Constraining cosmology with weak-lensing peak statistics

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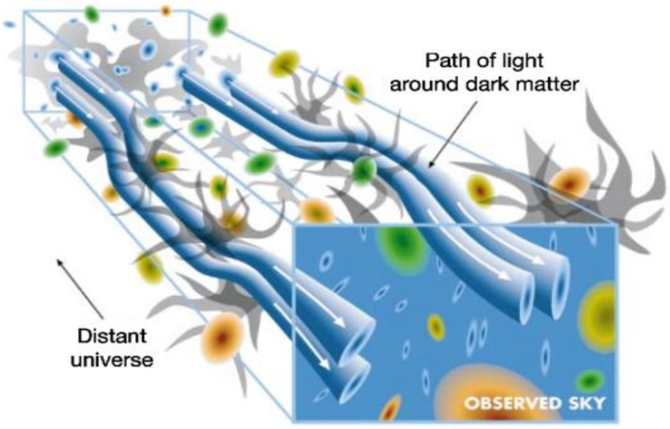
Outline:

- Introduction
- Weak-lensing peak abundances
- Cosmological constraints from observational WL peak abundance analyses
- Summary and discussion

Introduction



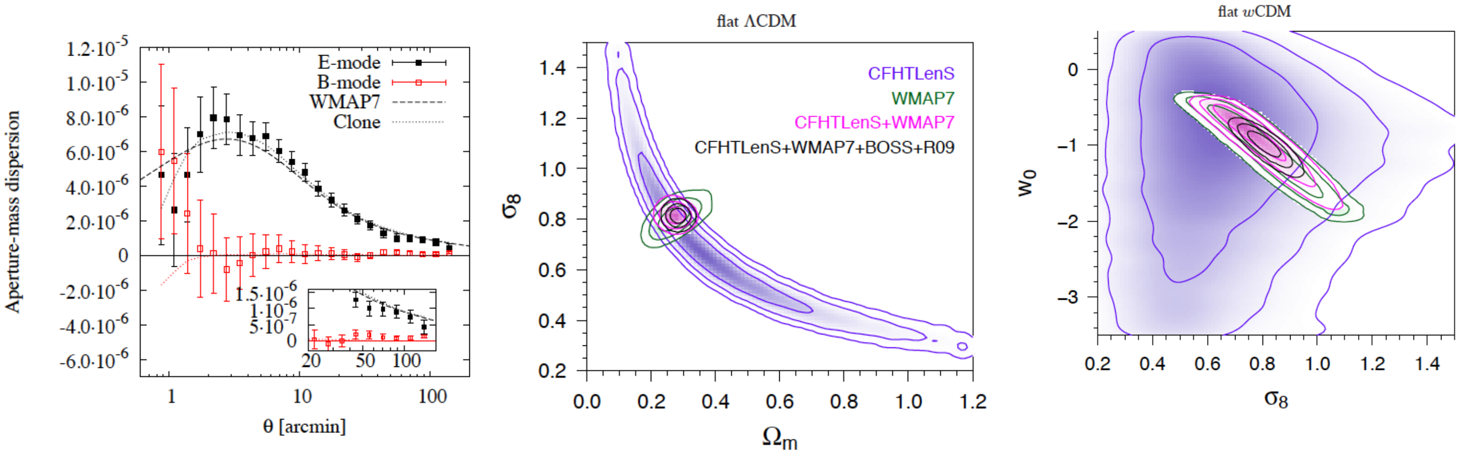
Wittman et al. 2000

Weak lensing effects:

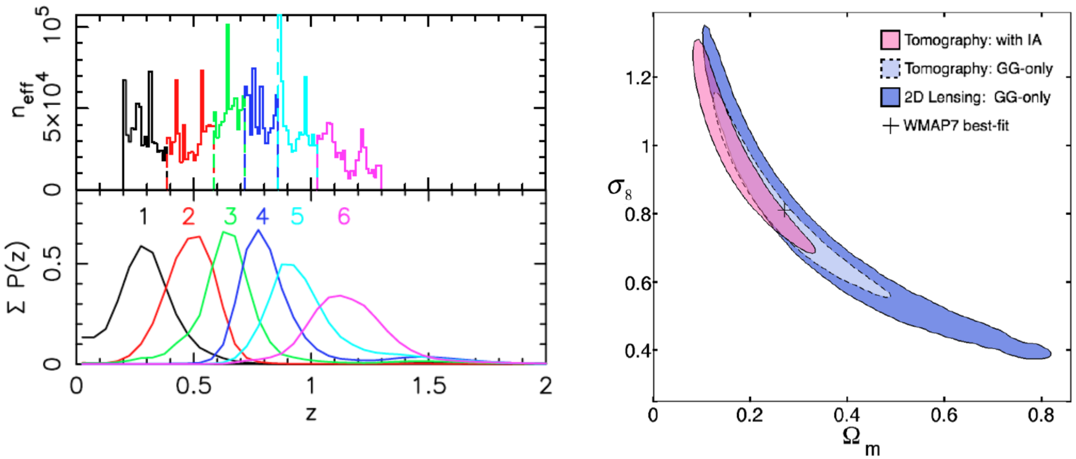
- "see" dark matter directly
  → powerful in probing the distribution of dark matter in the Universe
- sensitive to the formation of large-scale structures and the global geometry of the Universe
  → highly promising in dark energy studies

Weak signals → statistical analyses are necessary
Different statistics can allow us to extract different cosmological information

