Weak lensing and large-scale structure

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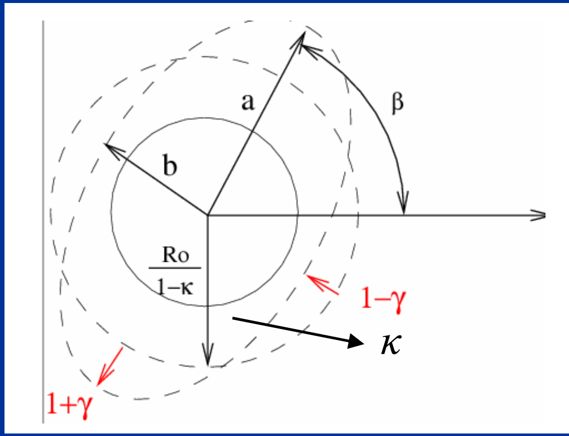
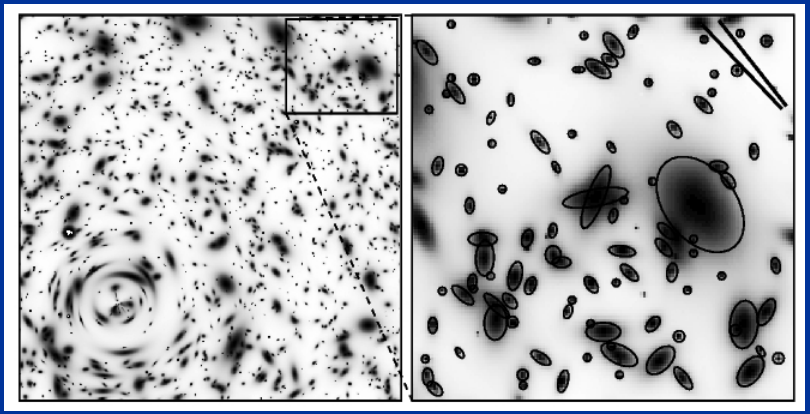
Weak gravitational lensing in brief

shear and galaxy ellipticity





Observed ellipticity of galaxies

↓

PSF anisotropy correction
Derived from star shape analysis.

↓

Deconvolved (true) ellipticity

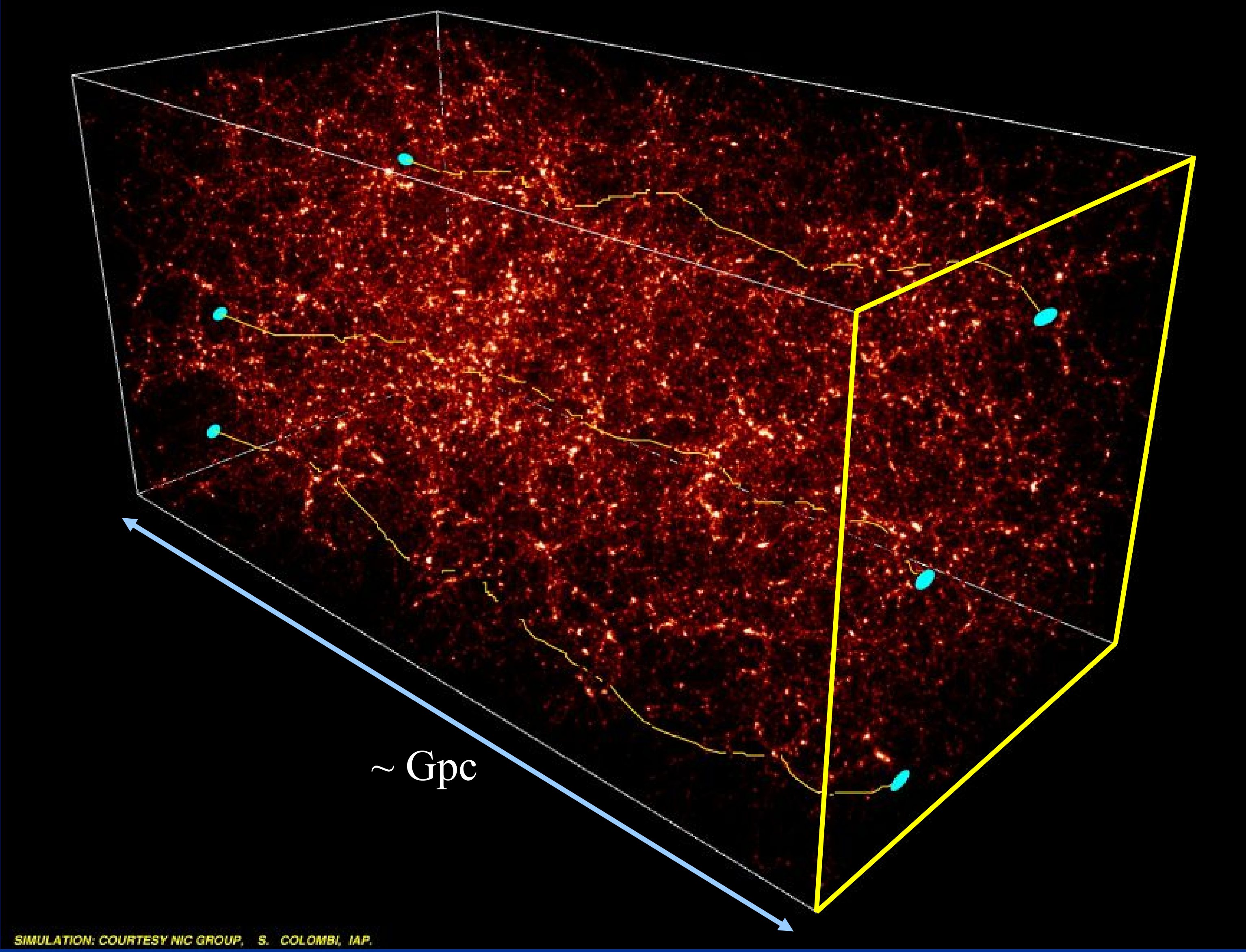
↓

Ellipticity predicted by lensing ~ 2γ

Assuming sources orientation is isotropic:

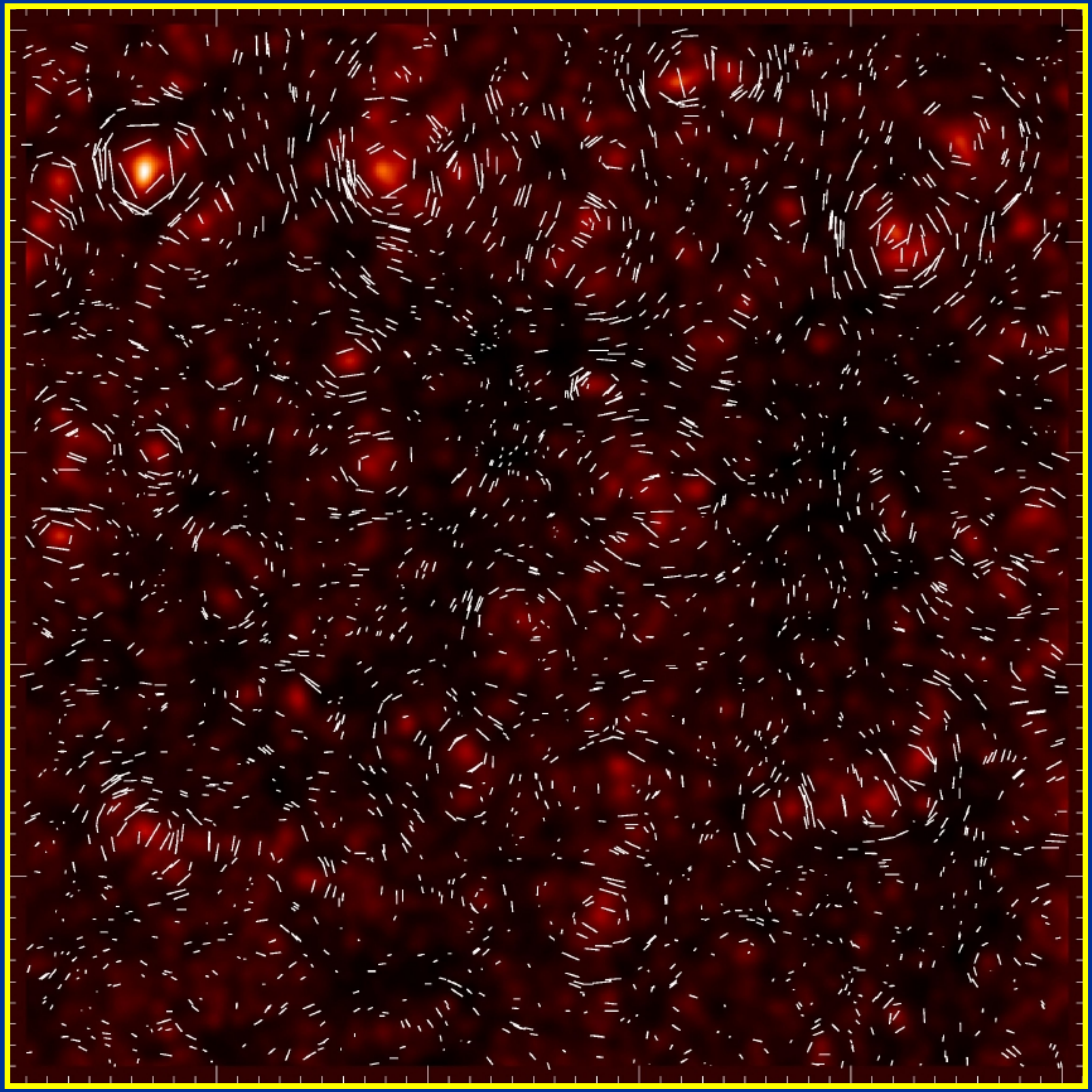
Weak lensing regime : shear ~ 2γ = mean ellipticity of galaxies

Cosmic shear : propagation of light through the cosmic web



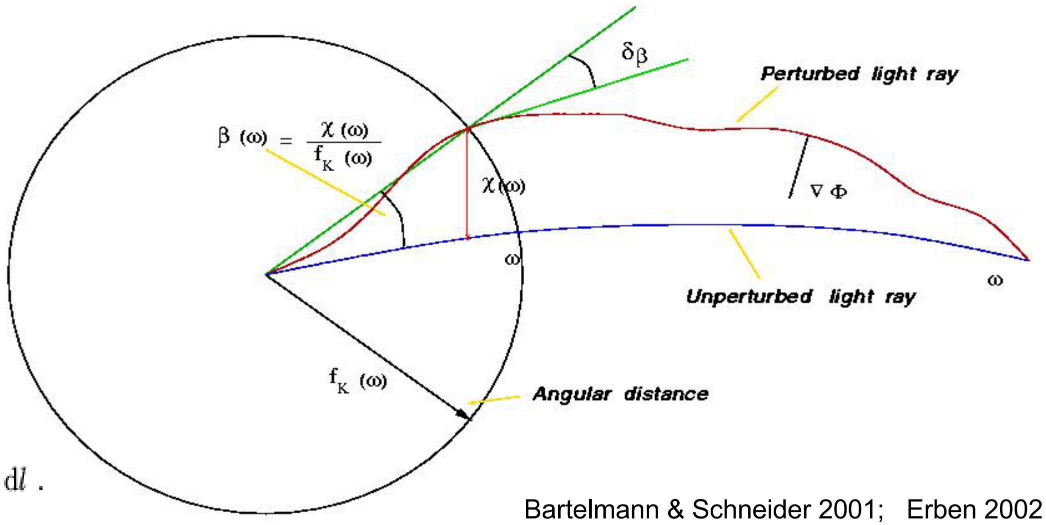
Cosmological distortion :

dark matter power spectrum projected on the sky



Gravitational convergence and shear from light propagation in an inhomogeneous universe

$$ds^2 = c^2 dt^2 - a^2(t)\,[dw^2 + f_K^2(w)\, d\omega^2]$$



Deflection angle:

$$\alpha = -\frac{2}{c^2}\int_S^O \nabla_\perp \Phi \, dl \, .$$

Bartelmann & Schneider 2001; Erben 2002

Distances

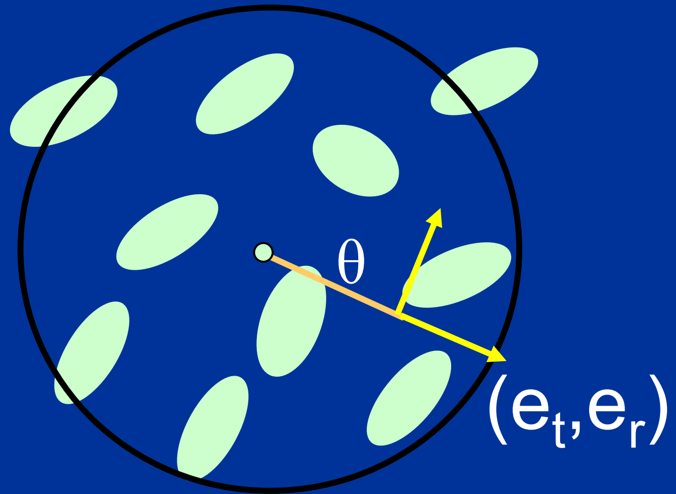
Power spectrum, growth rate of structure

$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2}\int_0^{\omega} \frac{f_K(\omega-\omega')\, f_K(\omega')}{f_K(\omega)} \frac{\delta\left[f_K(\omega')\,\boldsymbol{\theta};\omega'\right]}{a(\omega')} d\omega' \rightarrow \gamma$$

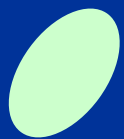
Both depend on the dark matter and dark energy content in the Universe

