Dark Energy with the LSS : the impact of non-linearity

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Based on :
1612.05958, 1703.03337,
1711.07372 & 1809.05437

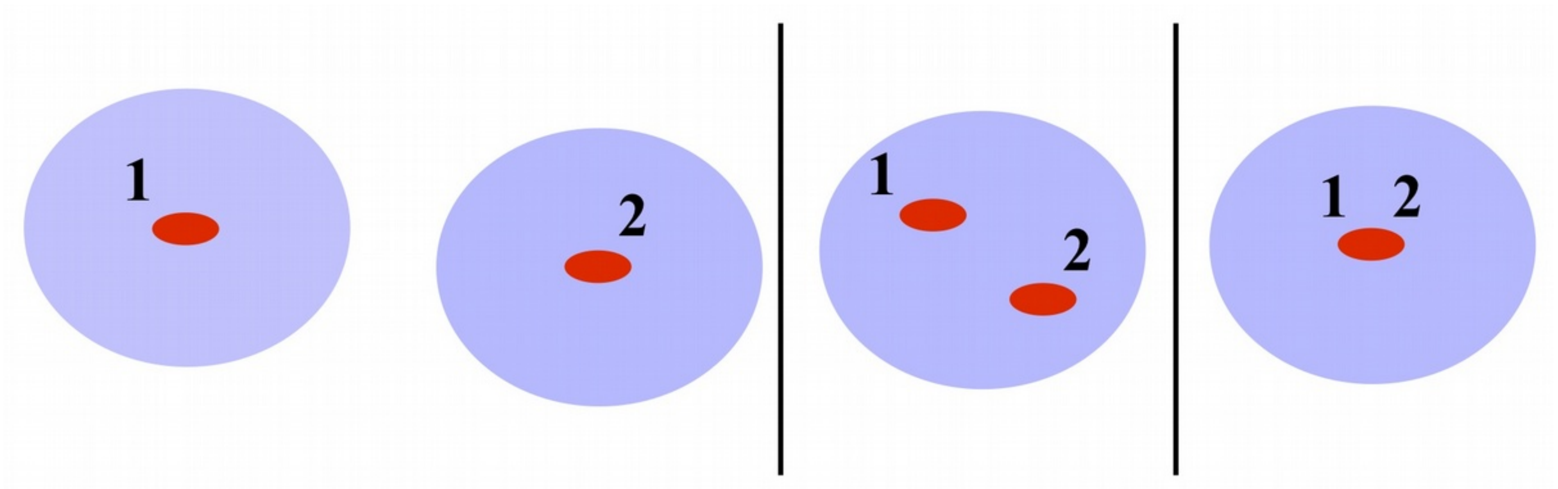
Cosmology with future surveys

Next gen surveys : constrain dark energy by mapping LSS to **small scales**

Need fine control for

- Prediction of observables
- Estimation of **covariances**
- Systematics, likelihood...

Non-linearity (NL)

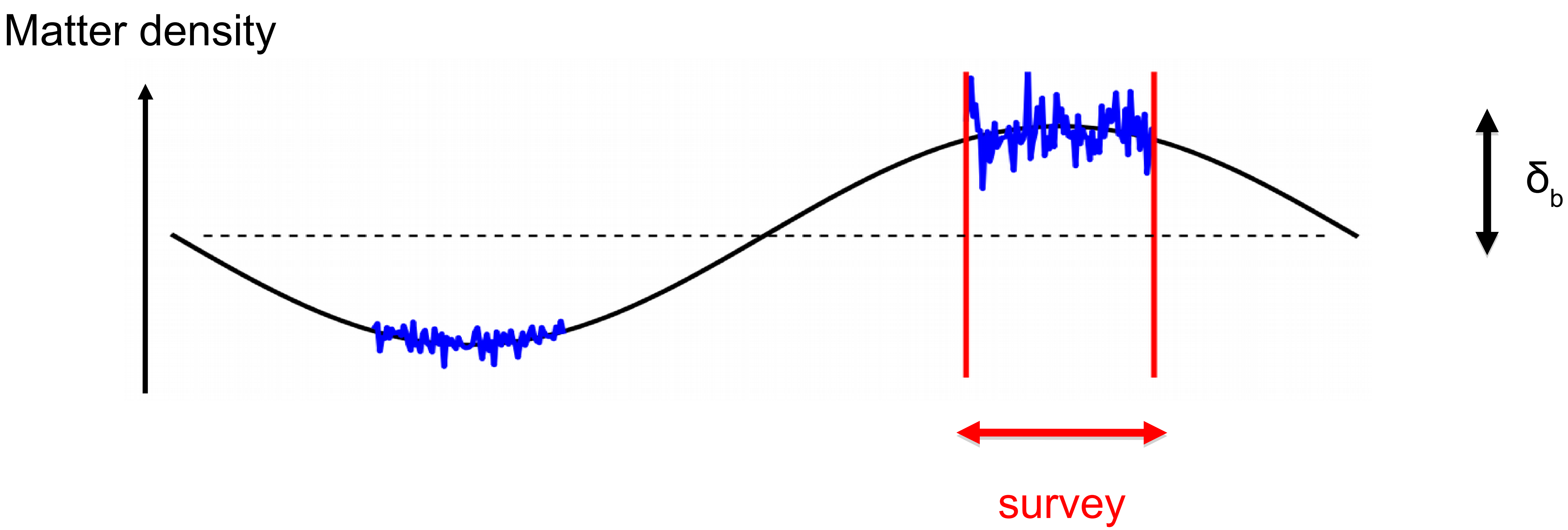


NL in power spectrum :

- Large scales
  - Evolution of matter (perturbation theory)
  - Relation matter ↔ halos (biasing)
- Small scales : presence of discrete objects
  - Halos (mass function)
  - Galaxies (halo occupation distribution)

