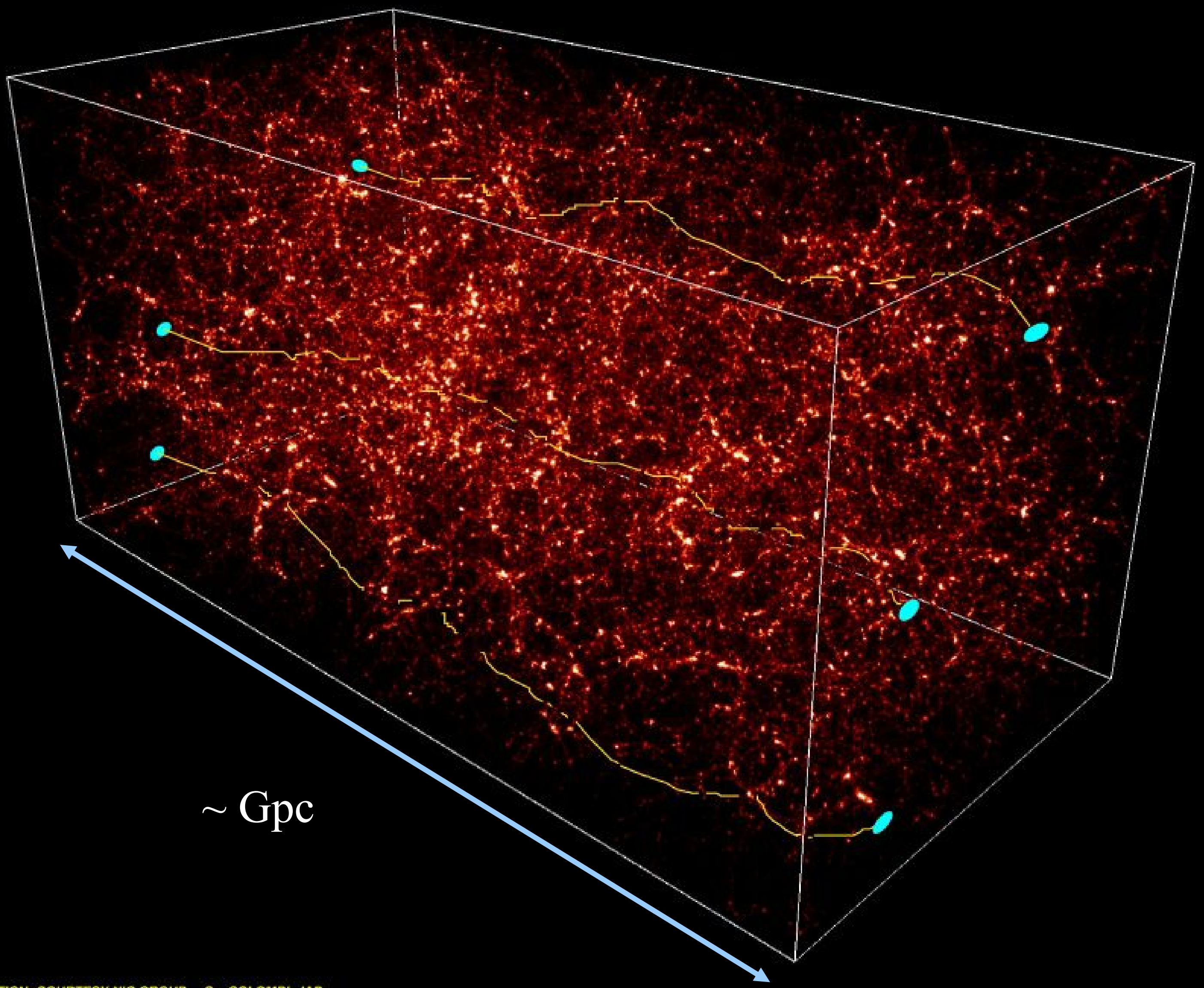
Cosmic Shear and WIRCAM

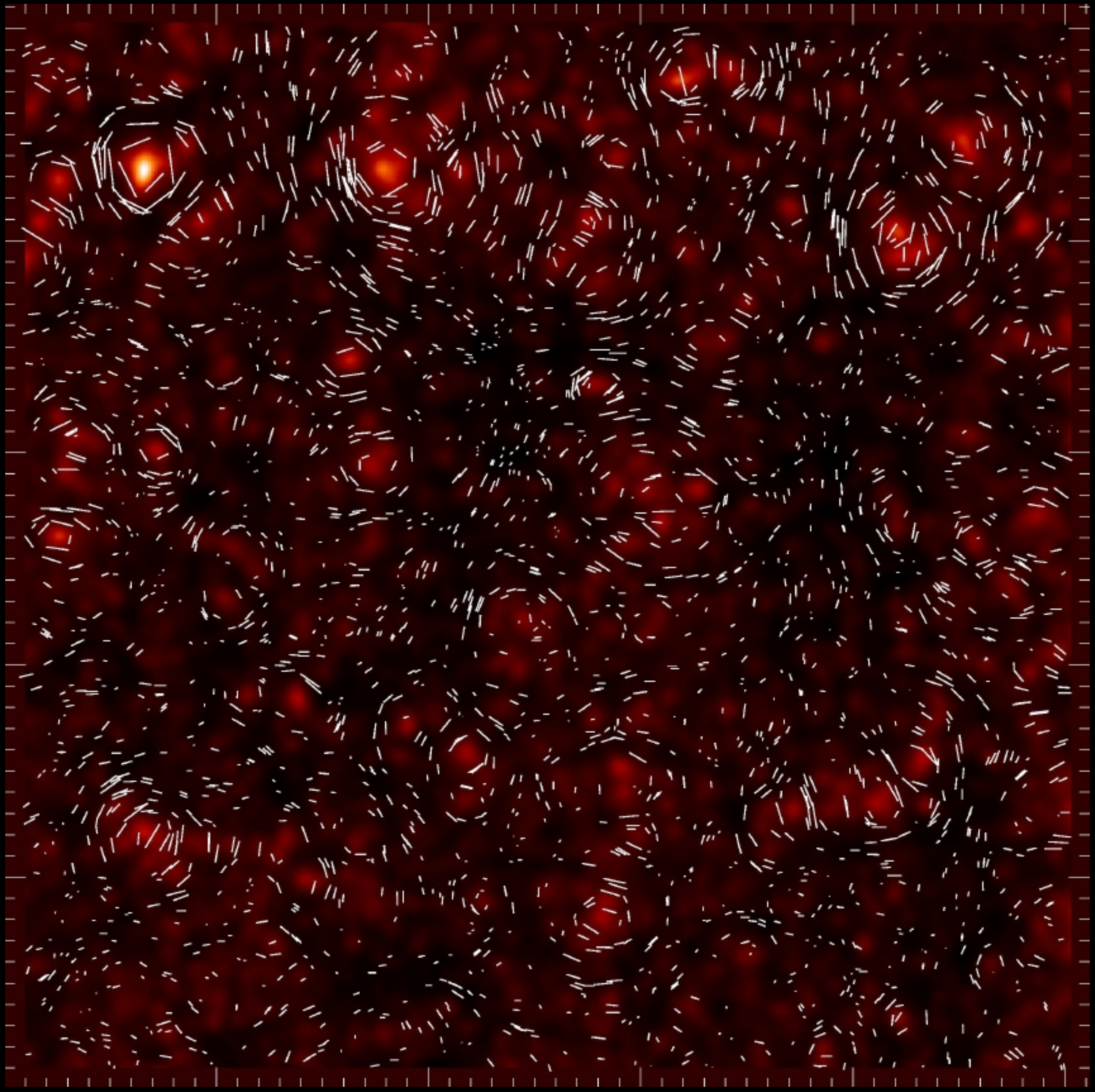
Mellier, van Waerbeke, Bertin, Tereno, Bernardeau, et al.

WIRCAM Workshop on LPs
November 5-6 , 2004

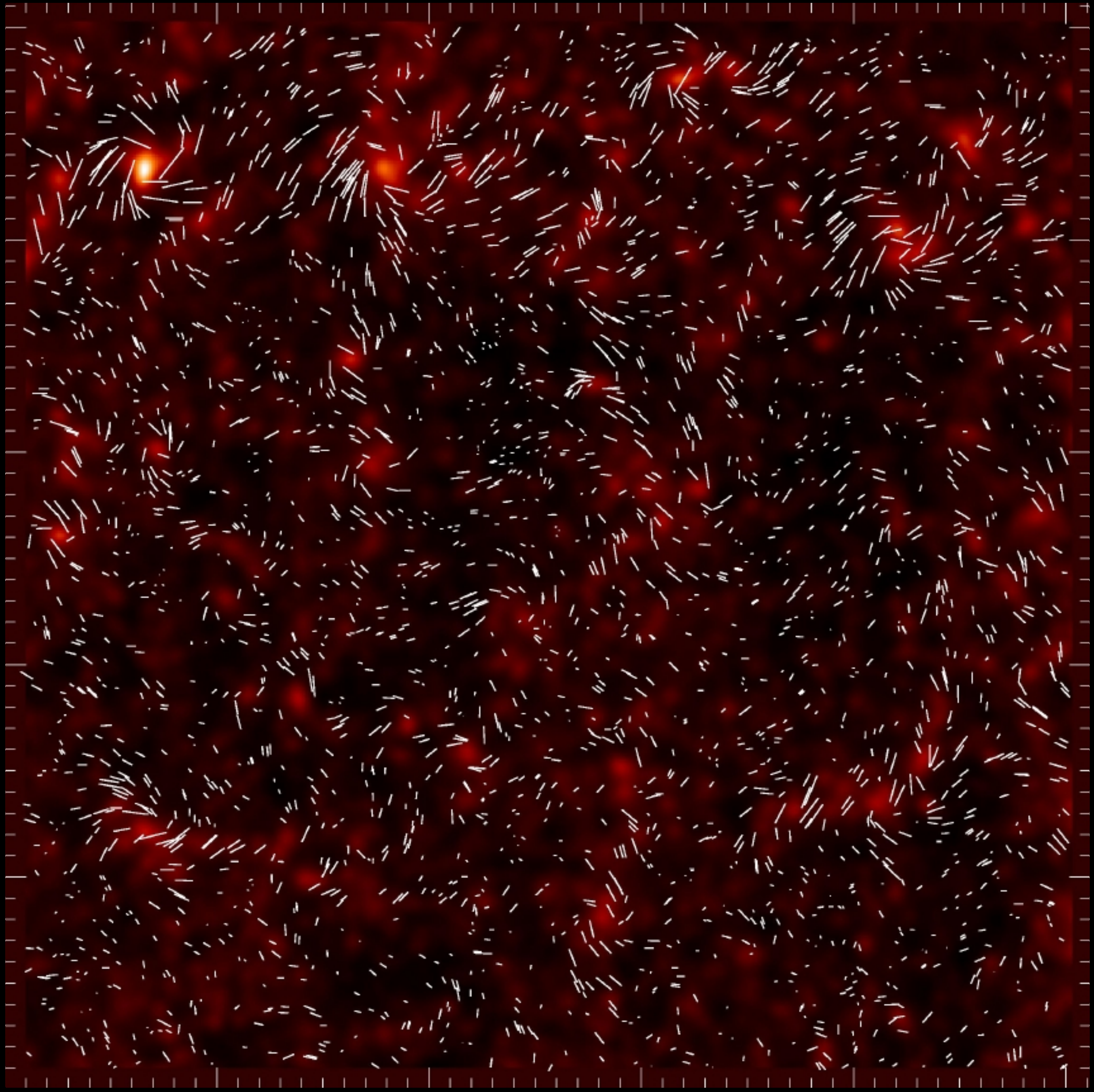
DEFLECTION OF LIGHT RAYS CROSSING THE UNIVERSE, EMITTED BY DISTANT GALAXIES



SIMULATION: COURTESY NIC GROUP, S. COLOMBI, IAP.



45 degrees rotated
galaxies, E -> B



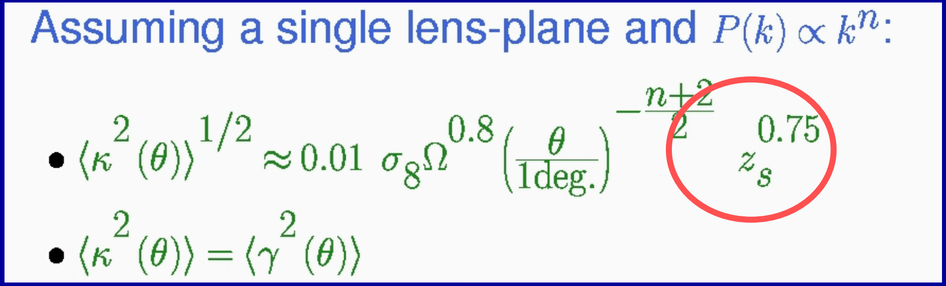
Gravitational lensing does not produce B-modes:

Dark matter properties with cosmic shear

(Blandford el al 1991, Miralda-Escudé 1991, Kaiser 1992, 1998, Bernardeau et al 1997, Jain & Seljak 1997, Schneider et al 1998)

Top-hat shear variance at scale θ_c:

$$\langle\gamma^2\rangle = \frac{2}{\pi\theta_c^2}\int_0^\infty \frac{\mathrm{d}\,k}{k} P_\kappa(k)\,[\mathrm{J}_1(k\theta_c)]^2$$



Assuming a single lens-plane and $P(k) \propto k^n$:

- $\langle\kappa^2(\theta)\rangle^{1/2} \approx 0.01\ \sigma_8 \Omega^{0.8} \left(\frac{\theta}{1\mathrm{deg.}}\right)^{-\frac{n+2}{2}} \boxed{z_s^{0.75}}$
- $\langle\kappa^2(\theta)\rangle = \langle\gamma^2(\theta)\rangle$

Aperture mass (Map) variance at scale θ_c :

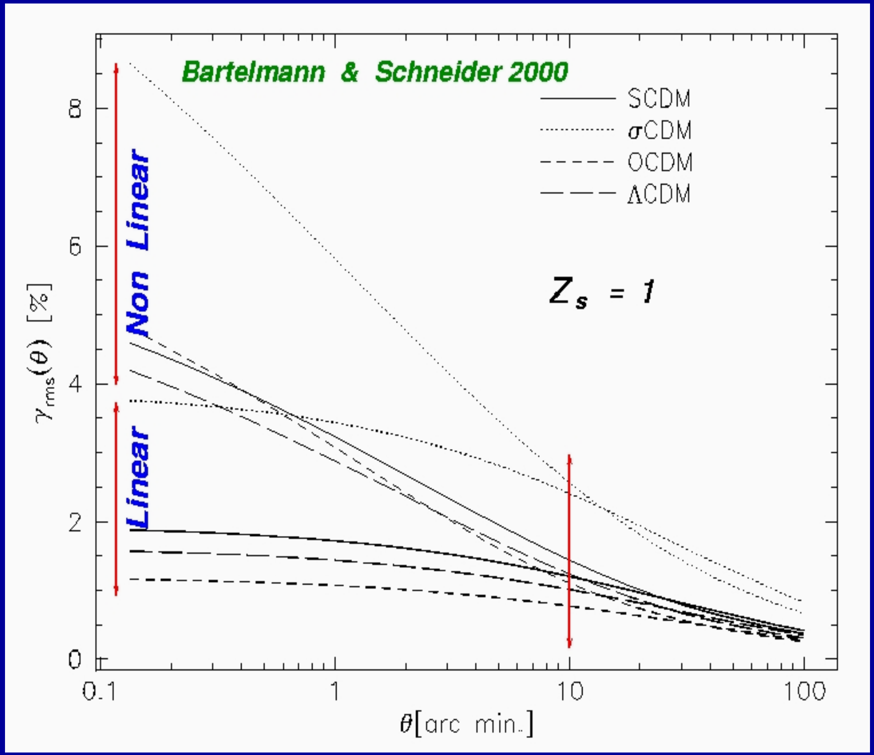
$$\langle M_{ap}^2\rangle = \frac{288}{\pi\theta_c^4}\int_0^\infty \frac{\mathrm{d}\,k}{k^3} P_\kappa(k)\,[\mathrm{J}_4(k\theta_c)]^2$$