Analysing the lensing signal: 2-points statistics

1. Map variance



2. Shear variance:



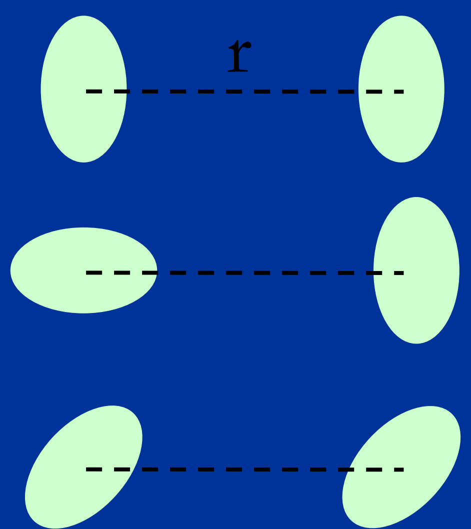
$\langle e^2 \rangle \sim \gamma^2$

Simple case, assuming a single lens plane and

$P(k) \sim k^n$

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

3. Shear correlation functions:



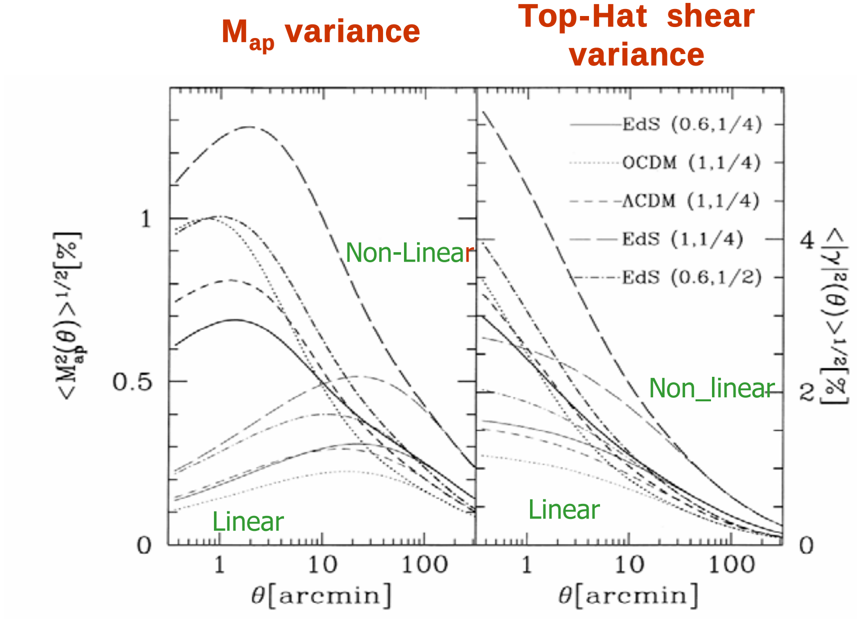
$\langle \gamma_t \gamma_t \rangle > 0$

$\langle \gamma_t \gamma_t \rangle < 0$

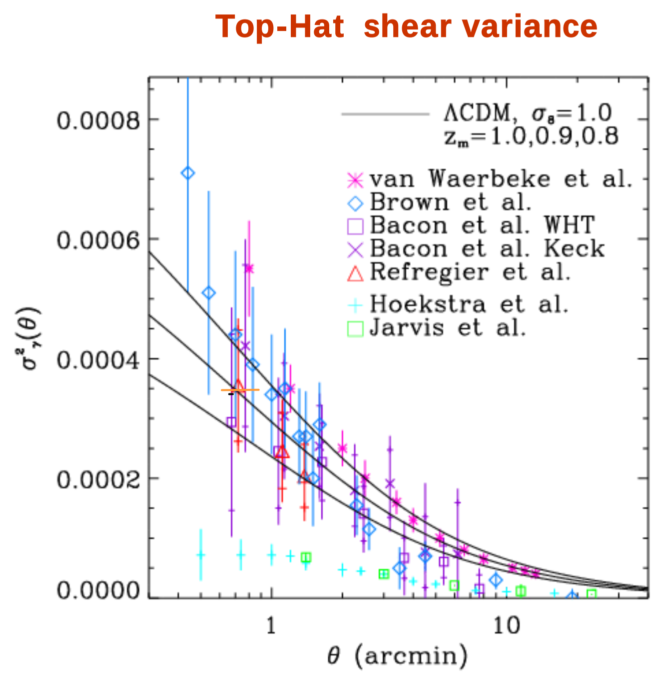
$\langle \gamma_r \gamma_r \rangle > 0$

Cosmic shear, 2-pt statistics and cosmological models

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



Bartelmann & Schneider 2001 : theoretical predictions from the gravitational instability scenario



Refregier et al 2002

See: Bacon et al 2000*, 2001 ; Benjamin et al 2007, Kaiser et al. 2000* ; Maoli et al. 2000* ; Rhodes et al 2001* ; Refregier et al 2002 ; van Waerbeke et al. 2000* ; van Waerbeke et al. 2000, 2001, 2005 ; Wittman et al. 2000* ; Hammerle et al. 2001* ; Hetterscheidt et al 2006, Hoekstra et al. 2002 * ; Brown et al. 2003 ; Hamana et al. 2003 * , 2006 ; Jarvis et al. 2003, 2006 ; Casertano et al 2003* ; Rhodes et al 2004 ; Massey et al. 2004, 2007 ; Heymans et al 2004* ; Semboloni et al 2006 ; Schrabback et al 2007, Hoekstra et al 2006

galaxy ellipticity = gravitational weak shear …. But…

Unfortunately…

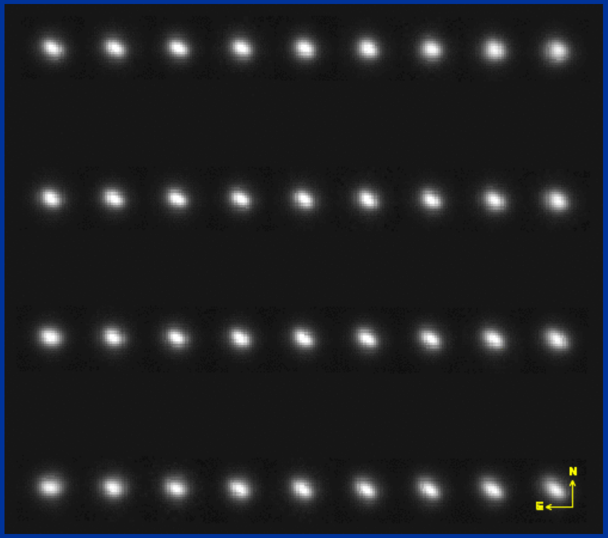
- Gravitational ellipticity signal is contaminated by non-gravitational distortion

- PSF anisotropy corrections is a key issue of weak lensing measurements

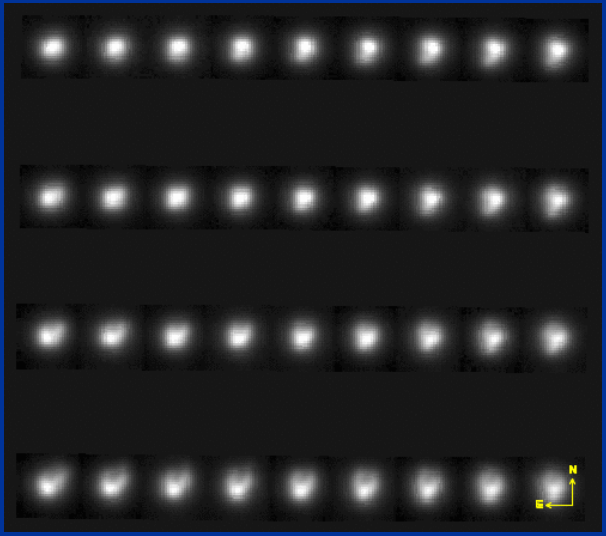
- Control of systematics residual is critical

The MegaPrime Point Spread Function (PSF): anisotropic and isotropic contaminations

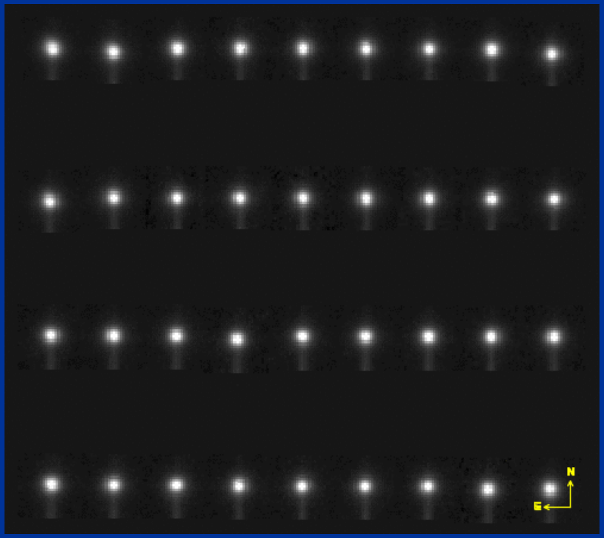
Telescope oscillating



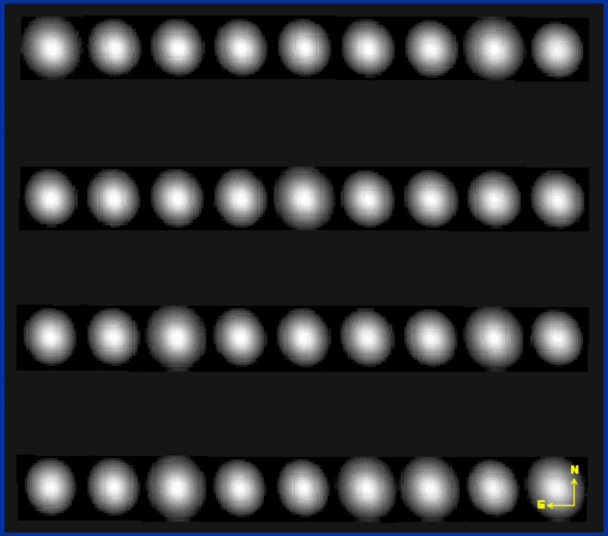
Telescope defocussed

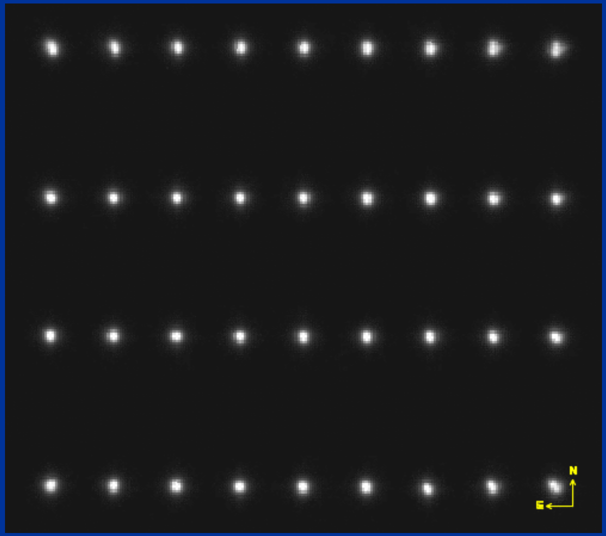


Telescope lost guiding



Seeing 2.5 ″





Seeing 0.55″

Cosmology with weak lensing

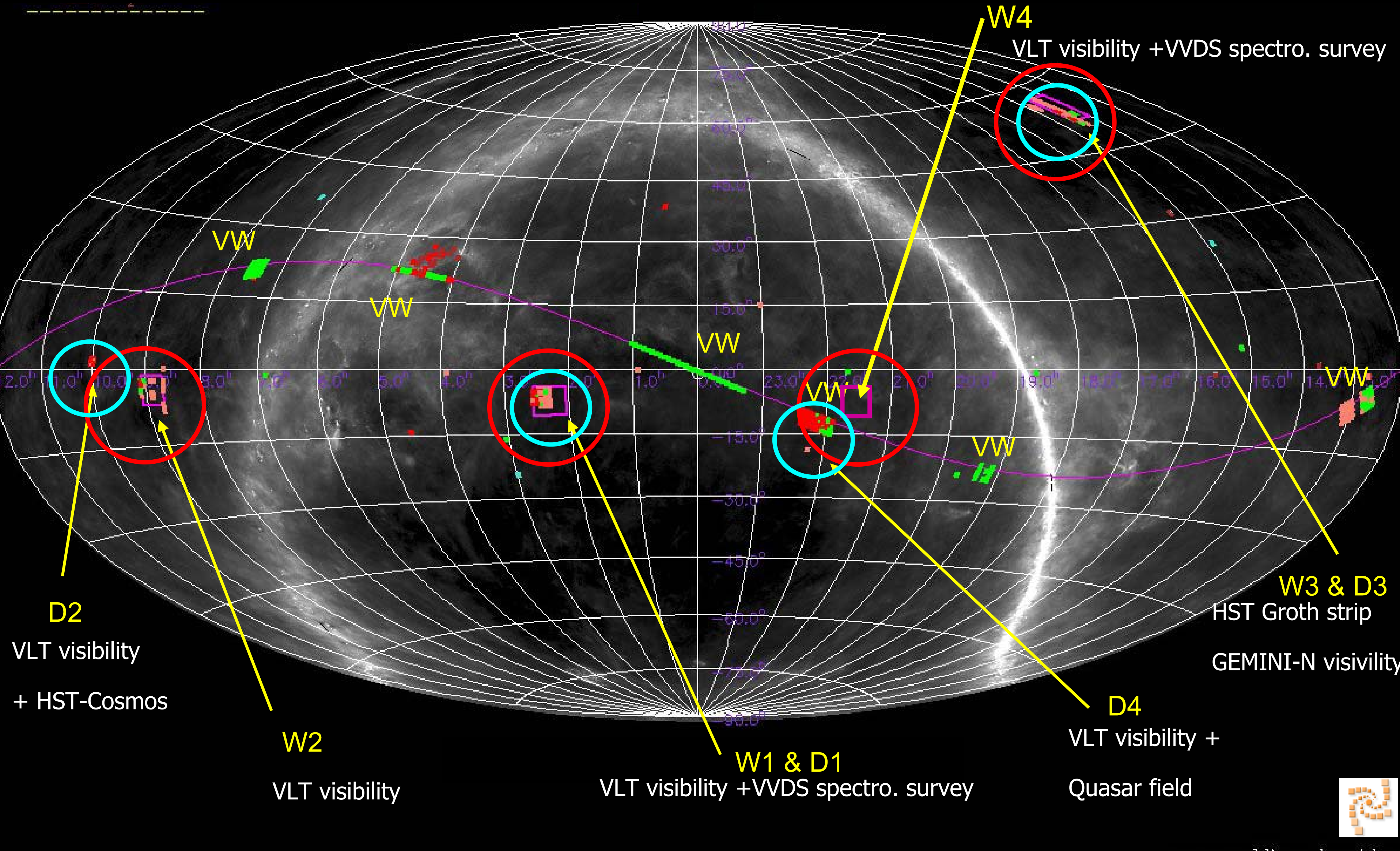
Importance of redshift distribution

Discussion of 4 WL surveys

- CFHTLS WL 1.5 yrs
- COSMOS
- The merging CFHTLS 1.5 yr+ GaBODS+ RCS
- CFHTLS 3yrs