NL **increases** covariances

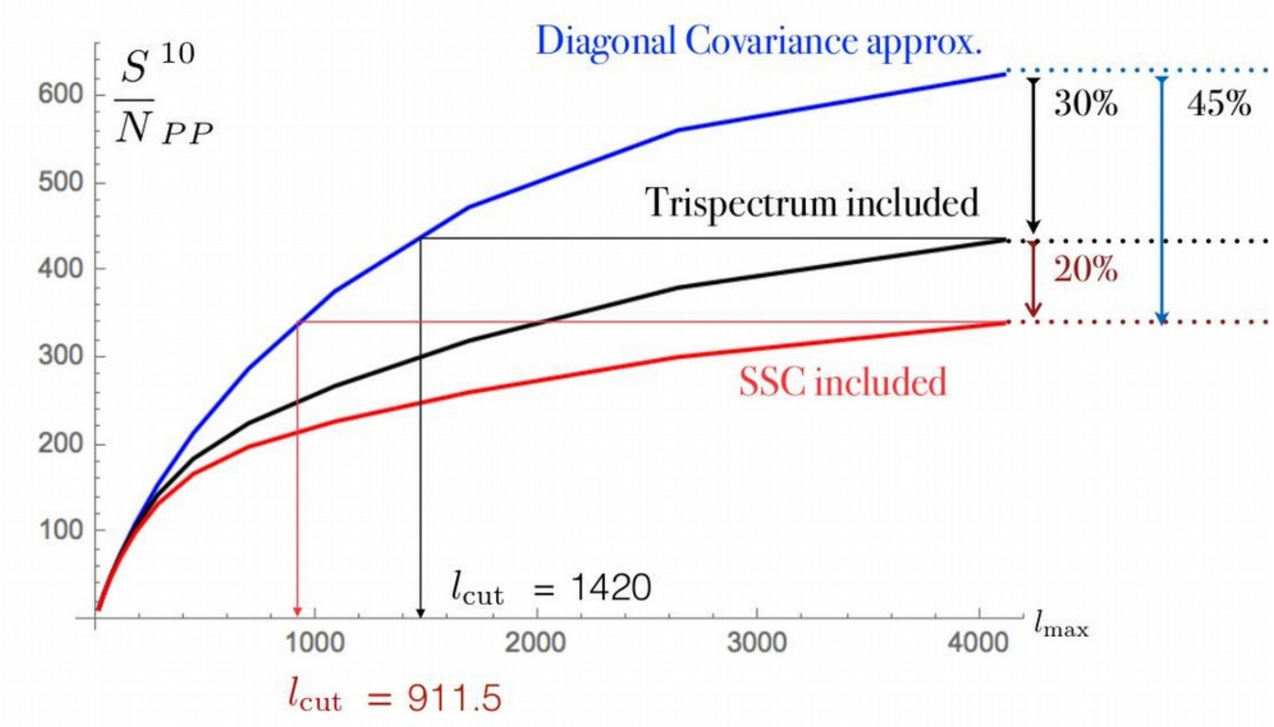
Super-sample covariance (SSC)

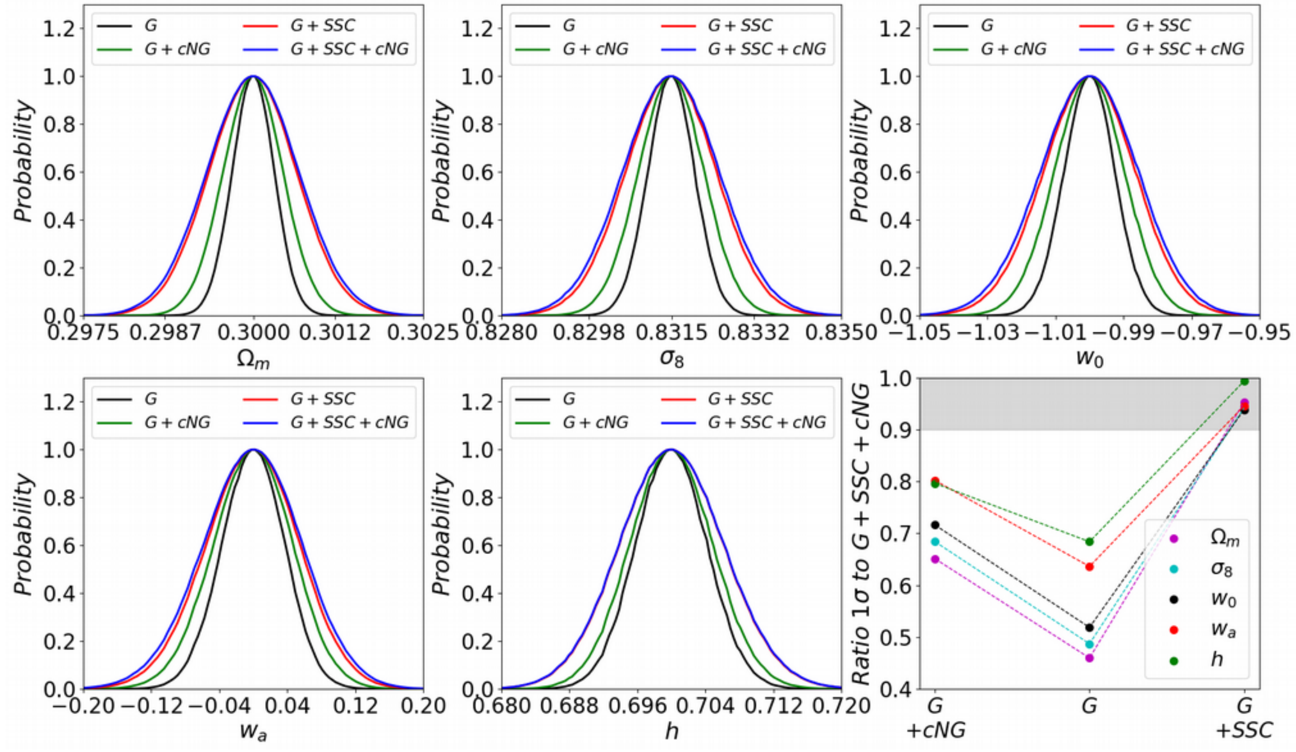


<u>Separate universe argument :</u> (Wagner et al. 2015)
can simulate region δ_b in cosmo Ω by change of cosmo $\Omega'(\Omega,\delta_b)$

Is SSC important ?