2-pt shear correlations are the most commonly applied analyses



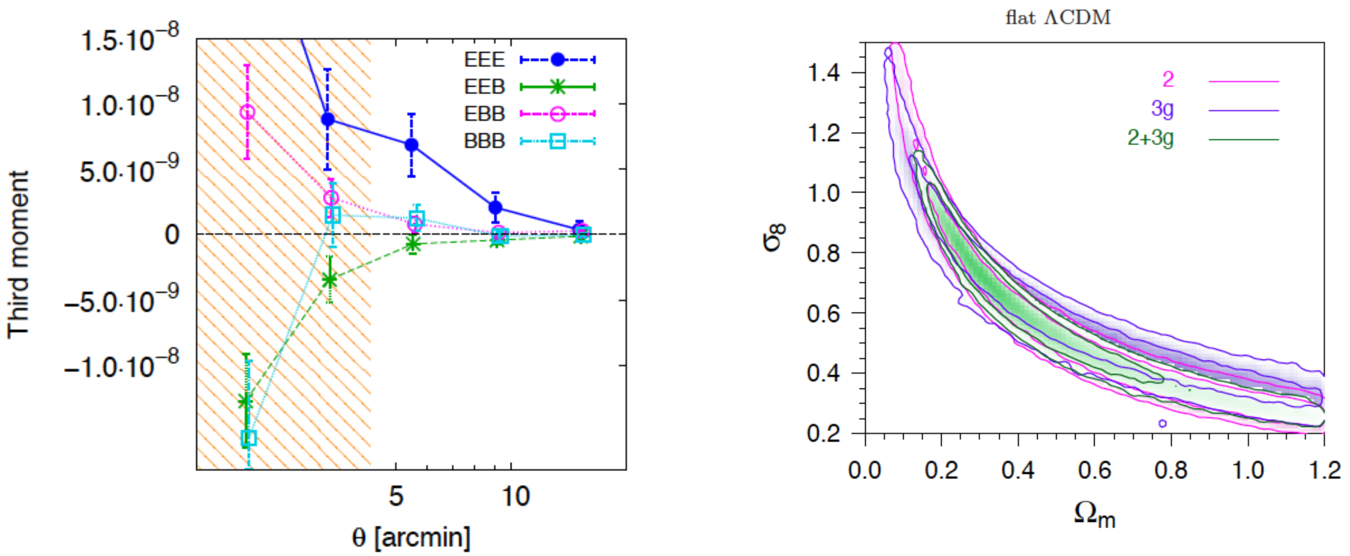
Kilbinger et al. 2013, CFHTLenS



Heymans et al. 2013, CFHTLenS

2-pt correlation analyses contain only part of the information, especially considering the nonlinear structure formation

Higher order correlation studies



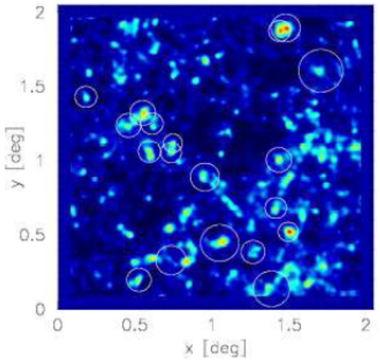
Fu et al. 2014, CFHTLenS

Weak-lensing peak analyses provide another important means

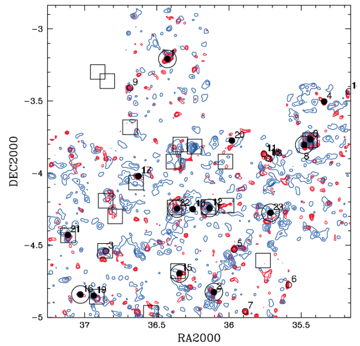
Massive structures, such as clusters of galaxies, are expected to generate high lensing signals and appear as peaks in weak-lensing convergence maps.

→ related to the mass function of dark matter halos and lensing efficiency factor → cosmology sensitive

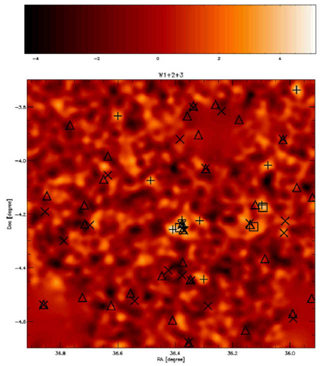
Complications: "false peaks" ← shape noise + LSS projection effects



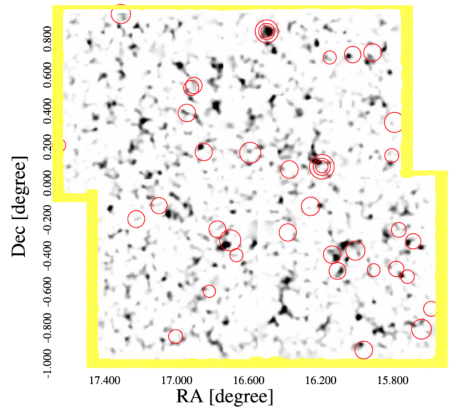
Hamana et al. 2004



Miyazaki et al. 2007

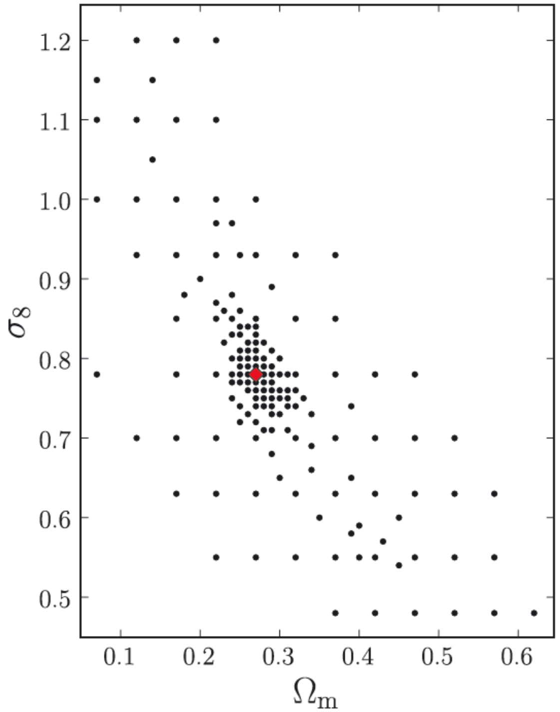


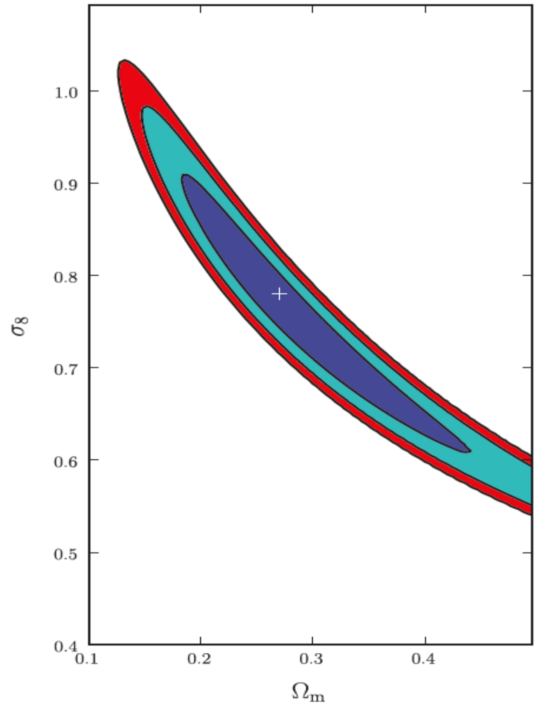
Shan et al. 2012, CFHTLS



Shan et al. 2014, CS82

For cosmological studies, it is not necessary to identify the correspondences between peaks and true clusters of galaxies.