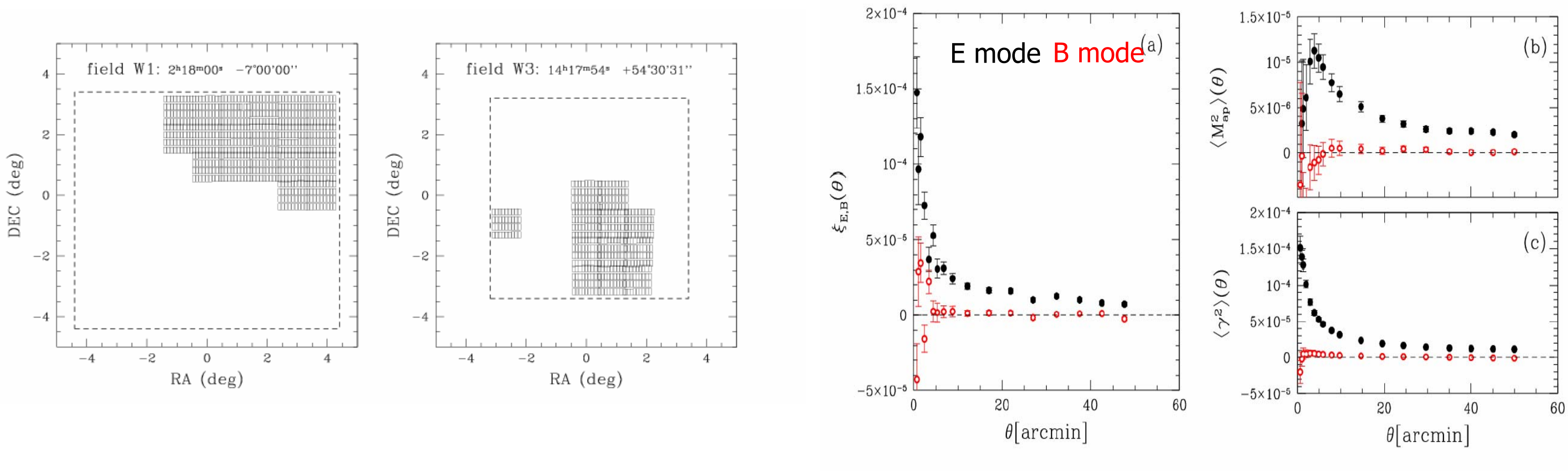
Canada-France-Hawaii Telescope Legacy Survey: Canada-France collaboration

- **4 W-fields of 50 deg²** (CFHTLS-Wide, 1h/filter), **4 D-deep fields of 1 deg²** (CFHTLS-Deep, 50hrs/filter)



Terapix/Skywatcher : all data 03A-08B : 25000 Megacam images

Cosmic shear:
the CFHTLS 1.5yr Wide



Hoekstra et al 2006

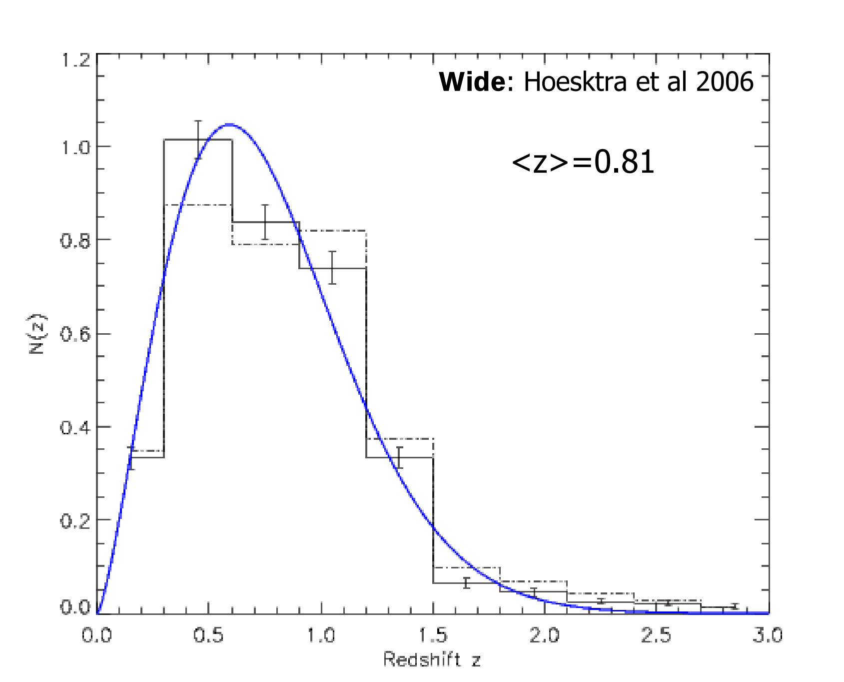
Total: ~25 deg^2, only 1 filter (no photo-z)

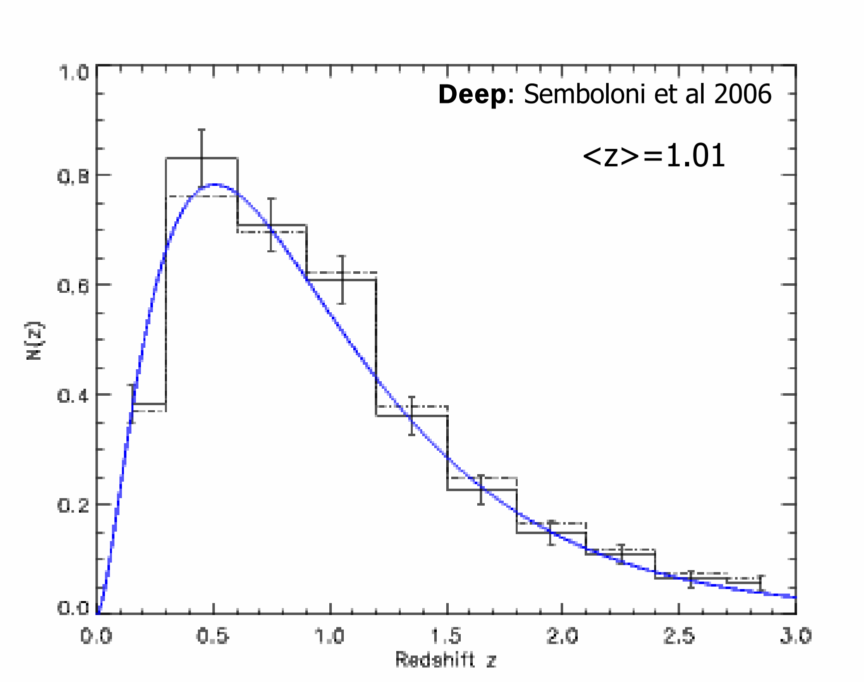
cosmological intepretation of the CFHTLS 1.5 yr data

Scaling the shear amplitude : Redshift distribution

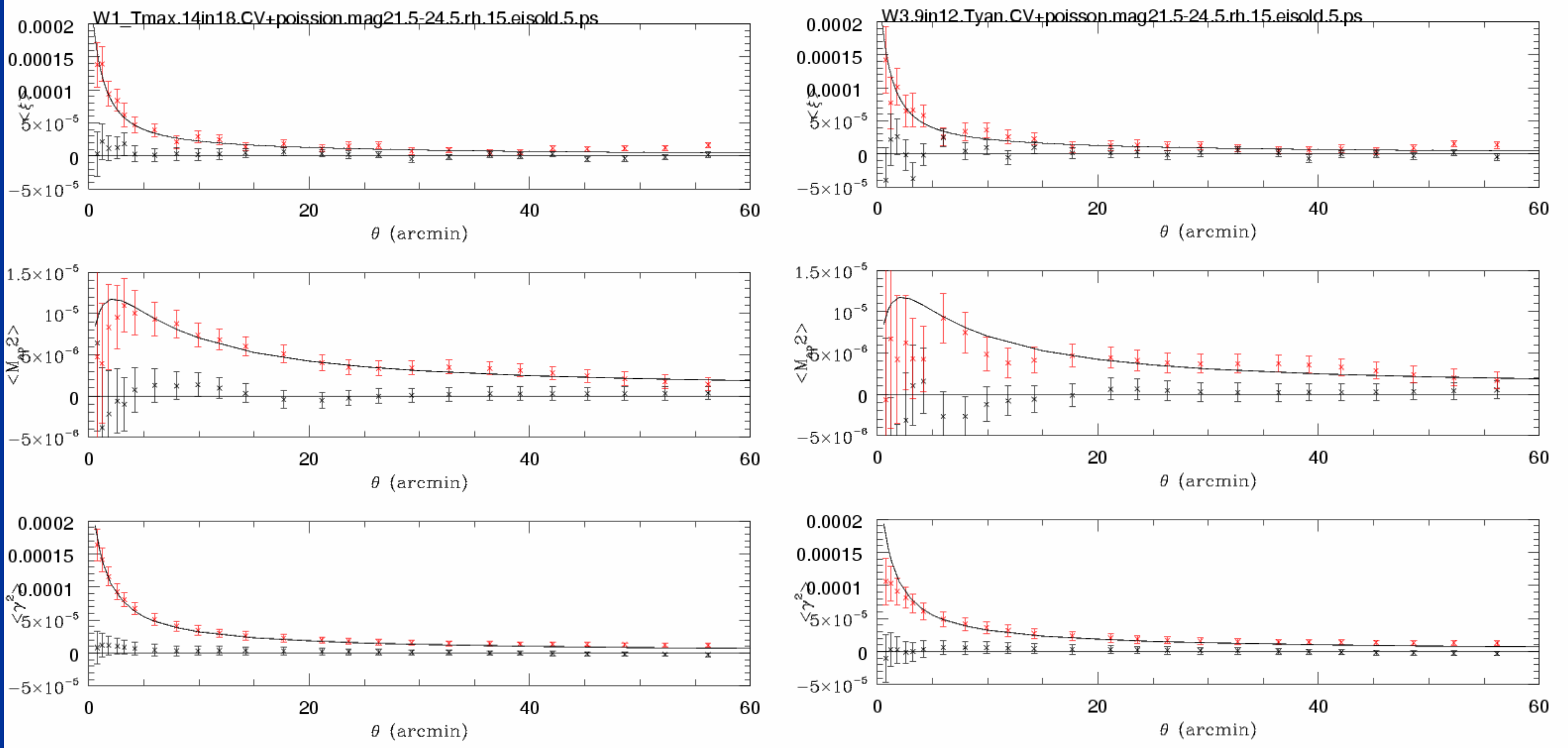
Photo-z from Hubble Deep Field optical+NIR data

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





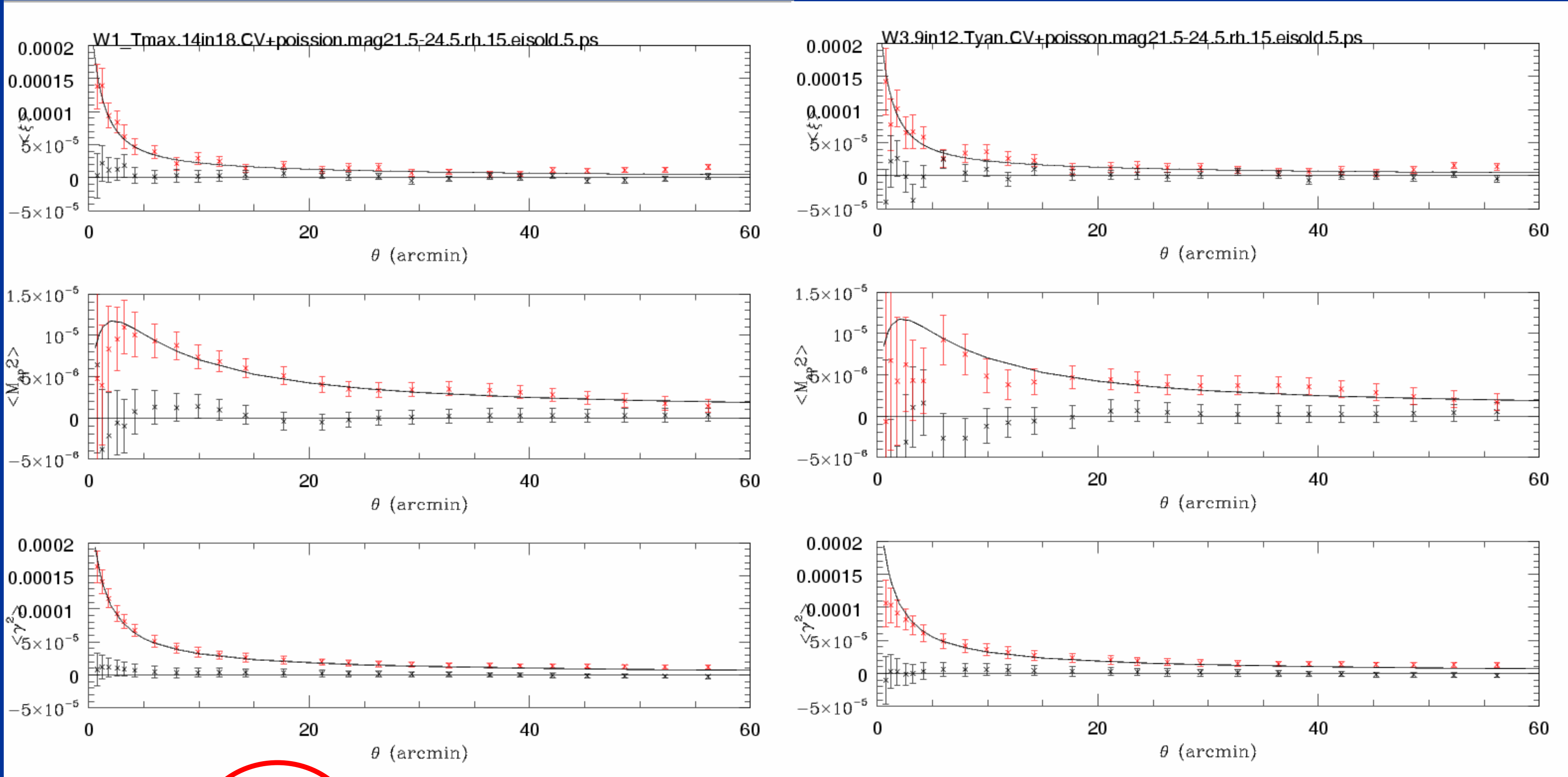
CFHTLS 1.5 yr in good agreement with the « concordance model »



- **Line: σ_8=0.85 ; Ω_m=0.27 ; Λ=0.73 ; h=0.71 ; $<z_s>$=0.85 ; σ_ε =0.36 ; n_{gal}=15 gal/arcmin^2**

Concordance model overplot: no fit

CFHTLS 1.5 yr in good agreement with the « concordance model »