Shear correlation function at separation θ:

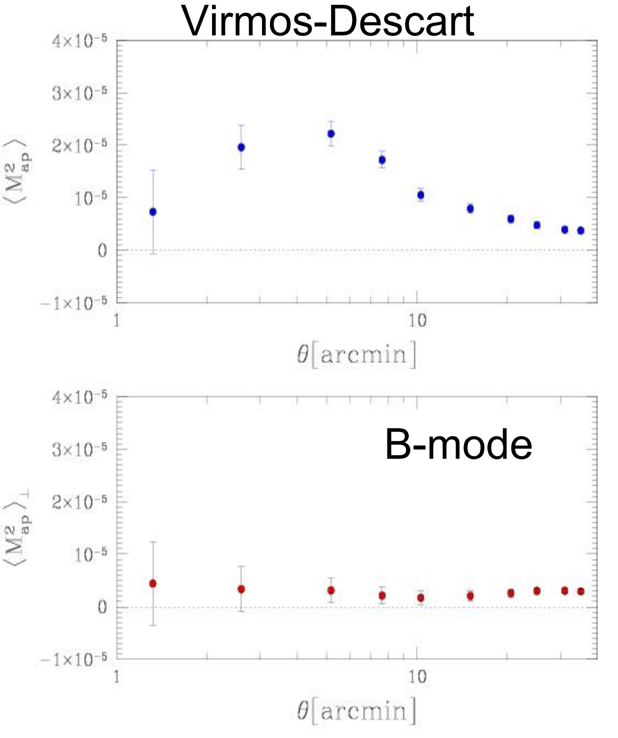
$$\langle\gamma(\mathrm{r})\gamma(\mathrm{r}+\theta)\rangle_\mathrm{r} = \frac{1}{2\pi}\int_0^\infty \mathrm{d}k\ k\ P_\kappa(k)\ \mathrm{J}_0(k\theta)$$

Convergence (projected mass) power spectrum:

$$P_\kappa(k) = \frac{9}{4}\Omega_0^2\int_0^\infty \mathrm{d}\,z\ \ .\ \mathrm{P}_{3\mathrm{D}}\left(\frac{k}{D_L(z)};z\right)\ .\ \mathrm{F}\left[z,z_{\mathrm{source}}\right]^2$$

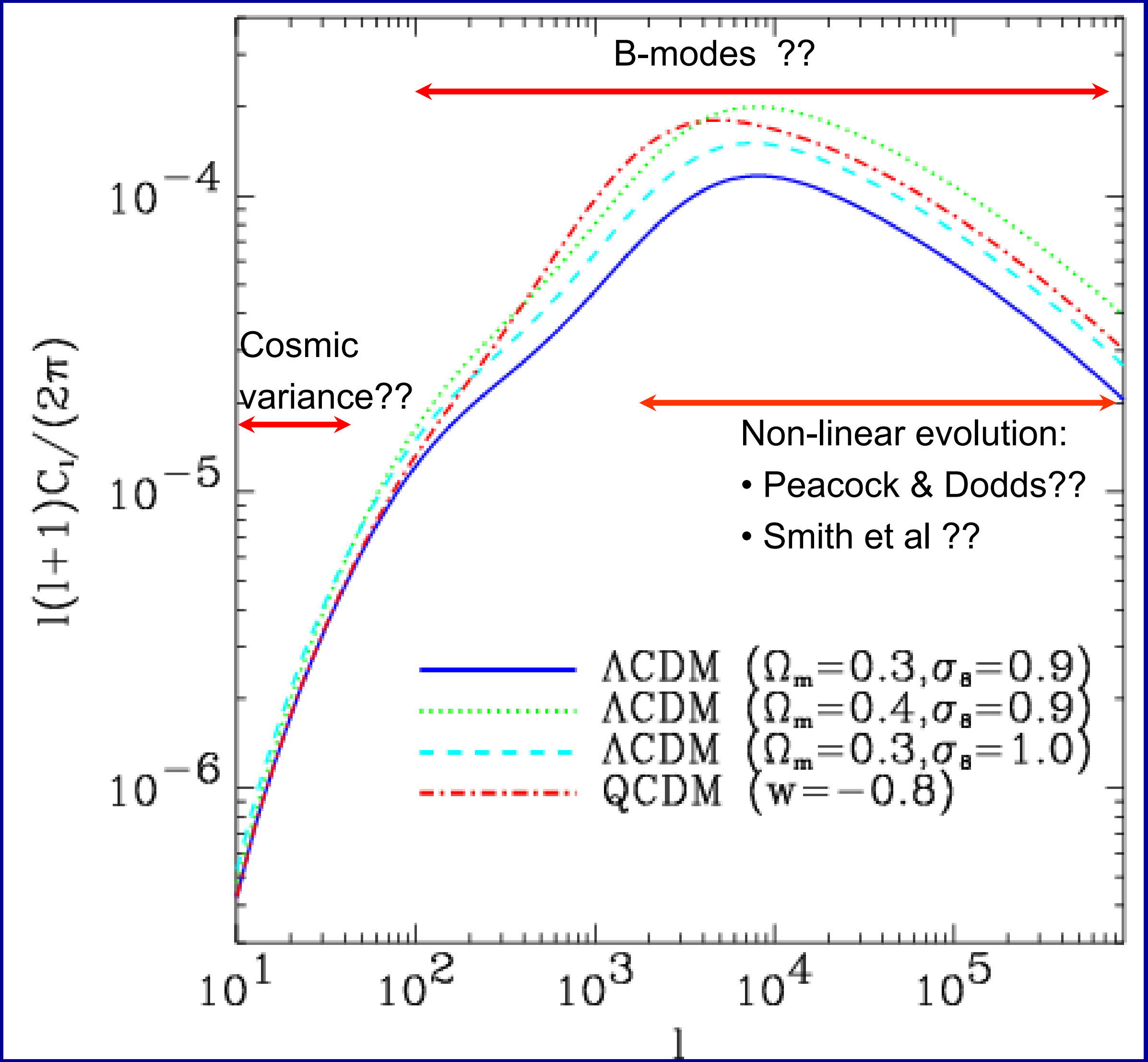


Cosmic shear surveys and dark energy: the goal is *P(k)* and *P(k,z)*



Virmos-Descart

B-mode



B-modes ??

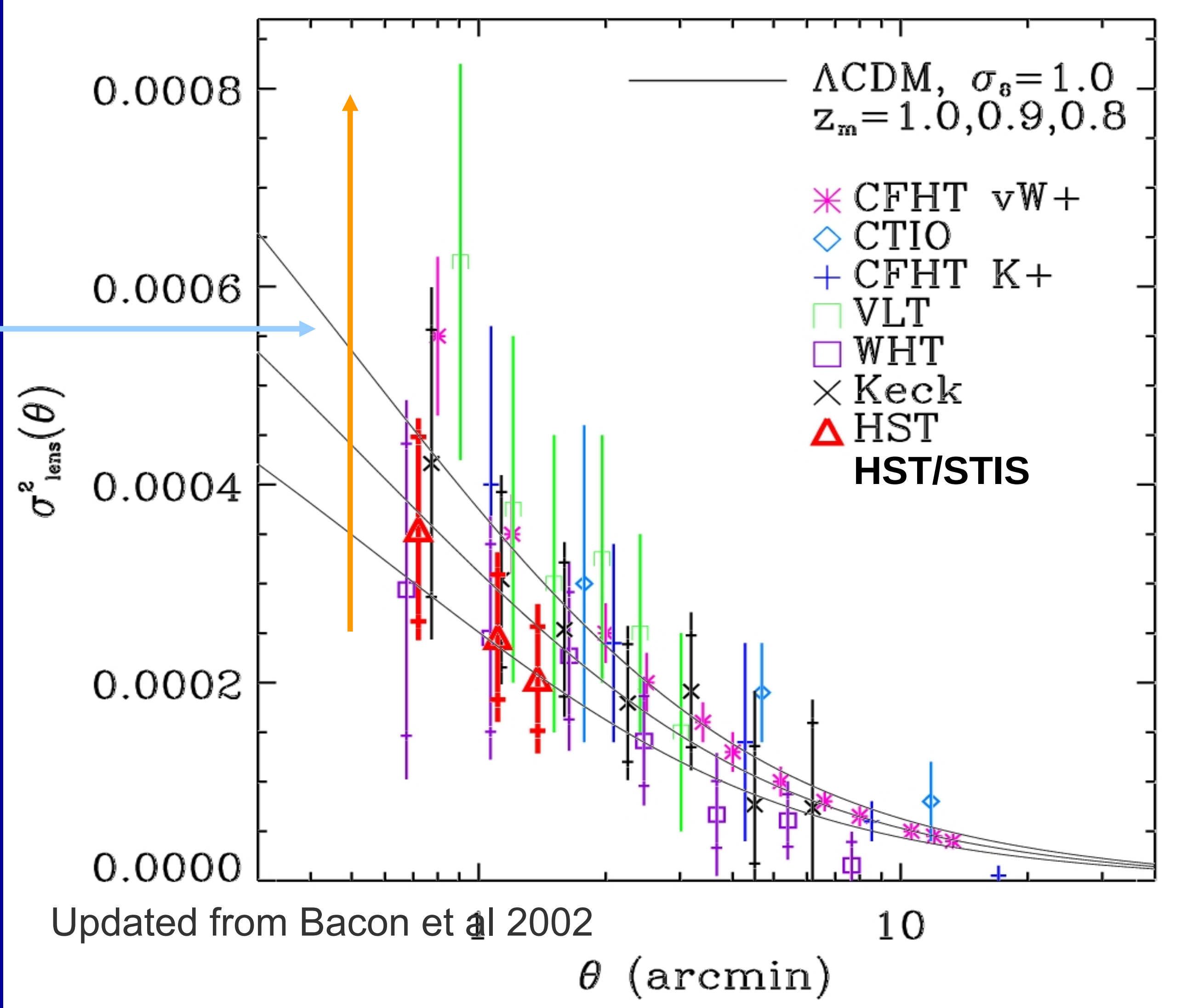
Cosmic variance??

Non-linear evolution:

- Peacock & Dodds??
- Smith et al ??

Cosmic shear surveys: $< \gamma^2 >$ *Consistency between the teams*

Theoretical expectations:
CDM + gravitational
instability paradigm

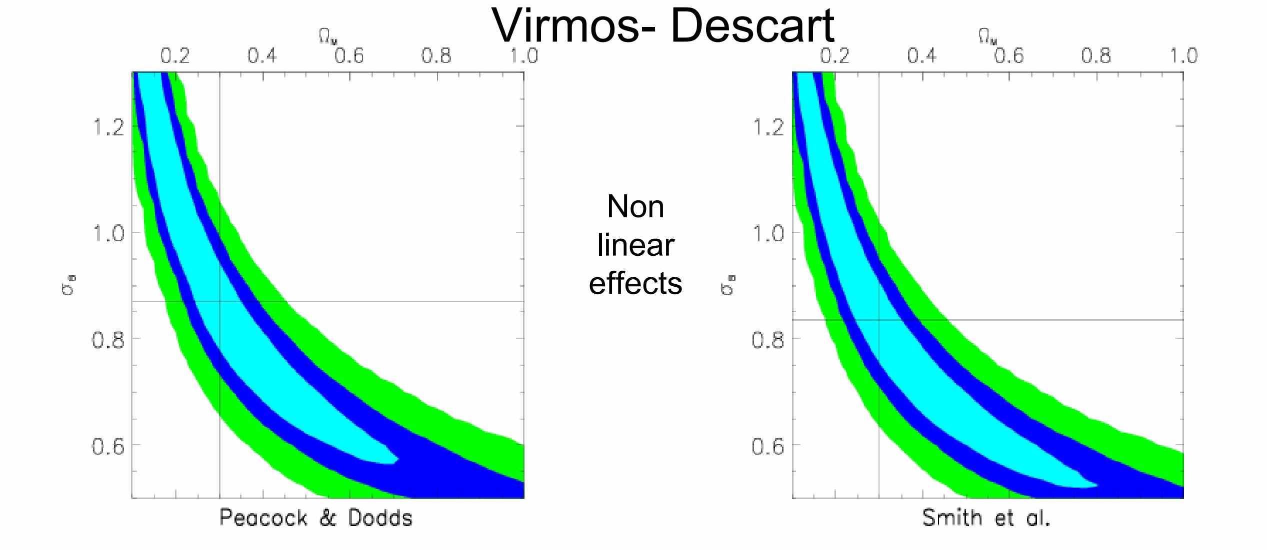


Updated from Bacon et al 2002

- More than 150 deg^2
- More than 200 uncorelated fields
- $0.1<z_s<1.2$
- More than 11 instruments
- 3 Space, rest from ground

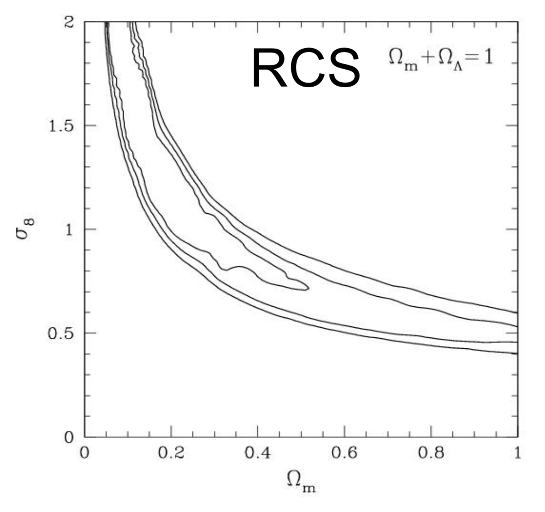
Van Waerbeke et al 2000, 2001, 2002, 2004; Wittman et al 2000; Bacon et al 2000, 2003; Kaiser et al 2000; Maoli et al 2001; Réfrégier et al 2002; Hoekstra et al 2002, Haemmerle et al 2001, Rhodes et al 2001, 2004, Brown et al 2002, Hamana et al 2002, Jarvis et al 2002, Massey et al 2004.