Weak lensing : yes





Courtesy of M. Rizzato

Euclid : decrease of S/N by factor ~2

Barreira et al. 2018

Euclid : error bars increase +30% to +110%

DE, σ_8 and Ω_m particularly affected

How can we estimate SSC ?

- From data itself (jackknife, bootstrap) : **NO**
  reason : does not contain super-survey modes

Lacasa & Kunz 2017
arXiv:1703.03337

- From simulations : **NO**
  unless sim is much larger than survey

- Full analytical : **YES**
  can account for arbitrary survey geometry

Lacasa, Lima & Aguena 2017
arXiv:1612.05958

- Semi-analytical : **YES**
  – Analytical for super-survey modes
  – Separate universe simulations for probe's response

Barreira, Krause & Schmidt 2018

Easy SSC

SSC problems :

- complex literature, many NL effects
- quickly need halo model
- only 1 public code
- do not know if relevant or not

Community need: sth easily usable, flexible, can see impact

$$\downarrow$$

$$\mathrm{Cov}_{\mathrm{SSC}}\left(C_\ell^A(i_z), C_{\ell'}^B(j_z)\right) \approx R_\ell^A\, C_\ell^A(i_z)\; R_{\ell'}^B\, C_{\ell'}^B(j_z)\; S_{i_z,j_z}$$

- S_{ij} : integral of P(k) — < 1 second on laptop
- R_l : probe's response — can take simple ansatz

Extendable to correlation function, cluster counts, bispectrum...

Lacasa & Grain 2018 arXiv:1809.05437

Easy **and fast** SSC

inverse covariance is correction to standard no-SSC case

→ fast S/N, Fisher, $\ln \mathcal{L}$

$$(S/N)^2 = \frac{(S/N)^2_{\rm std}}{1 + (S/N)^2_{\rm std}/(S/N)^2_{\rm max}}$$

$\to (S/N)^2_{\rm max}$ when $(S/N)_{\rm std} \gg (S/N)_{\rm max}$

$$(S/N)^2_{\rm max} = \frac{1}{R^2 \;\, S_{i,i}}$$

$$\ell_{\rm SSC} = \sqrt{\frac{2}{R^2 S_{i,i}}}$$

$$F_{\alpha,\alpha} = F^{\rm std}_{\alpha,\alpha} \left(1 - \cos^2\theta_\alpha \, \frac{Y}{1+Y}\right)$$

$$Y = \frac{(S/N)^2_{\rm std}}{(S/N)^2_{\rm max}}$$

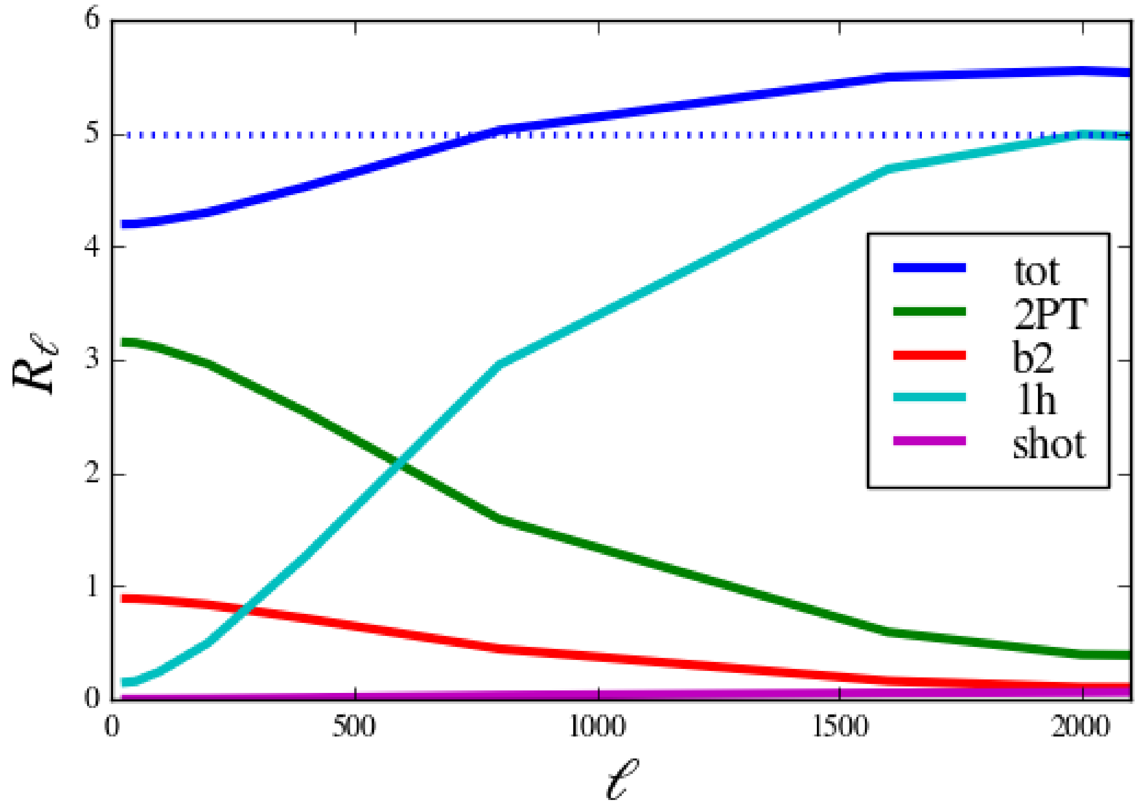
SSC relevant if $(S/N)_{\rm std} = \mathcal{O}\left((S/N)_{\rm max}\right)$ and $\cos\theta_\alpha = \mathcal{O}(1)$