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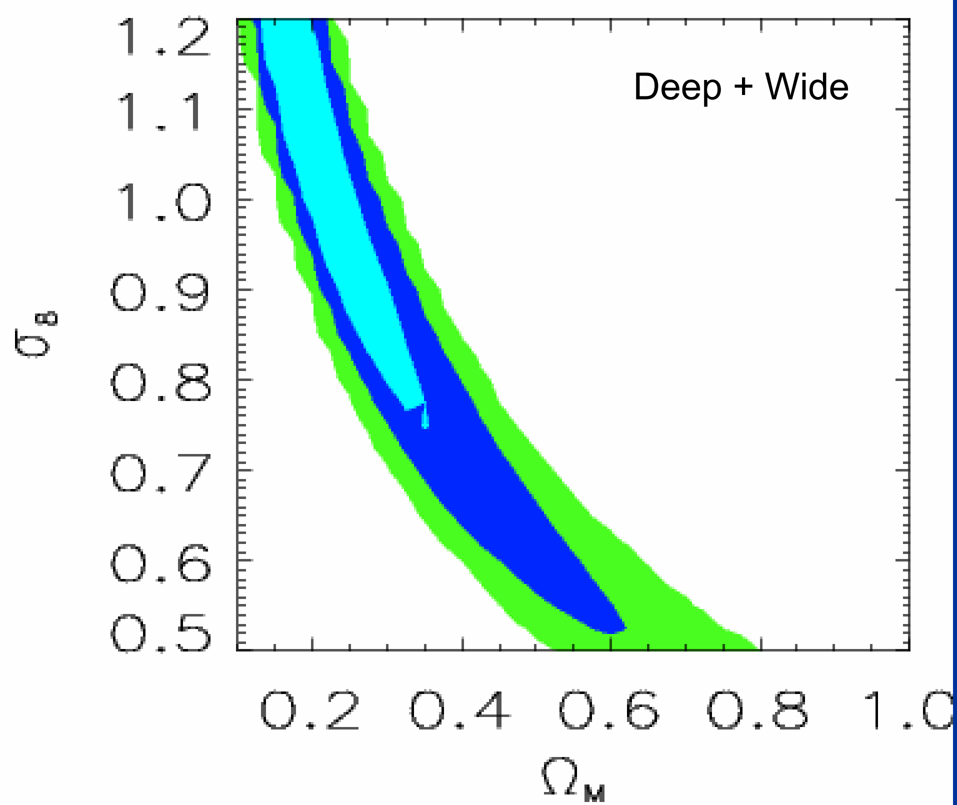
Concordance model overplot: no fit

CFHTLS 1.5 yr data: constraints on Ω_m-σ_8



Semboloni et al 2006 & Hoekstra et al 2006

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

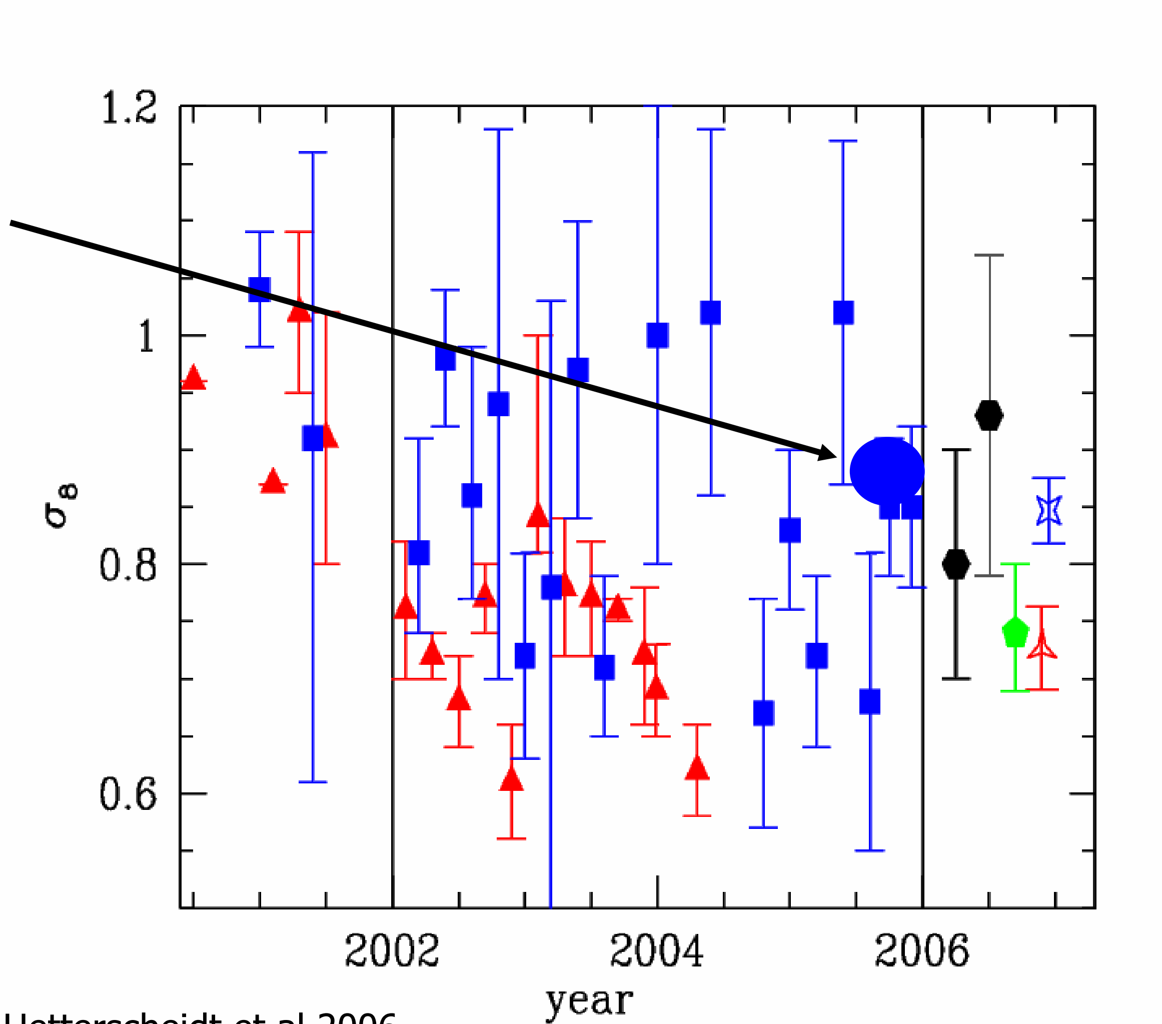
Deep+Wide assuming Ω_m=0.3 :

σ_8= 0.89 +/-0.06 (P&D)
σ_8= 0.86 +/-0.05 (Halo fit)

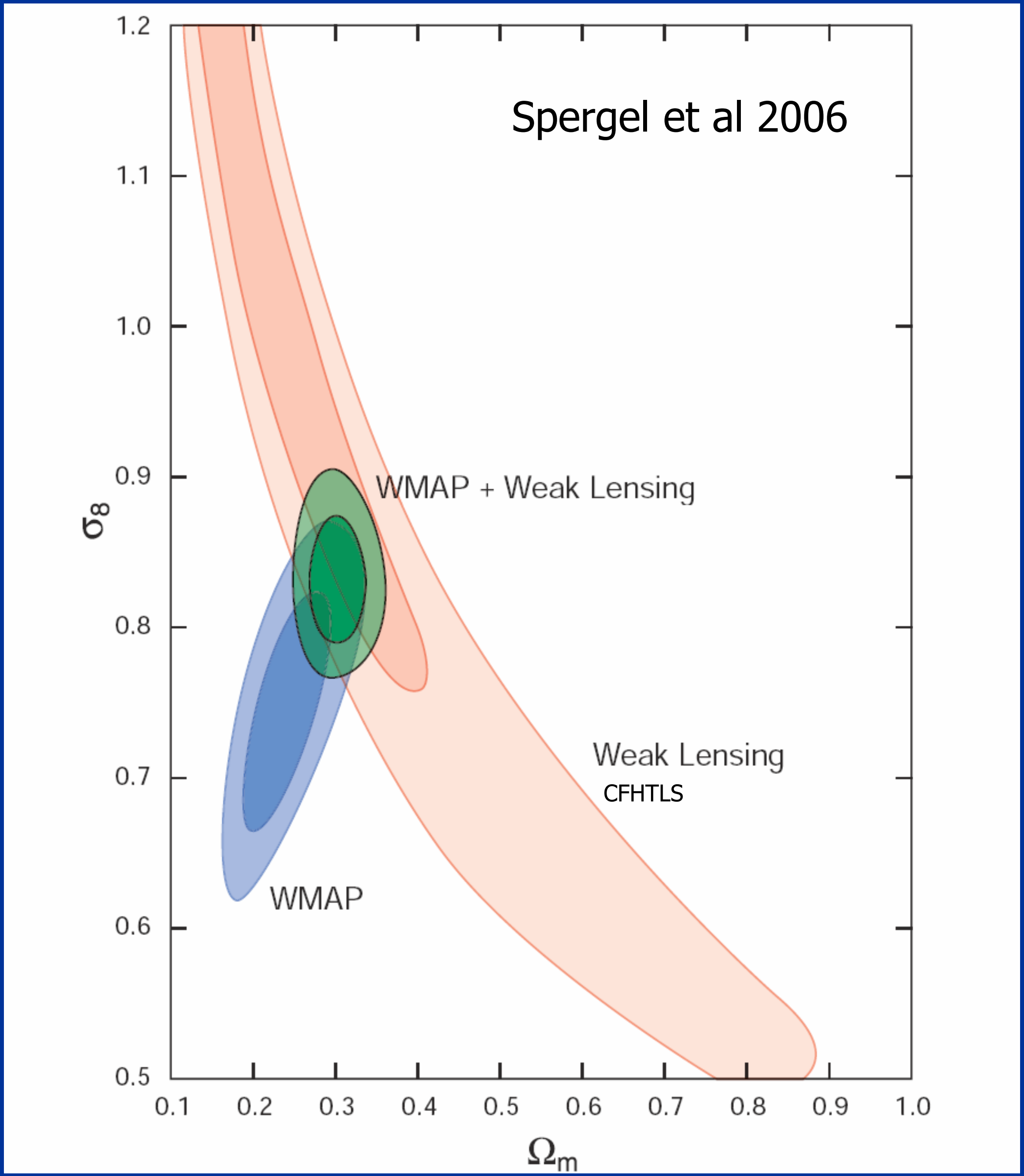
Deep effective area: 2.1 deg^2
Wide effective area : 22 deg^2

The puzzle : σ_8 derived from early WL surveys (blue) and clusters of galaxies (red)

CFHTLS 1.5yr



Hetterscheidt et al 2006



The puzzle :

WMAP3 and CFHTLS 1.5yr :

1.5-σ tension

Tension: a WL or a WMAP3 issue?

- Why so much scatter?

- Why this « tension » with respect to WMAP data?

- Why WL seems to lead to a higher value than WMAP?

- WLs agree with other observations.   But with other techniques that do have poorly controled astrophysical systematics

- Guess: the tension with WMAP3 comes from WL…

From ellipticity to cosmology : not obvious

Ellipticity badly measured (PSF anisotropy corrections, shape measurement)

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

$$\langle e^2 \rangle_\theta^{1/2} = \langle \gamma^2 \rangle_\theta^{1/2} \sim 0.01 \; \sigma_8 \, \Omega_m^{0.8} \; z_s^{0.75} \; \theta^{-(n+2)/2}$$

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

$\theta<15'$: Non-linear evolution of dark matter power spectrum unknown , extrapolation on small scales uncertain

Several issues may produce systematic errors:

Errors and systematics

- PSF corrections
- Redshift distribution
- Galaxy source/lens clustering
- Contamination by overlapping galaxies
- Intrinsic alignement
- Intrinsic foreground/backgound correlations
- Sampling variance
- Non-linear variance
- Non-linear dark matter power spectrum
- + cosmic variance (survey size, survey topology, depth)

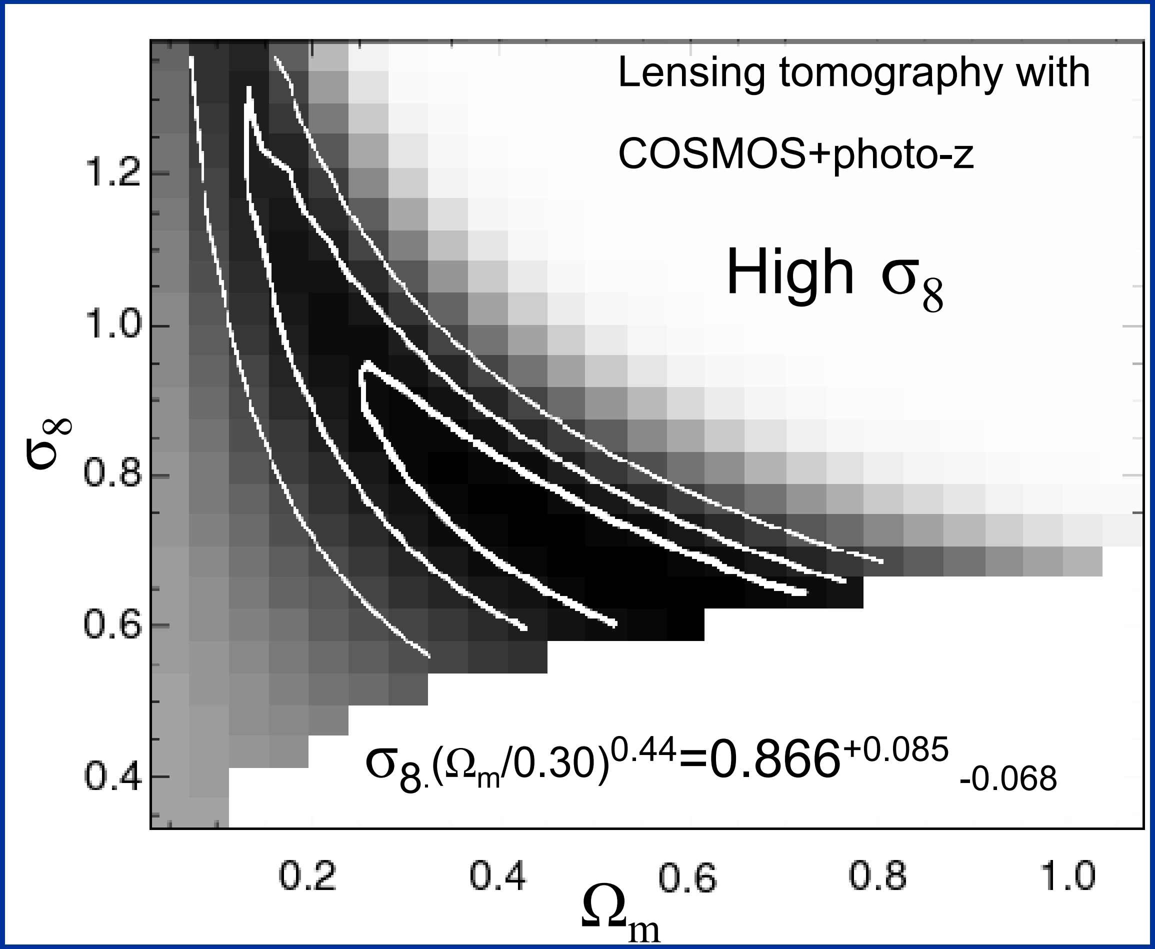
Cosmic Shear with The HST COSMOS Treasury Survey