Dietrich & Hartlap 2010

Prediction of cosmological dependence of WL peak abundances

→ computationally efficient enough in order to perform cosmological constraints

Weak-lensing peak abundance

Theoretical model of Fan et al. (2010):
halo+shape noise (dominant contamination)

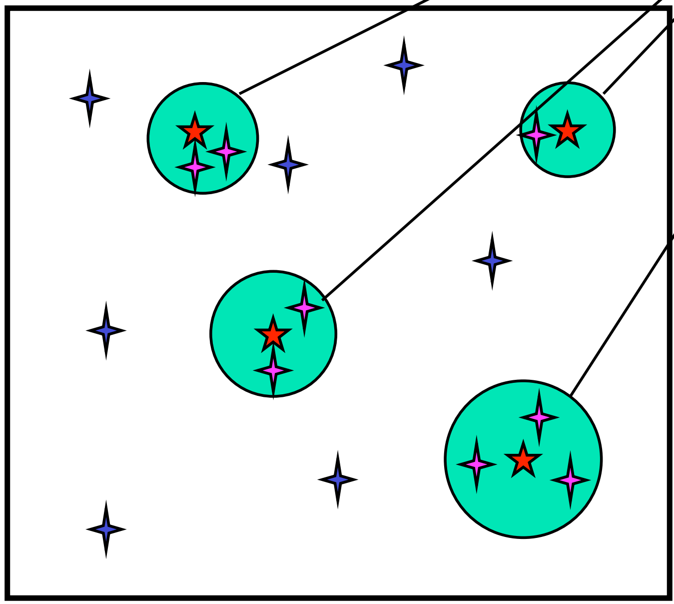
Halo region + field region

$$n^c_{peak}(\nu) = \int dz \frac{dV(z)}{dz d\Omega} \int dM \, \boxed{n(M,z)} \, \boxed{f(\nu, M, z)}$$

$$n_{peak}(\nu) d\nu = n^c_{peak}(\nu) d\nu + n^n_{peak}(\nu) d\nu$$

$$f(\nu, M, z) = \int_0^{R_{vir}} dR \, (2\pi R) \, n_{peak}(\nu, M, z)$$

$$n^n_{peak}(\nu) = \frac{1}{d\Omega}\left\{ n_{ran}(\nu) \left[d\Omega - \int dz \frac{dV(z)}{dz} \int dM \, n(M,z) \, (\pi R^2_{vir}) \right] \right\}$$

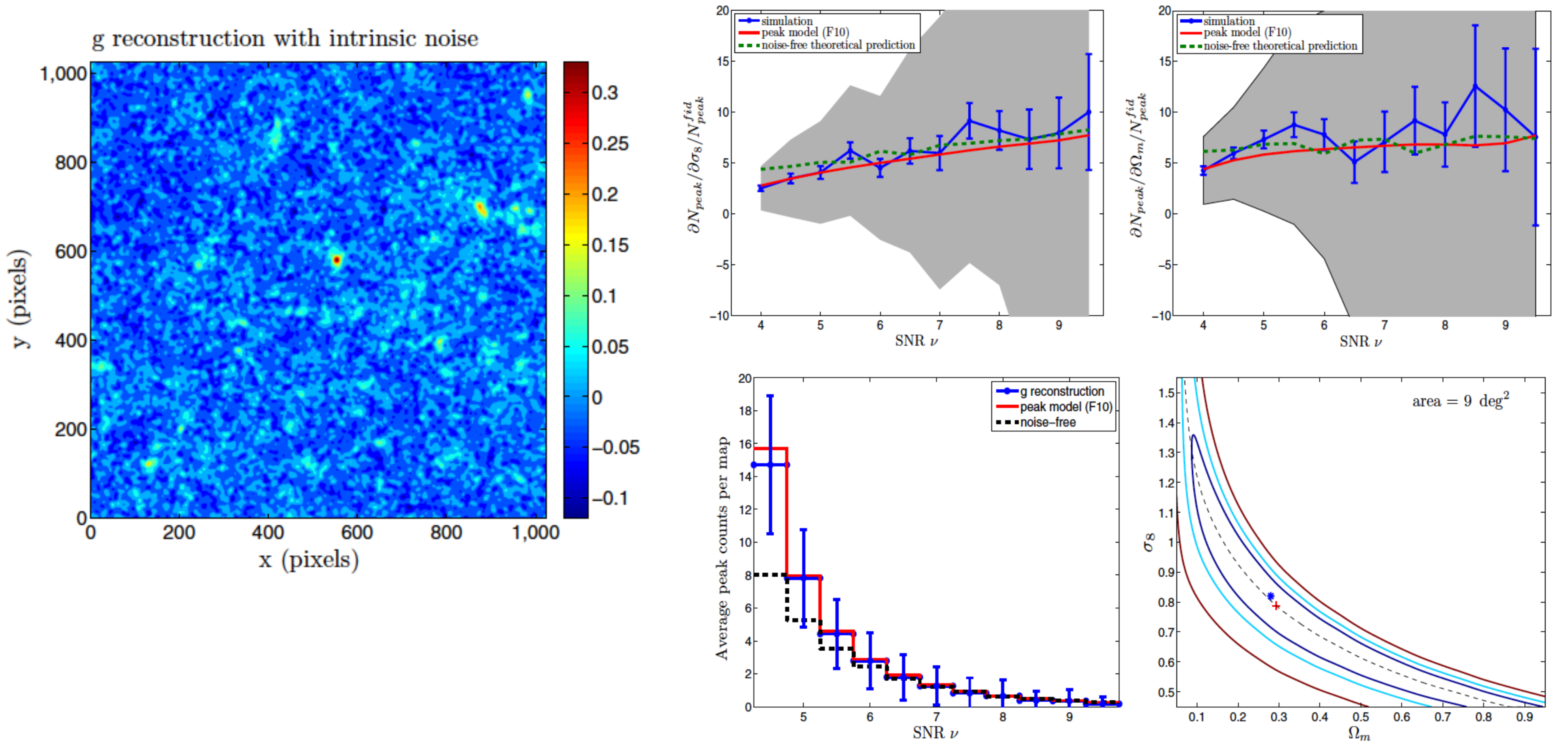


Halo region:

** Halo peak is affected by noise
** Number of noise peaks is
enhanced by halo mass distribution

* Unlike some other models, we do not need to group peaks together, and therefore can avoid possible artificial effects
* The dependence on halo profiles → possibility to constrain the profile parameters simultaneously with cosmological parameters
* Applicable to high peaks: LSS effects, lower halo mass cut in the model calculation ($10^{13.8}\ h^{-1}\ M_{sun}$)

We have done extensive simulation tests (Liu et al. 2014)



** The current model does not include the LSS projection effects, and the intrinsic non-sphericity and profile dispersion of halos. We are working on further improving the model.

** For current WL surveys, such as CFHTLenS and CS82, the shape noise dominates (effective number density $n_g <\sim 10 arc\min^{-2}$). We expect that the model should work well within the statistical error ranges.