Application I : relevance

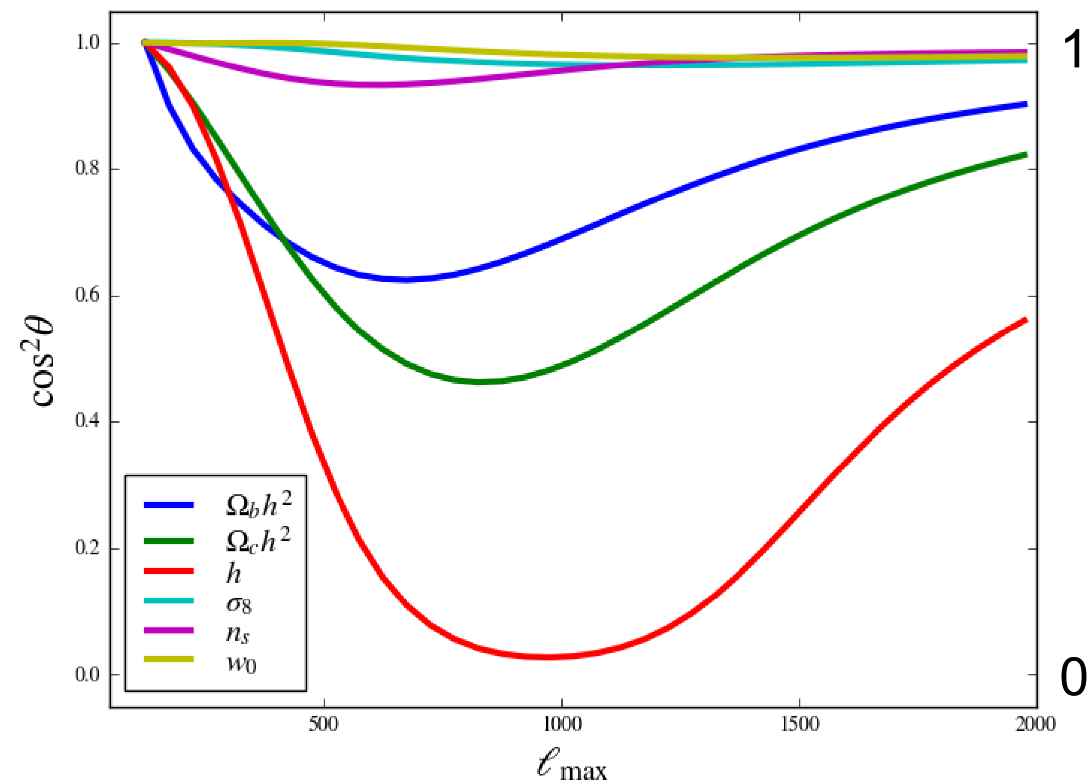
Forecast of GCphot C_l with Euclid-like specs at 0.9<z<1