Scoville et al 2007, Lilly et al 2007, Capak et al 2007, Massey et al 2007a,b, Leauthaud et al 2007, Rhodes et al 2007

- A compact 2 deg^2 field covered with HST/ACS camera
- Strength:
  - Outstanding image quality, unique for weak lensing
  - Large galaxy number density for statistics
  - On going spectroscopic survey : 40,000 redshifts with the VLT (once completed): z-COSMOS (Lilly et al 2007)
  - Large sample of photometric redshift available
- Weakness: only one field, cosmic variance important

Cosmic Shear Tomography with COSMOS:

ACS (shapes) + ACS/SUBARU/CFHT (photo-z) + z-COSMOS (photo-z calibration)

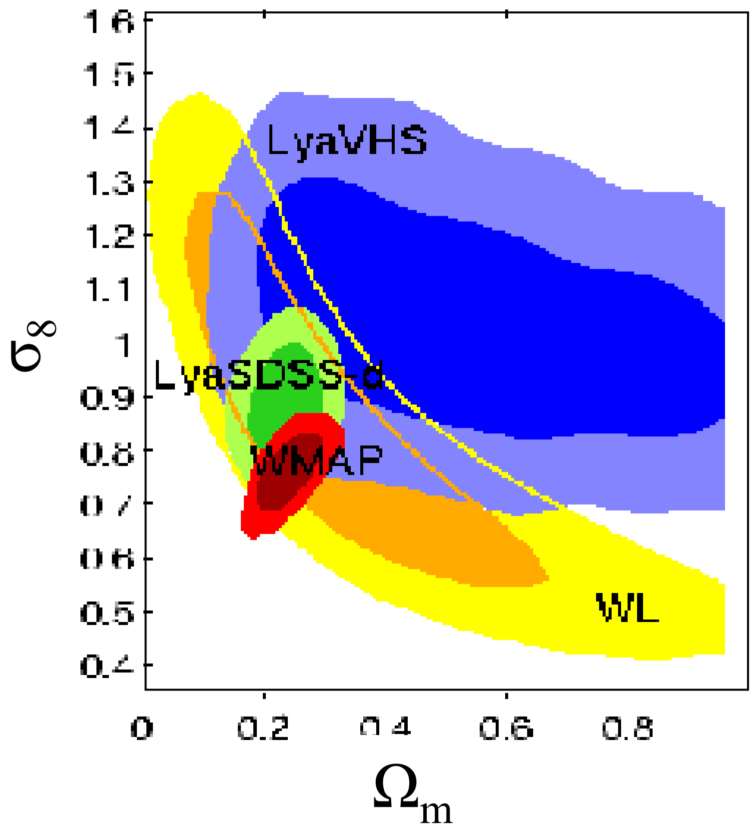


Rhodes et al 2007, Leauthaud et al 2007, Massey et al 2007a,b

Join analysis:

Cosmic Shear COSMOS + Lya VHS+ SDSS + WMAP3

Lesgourgues et al 2007



Still high σ_8

$\sigma_{8.}(\Omega_m/0.3)^{0.44}$=0.81+/-0.07

$\sigma_8 \sim 0.9$ if $\Omega_m = 0.25$

Improving the statistics very large sky coverage and consistency between surveys:

a join weak lensing survey (100deg^2) analysis+ better n(z)

- CFHTLS-Wide (1.5 yr):
  MEGACAM (Hoekstra et al 2006)

- CFHT-VIRMOS-Descart:
  CFHT12K (van Waerbeke, Mellier, Hoekstra 2005)

- CFHT-RCS:
  CFH12K (Hoekstra et al 2002)

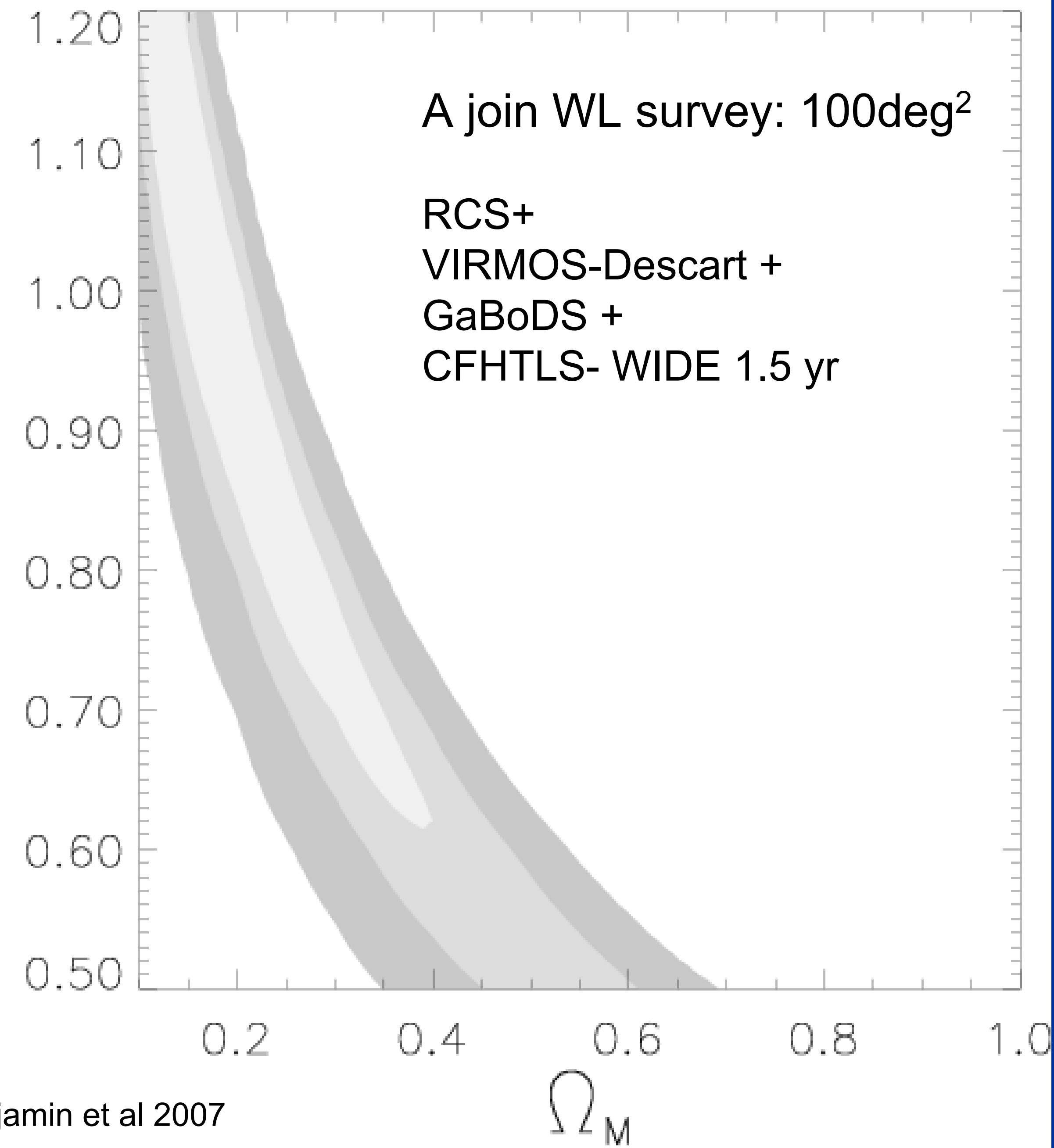
- ESO-GaBoDS:
  WFI (Hetterscheidt et al 2006)

- Benjamin et al 2007 : Merging 4 surveys + photo-z from VVDS/CFHTLS (Ilbert et al 2006) applied to all

- The largest sky coverage in WL surveys, n(z)

- But : heterogeneous in PSF, depth, + survey intercalib, + very large scales not explored

Join analysis



Benjamin et al 2007

- Merged Virmos-Descart and CFHTLS Deep+Wide
- Better error estimates on n(z) and non Gaussian cosmic variance

Join analysis

- Merged Virmos-Descart and CFHTLS Deep+Wide
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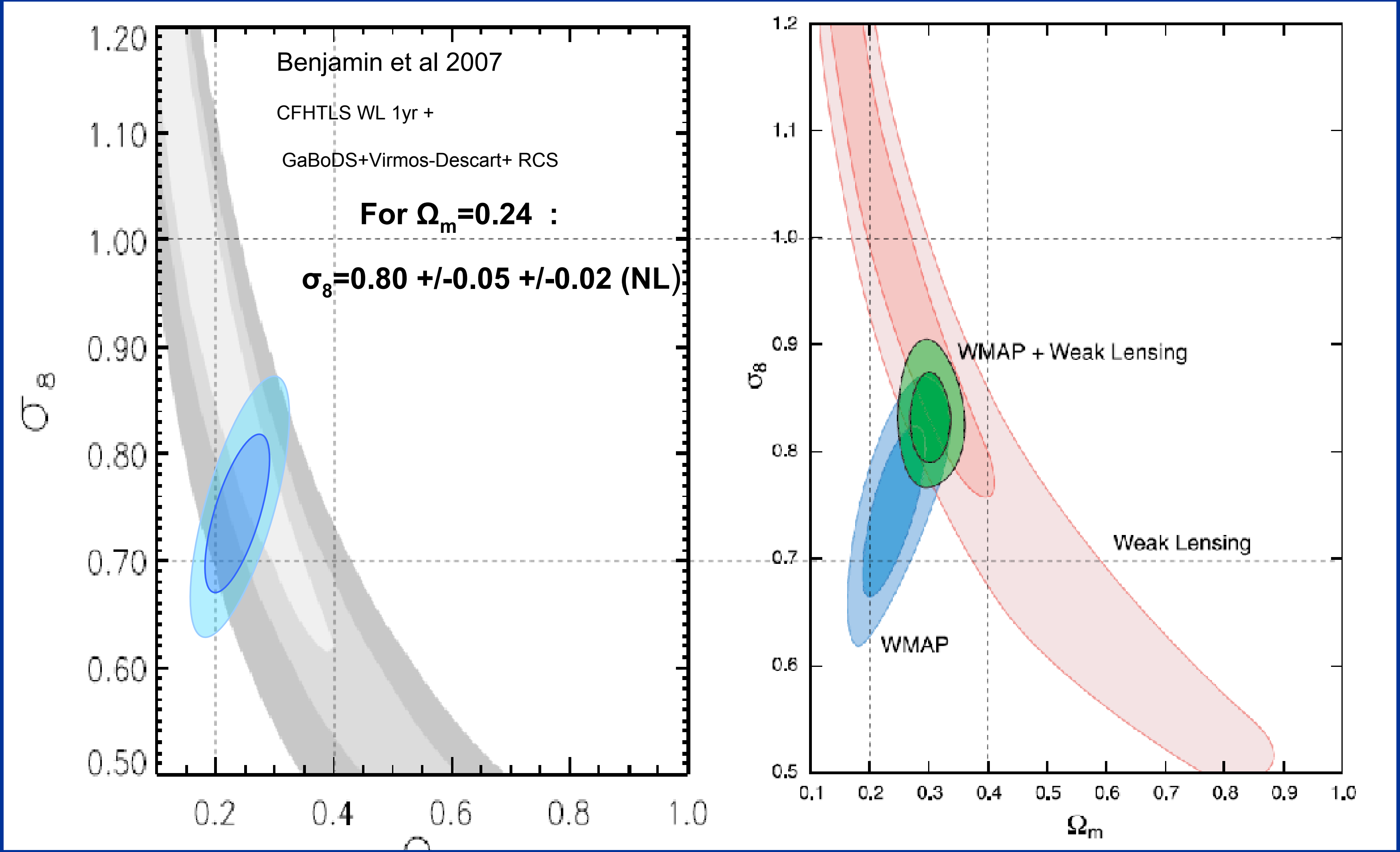
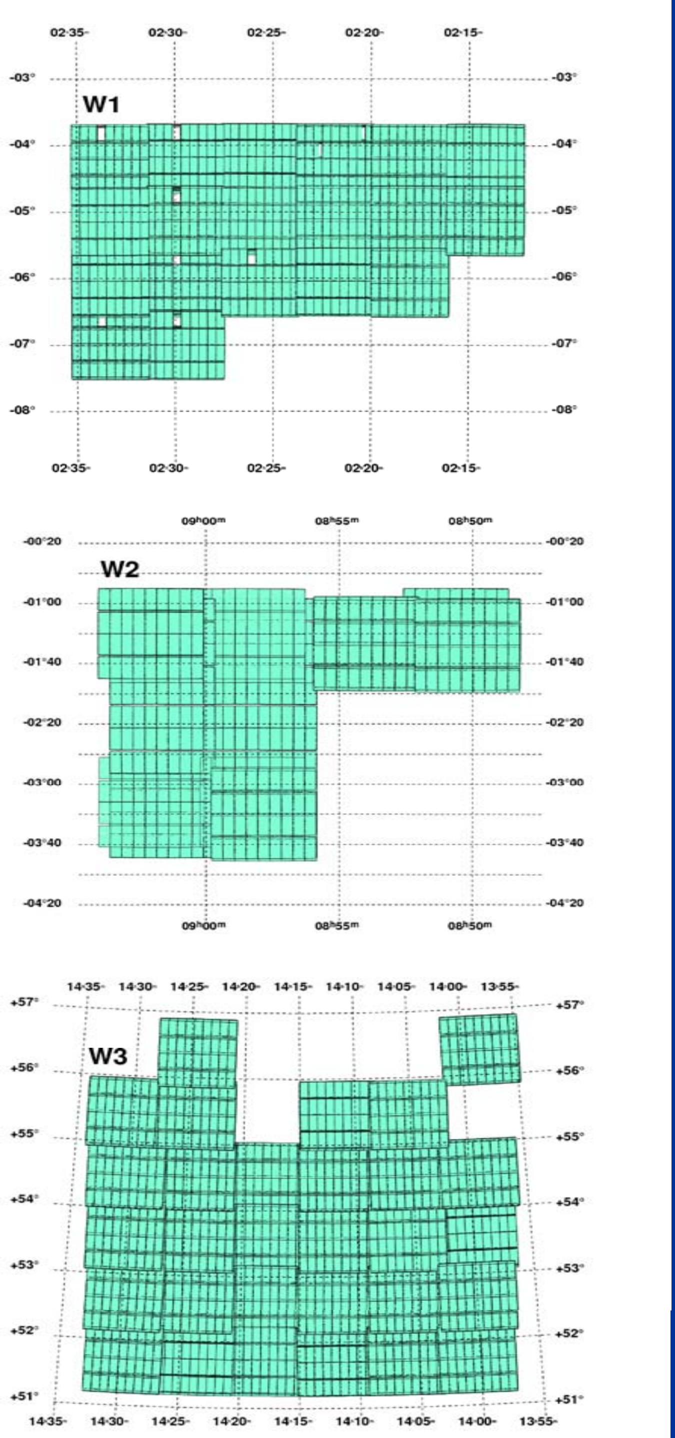




CFHTLS 3 yrs

- More sky coverage: 55 deg^2

- One more field: W1, W2, W3

- Explore very large angular scale : 7deg.

