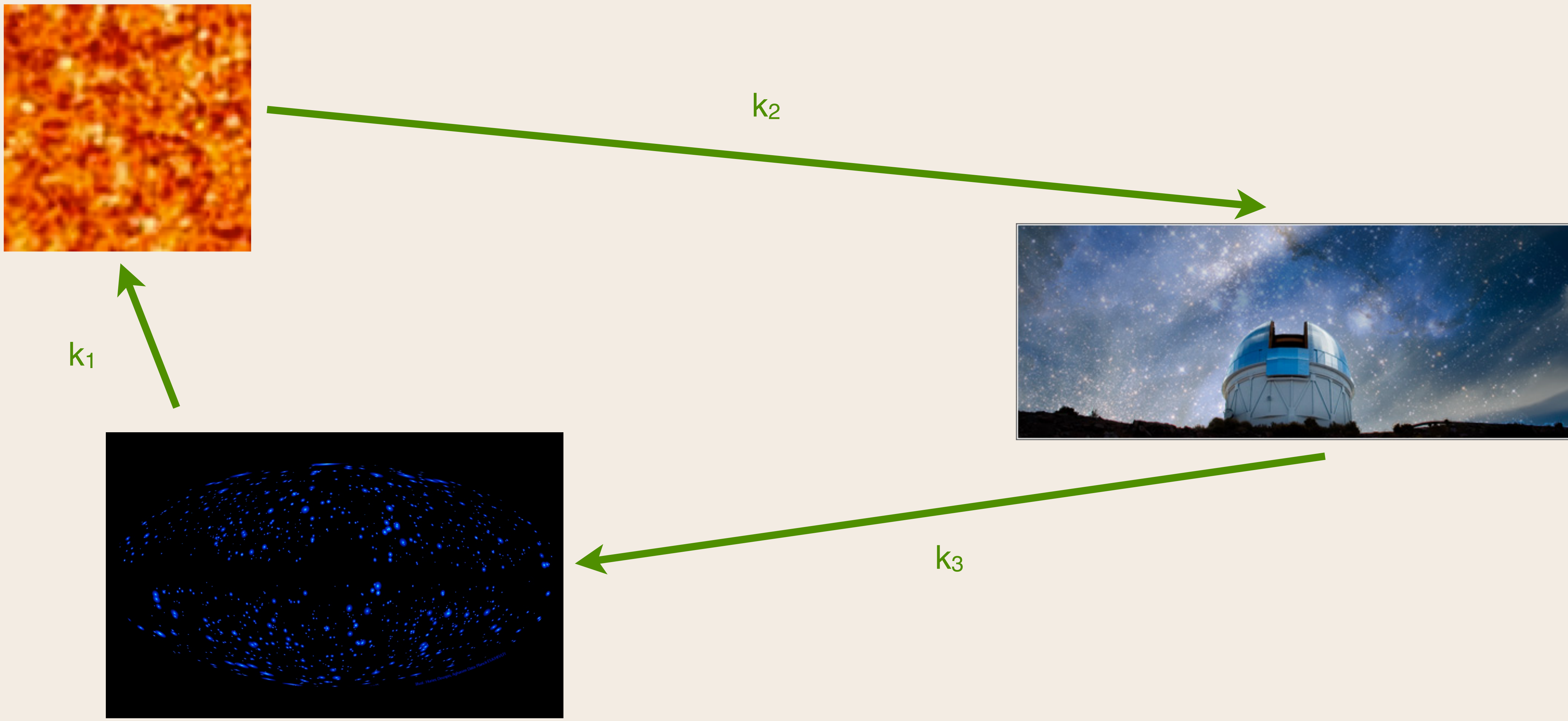
Non-Gaussian tools for the Large Scale Structure



Dark Energy Survey

Fabien Lacasa

São Paulo, Brasil

ICTP SAIFR

unesp

Outline

I. Non-Gaussianity with *Planck*

A. Primordial NG and point-sources

B. Cosmic Infrared Background

C. thermal Sunyaev-Zel'dovich effect

II. Combining probes for *DES*

A. Covariance of galaxy spectrum and cluster counts

B. Joint likelihood

Planck non-Gaussianity

A. Primordial NG and point-sources

• primary CMB NG constrains inflations models

• NG of most models is well described as linear combination of 3 shapes : local, equilateral and orthogonal

• *Planck* puts quasi-optimal constraints on these amplitudes in temperature.
Polarization information further decreases error bars.