Virmos- Descart



Non
linear
effects

van Waerbeke, Mellier, Hoekstra 2004



Hoekstra, Yee, Gladders, 2002

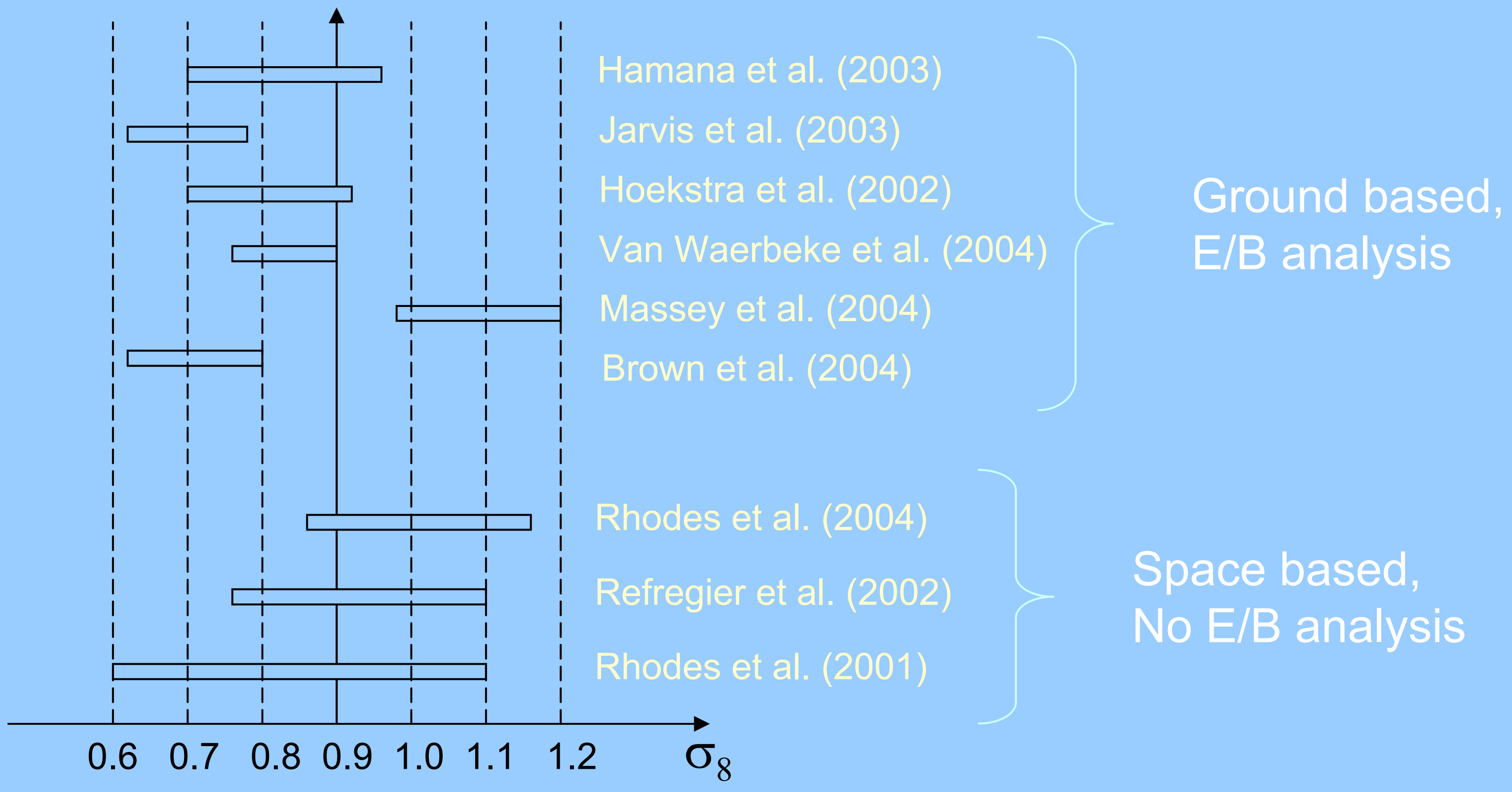
Virmos-Descart + RCS:

Ω_m= 0.30 +/- 0.10

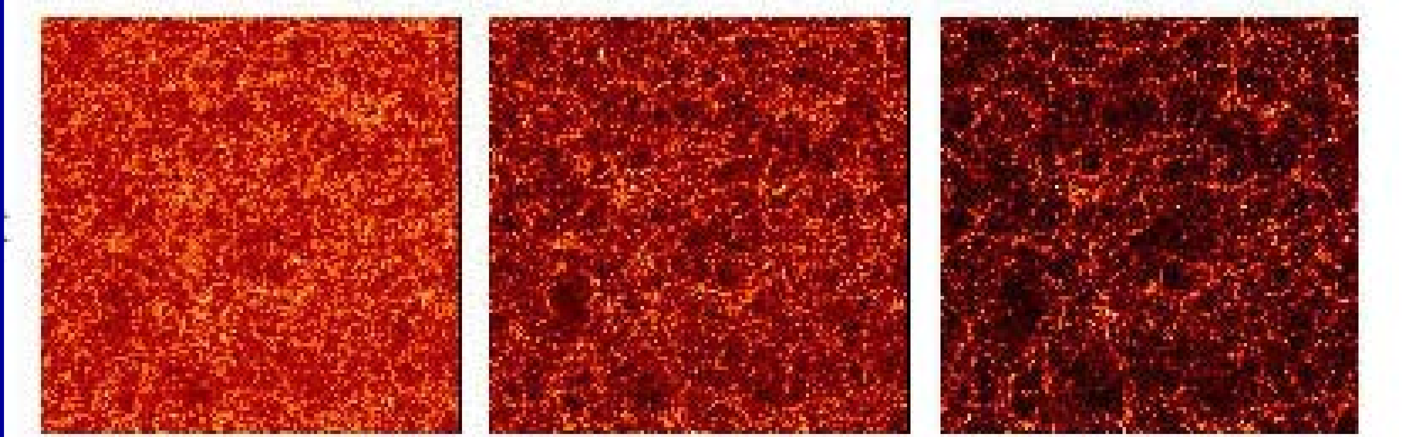
σ_8= 0.85 +/- 0.10 (99.5%)

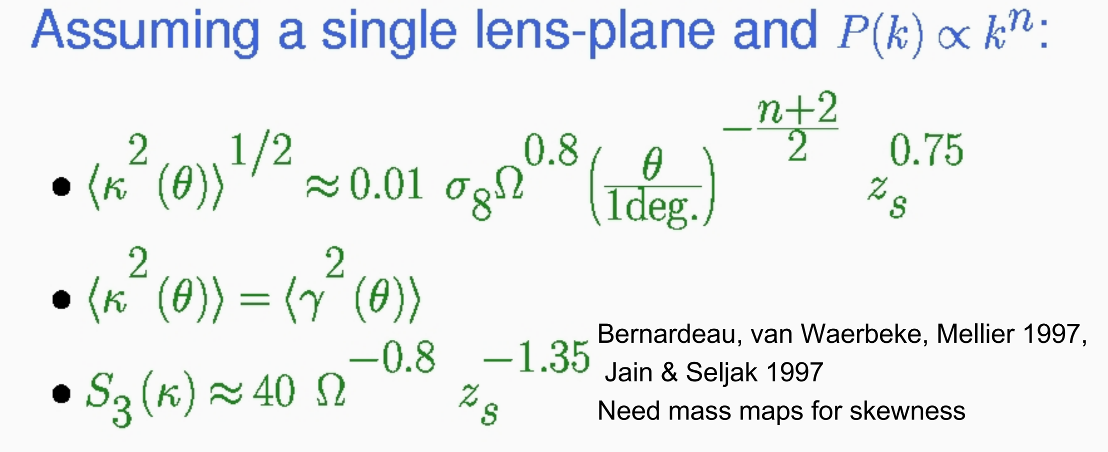
Summary of the most recent results

1σ measures of σ_8 for the ground E/B analysis and for all space based observations.



Ω_m-σ_8 degeneracy with higher order statistics: Skewness of the convergence





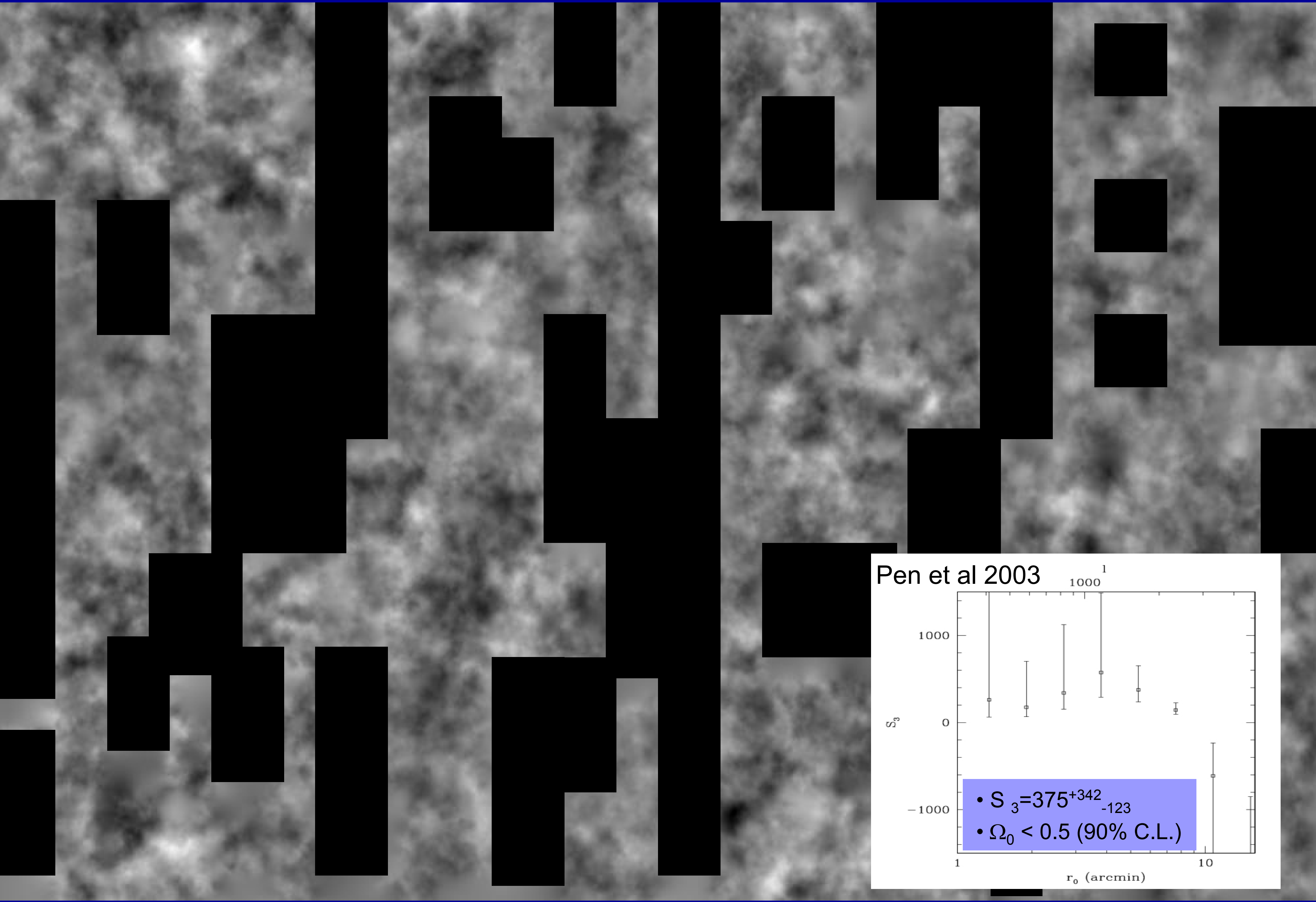
Assuming a single lens-plane and $P(k) \propto k^n$:

- $\langle\kappa^2(\theta)\rangle^{1/2} \approx 0.01\ \sigma_8 \Omega^{0.8} \left(\frac{\theta}{1\text{deg.}}\right)^{-\frac{n+2}{2}} z_s^{0.75}$
- $\langle\kappa^2(\theta)\rangle = \langle\gamma^2(\theta)\rangle$
- $S_3(\kappa) \approx 40\ \Omega^{-0.8}\ z_s^{-1.35}$

Bernardeau, van Waerbeke, Mellier 1997,
Jain & Seljak 1997
Need mass maps for skewness

- Distribution increasingly skewed by gravity that will produce non-linear structures (clusters, groups, galaxies):
- $S_3(\kappa)$ will provide a statistical description of these non-linear systems

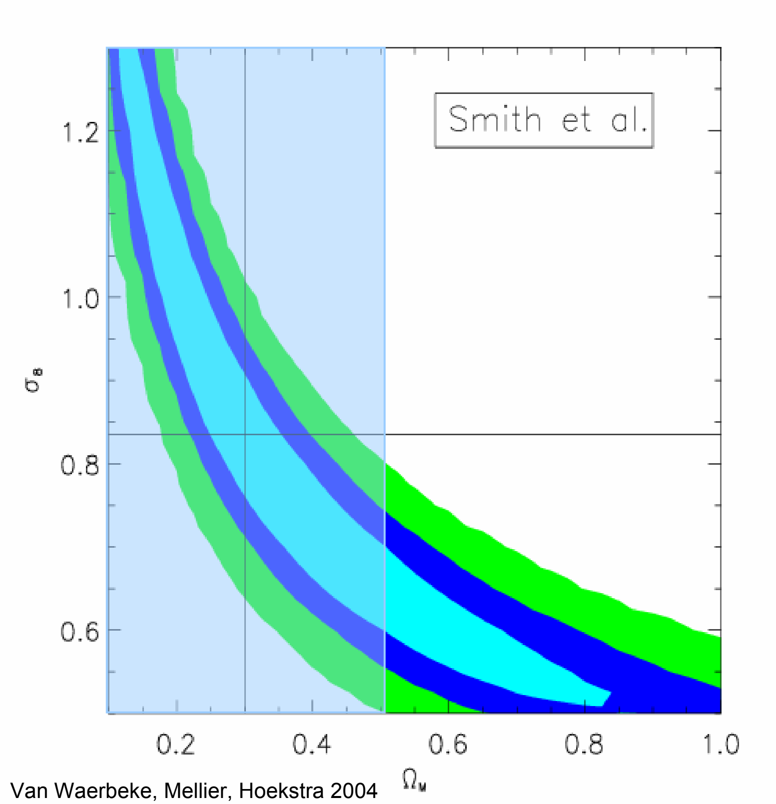
… to MASS MAP Skewness of the convergence measured in VIRMOS-Descart data



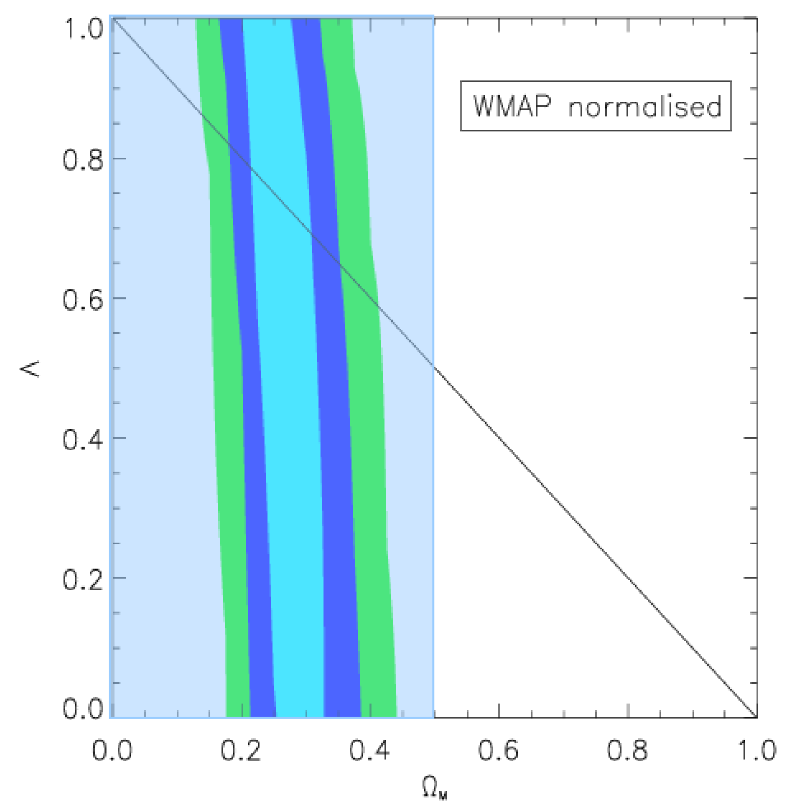
Pen et al 2003

- $S_3 = 375^{+342}_{-123}$
- $\Omega_0 < 0.5$ (90% C.L.)