Results : $S_{i,i} = 6.2 \times 10^{-7}$ maximum S/N = 250 $l_{SSC} = 360$

Response



$\cos^2 \theta_\alpha$

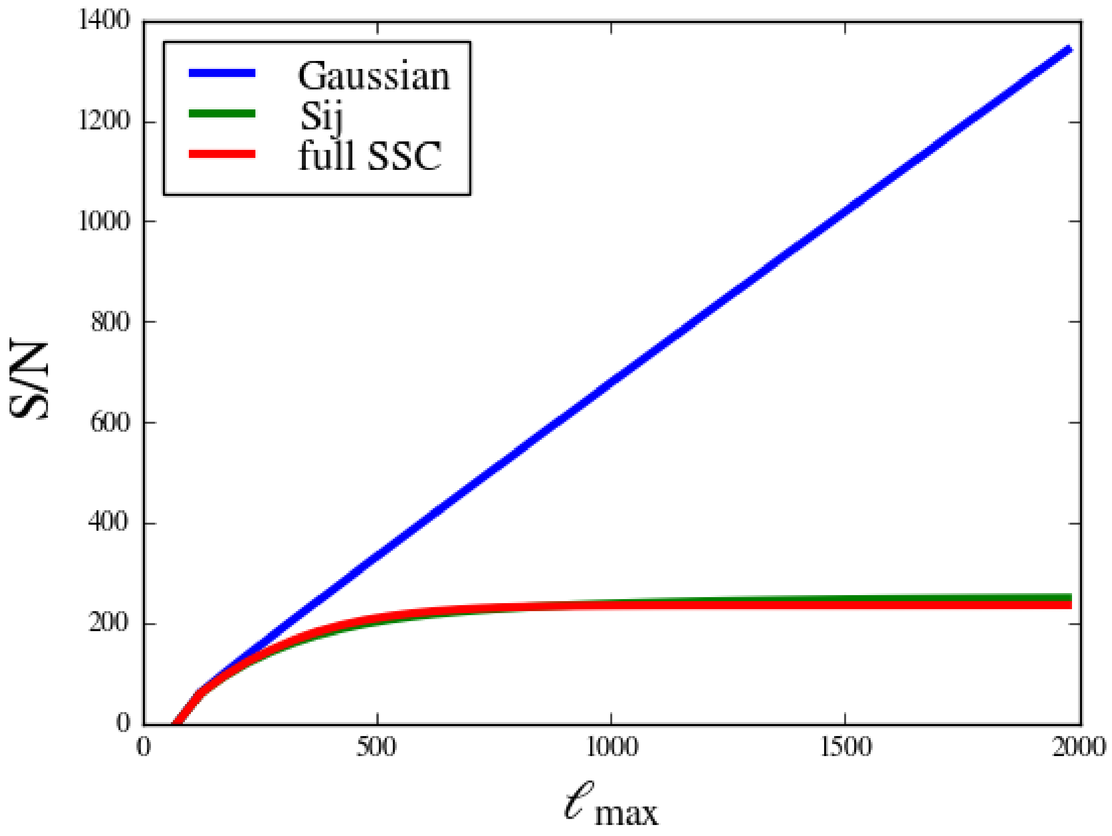


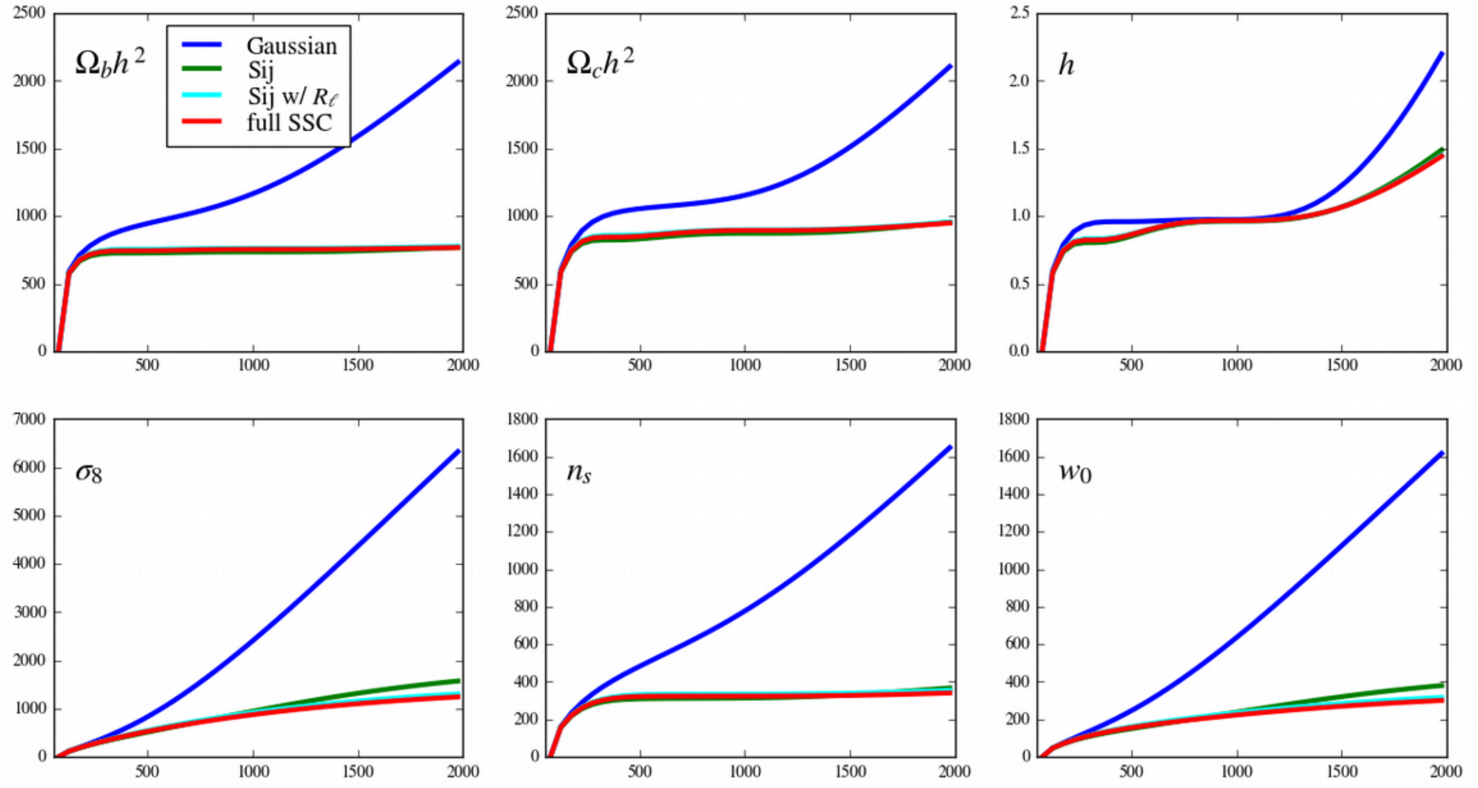
Lacasa & Grain 2018 arXiv:1809.05437

Application II : comparison with full SSC

Cumulative S/N vs lmax

Cumulative (square root of) Fisher element, for each cosmo parameter





Lacasa & Grain 2018 arXiv:1809.05437

Conclusions / perspectives

- Non-Gaussian covariances are important, in part. SSC
- Best tackled analytically
- Have developed easy to use SSC approximation
- Relevant for Euclid

- Deal with SSC at the likelihood level
- Other NL covariance terms ?

  Derived for GC in Lacasa 2018 1711.07372

  Some implemented and shown relevant for Euclid

  Others not yet implemented, hints they could be relevant.
- What happens on smaller scales ?

Thanks for the attention

Additional slides

Accurate NL covariances : why ?

- Not to underestimate cosmological errors

ex : if we underestimate error by factor 3,
then a 1σ fluctuation become a 3σ discovery
→ "ruling out" Λ ...

- Bias on cosmological parameters

ex : KiDS-450 analysis (Hildebrandt+ 2017) tried different approaches to the covariance. Impact :

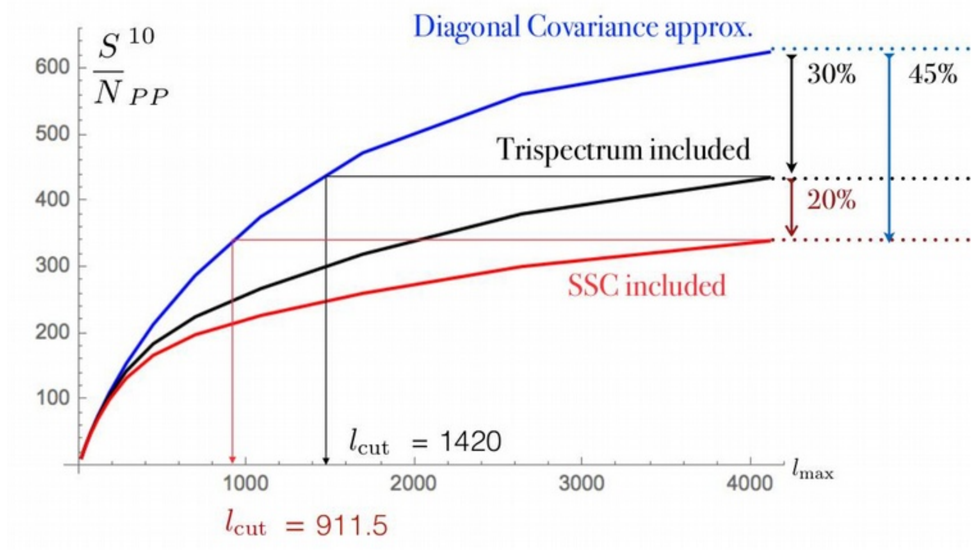
"There is however a shift in the central values of the best-fit parameters [...] **This shift is equivalent to the size of the 1σ error on S_8** […]
We attribute these shifts to super-sample-covariance terms […] "