Constraints

after substraction of the lensing-ISW bias

	T 2013	T+E 2014 (preliminary)
f_{NL}^{local}	2.7 ± 5.8	0.71 ± 5.1
$f_{NL}^{equilateral}$	-42 ± 75	-9.5 ± 44
$f_{NL}^{orthogonal}$	-25 ± 39	-25 ± 22

A. Contamination of PNG estimation

- estimation of f_{NL} is biased by contaminants :
  - secondary anisotropies : lensing, iSW, SZ
  - Galactic emission : synchrotron, free-free, AME, dust
  - extragalactic point-sources :

  - radio sources
  - Cosmic Infrared Background

radio sources can be considered as *white-noise* :
unclustered, simple NG given by counts and flux cut

CIB is more complex :
strongly clustered enhancement of NG on large scales
→ phenomenological prescription
by **Lacasa et al. 2011**

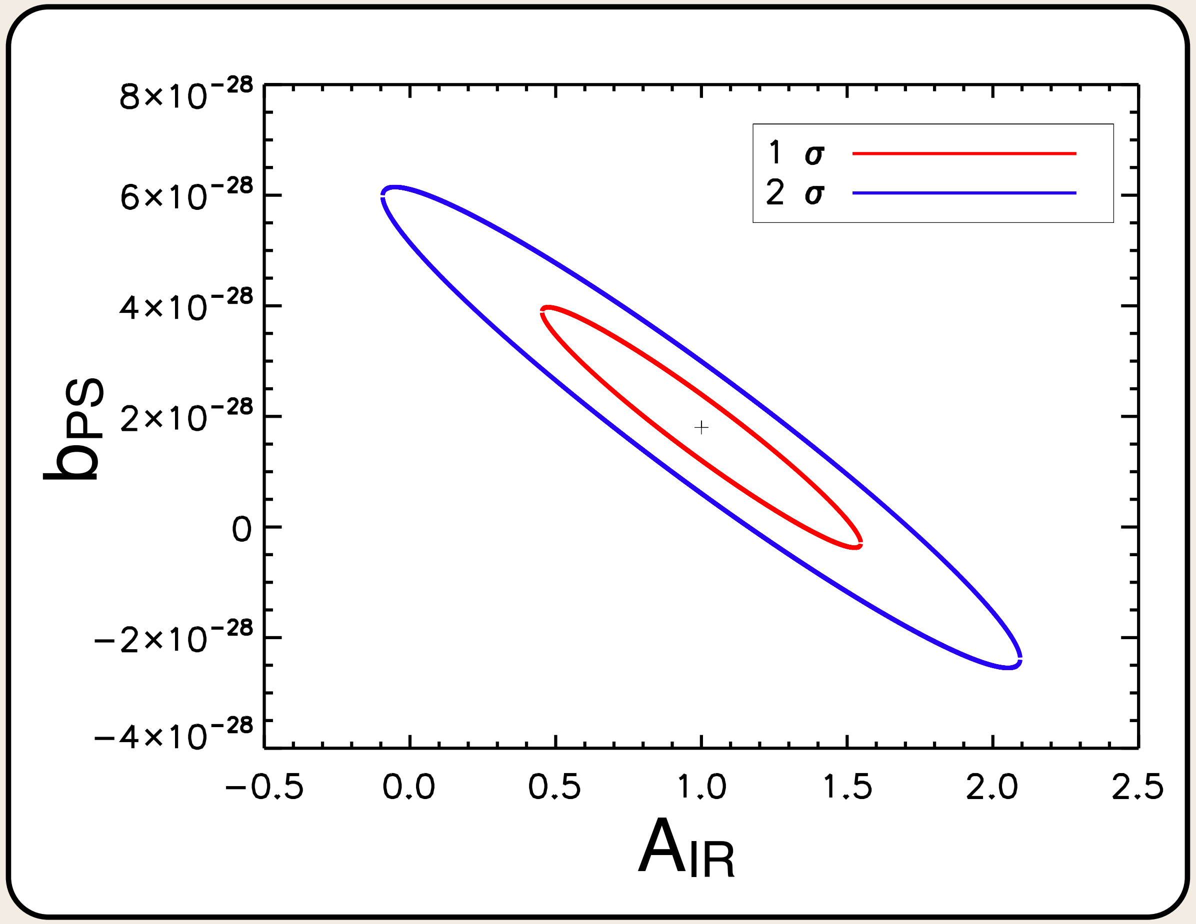
A. Point-source NG

- contamination of f_{NL}^{local} after masking bright sources

