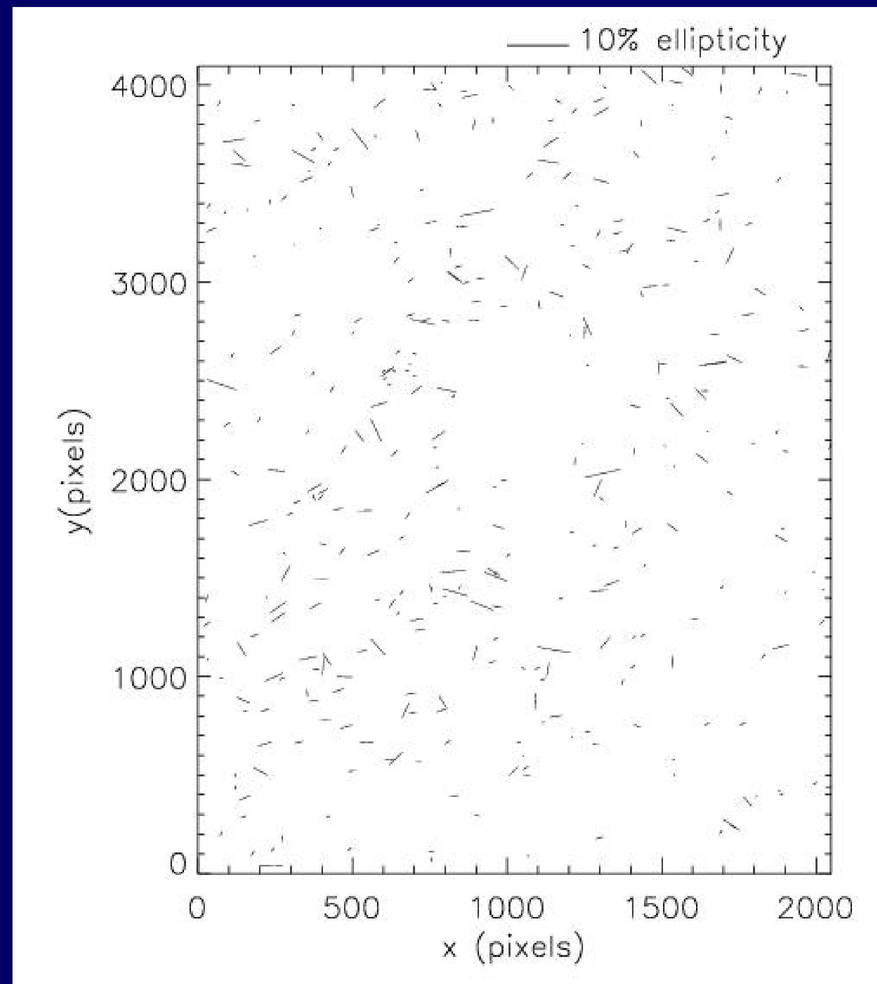




Dithered fields

PSF anisotropy





3-10% rms reduced to ≈0.1%

Correction Method

KSB Method: (Kaiser, Squires & Broadhurst 1995)

PSF Anisotropy:

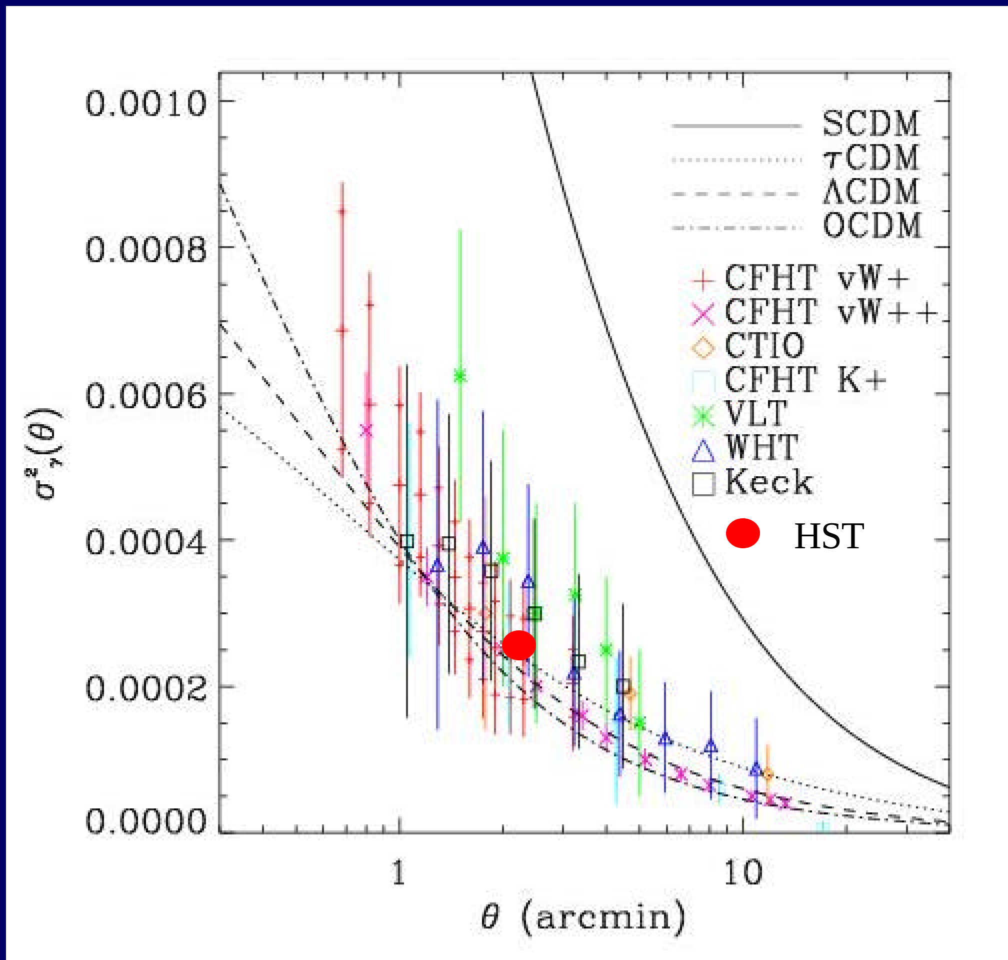
$$e_g = e'_g - \frac{P_g^{sm}}{P_*^{sm}} e_*$$

PSF Smear & Shear Calibration:

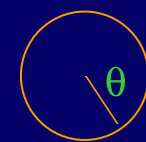
$$g = (P^g)^{-1} e_g$$

Other Methods: Kuijken (1999), Kaiser (1999), Rhodes, Refregier & Groth (2000), Refregier & Bacon (2001)

Current Observational Status



Shear variance in circular cells:



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

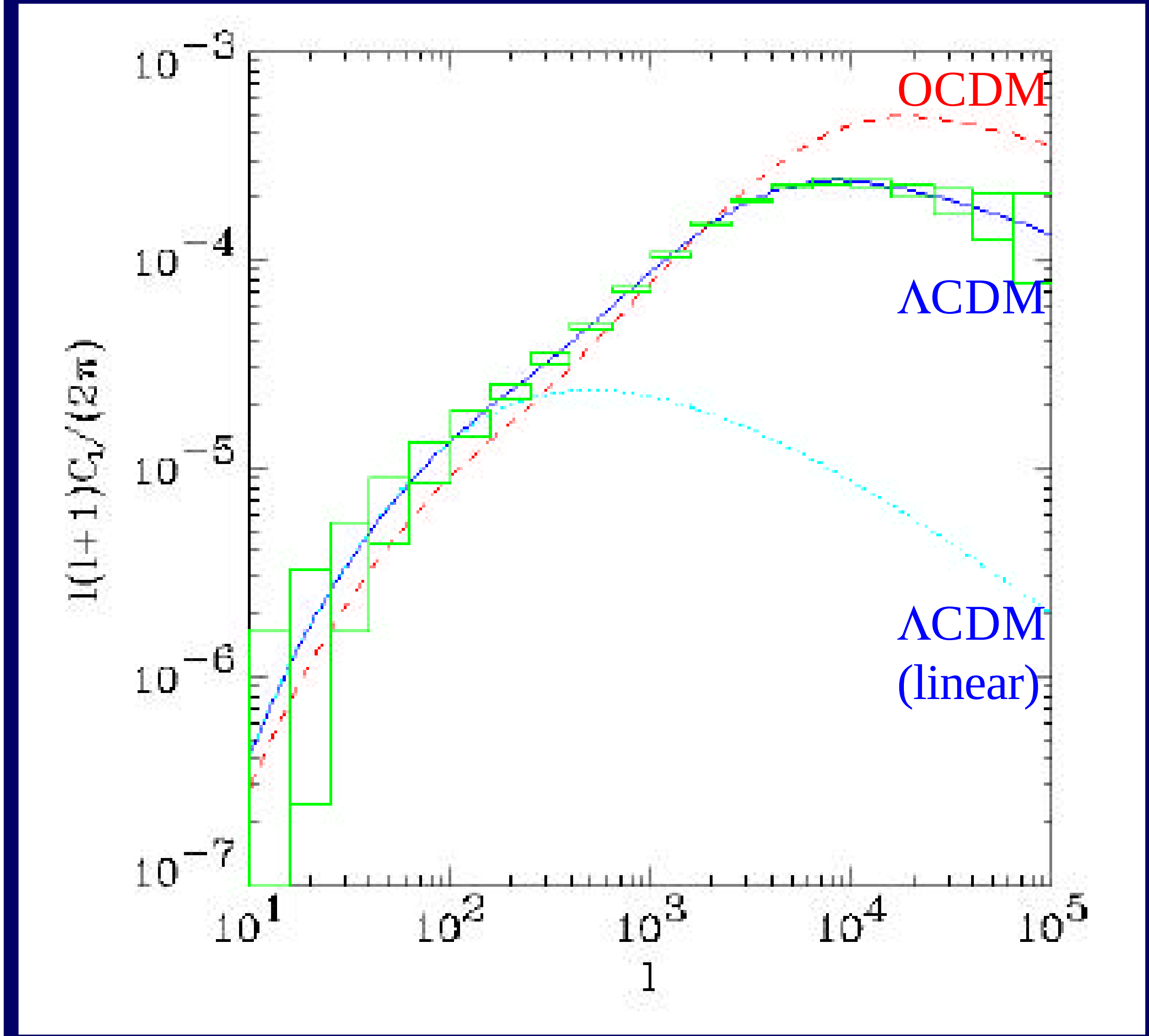
→ Different measurements are consistent

→ In agreement with cluster-normalised CDM model

→ measure of the amplitude of mass fluctuations:
$\sigma_8(\Omega_m/0.3)^{0.5} = 1.07 \pm 0.23$

Cluster counts (Viana & Liddle, Eke et al.): $\sigma_8(\Omega_m/0.3)^{0.5} = 1.02 \pm 0.11$
→ In agreement, test of primordial non-gaussianity