Breaking degeneracies with the skewness of the convergence



Van Waerbeke, Mellier, Hoekstra 2004

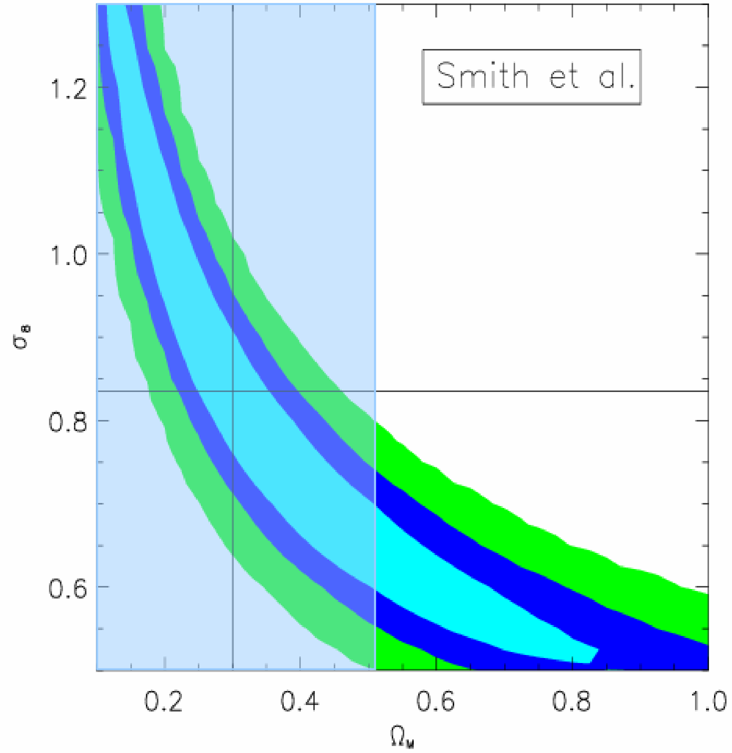


Uncertainties

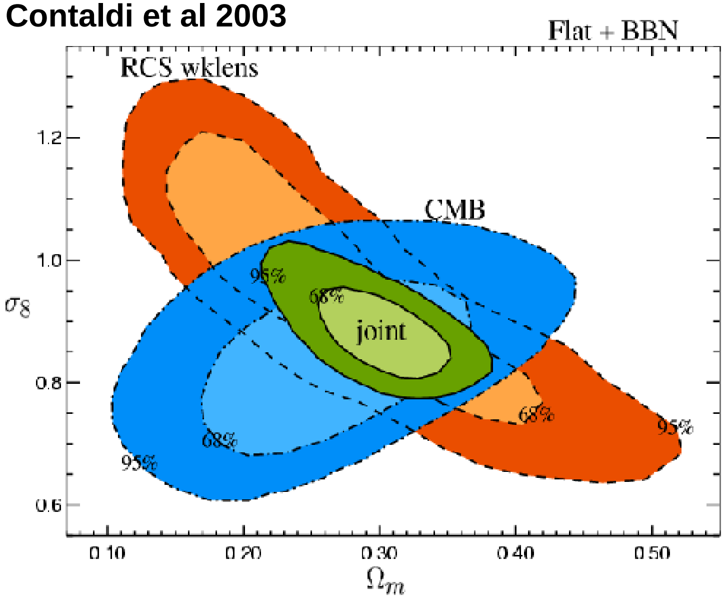
- Mass reconstruction in a Swiss cheese image
- N(z) and source/lens clustering (Hamana et al 2000)

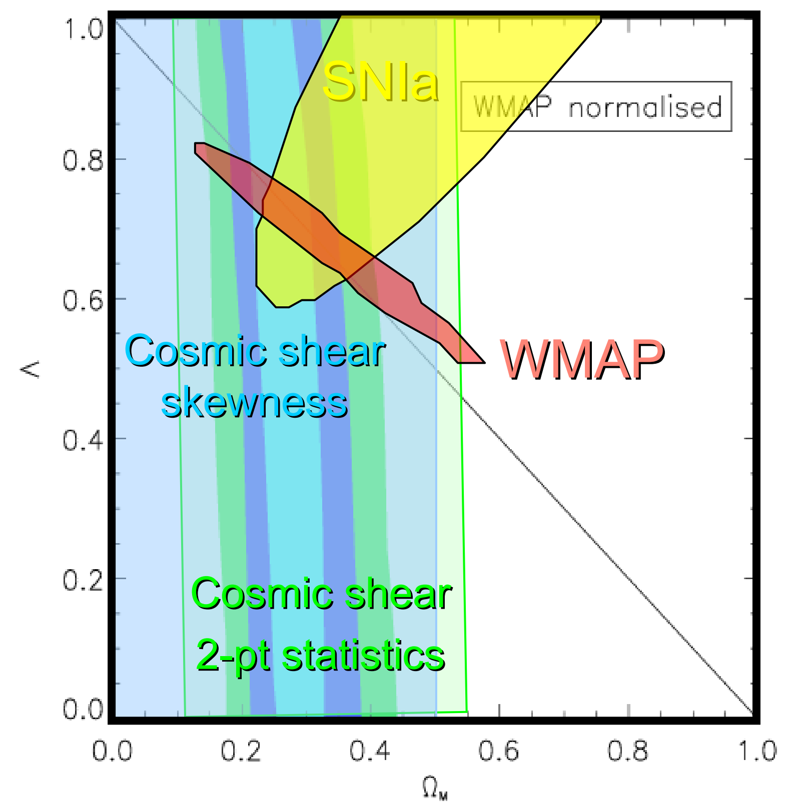
Joint analyses

Van Waerbeke et al 2004 + Pen et al 2003



Contaldi et al 2003





WMAP+CBI+New VIRMOS-Descart

(van Waerbeke, Mellier, Hoekstra, 2004)

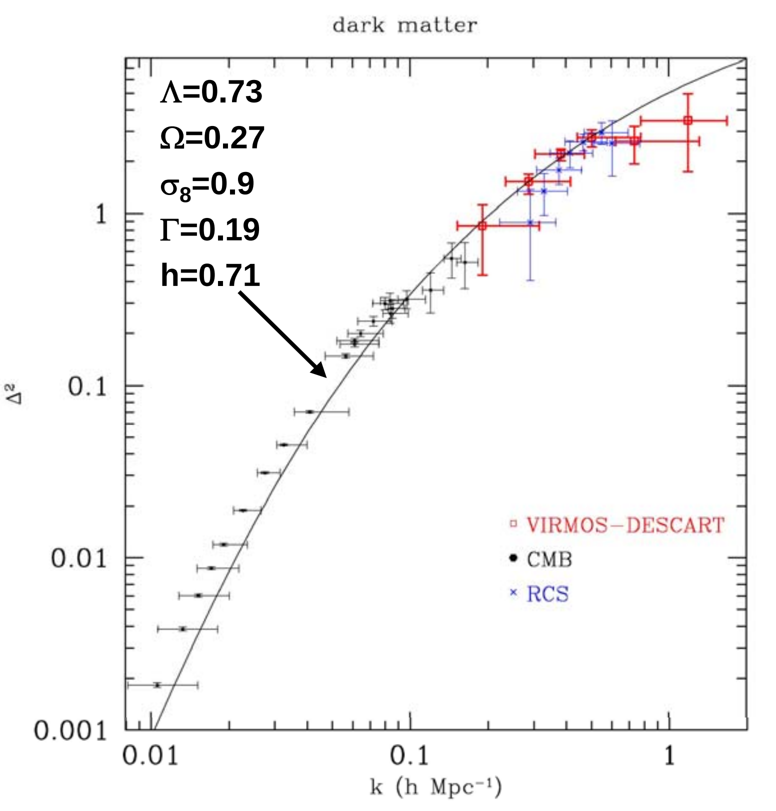
+ RCS (Hoektra et al 2002) :

σ_8=0.85 +/- 0.06

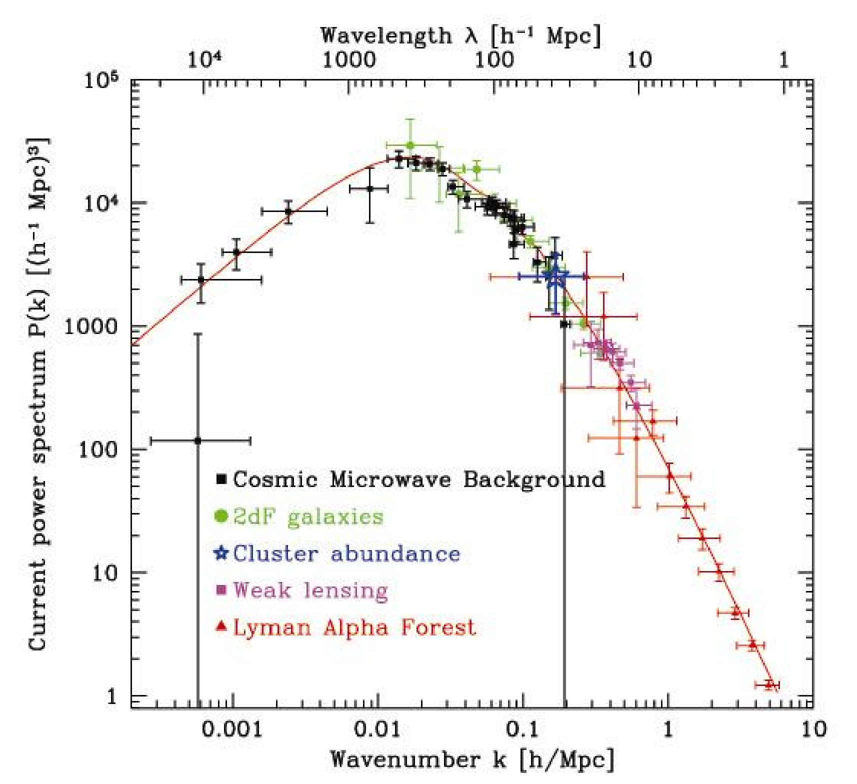
Ω_m=0.30 +/- 0.07

3D dark matter reconstruction

3D inversion from 2D spectra (galaxies & DM), using broad bands estimates (M_{ap})



Pen, Lu, van Waerbeke, Mellier 2003



Tegmark & Zaldarriaga (2002)

Still in a early phase, but

- Very promising for next generation surveys
- Evolution with photo-z +spectro-z likely feasible

(see also, Heavens 2003, Taylor et al 2003)

Biasing : Galaxy light vs. (dark) matter

Characterization of the relation between galaxies and matter?

- Mean biasing ($<n>=b \, . <\delta>$)
- Deviation to linearity
- Scatter
- Time evolution

Schneider 1998, van Waerbeke 1998

$$< N_g \; M_{ap} > / \sqrt{<N_g{}^2>.<M_{ap}{}^2>} = f_1(\Omega_m;\Lambda) \; . \; r$$

$$< M_{ap}{}^2 >/<N_g{}^2> = f_2(\Omega_m;\Lambda) \, . \, [\Omega_m/b]^2$$

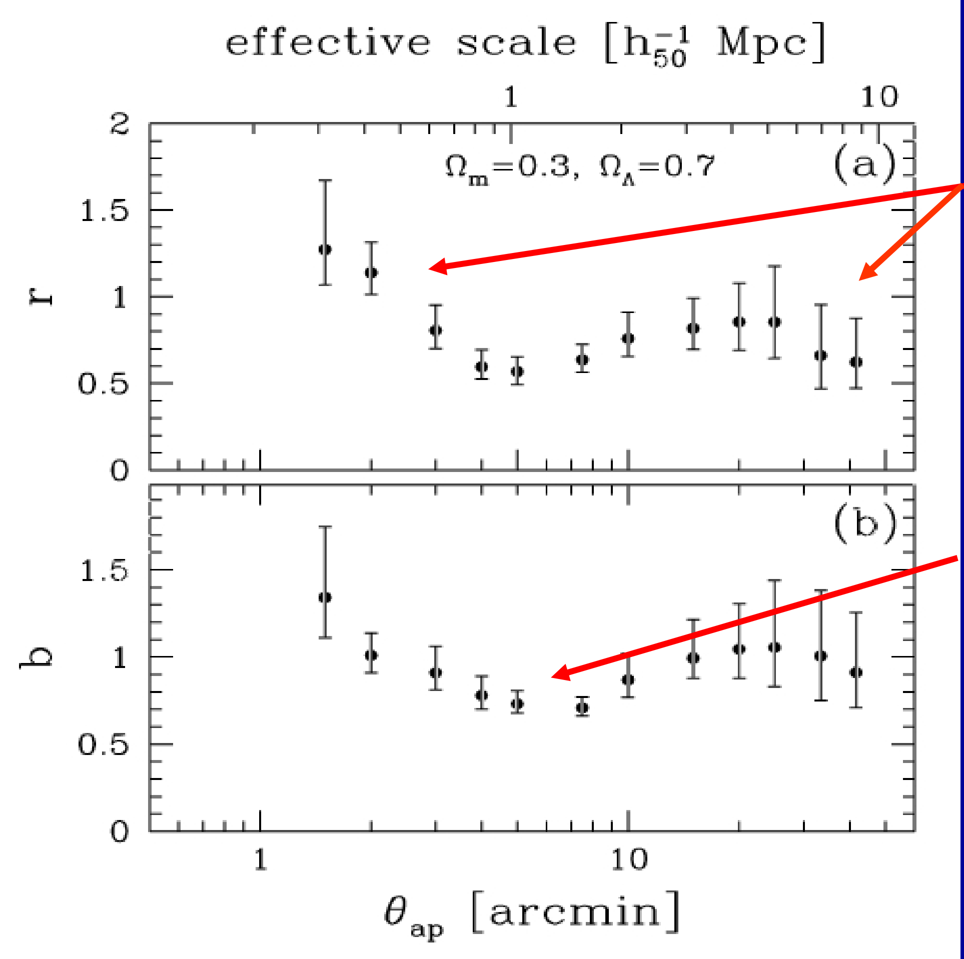
Foreground

If and only if linear and deterministic biasing:: $r = 1$

- Linear + deterministic biasing : $r=1$; $<n>=b \, . <\delta>$
- Non linear + deterministic: $1/r$
- Linear + Stochastics: $\sigma_b = b \, . \, (1-r^2)^{1/2}$

VIRMOS-DESCART+RSC: Total : 11 + 40 deg^2

Hoekstra, van Waerbeke, Yee, Mellier, Gladders 2002



***r* = 1 :** good correlation between mass and light on small scales… Luminous galaxies are surrounded by massive halos.

***b* =0.7 :** matter more strongly clustered than galaxies

- •Strength : direct measurement of biasing, mass/DM correlation
- •Weakness: non-linearity/ stochasticity degeneracy;
  hard to interpret without high res. simulations

Cosmic shear and cosmology

GOOD:

- $f(z_l, z_s, \Omega_k, \Omega_b, \Omega_\nu, \Omega_\gamma, \Omega_{CDM}, \Omega_X, \Omega_\Lambda)$: cosmological parameters
- $P(k,z)$:
  - amplitude, shape, distortion, evolution;
  - direct description of the non-linear matter power spectrum;
  - halos properties (mass, profile, typical scale) : galaxies (galaxy-galaxy lensing), clusters of galaxies (mass maps; strong+weak lensing)
- Mass and light: properties of biasing as function of scale and *redshift*
- Poisson equation: test of gravity properties far beyond solar system scale
- B-mode analysis can be used to estimate systematic residual (non lensing signal)

BAD:

- Very weak signal on large scale: measuring very small changes in galaxy ellipticity is technicallly challenging (systematic residuals critical)
- Degeneracies: geometry *x* power spectrum
- Sensitive to redshift distribution of lenses/sources
- Signal higher on small scales, but non linear DM power spectrum unknown
- Contaminated by intrinsic correlation of elleipticities

Errors in σ_8

Ellipticity badly measured (PSF anisotropy corrections, shape measurement)

Redshift of sources badly estimated (photo-z, too deep for spectroscopy)

$$\langle e^2 \rangle = \langle \gamma^2 \rangle \sim 0.01 \ \sigma_8^{\,2} \ \Omega^{1.6} \ z_s^{\,1.4} \ \theta^{-(n+2)/2}$$

Shear is contaminated by non-lensing signal (instrinsic alignment of galaxies)

Non-linear evolution of dark matter power spectrum unknown , extrapolation on small scales wrong