** We develop a fast model calculation algorithm, which makes it possible to perform cosmological constraints from WL peak abundances

We are grateful for the access of the computing facilities at Shanghai Normal University and of Laohu at NAOC

Cosmological constraints

CFHTLenS

Erben et al. 2013

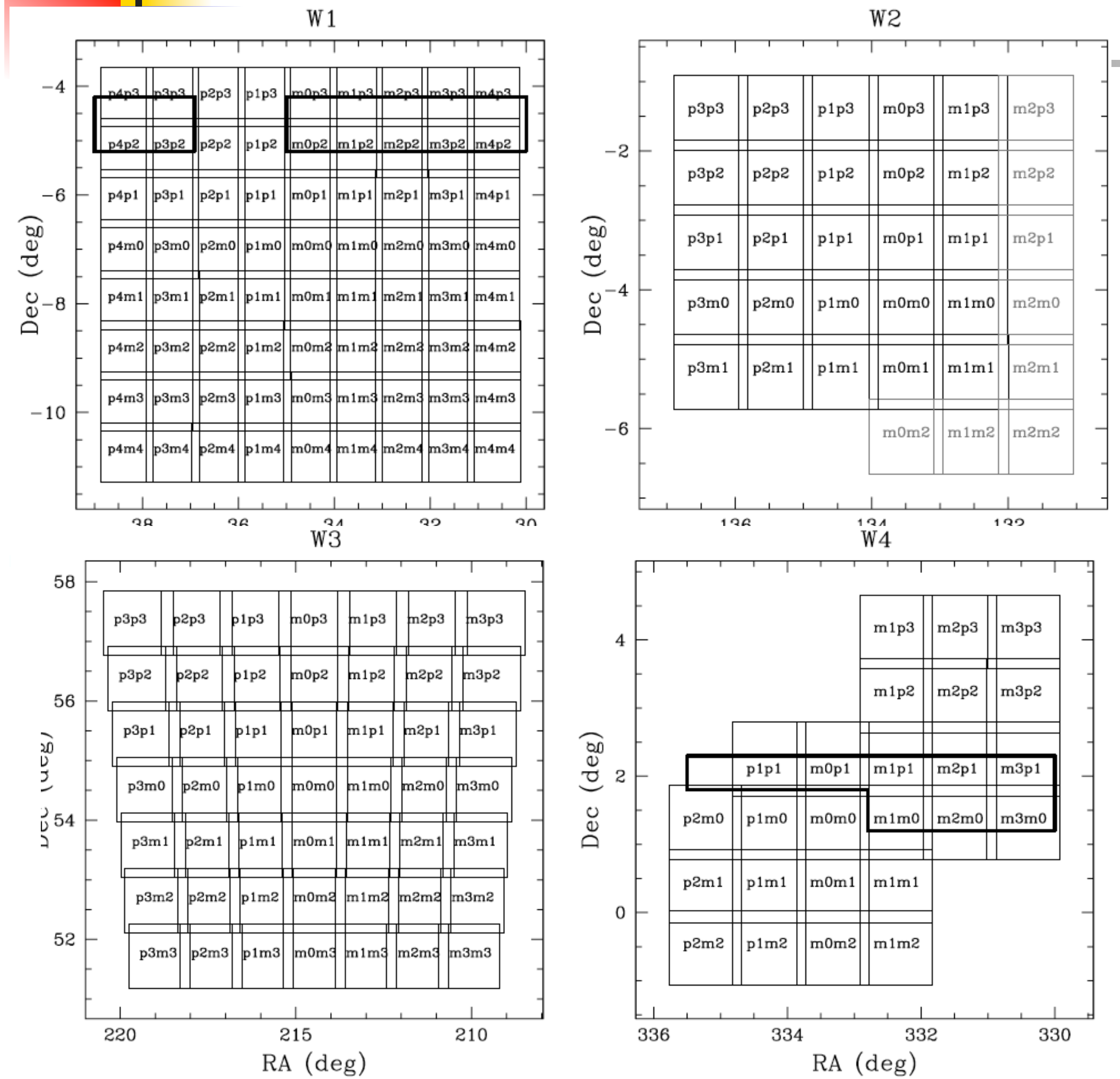
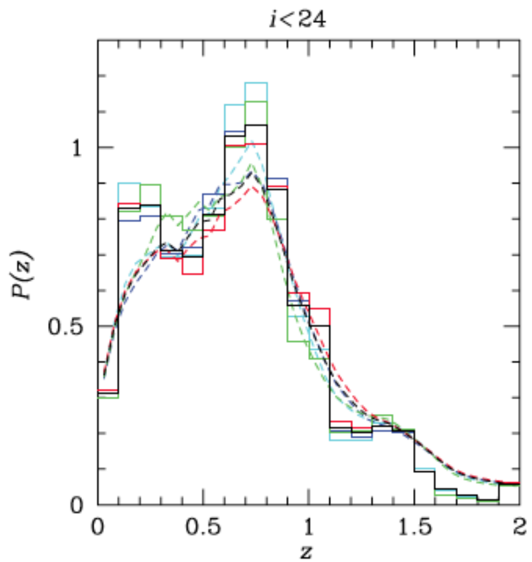


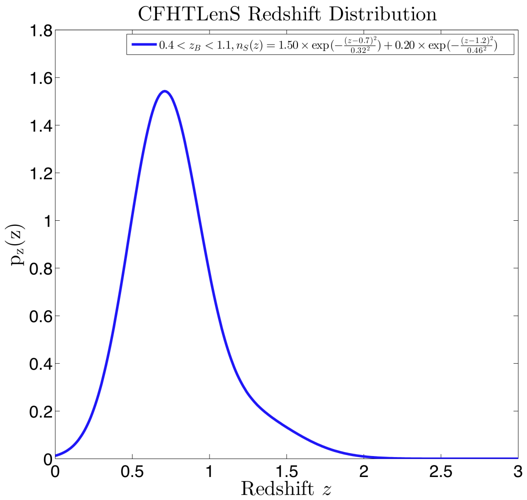
Table 1. Characteristics of the final CFHTLenS co-added science data (see the text for an explanation of the columns).

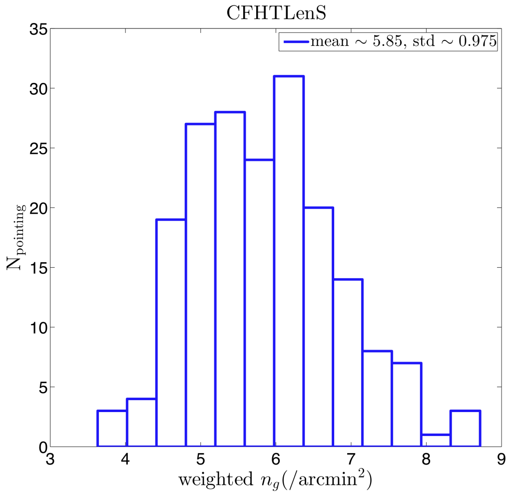
Filter	expos. time [s]	$m_{\rm lim}$ [AB mag] 5-σ lim. mag. in a 2.″0 aperture	seeing [″]
u^* ($u.MP9301$)	5×600 (3000)	25.24 ± 0.17	0.88 ± 0.11
g' ($g.MP9401$)	5×500 (2500)	25.58 ± 0.15	0.82 ± 0.10
r' ($r.MP9601$)	4×500 (2000)	24.88 ± 0.16	0.72 ± 0.09
i' ($i.MP9701$)	7×615 (4305)	24.54 ± 0.19	0.68 ± 0.11
y' ($i.MP9702$)	7×615 (4305)	24.71 ± 0.13	0.62 ± 0.09
z' ($z.MP9801$)	6×600 (3600)	23.46 ± 0.20	0.70 ± 0.12