  (1' – 4 degrees: 85 Mpc at z=0.5)

-Homogenous data set :

WL catalogs from CFHTLS T0003 Wide with photo-z from CFHTLS T0003 Deep

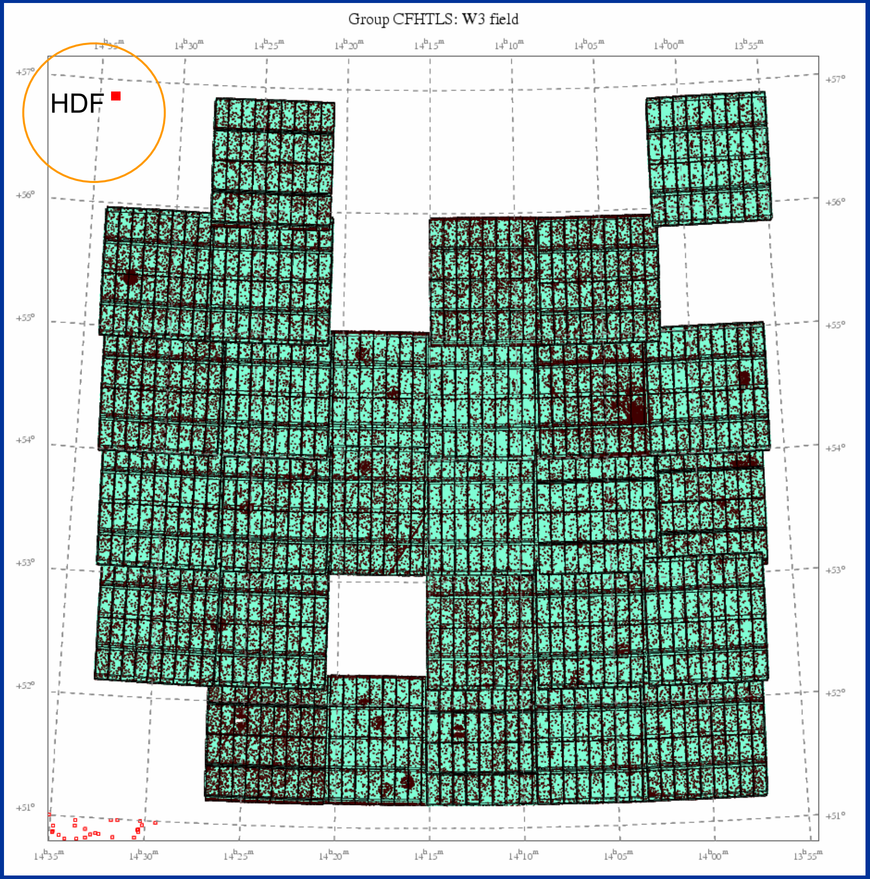
Wide fields include Deep fields

Fu et al 2007

CFHTLS 1.5 yr weak lensing data :

redshift calibrated with one HDF field

- Only one field
- HDF field size: 150000 smaller than total wide

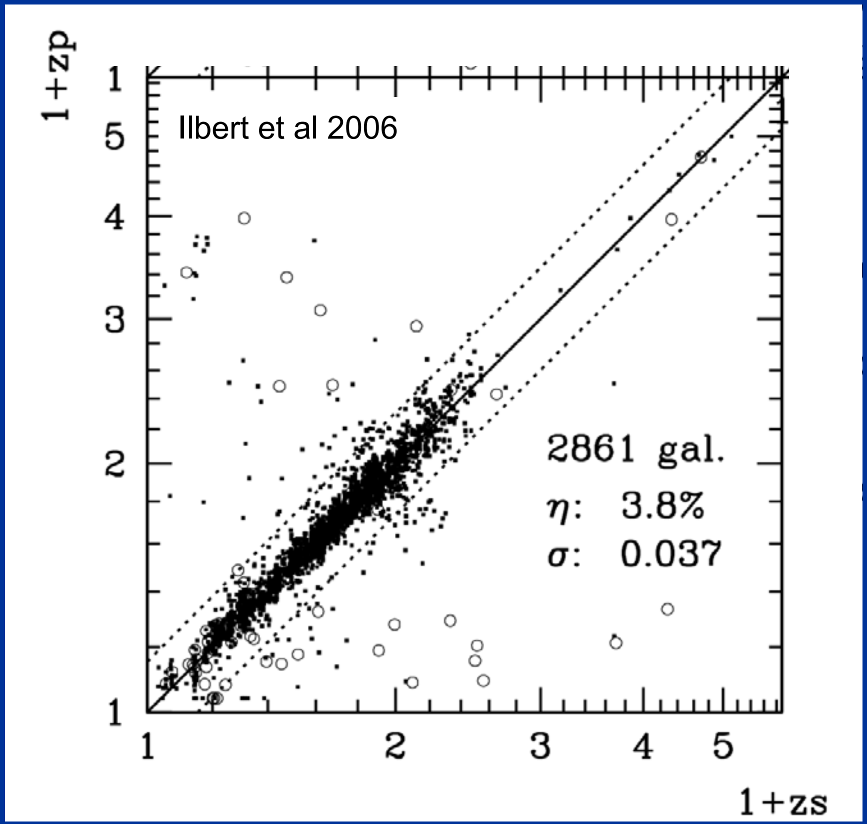


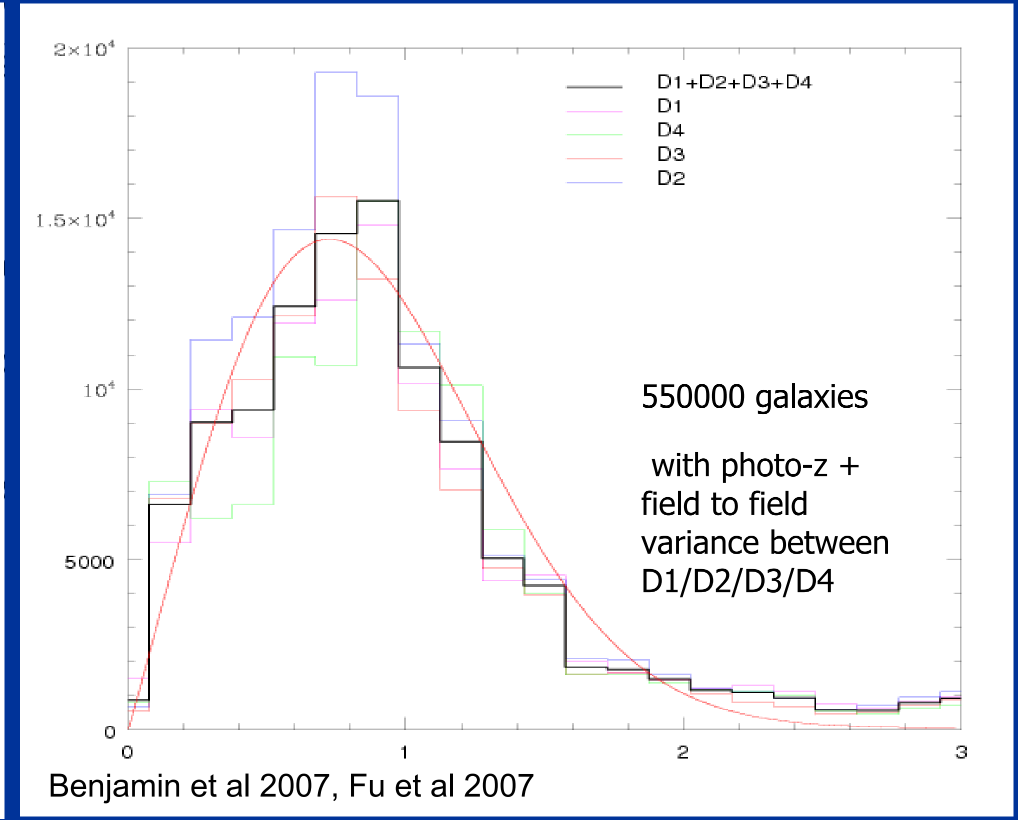
CFHTLS 3 yr weak lensing data :

redshift calibrated with 4 VVDS fields chosen inside the CFHTLS fields

Illustration, not true VVDS field location

CFHTLS calibrated with VVDS spectra





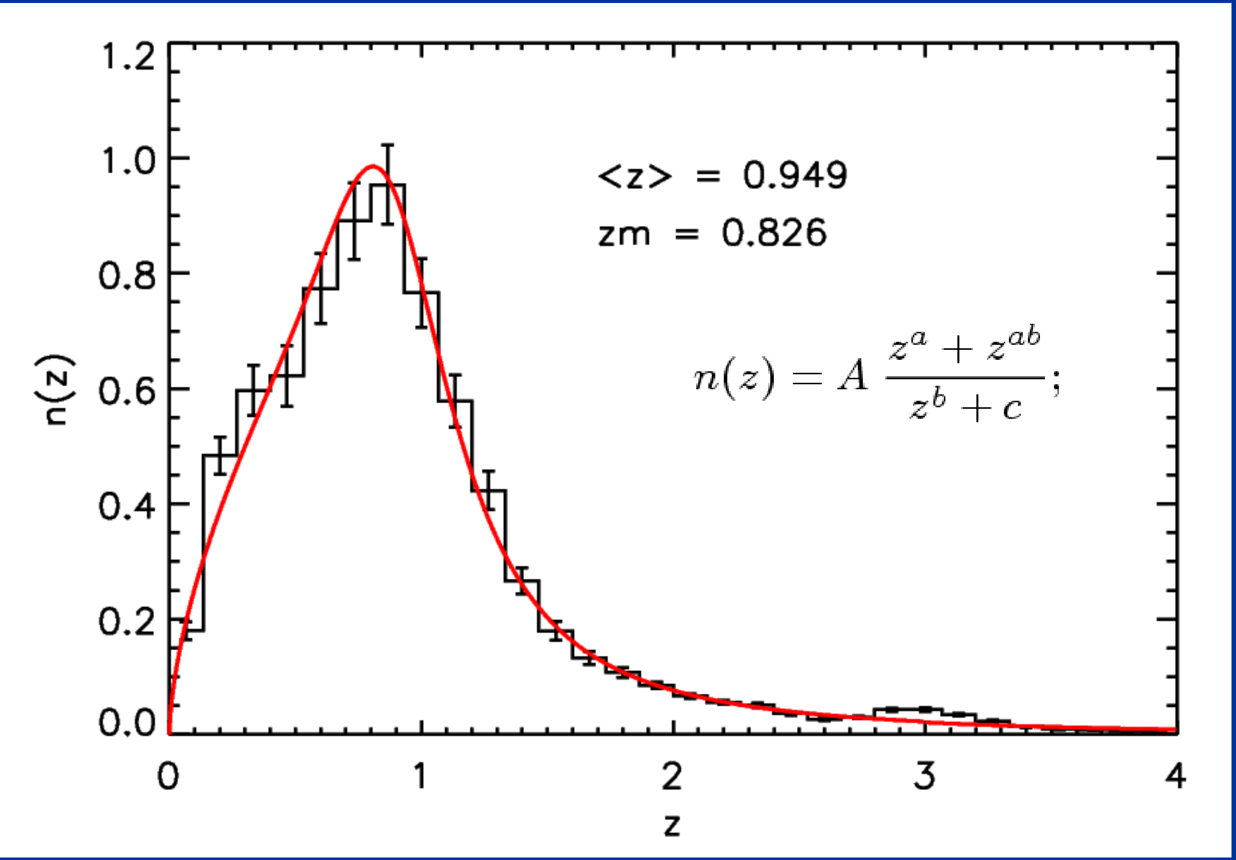
- CFHLTS Deep photometry + VLT / VVDS spectroscopic survey of CFHTLS D1 field (Le Fèvre et al 2005, Ilbert et al 2006) :

wide survey calibrated by internal spectoscopic data

- Accurate redshift distribution, field to field scatter controled, the mean redshift peaks at higher *z* than the HDF *z*-calibration.