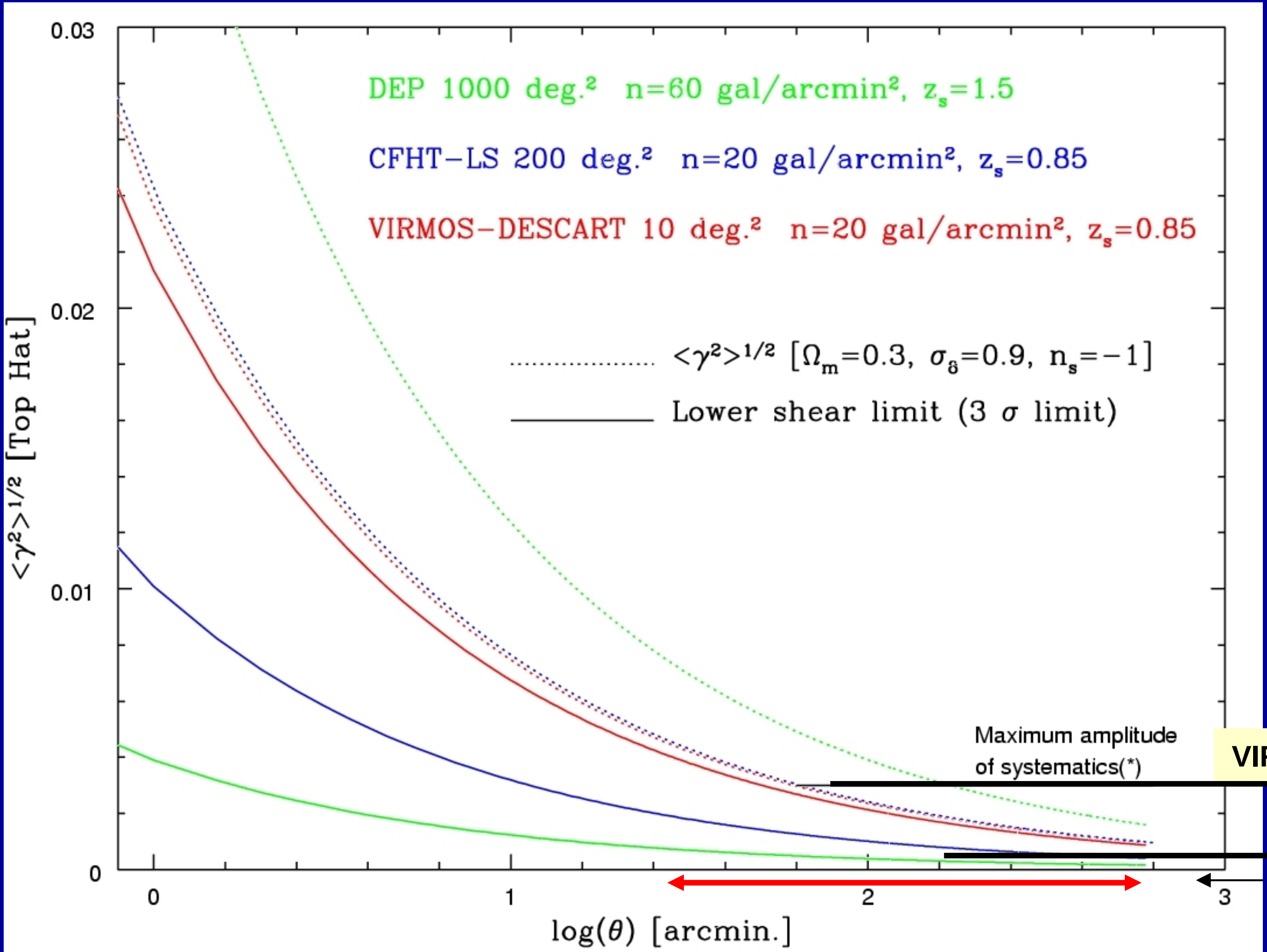
Most critical: PSF anisotropy correction (B-mode analysis) + redshift of sources

The next challenges

- Dark matter power spectrum:
  - On larger scales (linear regime)
  - With better accuracy
  - As function of z
- Biasing of galaxies:
  - As function of scales
  - As function of local density/environment
  - As function of redshift

- New specifications
  - Poisson noise: depth
  - Multi-lens plane: depth, good z
  - Larger sky coverage
  - Better shape measurements: better image quality
  - Full B-mode suppression

Expectations from cosmic shear surveys



(*) Assuming the shear measured on the largest VIRMOS-DESCART scale is an upper limit of systematics

VIRMOS-DESCART

New VIRMOS-DESCART

0.2° < θ < 5.5°

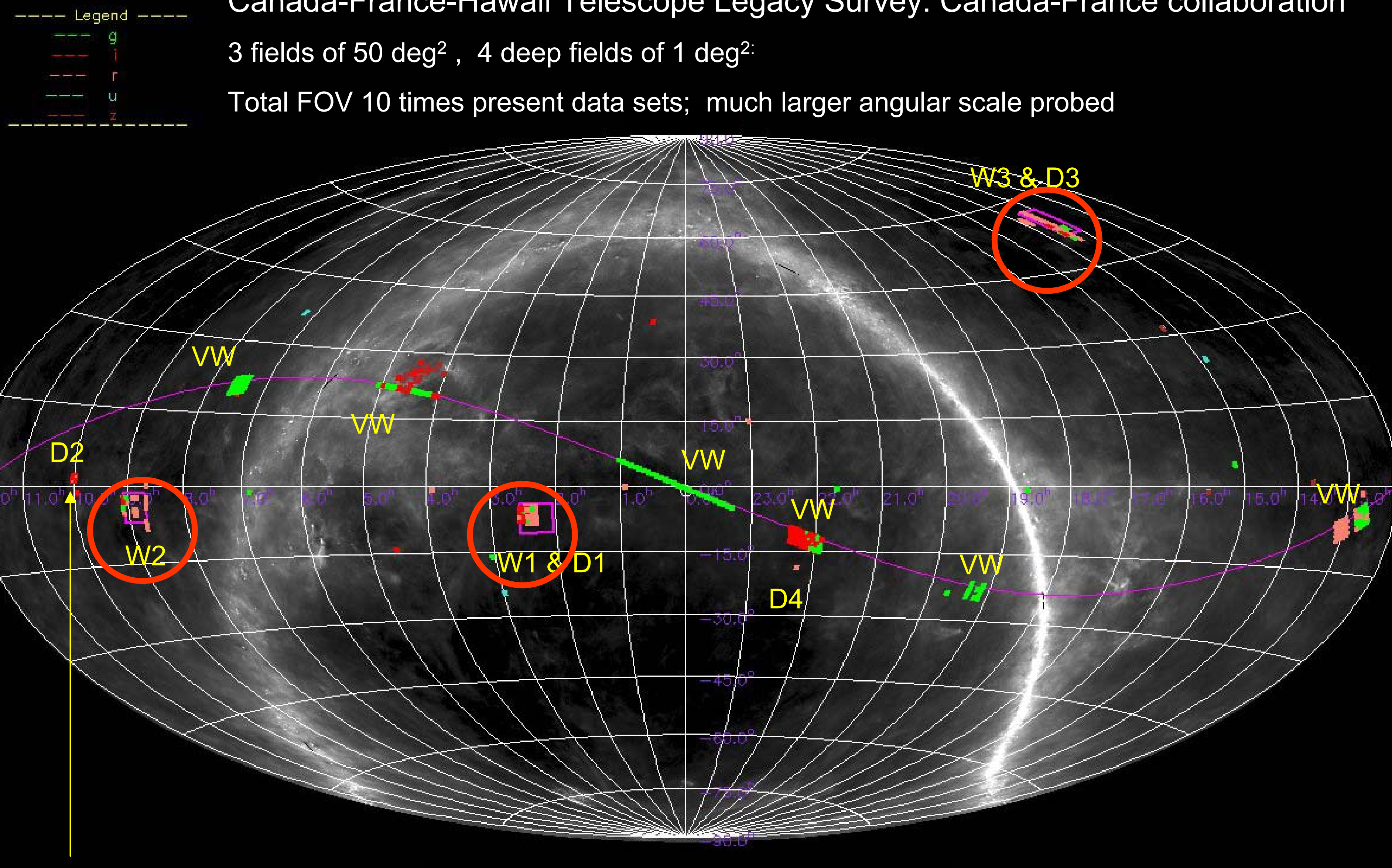
$$<\gamma(\theta)^2>^{1/2}_{limit} = 1.2\% \left[\frac{A_T}{1\ deg^2}\right]^{-\frac{1}{4}} \times \left[\frac{\sigma_{\epsilon_{gal}}}{0.4}\right] \times \left[\frac{n}{20\ gal/arcmin^2}\right]^{-\frac{1}{2}} \times \left[\frac{\theta}{10'}\right]^{-\frac{1}{2}}$$

$$<\gamma(\theta)^2>^{1/2} \approx 1\%\ \sigma_8\ \Omega_m^{0.75}\ z_s^{0.8} \left(\frac{\theta}{1^{o}}\right)^{-\left(\frac{n+2}{2}\right)}$$

Canada-France-Hawaii Telescope Legacy Survey: Canada-France collaboration

3 fields of 50 deg^2 , 4 deep fields of 1 deg$^{2:}$

Total FOV 10 times present data sets; much larger angular scale probed

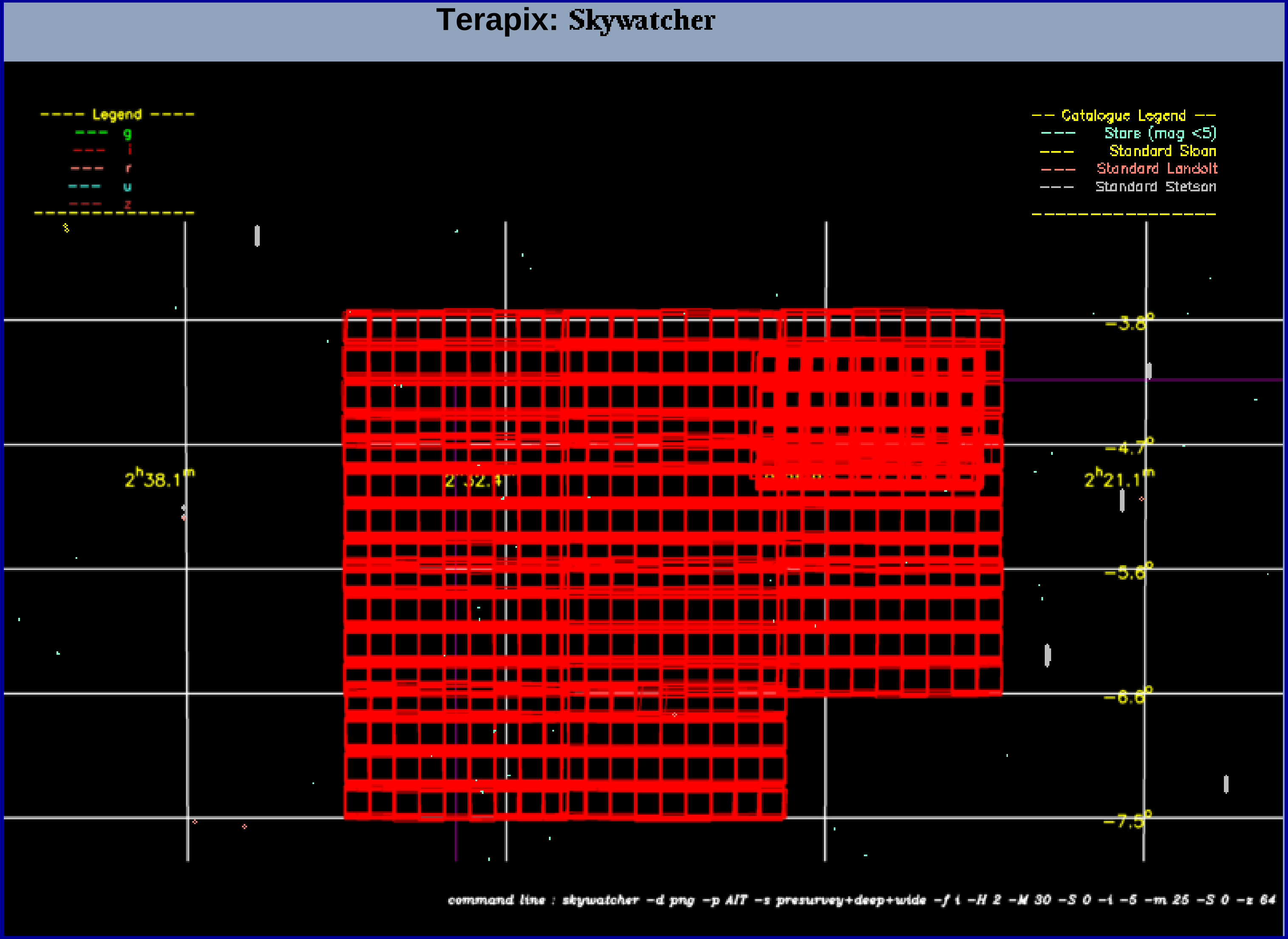


Cosmos

Terapix/Skywatcher : all data 03A-03B :   4200 Megacam images

←command line : skywatcher

CFHTLS : Wide1 and Deep1 fields in I-band



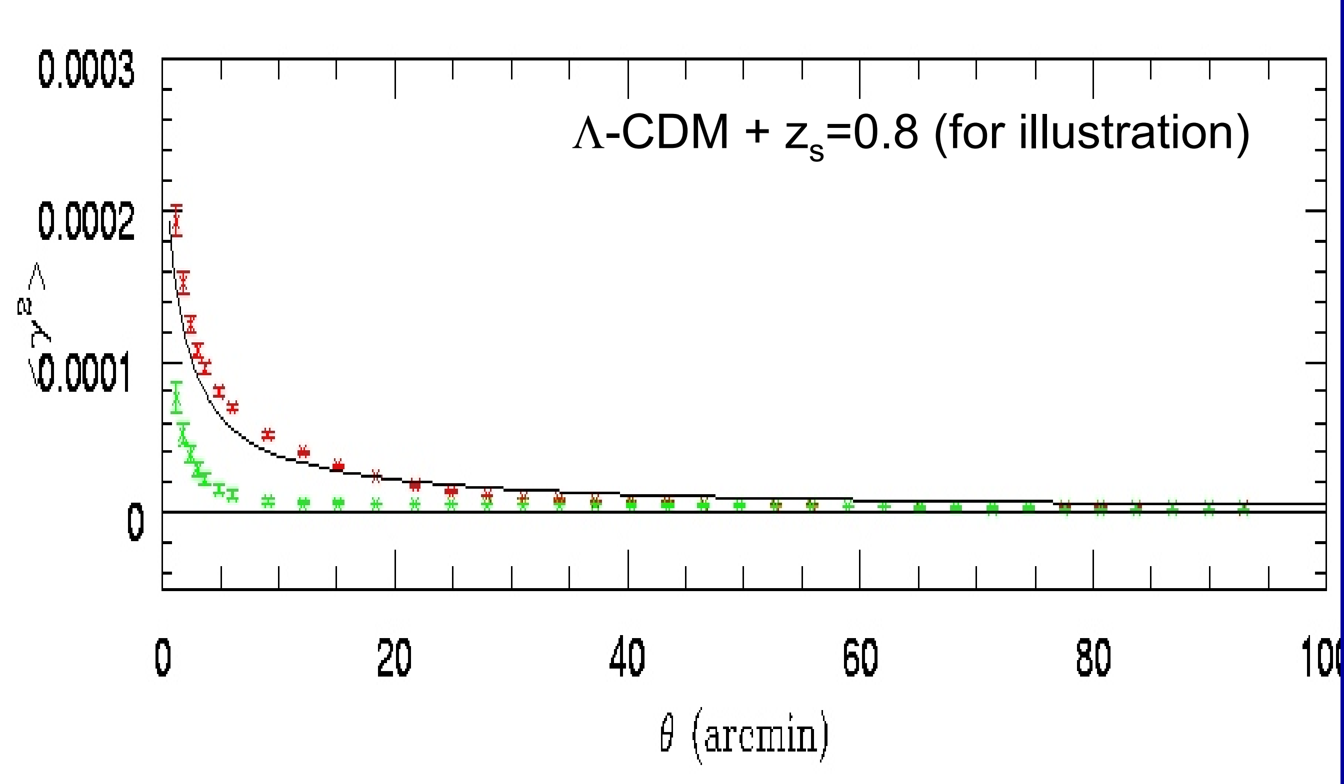
Terapix: Skywatcher

```
command line : skywatcher -d png -p AIT -s presurvey+deep+wide -f i -H 2 -M 30 -S 0 -i -5 -m 25 -S 0 -z 64
```

First exploration of cosmic shear on CFHTLS Wide

CFHTLS-W1 :