Weak Lensing Power Spectrum

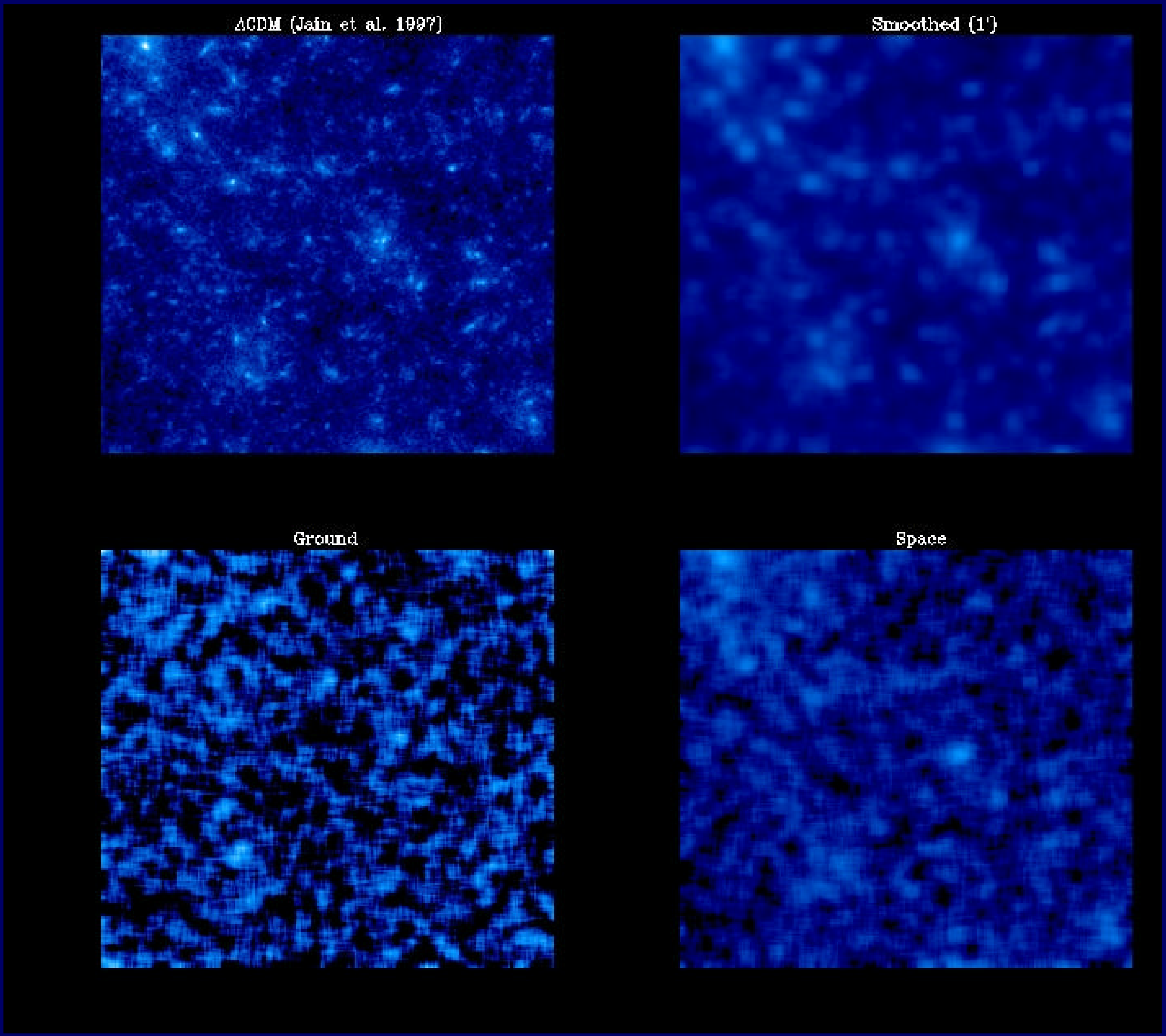


Future surveys:
Megacam, Subaru, VISTA, LSST, WHFRI, SNAP, etc

→ Measure cosmological parameters (σ_8, Ω_m, Ω_Λ, Γ, etc)
→ very sensitive to non-linear evolution of structures