NL impact on weak lensing

- Impact on S/N (courtesy of M. Rizzato, IAP)

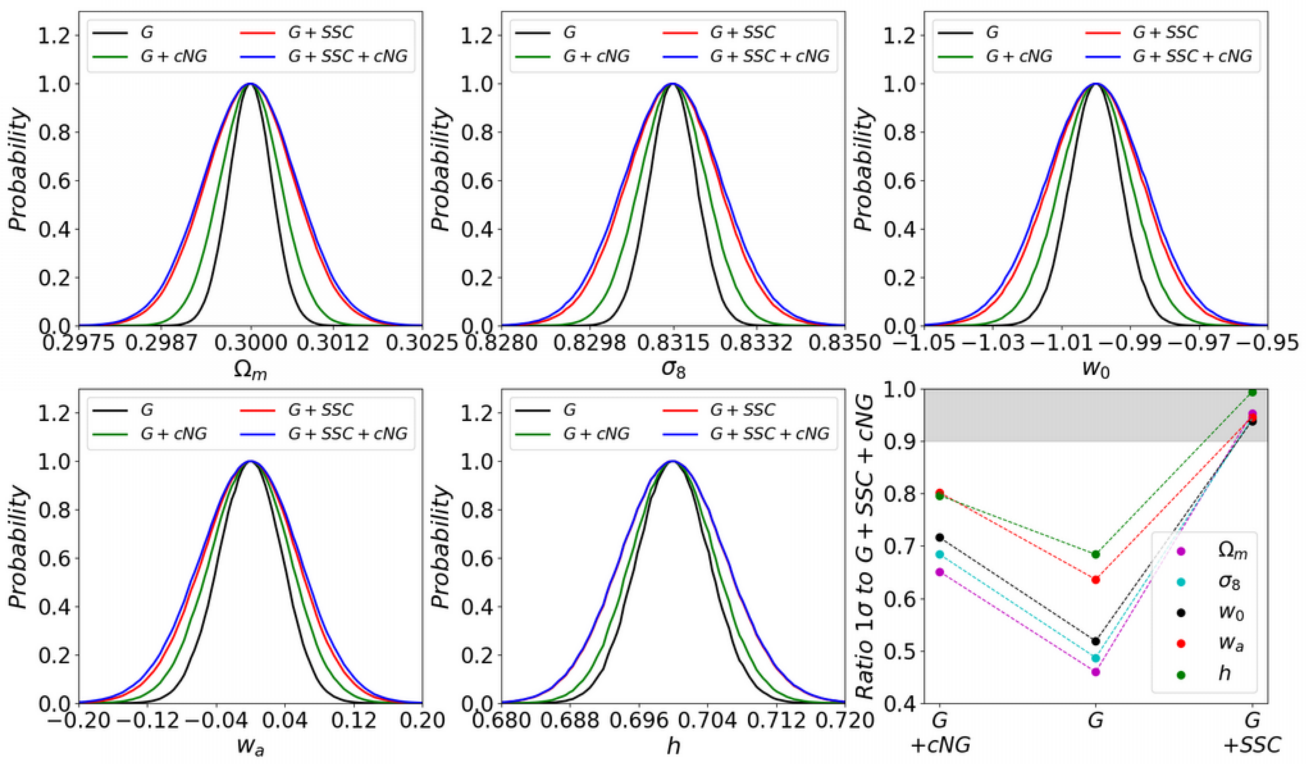
  - 10-bins tomographic WL power spectrum with Euclid-like specifications
  - NG impact wrt Gaussian cov : equivalent to cutting the data from lmax=5000 down to lmax=1400 (w/o SSC)

  or lmax=910 (w/ SSC)



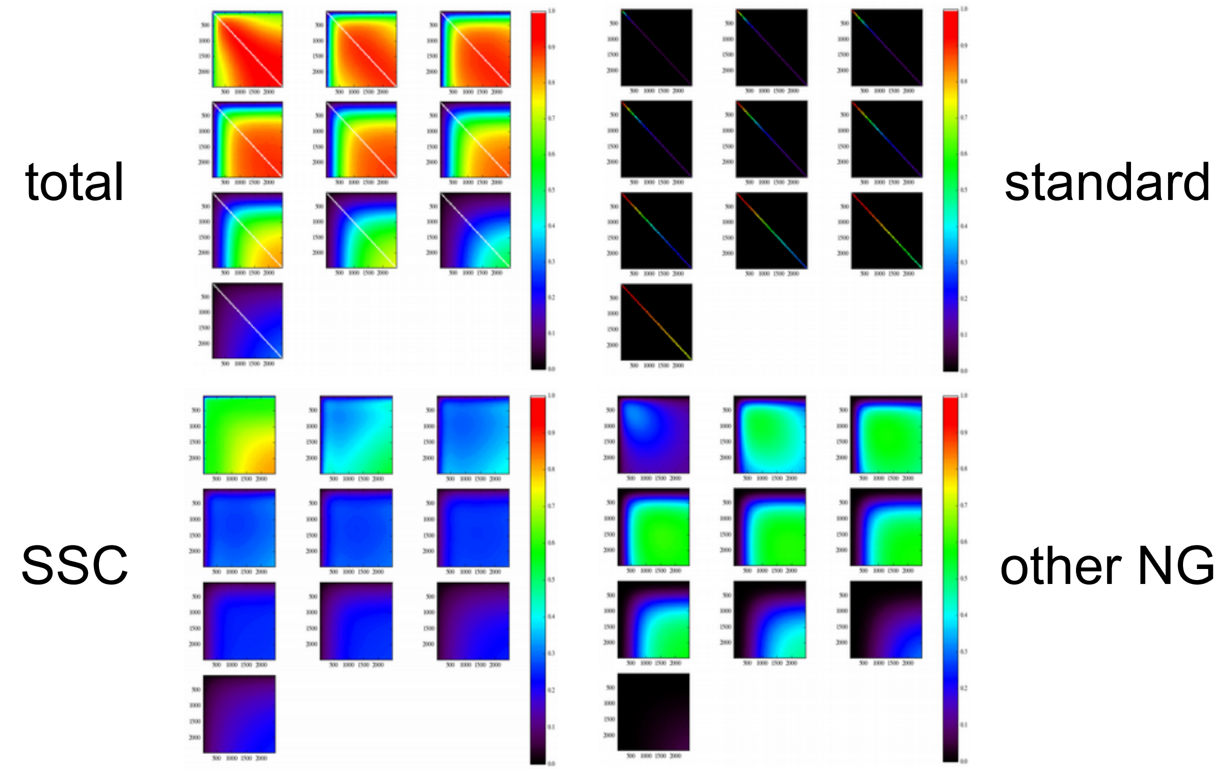
- Impact on param constraints : Barreira+ 2018