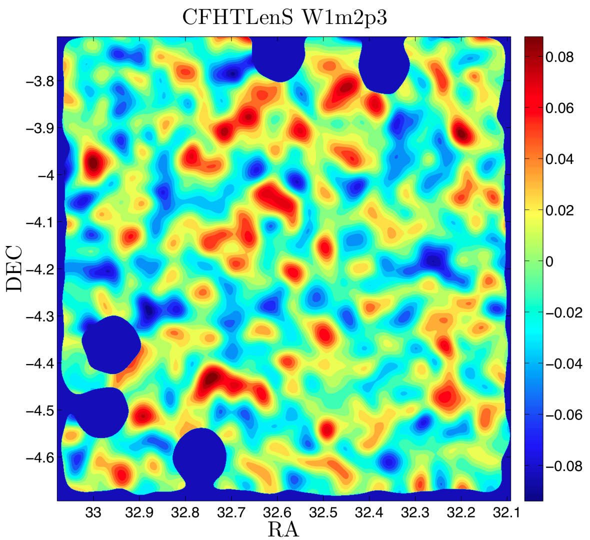
Hildebrandt et al. 2012

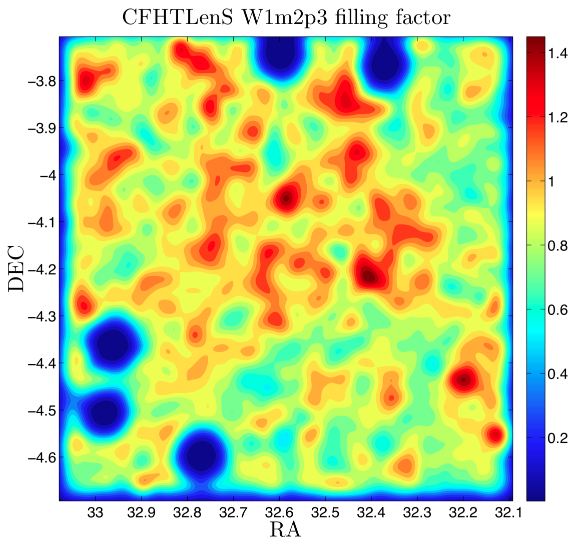


For peak analyses, we follow van Waerbeke et al. (2013) to select background galaxies







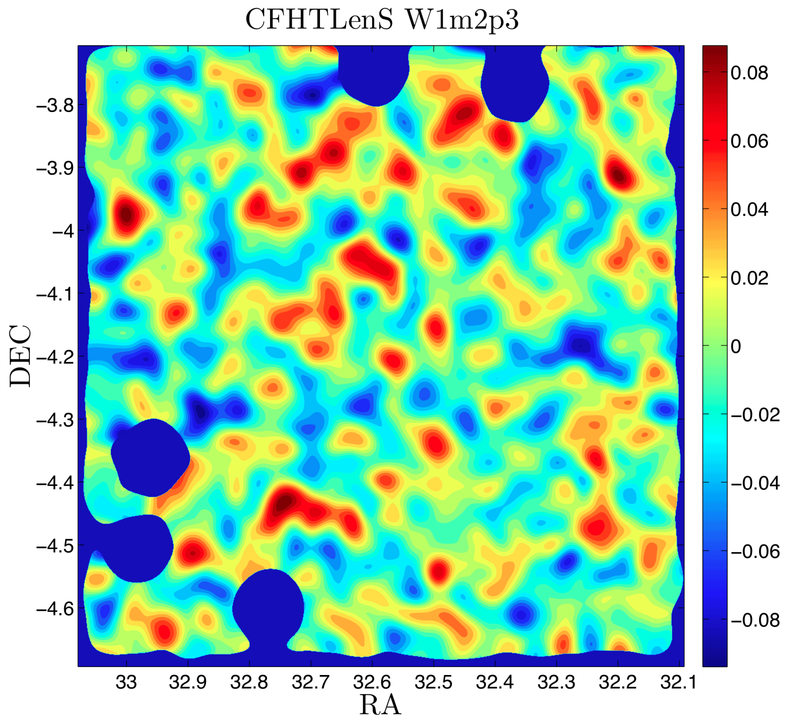


Reconstructed convergence

Galaxy filling factor

Counting peaks in regions with the filling factor >0.5 →122 deg^2
(van Waerbeke et a. 2013, Liu et al. 2014)

Gaussian smoothing with the smoothing scale 1.5 arcmin
nonlinear reconstruction with iterations



Covariance matrix is estimated using bootstrap analyses

Parameter fitting (CosmoMC):

$$\chi^2_{p'} = dN^{(p')}(\widehat{C^{-1}})dN^{(p')} = \sum_{ij=1,\dots,11} dN_i^{(p')}(\widehat{C_{ij}^{-1}})dN_j^{(p')}$$

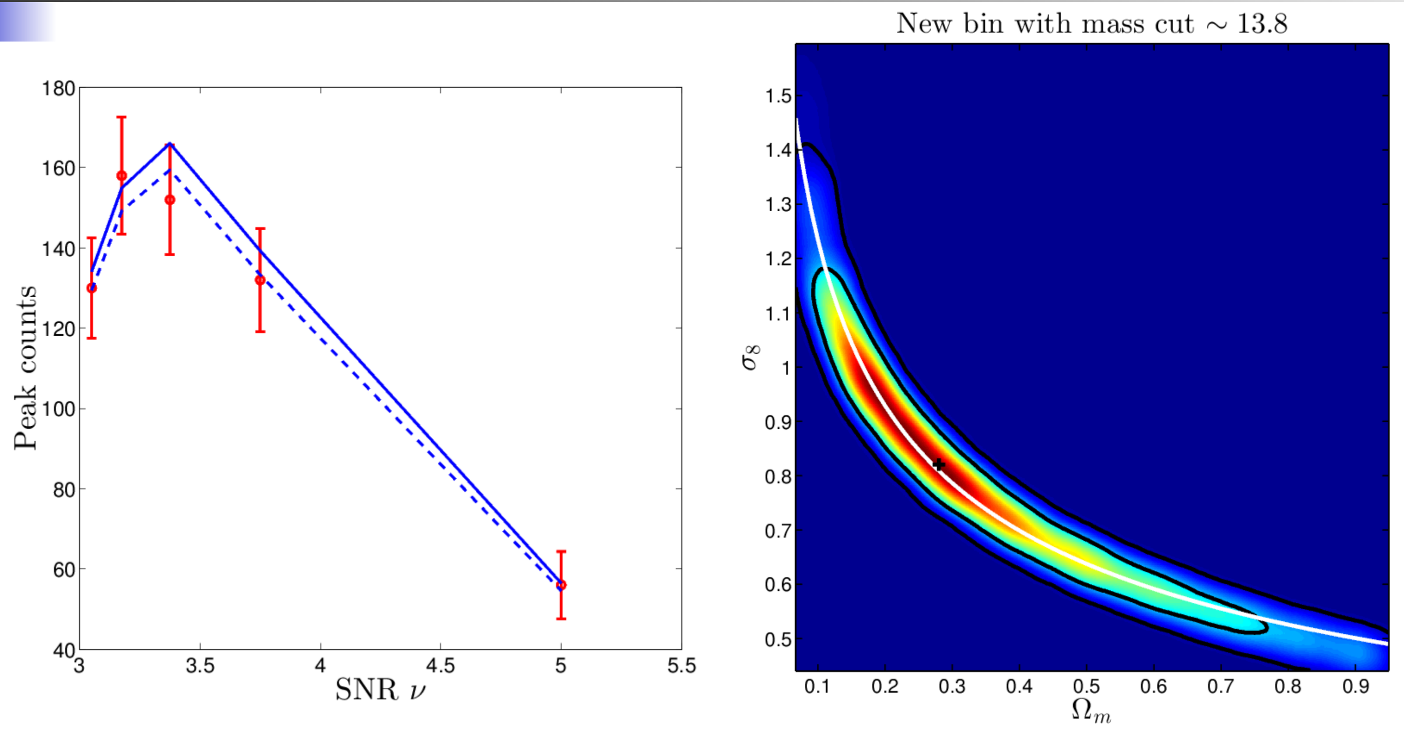
$$dN_i^{(p')} = N_{\text{peak}}^{(p')}(\nu_i) - N_{\text{peak}}^{(d)}(\nu_i)$$