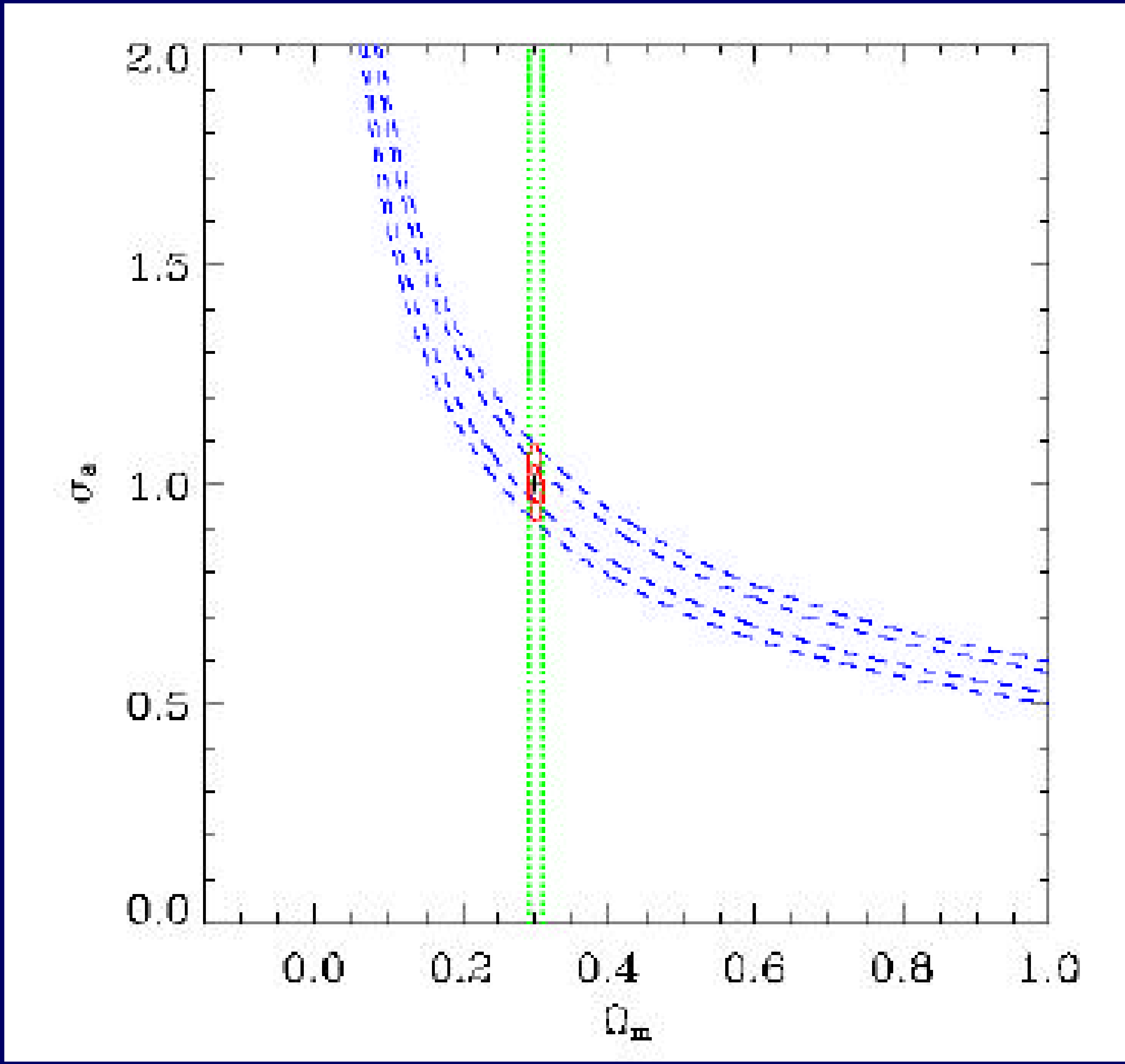
SNAP WF survey [300 deg^2 ; 100 g $arcmin^{-2}$; HST image quality]

Mapping the Dark Matter



LCDM
0.5x0.5 deg
Jain et al. 1998

Skewness



Cf. Bernardeau et al. 1997

Variance: $\langle k^2 \rangle$

Skewness: $\langle k^3 \rangle$

$\rightarrow$ Skewness breaks degeneracies (e.g. Ω_M and σ_8)