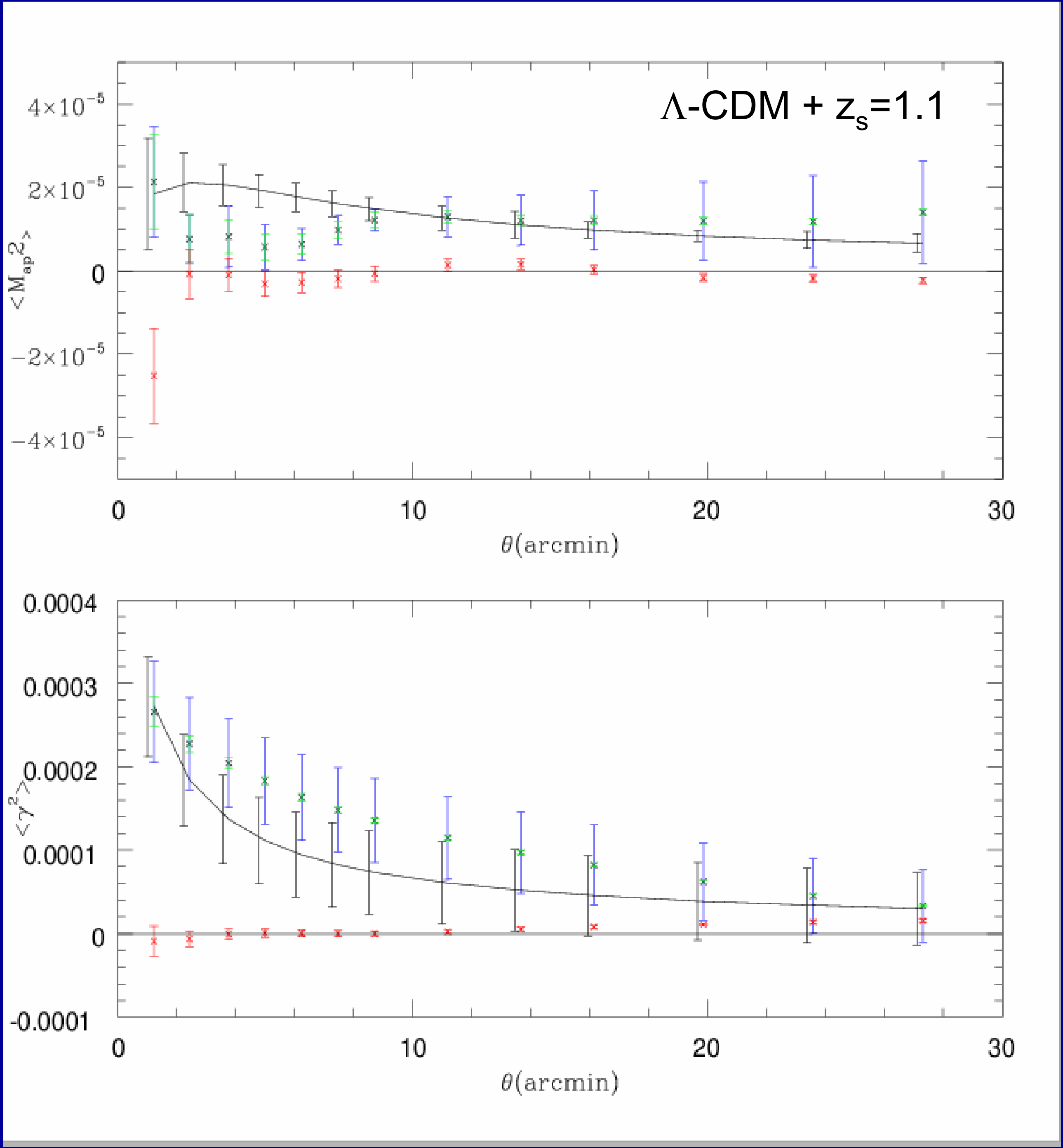
- shear variance i-band,11 deg^2
- Preliminary: data still in evaluation phase
- No-B modes at larger scales (most interesting)



The CFHTLS cosmic shear collaboration: Semboloni, Hoekstra, van Waerbeke, Mellier, Tereno, et al…

CFHTLS Deep field D1 from Terapix:

preliminary estimates for quality assesments



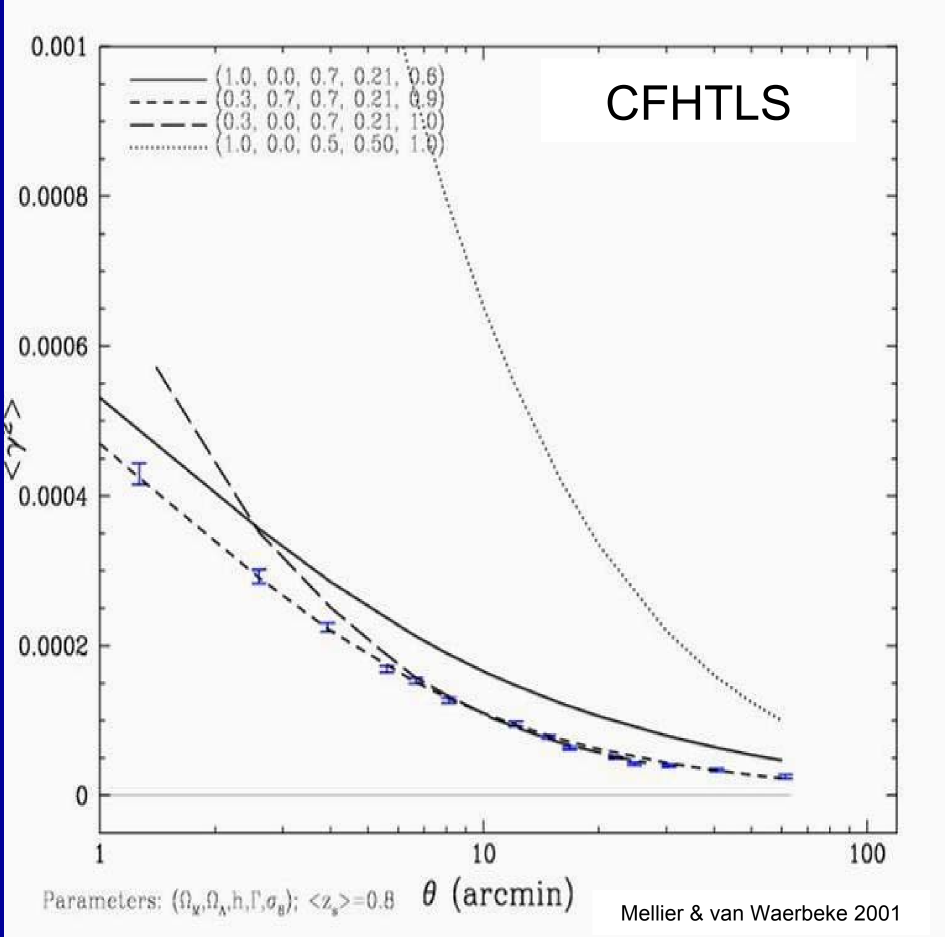
Good: Amplitude ratio beween CFHTLS D1 and Virmos-Descart agrees with expectations from depth ratio (source redshift ratio)

D1 = deg^2 dominated by cosmic variance

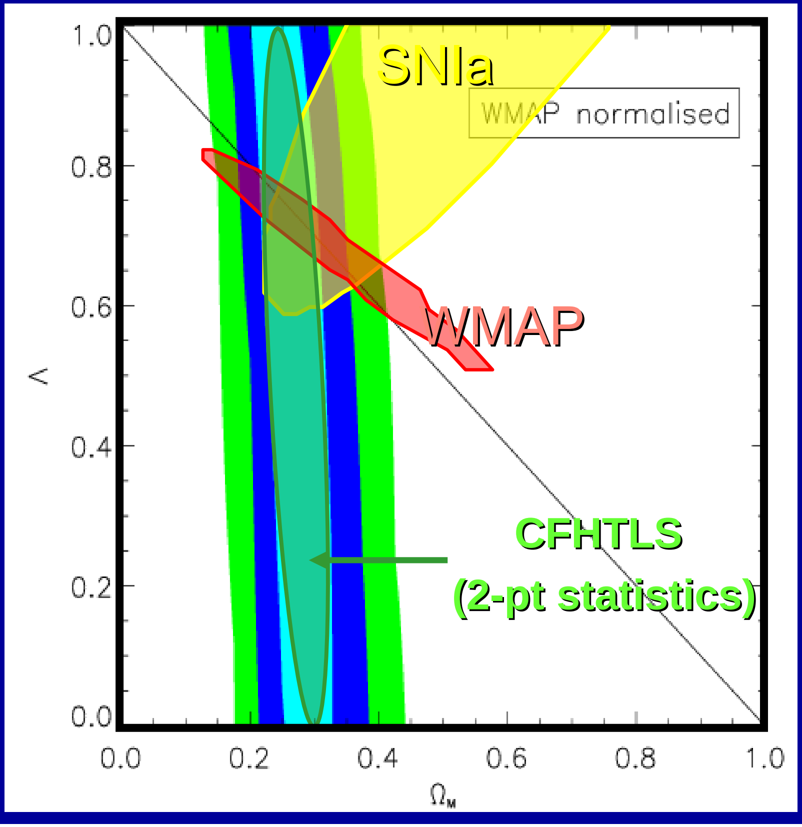
The CFHTLS cosmic shear collaboration: Hoekstra, Semboloni, van Waerbeke, Mellier, Tereno, et al…

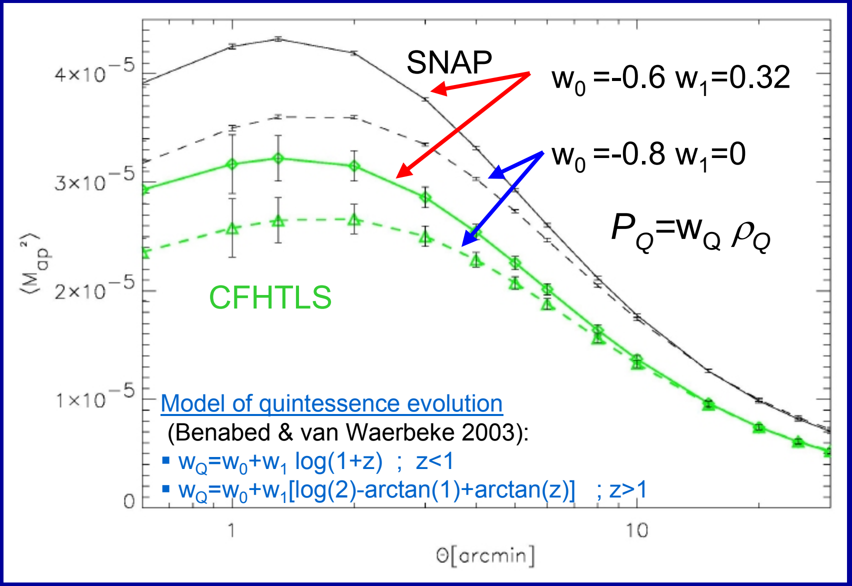
CFHTLS

goals in view of preliminary data



Mellier & van Waerbeke 2001



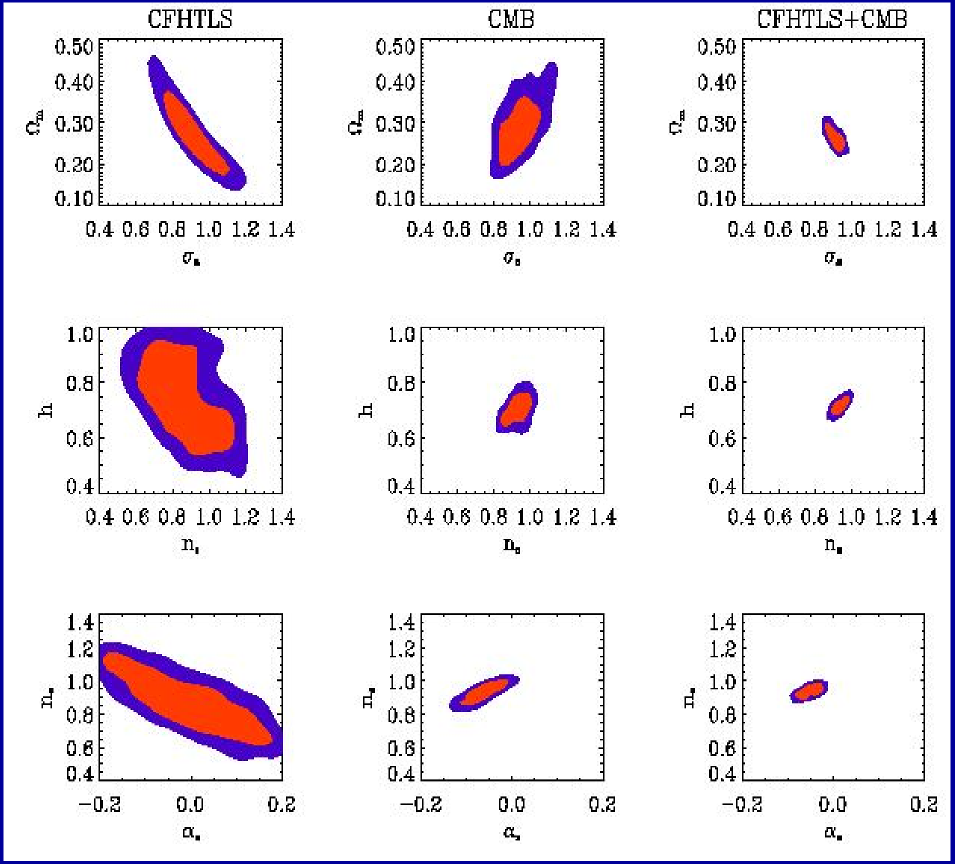


Model of quintessence evolution (Benabed & van Waerbeke 2003):

- $w_Q=w_0+w_1\log(1+z)$; $z<1$
- $w_Q=w_0+w_1[\log(2)-\arctan(1)+\arctan(z)]$; $z>1$

Cosmic shear CFHTLS + CMB

7 parameters MCMC ($\omega_b, \omega_c, h, n_s, \alpha_s, A_s, \tau$) : **CMB** (WMAP + CBI) and **Cosmic shear + CMB** (flatness imposed)



Tereno et al 2004

	gain
ω_b	1.4
ω_c	3.6
h	1.9
n_s	1.7
α_s	1.7
σ_8	2.5
Ω_m	2.8

gain = 1σ(CMB) / 1σ(cosmic shear+CMB)

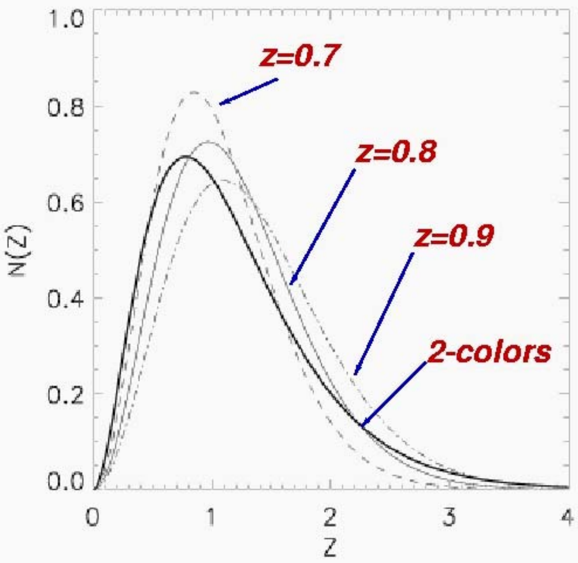
(see also Ishak et al 2004, which does a 1d joint cosmic shear + CMB forecast)