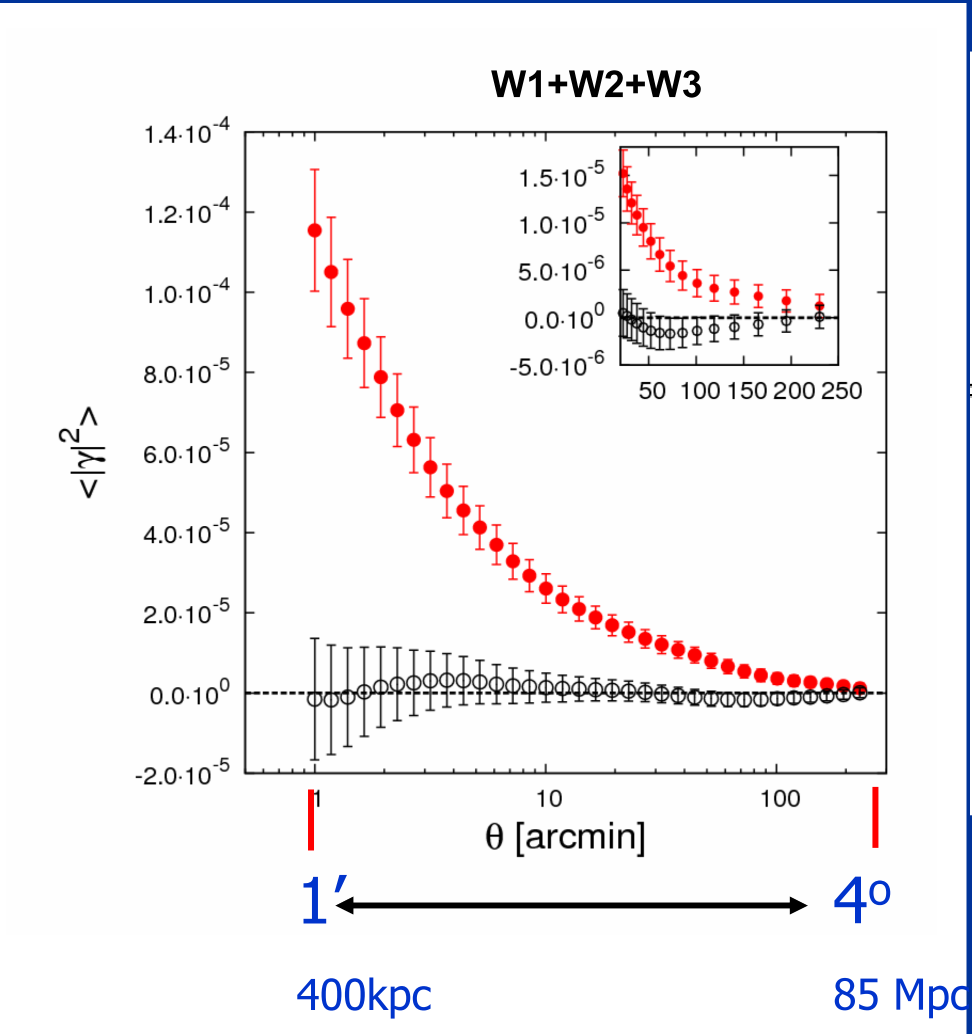
CFHTLS T0003, 3yr:

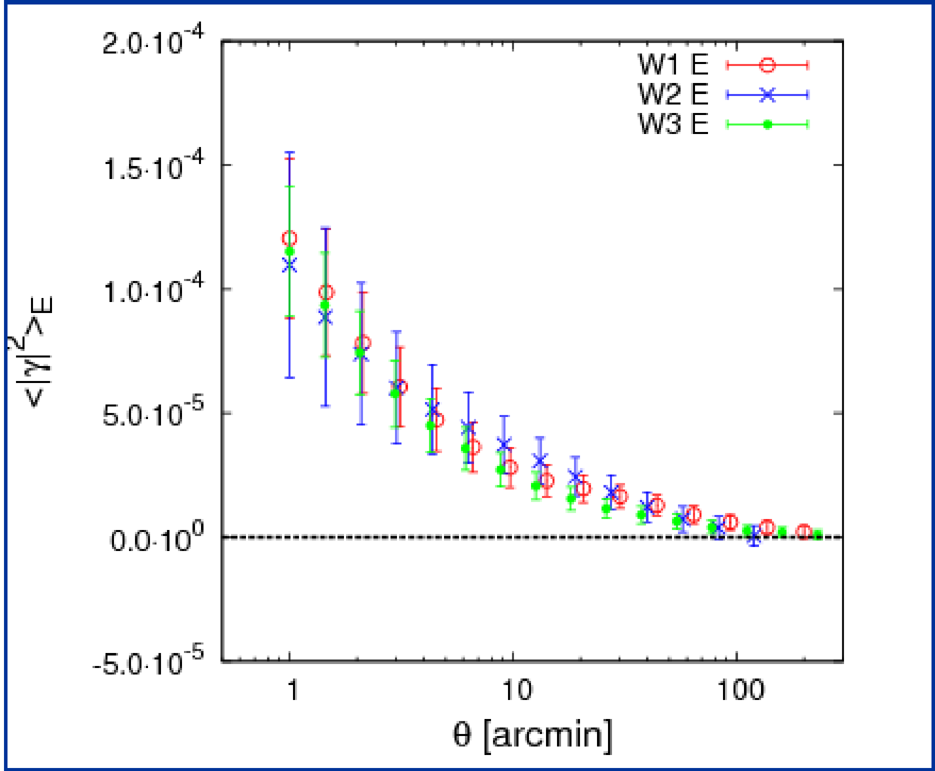
n(z) Wide weighted galaxies selected for weak lensing



Fu et al 2007

CFHTLS T0003 3yr: 3 fields W1, W2, W3
much wider and very large scales covered





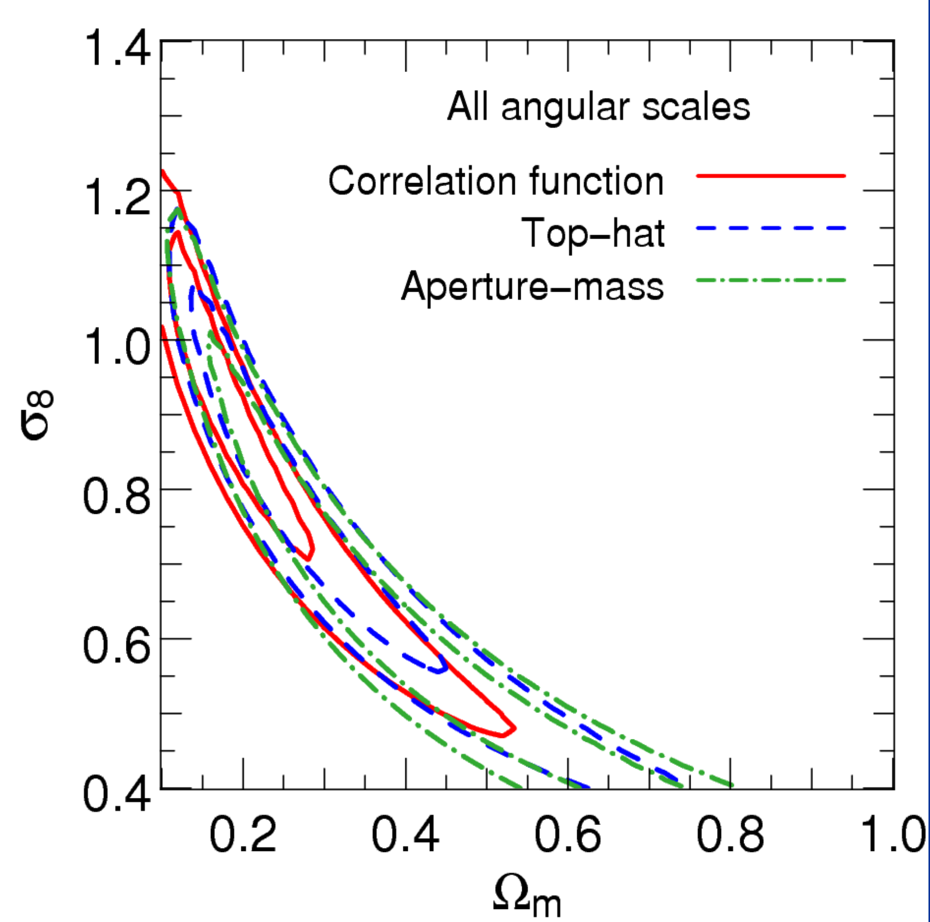
Fu et al 2007

CFHTLS 3yrs :

cosmological interpretation

CFHTLS T0003 3yrs:

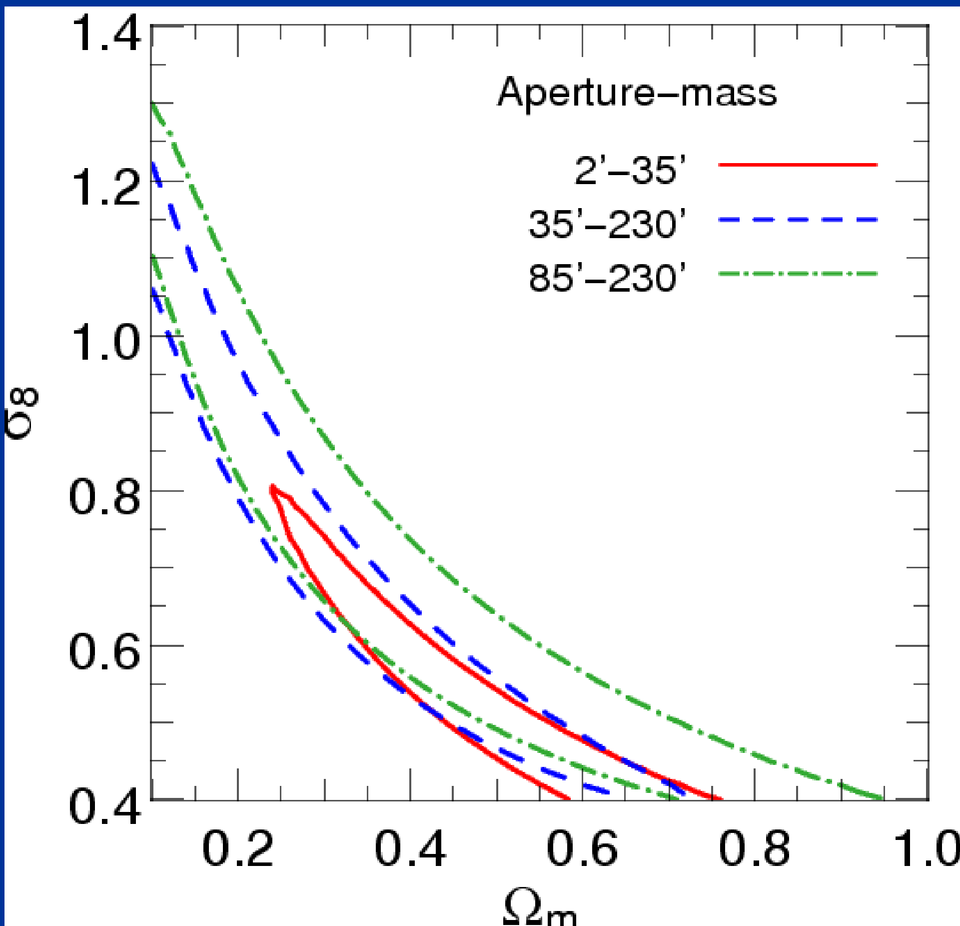
sensitivity to statistics



$$\sigma_8(\Omega_m/0.25)^{0.46} = 0.784 \pm 0.049 \quad \text{for} \quad \xi_E;$$
$$\sigma_8(\Omega_m/0.25)^{0.53} = 0.795 \pm 0.042 \quad \text{for} \quad \langle|\gamma|^2\rangle_E$$
$$\sigma_8(\Omega_m/0.25)^{0.64} = 0.785 \pm 0.043 \quad \text{for} \quad \langle M_{ap}^2\rangle.$$

Fu et al 2007

CFHTLS T0003 3yrs:
sensitivity to scales



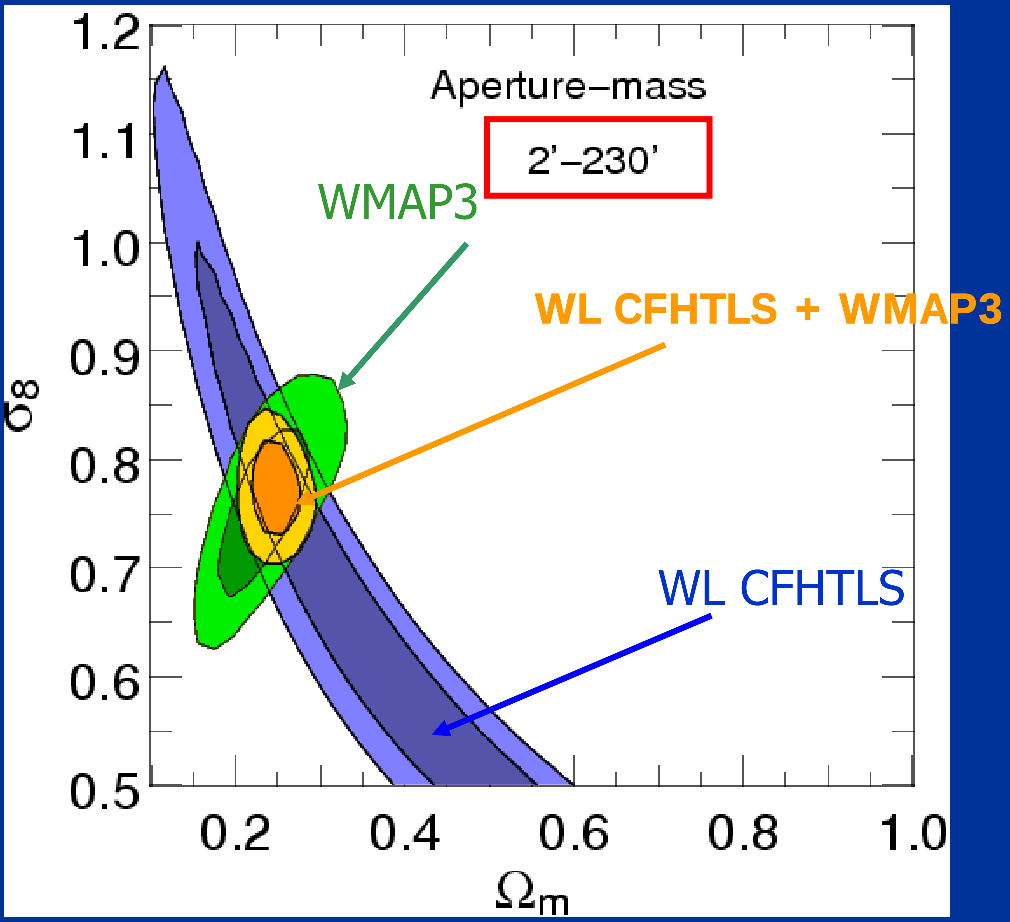
$$\sigma_8(\Omega_m/0.25)^{0.66} = 0.780 \pm 0.044 \quad \text{for} \quad 2' < \theta < 35';$$
$$\sigma_8(\Omega_m/0.25)^{0.54} = 0.780 \pm 0.060 \quad \text{for} \quad 35' < \theta < 230'$$
$$\sigma_8(\Omega_m/0.25)^{0.53} = 0.837 \pm 0.084 \quad \text{for} \quad 85' < \theta < 230'$$