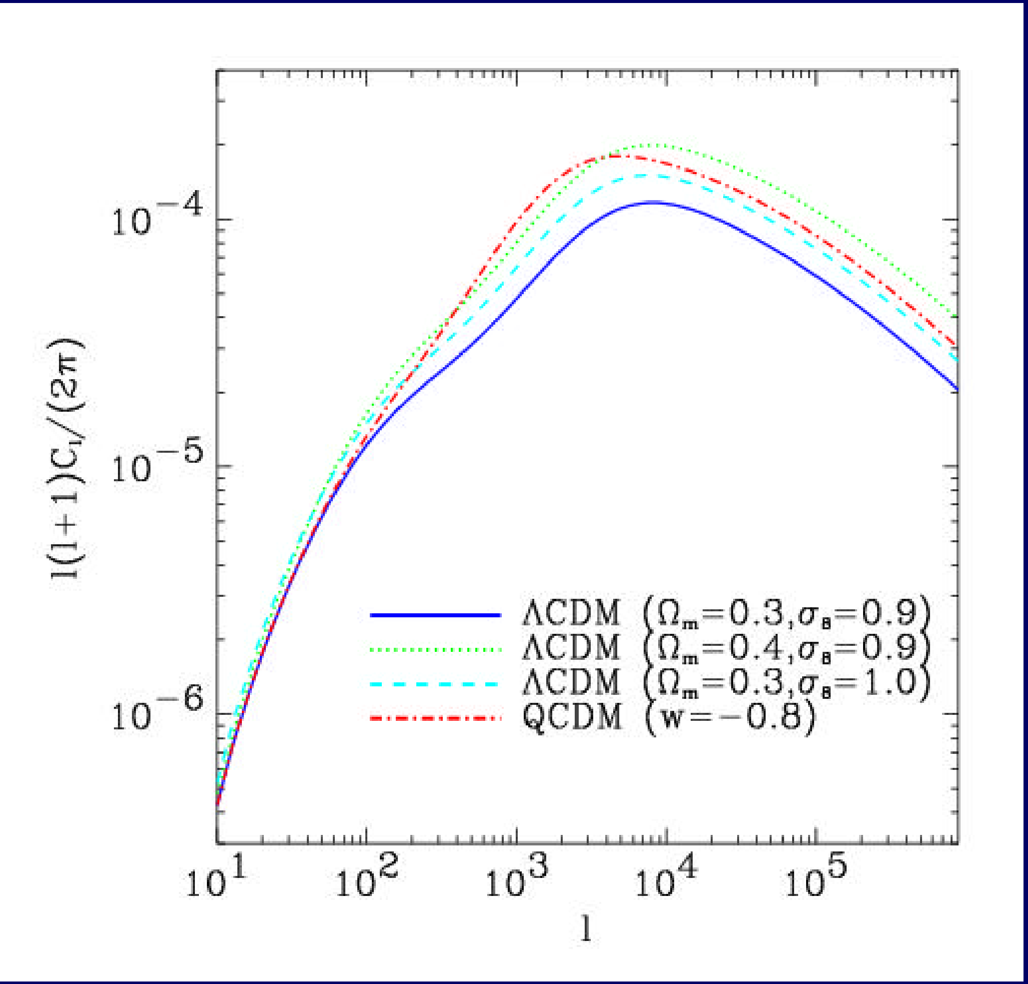
Dark Energy

Effect of Dark Energy on Weak Lensing Statistics:

- Modifies the Angular-Diameter Distance +
- Modifies the rate of growth of structures +
- Modifes the shape of the linear matter power spectrum -

Cf. Benabed & Bernardeau 2001
Huteterer 2001
Refregier et al. 2001 (in preparation)