Redshift distribution:

a crucial issue for next generation surveys

Sensitivity to redshift of sources

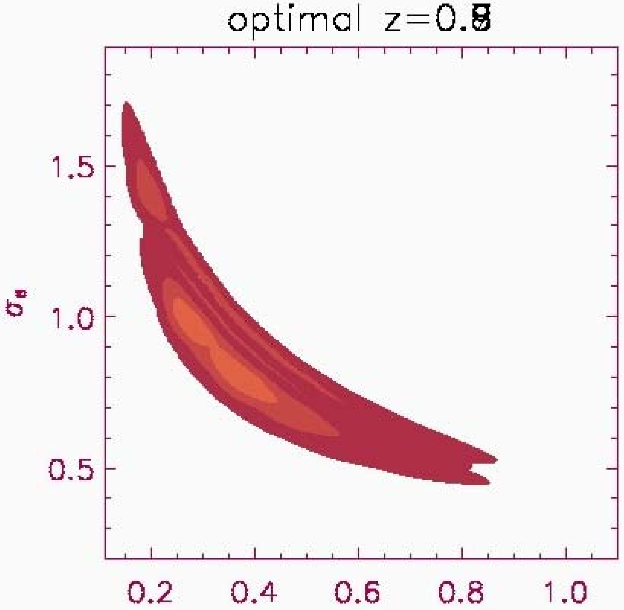
Redshift distribution of sheared sources



$$n(z_s) = \frac{\beta}{z_0\ \Gamma\left(\frac{1+\alpha}{\beta}\right)} \left(\frac{z_s}{z_0}\right)^{\alpha} \exp\left[-\left(\frac{z_s}{z_0}\right)^{\beta}\right]$$

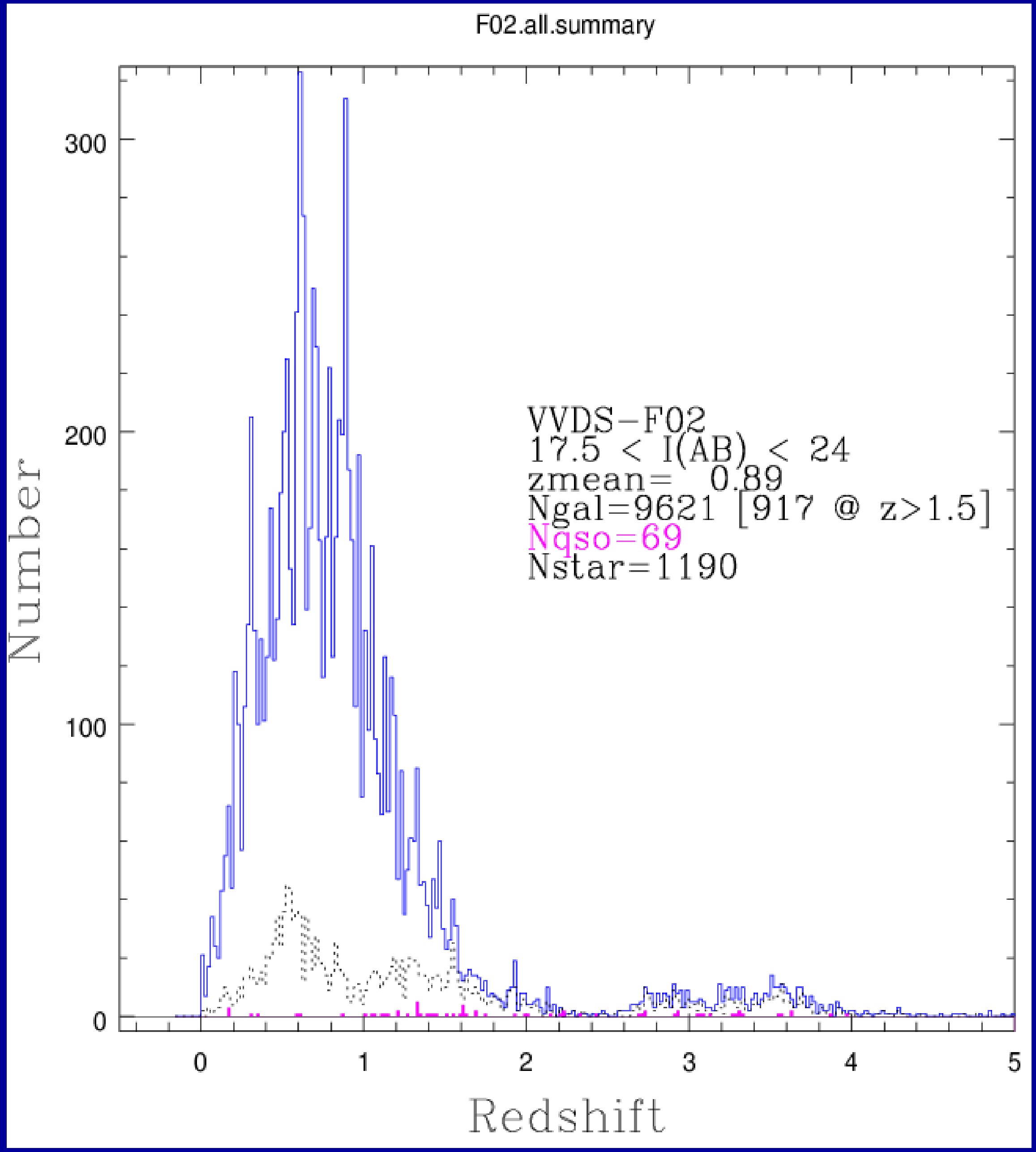
van Waerbeke et al 2001

VIRMOS-DESCART CFH survey



6.5 deg^2 - 450, 000 galaxies - I=24

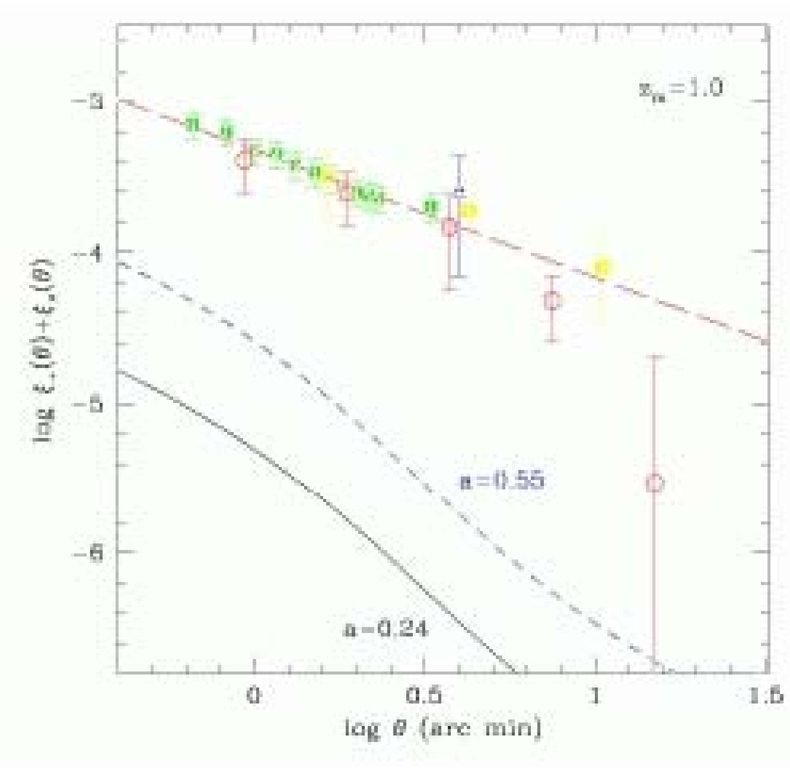
z_s = 0.7+08+09 - Open CDM - $\Lambda=0$, $\Gamma=0.21$

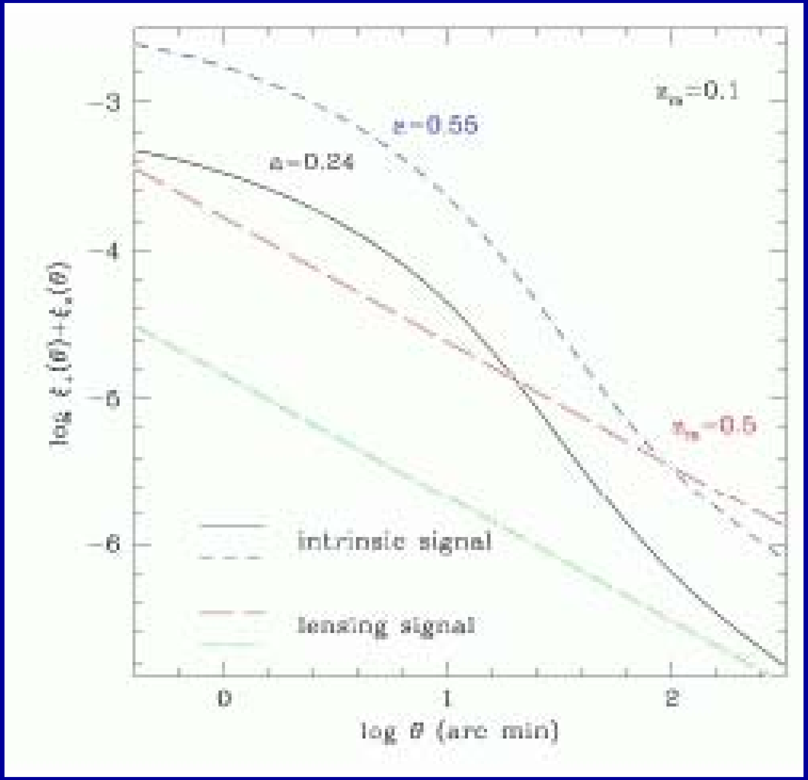


The VIRMOS-VVDS spectroscopic survey

Le Fèvre et al 2004

Intrinsic ellipticities: critical for low-z surveys



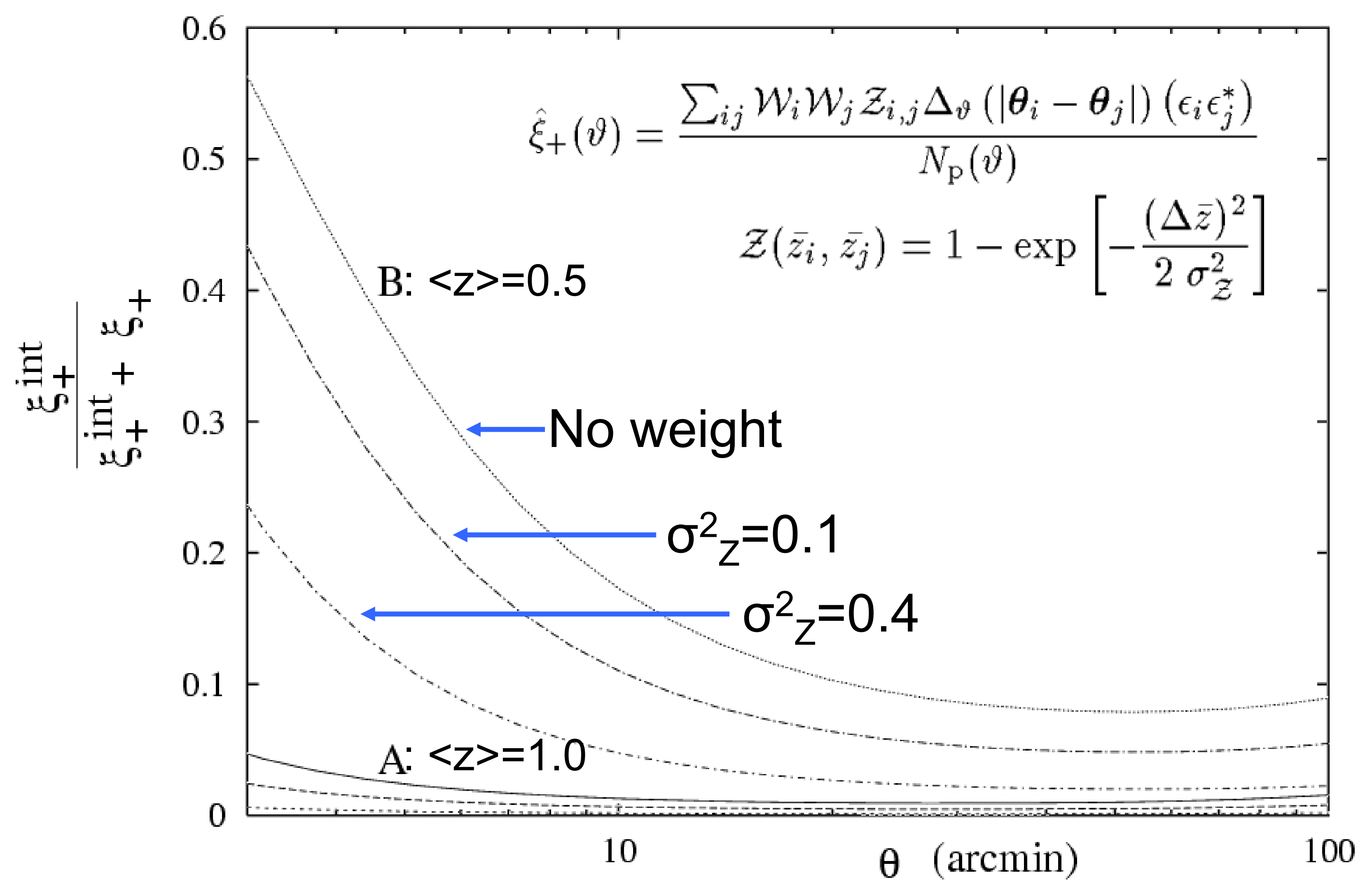


Crittenden et al 2001

See also : Mackey et al 2001; Catelan et al 2001; Croft & White 2001…

Minimising intrinsic alignments with photo-z

King & Schneider 2002 (see also Heymans & Heavens 2002)

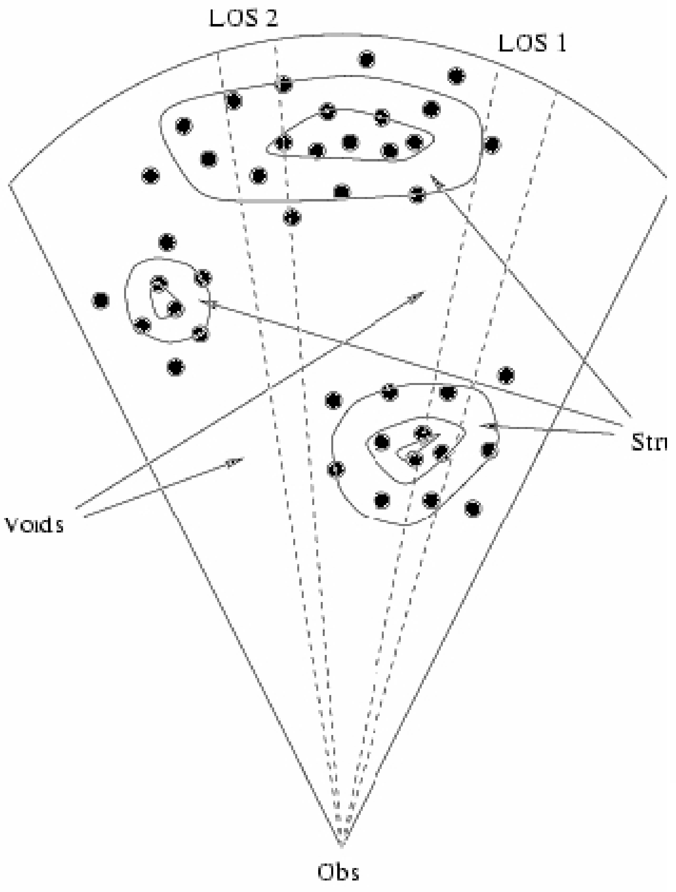


$$\hat{\xi}_+(\vartheta) = \frac{\sum_{ij} \mathcal{W}_i \mathcal{W}_j \mathcal{Z}_{i,j} \Delta_\vartheta \left(|\boldsymbol{\theta}_i - \boldsymbol{\theta}_j|\right) \left(\epsilon_i \epsilon_j^*\right)}{N_\mathrm{p}(\vartheta)}$$