Flat prior: $\Omega_m \in [0.05, 0.95]$

$\sigma_8 \in [0.45, 1.55]$

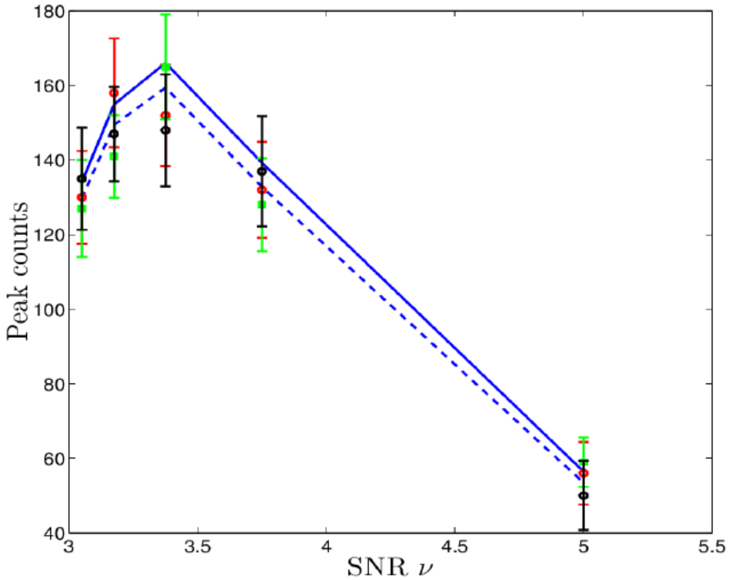
Using ray-tracing simulation to generate mock CFHTLenS data for test

peak binning: unequal bins so that the peak number in different bins are comparable

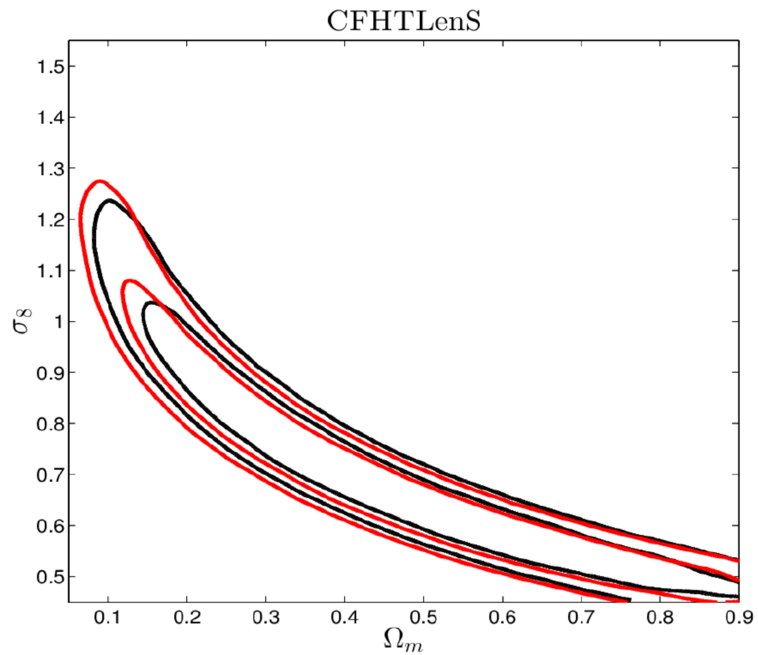


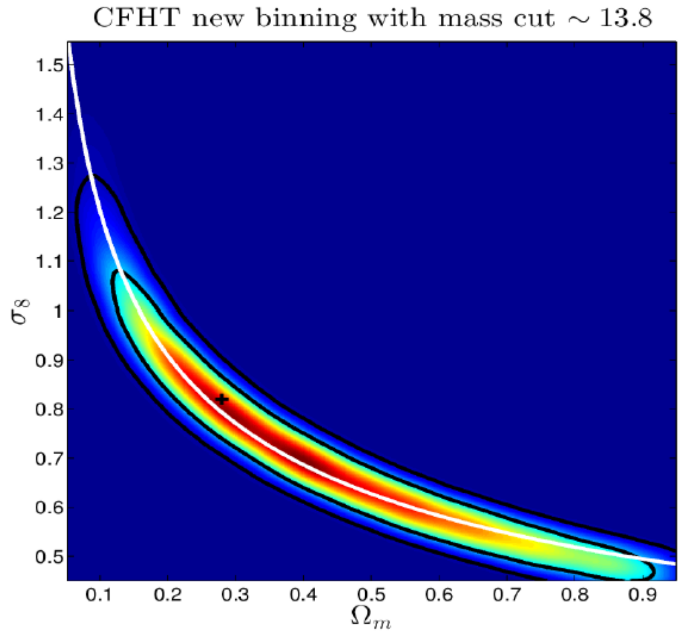
Also tried equal bins, the results are consistent

Real CFHTLenS data (black – data, others – mocks)