Power Spectrum with Dark Energy



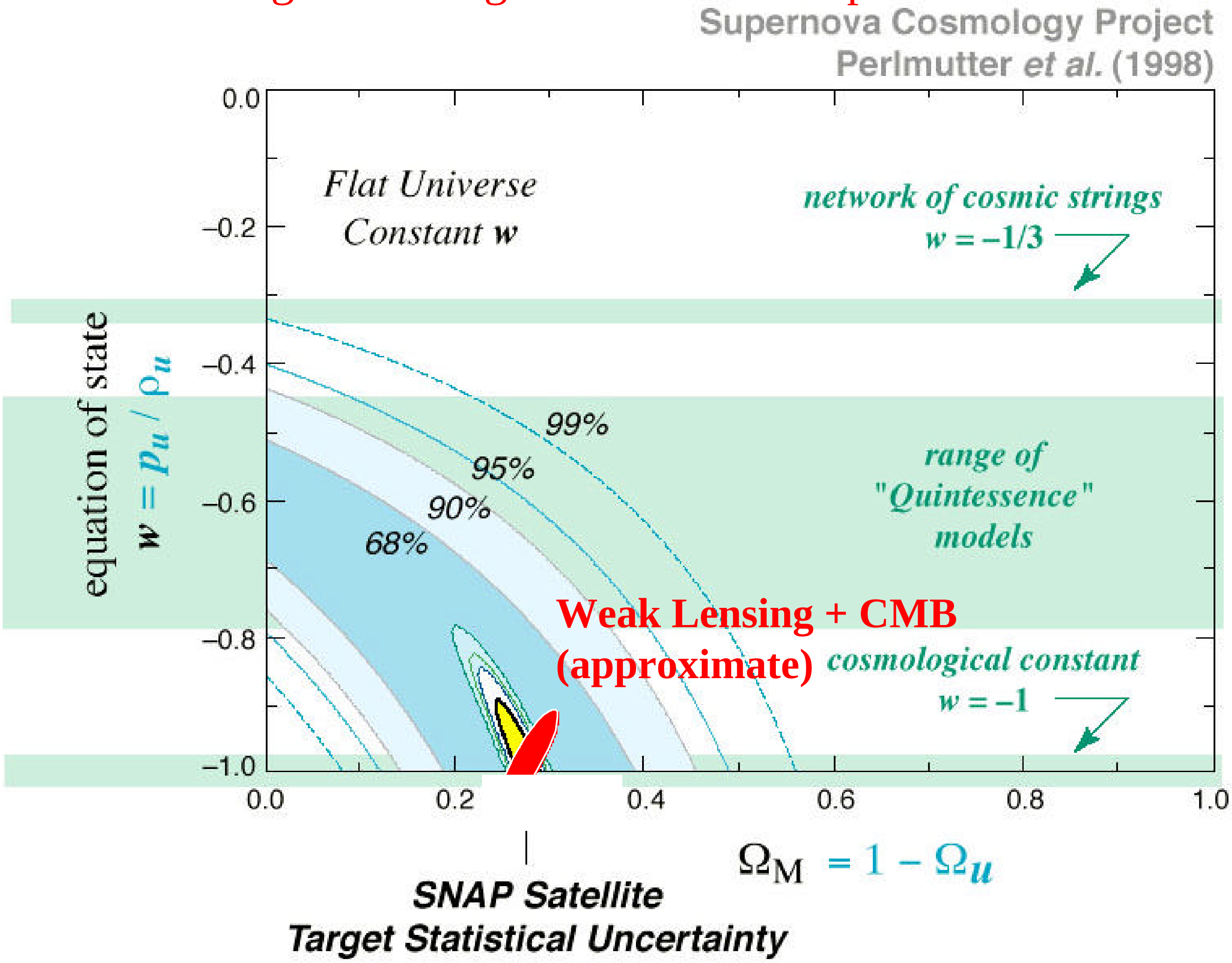
Use the non-linear power spectrum for quintessence models of Ma, Caldwell, Bode & Wang (1999)

→ The Dark Energy equation of state ($w=p/\rho$) can be measured from the lensing power spectrum

→ But, there is some degeneracy between w, Ω_M and σ_8

Complementarity of Weak Lensing and Supernovae

Weak Lensing breaks degeneracies in ***w-W*** plane



Good News and Bad News

Caveats:

• Very sensitive to Non-linear Power spectrum: need very accurate fitting formulae from N-body simulations
• Requires knowledge of the redshift distribution of the galaxies
• requires tight control of systematic effects

Additional information:

• Power spectrum for different redshift bins (tomography)
• High-order moments (skweness or bispectrum, etc)
• Mass-selected cluster catalogues

Conclusions

- Weak Lensing is emerging as a powerful technique to measure large-scale structure
- It is based on clean physics and directly measures the mass (as opposed to light)
- It will provide precise measurements of cosmological parameters, complementing other techniques (Sne, CMB, etc)
- Weak Lensing can set tight constraints on the Dark Energy
- Require tight control of systematics
- Wide prospects with upcoming and future surveys (Megacam, Subaru, VISTA, LSST, WHFRI, SNAP, etc)