Cosmic shear

at non linear or linear scales

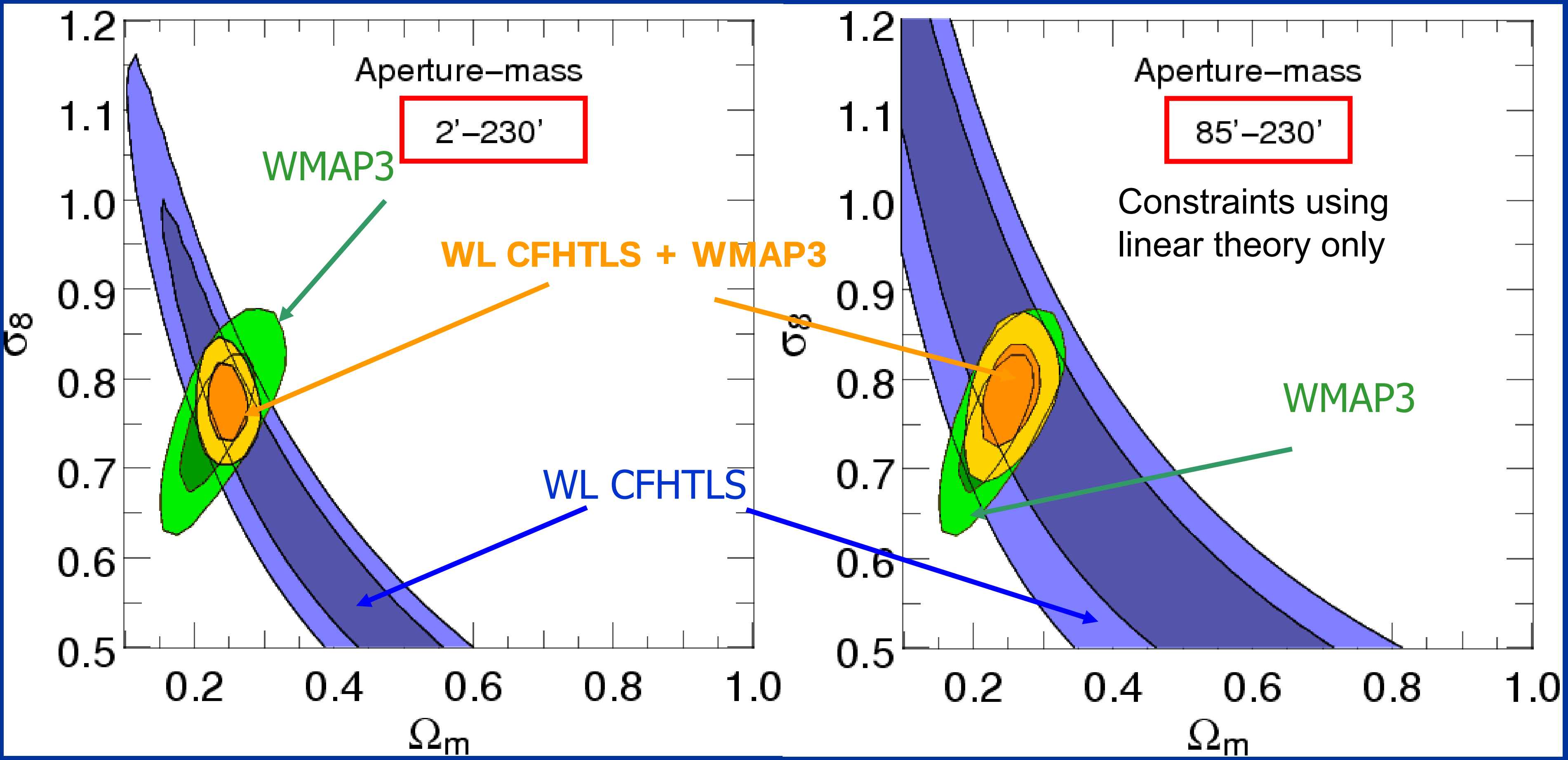
Fu et al 2007

CFHTLS T0003 and WMAP3



Fu et al 2007

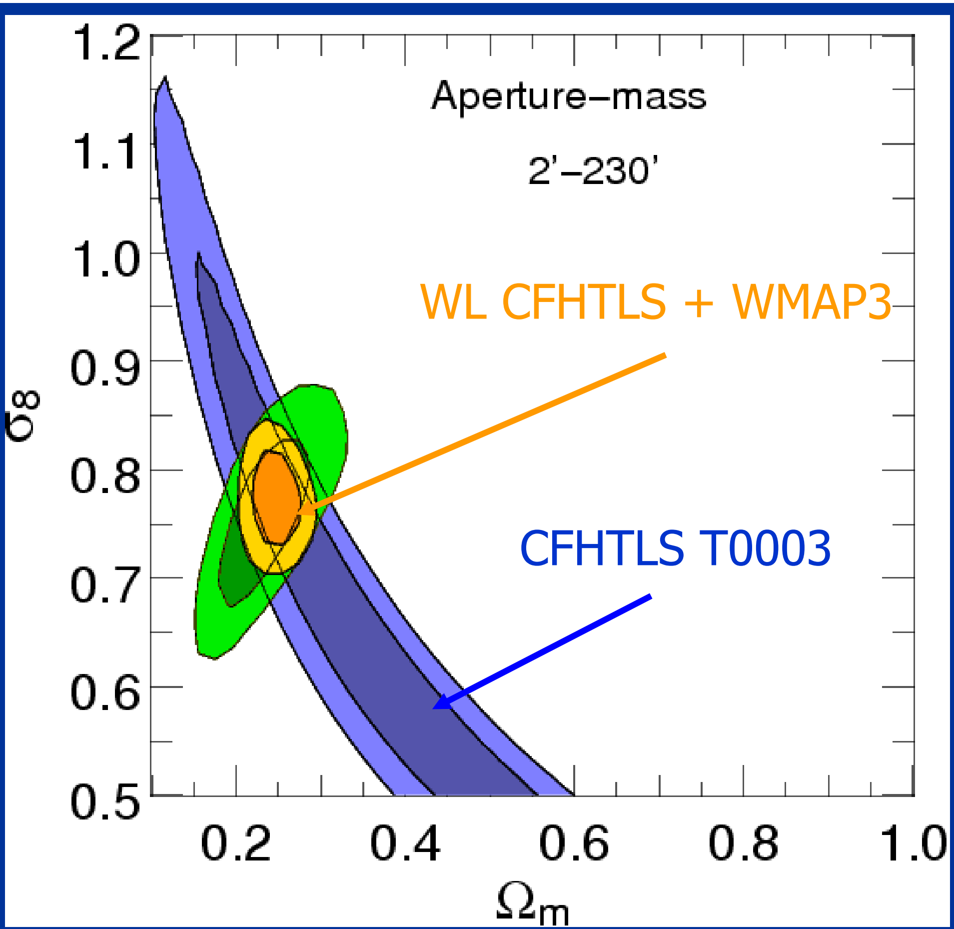
CFHTLS T0003 and WMAP3



Fu et al 2007

CFHTLS T0003 and WMAP3

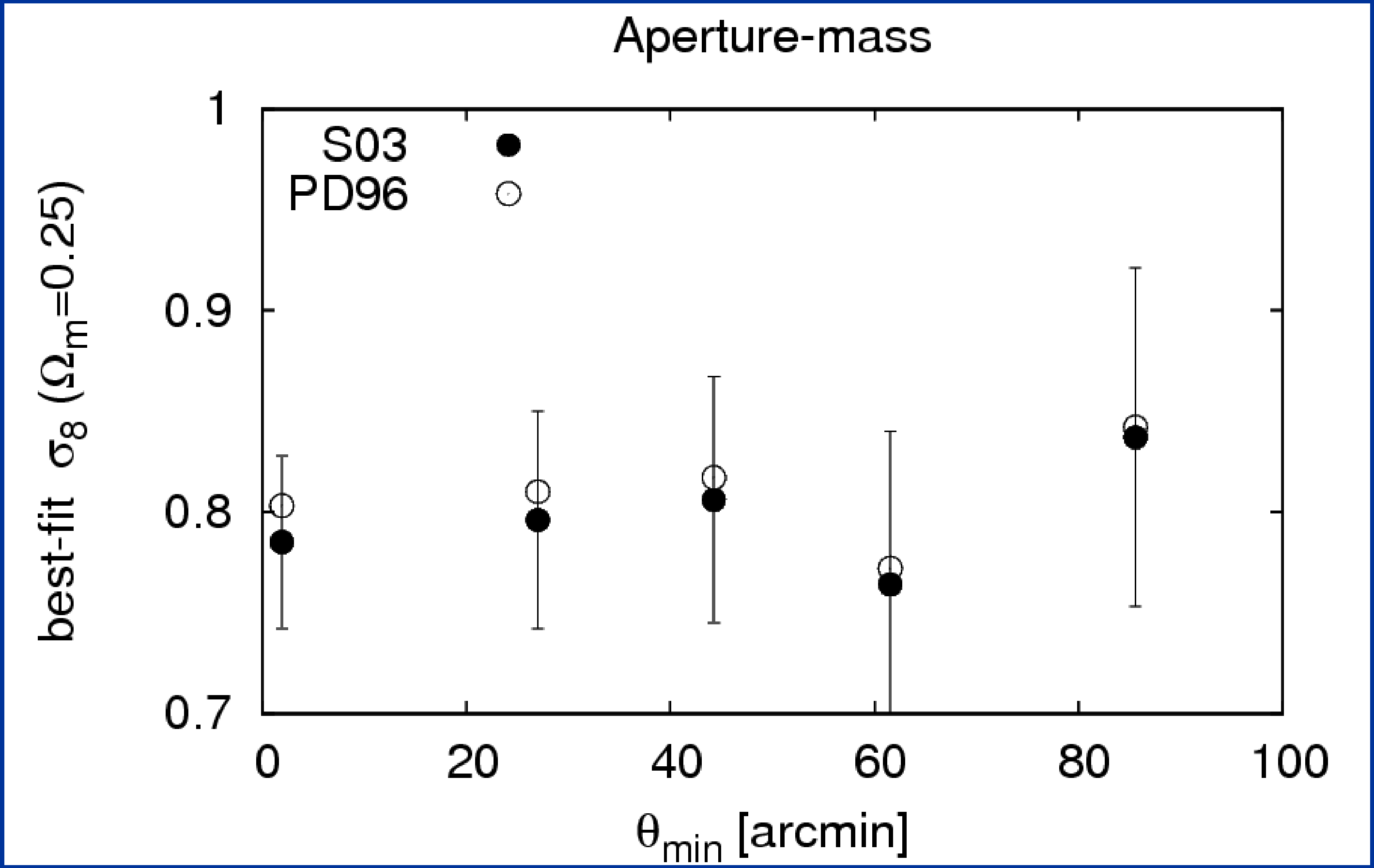
Two-point function	Angular scales	Ω_m	σ_8
ξ_E	$(1' < \theta < 230')$	0.243 ± 0.020	0.771 ± 0.030
$\langle \lvert\gamma\rvert^2 \rangle_E$	$(2' < \theta < 230')$	0.249 ± 0.019	0.776 ± 0.029
$\langle M_{ap}^2 \rangle$	$(2' < \theta < 230')$	0.248 ± 0.019	0.771 ± 0.029
$\langle M_{ap}^2 \rangle$	$(85' < \theta < 230')$	0.255 ± 0.027	0.782 ± 0.038



Fu et al 2007

CFHTLS T0003 3yr:

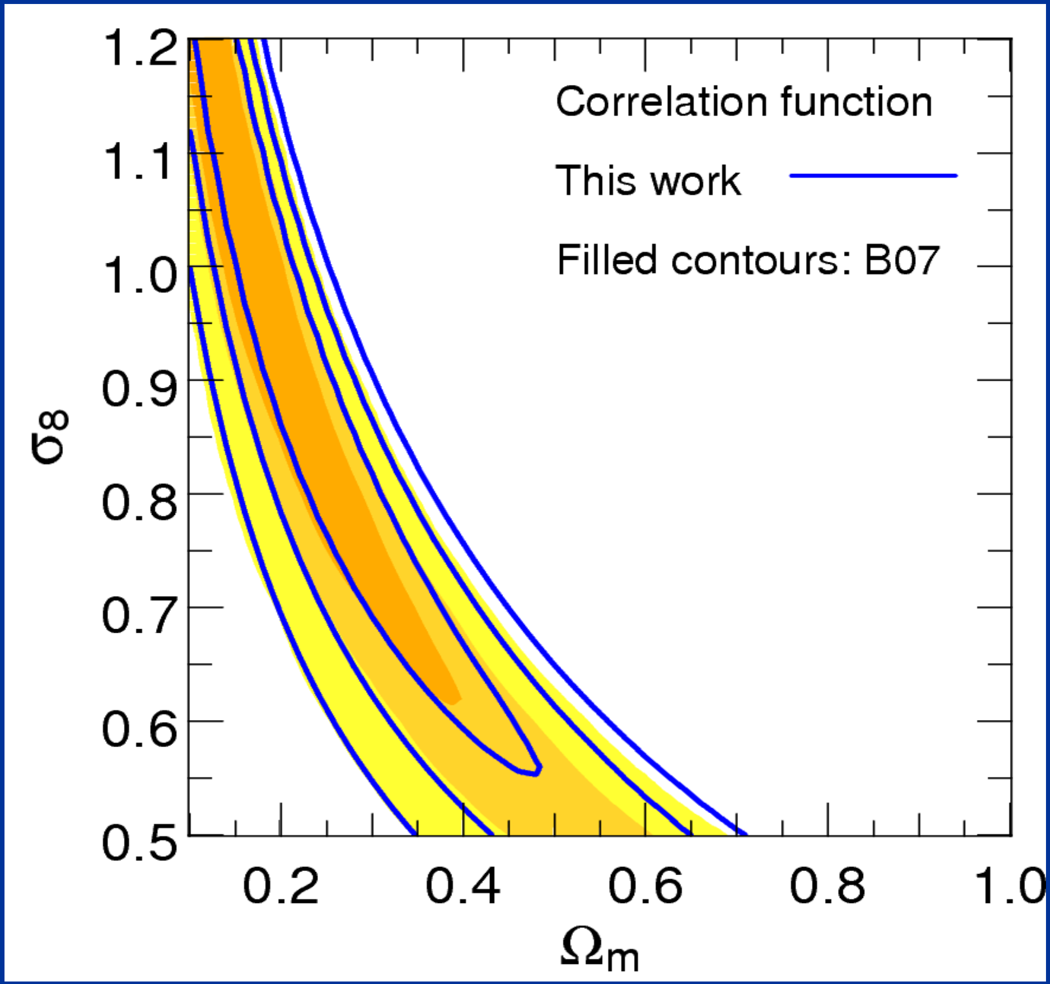
sensitivity to non linear evolution prescription PD vs HaloFit (S03)



Fu et al 2007

CFHTLS T0003 3yr:

Comparison with Benjamin et al 2007 (100 deg^2, 4 surveys merged)



Fu et al 2007

Summary

- New surveys have much better PSF and n(z) calibrations

- Calibrated photo-z with large spectroscopic done inside the fields:
  n(z) = most important issue for the cosmological constraints.
  - VVDS+CFHTLS = ideal
  - COSMOS + z-COSMOS = ideal

- CFHTLS 3yr: a major improvement in cosmic shear surveys (also thanks to STEP)

  - Sky coverage increasing and 3 uncorrelated fields (W4 added in T0004)

  - WL linear : shear up to 4^o = 80 Mpc: weak lensing with linear theory, as CMB

  - Very good and robust contraints on $\Omega_m - \sigma_8$ obtained with WL :
    ~ 7.5% accuracy on Ω_m , ~ 3.5% accuracy on σ_8

  - In excellent agreement with WMAP3 (Spergel et al 2006):

$$\Omega_m = 0.248 \pm 0.019 \quad \sigma_8 = 0.771 \pm 0.029$$