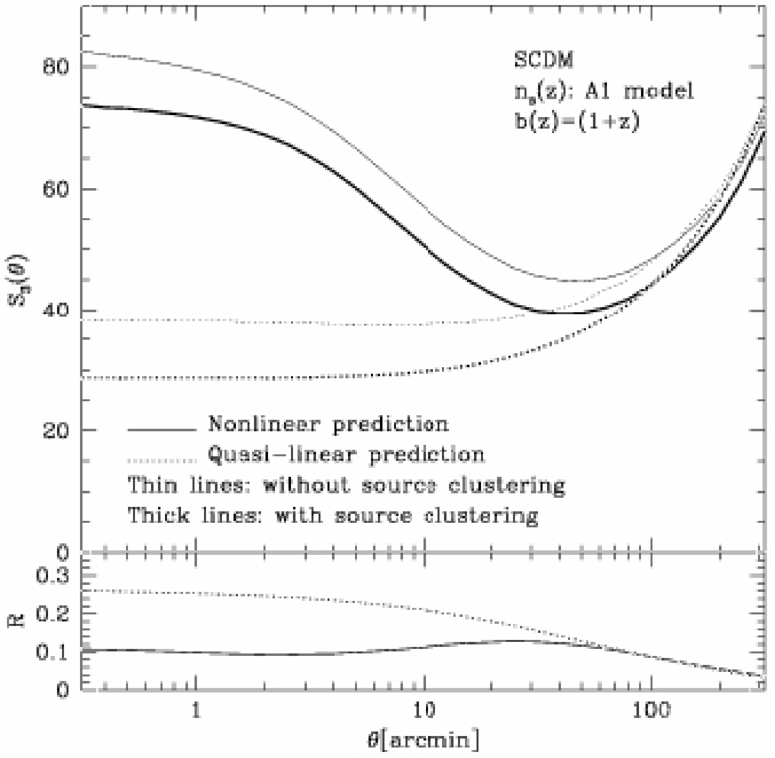
$$\mathcal{Z}(\bar{z}_i, \bar{z}_j) = 1 - \exp\left[-\frac{(\Delta \bar{z})^2}{2\,\sigma^2_{\mathcal{Z}}}\right]$$

Impact of source clustering

Hamana et al 2000



Hamana et al 2000



$$R = S_3^{sc} \; / \; S_3$$

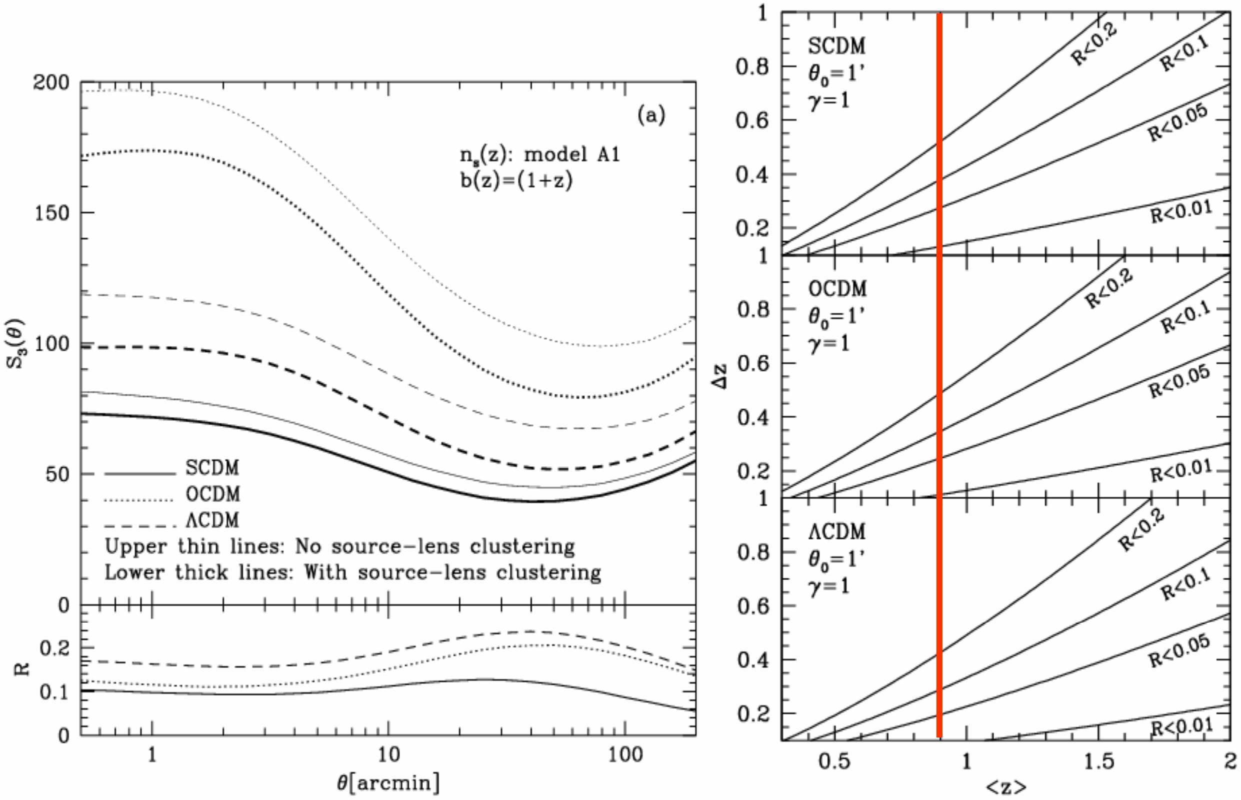


Figure 4. Sensitivity of the convergence skewness to source-lens clustering. The top-left panel shows how the amplitude of the skewness varies with source-lens clustering for three cosmological models. The lower plot gives the relative variation. In all cases, the skewness decreases by a factor larger than 10%, a serious limitation to precision cosmology with cosmic shear. To solve this issue, one needs to get the redshift of source-lenses. On the right panel, the width of the source distribution is plotted as function of the averaged source-redshift. In order to minimize the clustering effect, the source distances must be large as possible and spread over a narrow redshift range. Clearly, the accuracy of photometric redshift must be better than 10%. This goal can be achieved if *UBVRIJ* and *JHK* band data are obtained for most lensed galaxies, with a photometric accuracy of about 5%-10% in each filter.

Decoupling geometry and matter power spectrum

$$P_{g\gamma}(\ell; f, b) = \frac{3\Omega_{m0} H_0^2}{2c^2} \int \frac{d\chi_f}{a(\chi_f)} W_f(\chi_f) \int d\chi_b W_b(\chi_b) \times \frac{\chi_b - \chi_f}{\chi_b \chi_f} P_{g\delta}\left(\frac{\ell}{\chi_f}, \chi_f\right) \Theta(\chi_b - \chi_f) \quad (2)$$

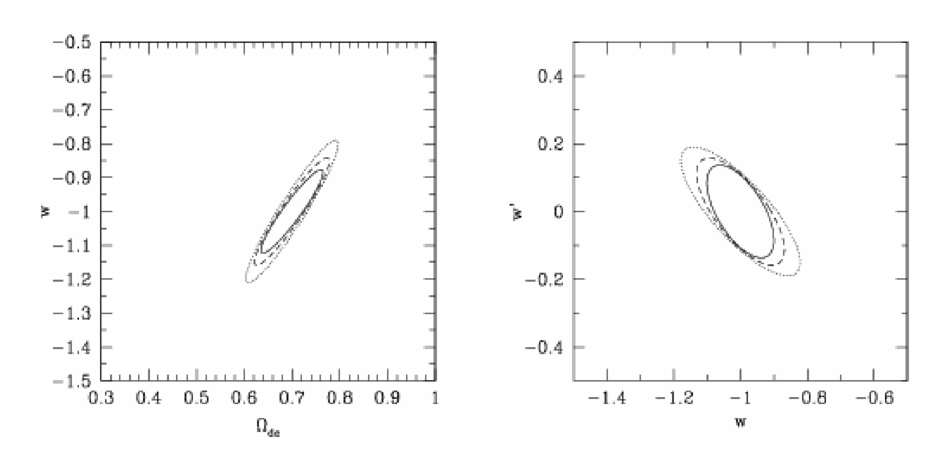
$$\begin{aligned} P_{\gamma\gamma}(\ell; f; b) &= \left(\frac{3\Omega_{m0} H_0^2}{2c^2}\right)^2 \qquad (3) \\ &\times \int d\chi_f W_f(\chi_f) \int d\chi_b W_b(\chi_b) \\ &\times \int \frac{d\chi}{a(\chi)^2} \frac{\chi_b - \chi}{\chi_b} \frac{\chi_f - \chi}{\chi_f} P_{\delta\delta}\left(\frac{\ell}{\chi}, \chi\right) \Theta(\chi_b - \chi) \Theta(\chi_f - \chi). \end{aligned}$$

If small overlap between lensed populations :

$$P_{g\gamma}(\ell; f, b) \approx F(\ell; f) + G(\ell; f)/\chi_{\rm eff}(b)$$
$$P_{\gamma\gamma}(\ell; f, b) \approx A(\ell; f) + B(\ell; f)/\chi_{\rm eff}(b)$$

Signal can be scaled without regards on power spectrum: ratio only sensitive to geometry

$$\frac{P(\ell; f, b) - P(\ell; f, b')}{P(\ell; f, b'') - P(\ell; f, b''')} = \frac{\chi_{\rm eff}(b)^{-1} - \chi_{\rm eff}(b')^{-1}}{\chi_{\rm eff}(b'')^{-1} - \chi_{\rm eff}(b''')^{-1}}$$

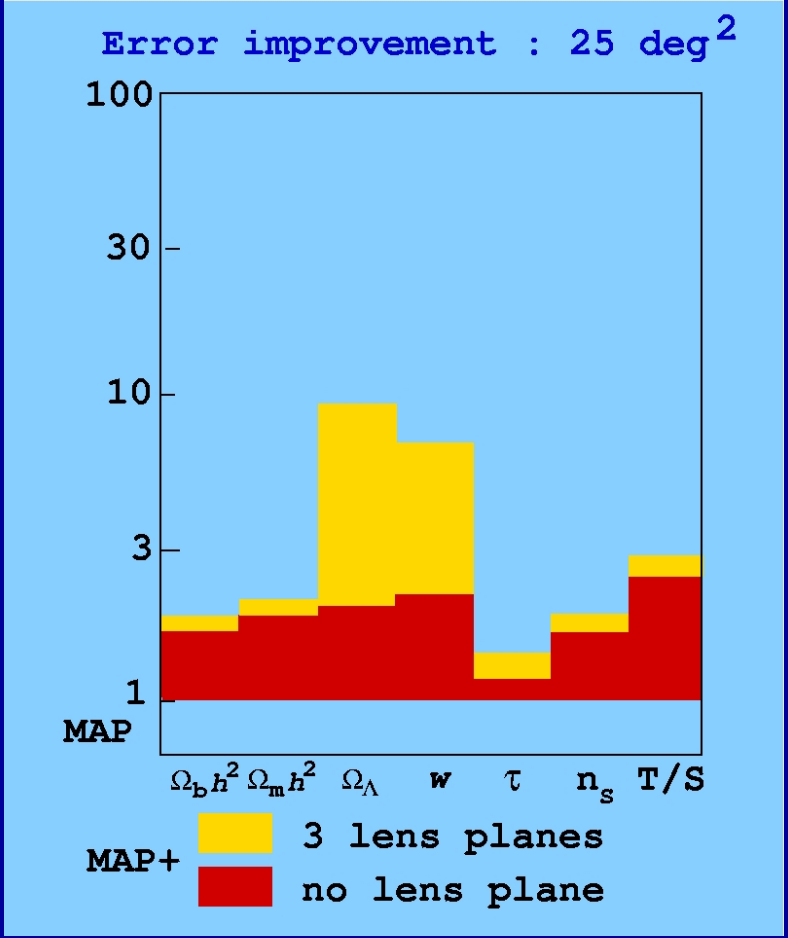


But need photo-z for at least 3 source planes

Zhang, Hui, Stebbins 2003:

4000 deg^2

Error photo-z: 0.01, 0.02, 0.05

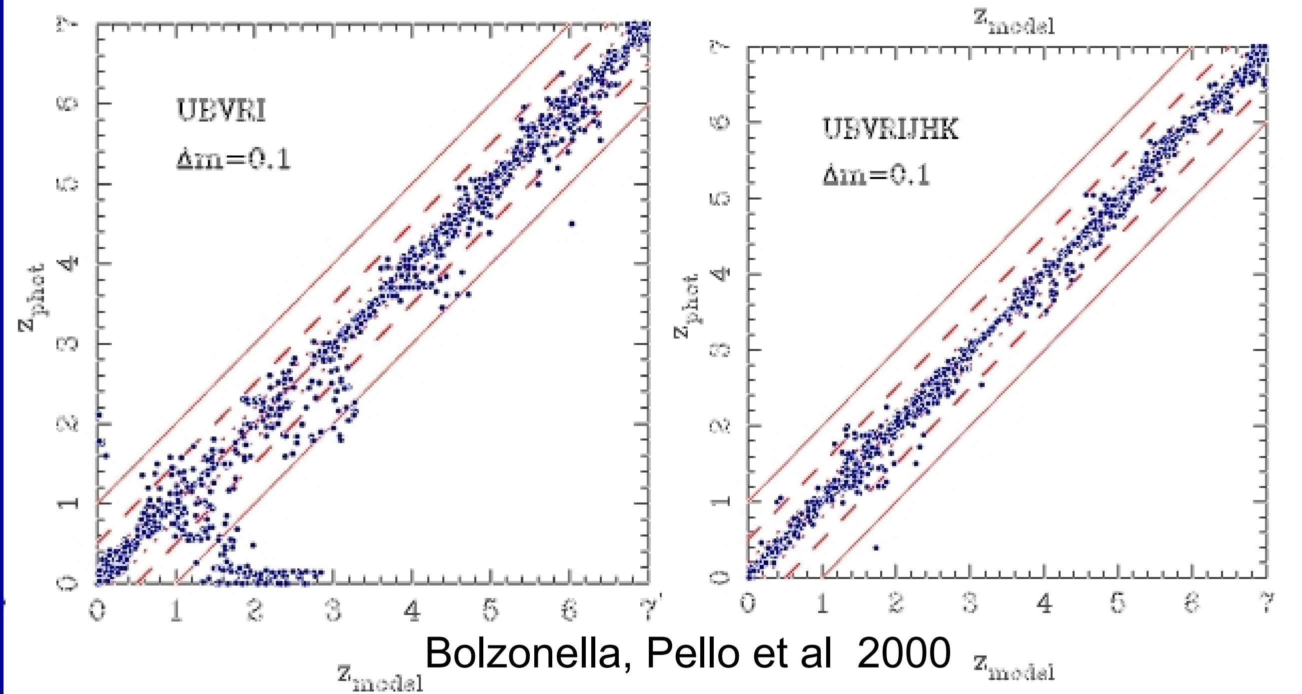


Breaking degeneracies with N(z)

CFHTLS (Megacam+Wircam): intermediate: 200 deg^2

- It must be done in both visible and NIR… Another challenge!!

Need for redshift information



Bolzonella, Pello et al 2000

- Rough N(z): Δz = 0.05
- Give a photo-z to all galaxies (weight galaxies for wl and intrinsic correlations of ellipticities): Δz = 0.10
- Provide multi-lens planes information dark energy: Δz = 0.10 sample 0.3/0.4/>0.5
- Partially constrain clustering: 3-pt function: Δz = 0.05
- Redshifts of arcs and lensing clusters: Δz = 0.10
- Break power spectrum / geometry: Δz = 0.05
- Biasing background / foreground: Δz = 0.10 foreground z<0.2
- Biasing as function of redshift: 3 planes: Δz = 0.10 sample: 0.2/0.4/>0.5

Wircam and cosmic shear with CFHTLS

- Ideal: Photo-z informations for all galaxies used for weak lensing :
- I_{ab}=24.: extended object 5σ, 80% completness of the I-band sample: J=22.8 (1hr), H=21.8 (1hr), K=21.3 (1hr) .
- FOV Megacam/Wircam: R= 9
- Covering the W1 field : Ct=time*1.2 (overlap between fields) : 72 (W1) x 9 (R) x 3 (filter)*1.2 (Ct) = 2333 hrs, 360 nights (65% efficiency)
- Covering the 3 Wide fields: 850 nights
- Redshift survey cannot provide all z, but must be used to calibrate photo-z and errors/systematic
- Suggestion:
    - 30% of W1 (110 nights) + 30% W3 (cosmic varian
    - Or 30% I=24 W1 + 70% I=22.5 W1(full W1)
- Cosmic shear also use Deep fields
- Priority to
    - Deep D1
    - Wide W1 and W3 (spectro z exist)