Different binning



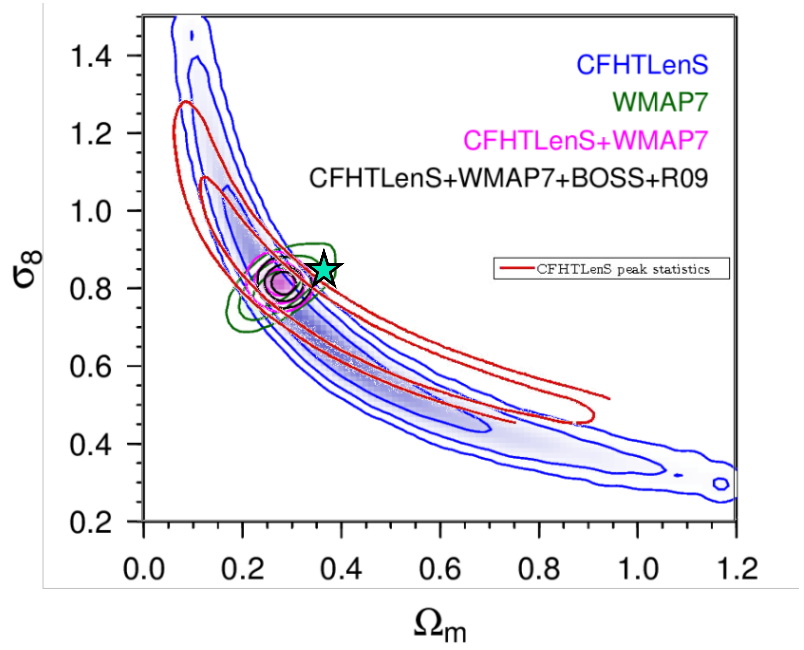


The constraints on (Ω_m, σ_8) are strongly degenerate

$$\Sigma_8 = \sigma_8(\Omega_m/0.27)^{\alpha} \qquad \alpha = 0.405 \pm 0.036, \quad \Sigma_8 = 0.805 \pm 0.017$$

Comparing with the 2-pt correlation analyses

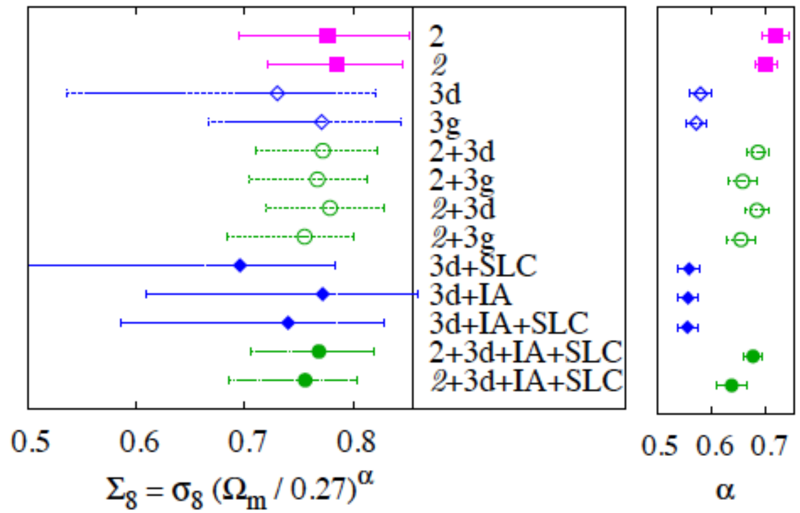
Kilbinger et al. 2013



$$\Sigma_8 = \sigma_8(\Omega_m/0.27)^{0.6} = 0.79 \pm 0.03$$

Parameter	flat ΛCDM	flat wCDM	curved ΛCDM	curved wCDM
$\sigma_8\ (\Omega_m/0.27)^{\alpha}$	0.79 ± 0.03	$0.79^{+0.07}_{-0.06}$	$0.80^{+0.05}_{-0.07}$	$0.82^{+0.05}_{-0.07}$
α	0.59 ± 0.02	0.59 ± 0.03	0.61 ± 0.02	0.61 ± 0.03

Fu et al. 2014



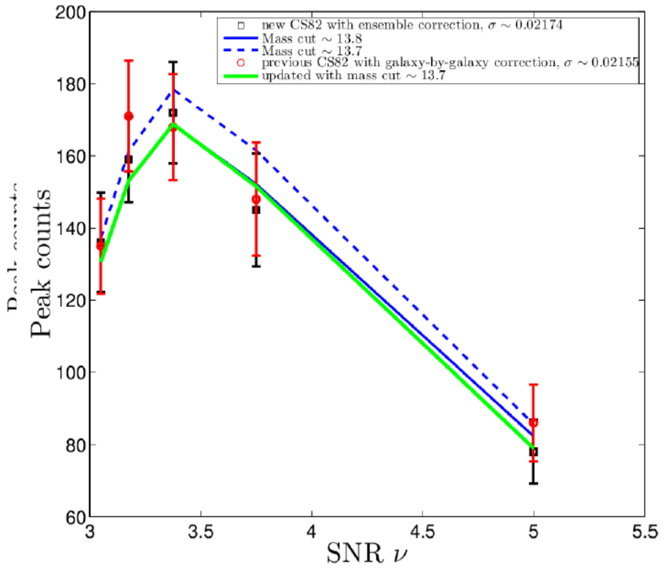
The degeneracy direction is much flatter
→complementary to correlation analyses
** full covariance

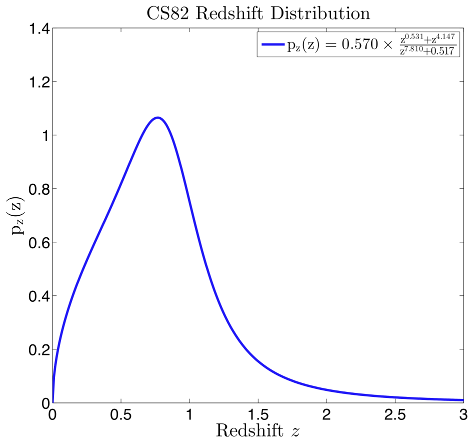
* The constraints from the peak abundance analyses are fully consistent with the results from correlation analyses

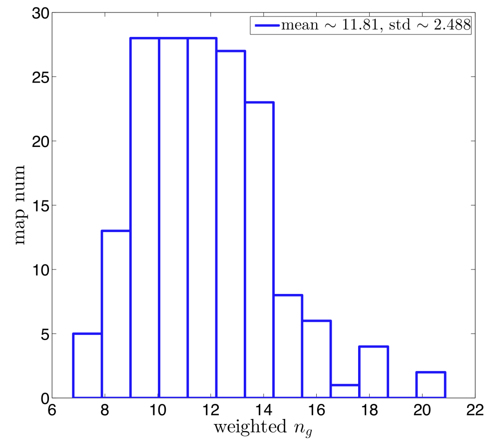
* The constraints are fully consistent with the current best model

* Flatter degeneracy direction between (Ω_m, σ_8) is obtained
  → important and complementary information