  - Error bars increased by +30% to +110%
  - DE heavily affected (as σ_8 & Ω_m)
  - SSC is dominant beyond Gauss, and with ~5% error on errors we can forget other trispectrum terms (really true ? Not sure for other cosmo params because impact on cov mat is ~15% median)



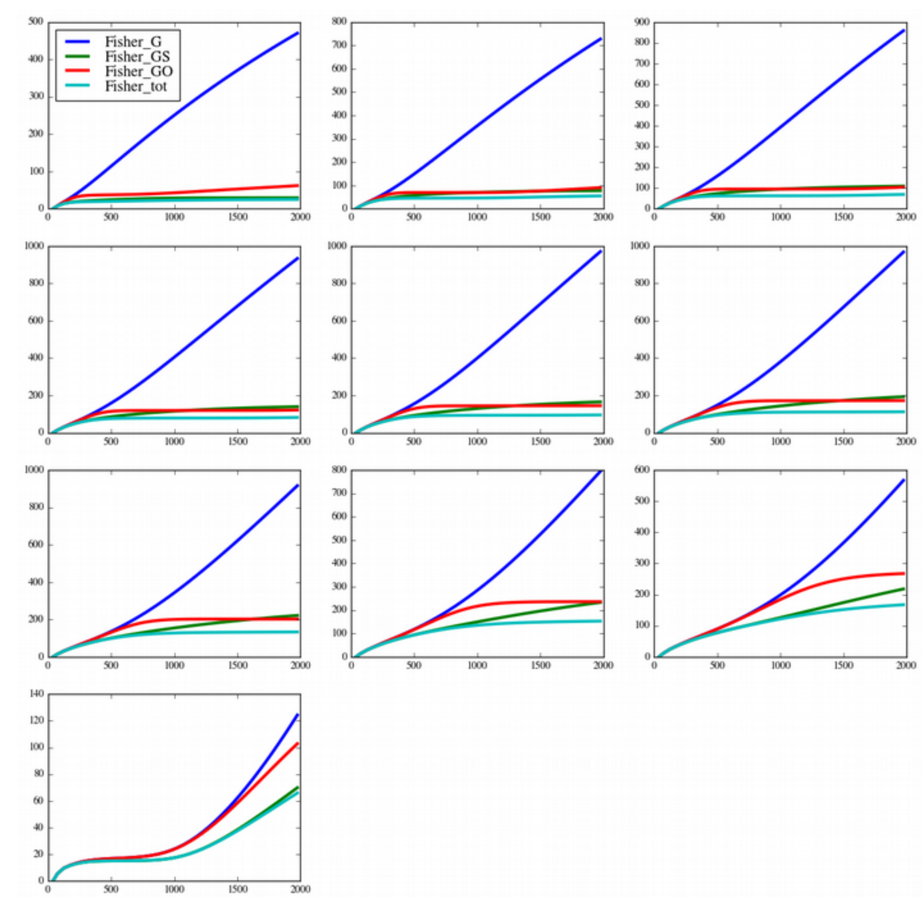
NL impact on galaxy clustering

- Impact on cov matrix for Euclid-like GCphot

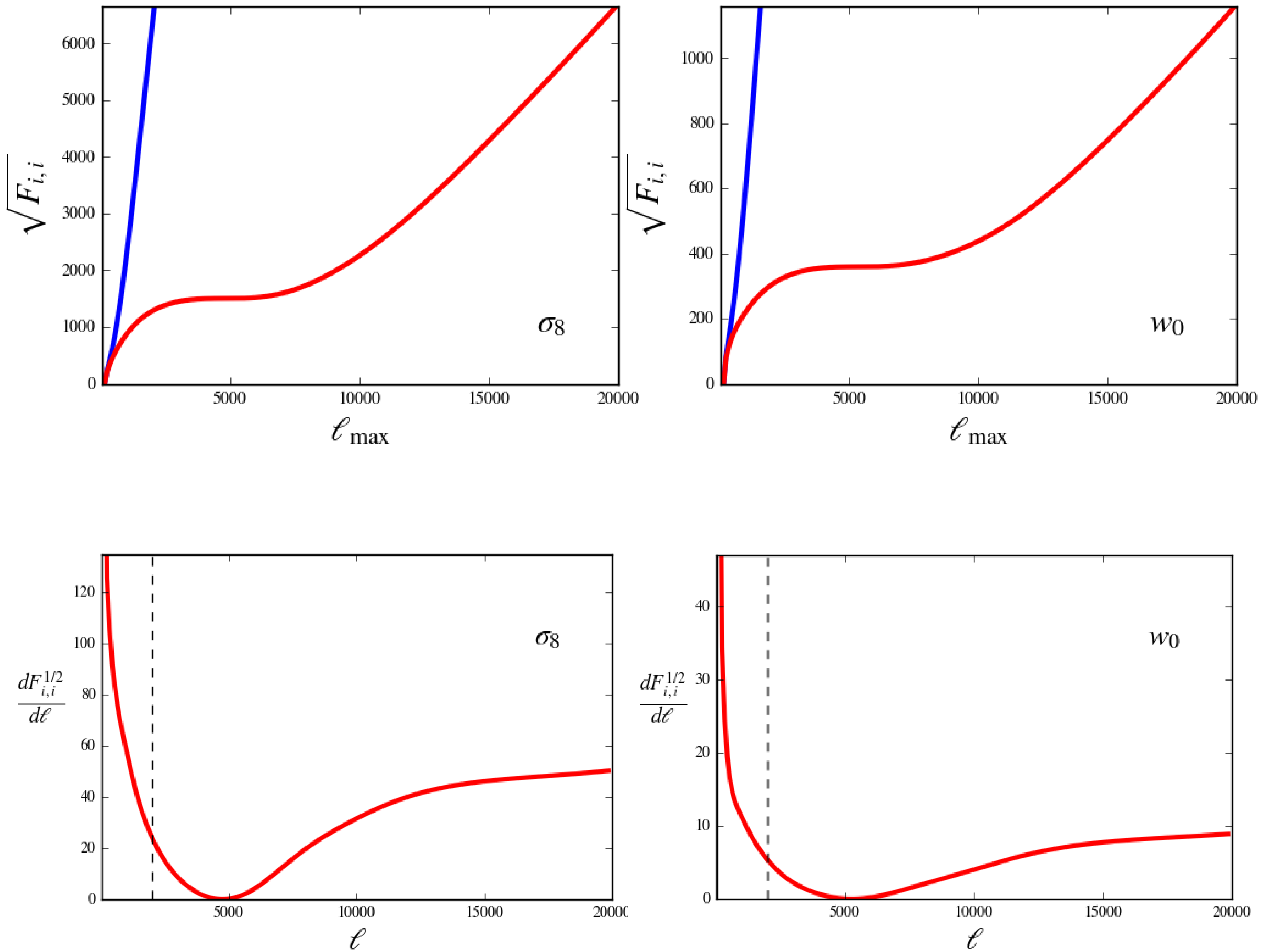


- Information content on DE cumulative F_{ww} vs lmax in the 10 redshift bins

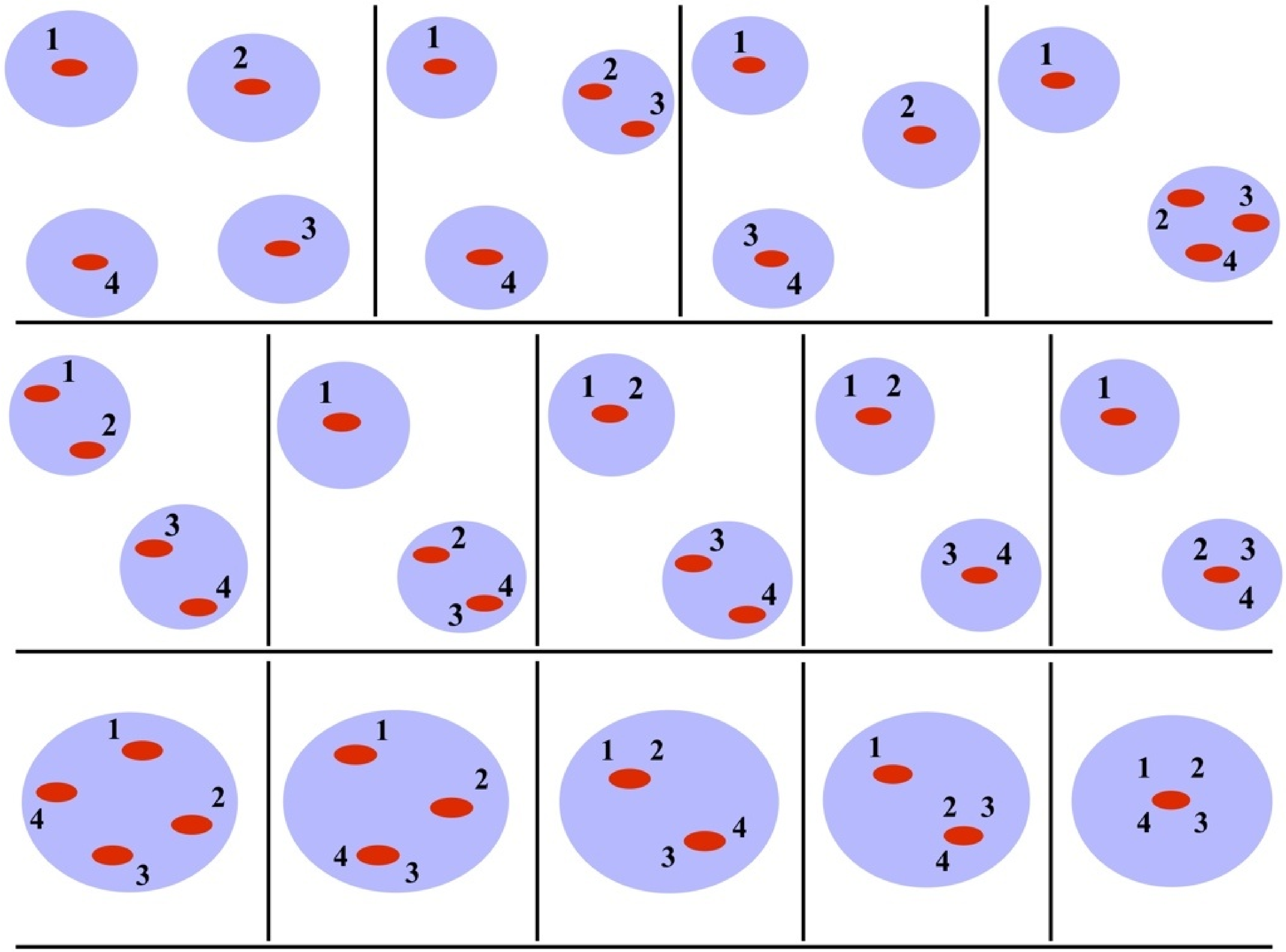
  (no marginalisation on any other parameter, just to show the qualitative importance of the covariance terms)



Hope ? The small scale miracle



Covariance of the galaxy power spectrum : diagrammatic approach



Lacasa 2018 arXiv:1711.07372