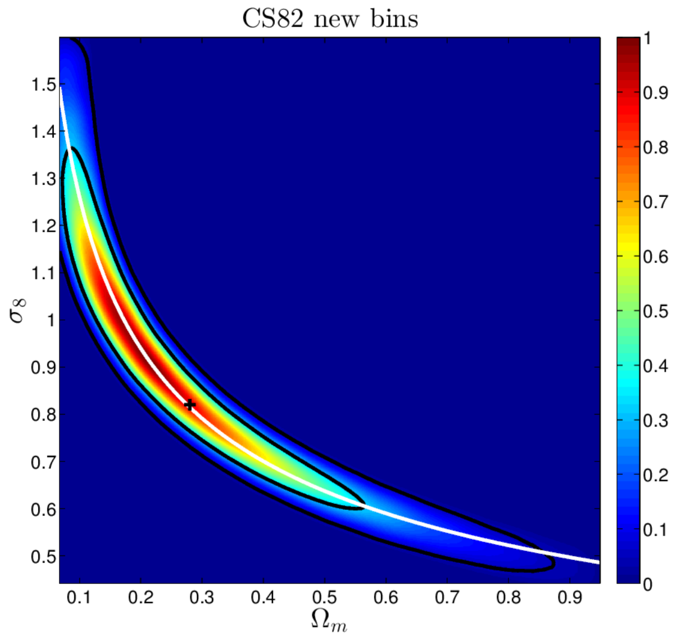
CS82 survey data: higher effective number density of galaxies (redshift distribution from luminosity calibrated ones)

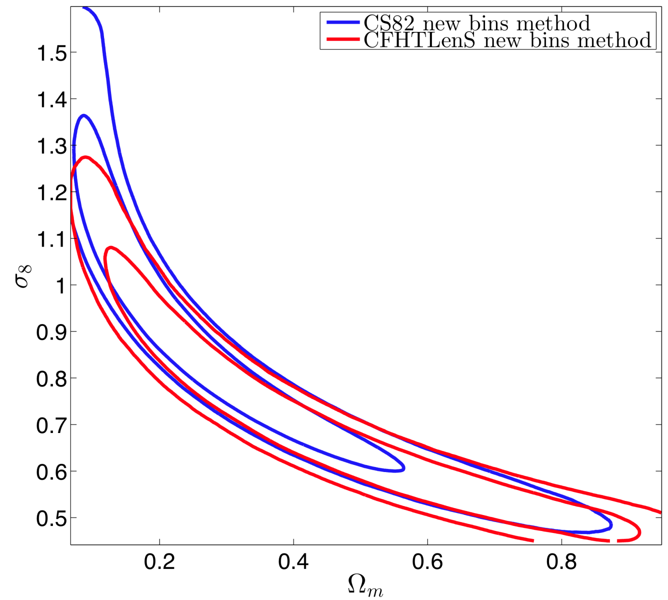






Comparison with CFHTLenS results



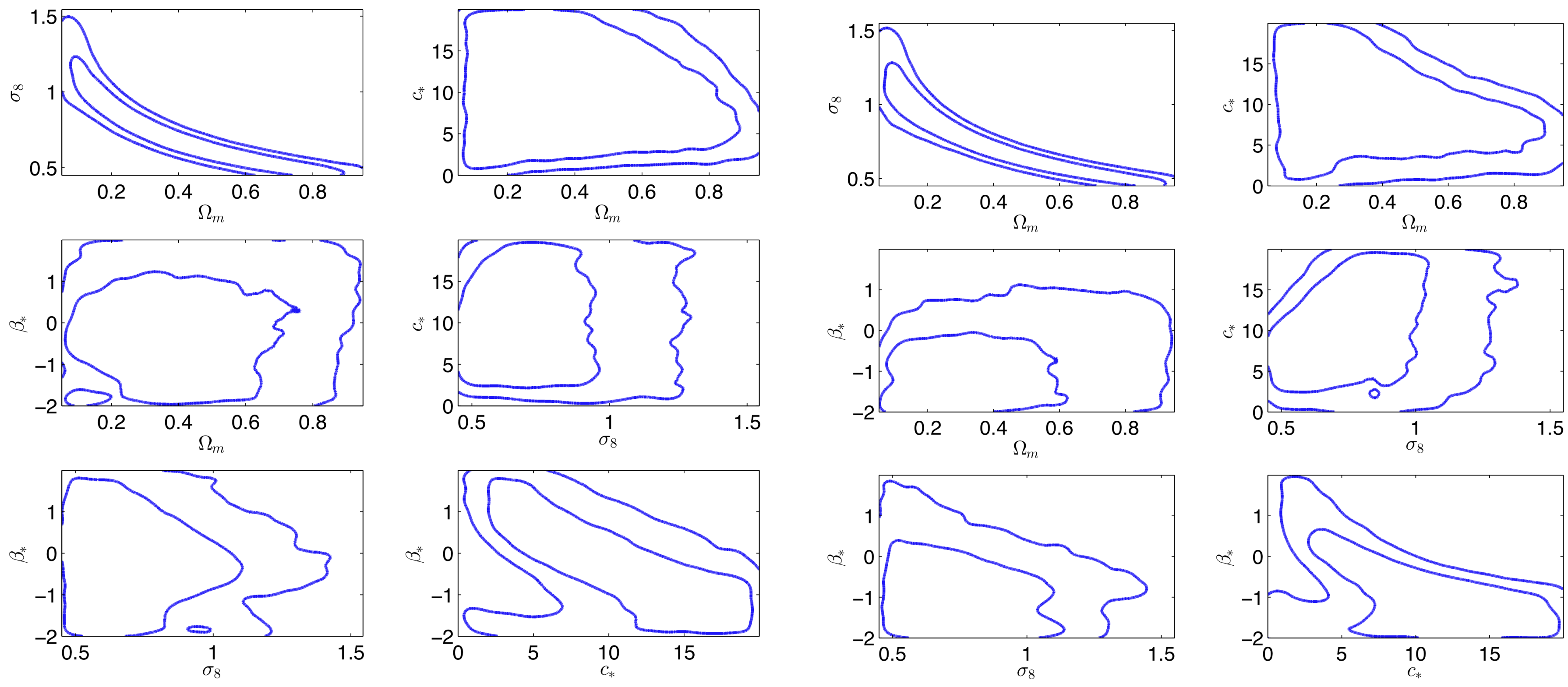


CS82 survey data

Four parameter constraints (Ω_m, σ_8) and (c_*, β) $\quad c = c_* / (1+z)(M/M_{14})^{-\beta}$

Flat priors: $\Omega_m \in [0.05, 0.95]$ $\quad c_* \in [0., 20.]$

$\sigma_8 \in [0.45, 1.55]$ $\quad \beta \in [-1., 1.]$



CS82 mock

CS82 data

Summary and discussion

- First cosmological constraints from observational WL peak analyses
- The results are fully consistent with other WL analyses and with the current best flat ΛCDM model
- Show potential complementarities to correlation studies
- Promising in constraining halo density profiles simultaneously

  → probing baryonic effects

We are * running more simulation sets →

more accurate estimate for the covariance matrix

* improving the model taking into account LSS projection effects, non-sphericity of halo mass distribution, and intrinsic dispersion of c-M relation, etc. → extend the analyses to low peaks

* developing aperture mass peak abundance model → avoid the reconstruction process. However, it is computationally very complex and time consuming

* WL peak statistics are very promising in cosmological studies
  peak abundance, peak correlations, peak profiles

* detailed studies for a representative sample of clusters
  can provide M-c relation priors

Thank you