ν [GHz]	143	217	353
Δf_{NL}^{RAD}	0.269	0.089	0.046
Δf_{NL}^{IR}	0.006	0.108	19.3

- optimal estimator for A_{IR}
- joint estimation of f_{NL} b_{PS} and A_{IR} with a coupling matrix

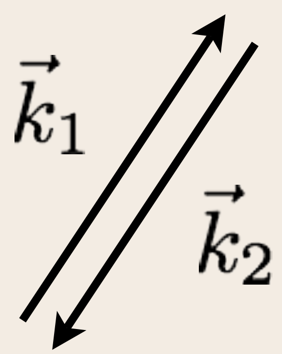
forecasts of (b_{PS}, A_{IR}) joint constraints at 217 GHz : ellipses at 1σ and 2σ



Lacasa & Aghanim 2013

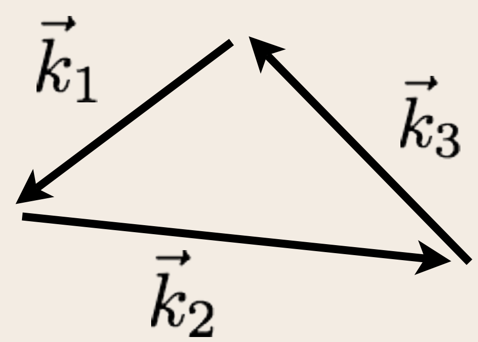
B. Interlude I :
how to quantify NG

Power spectrum : 2-point correlation function in Fourier space



P(k)

Bispectrum : 3-point correlation function in Fourier space



$B(k_1,k_2,k_3)$

Bispectrum : lowest order indicator of NG

Important triangle shapes :
equilateral, flat and mostly squeezed ($k_1 << k_2, k_3$)

B. Cosmic Infrared Background : *Planck* maps cleaning

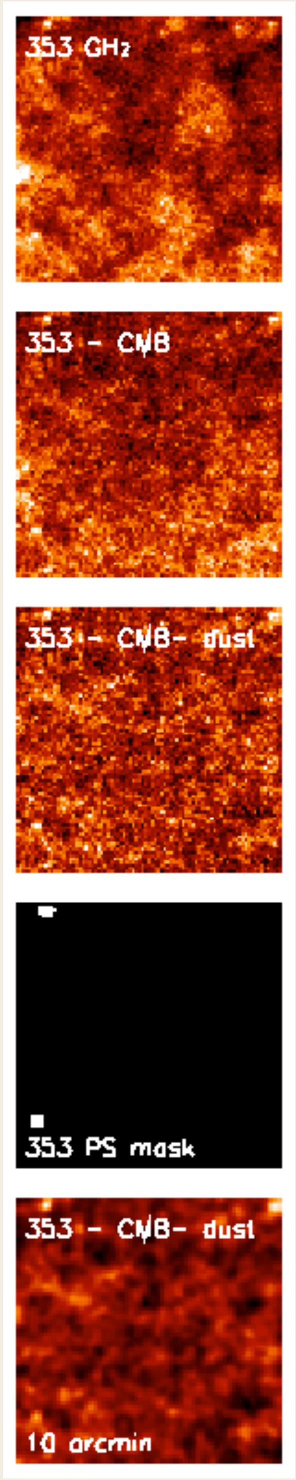
- original map
- CMB substraction

(Wiener filter of the 100 GHz map)

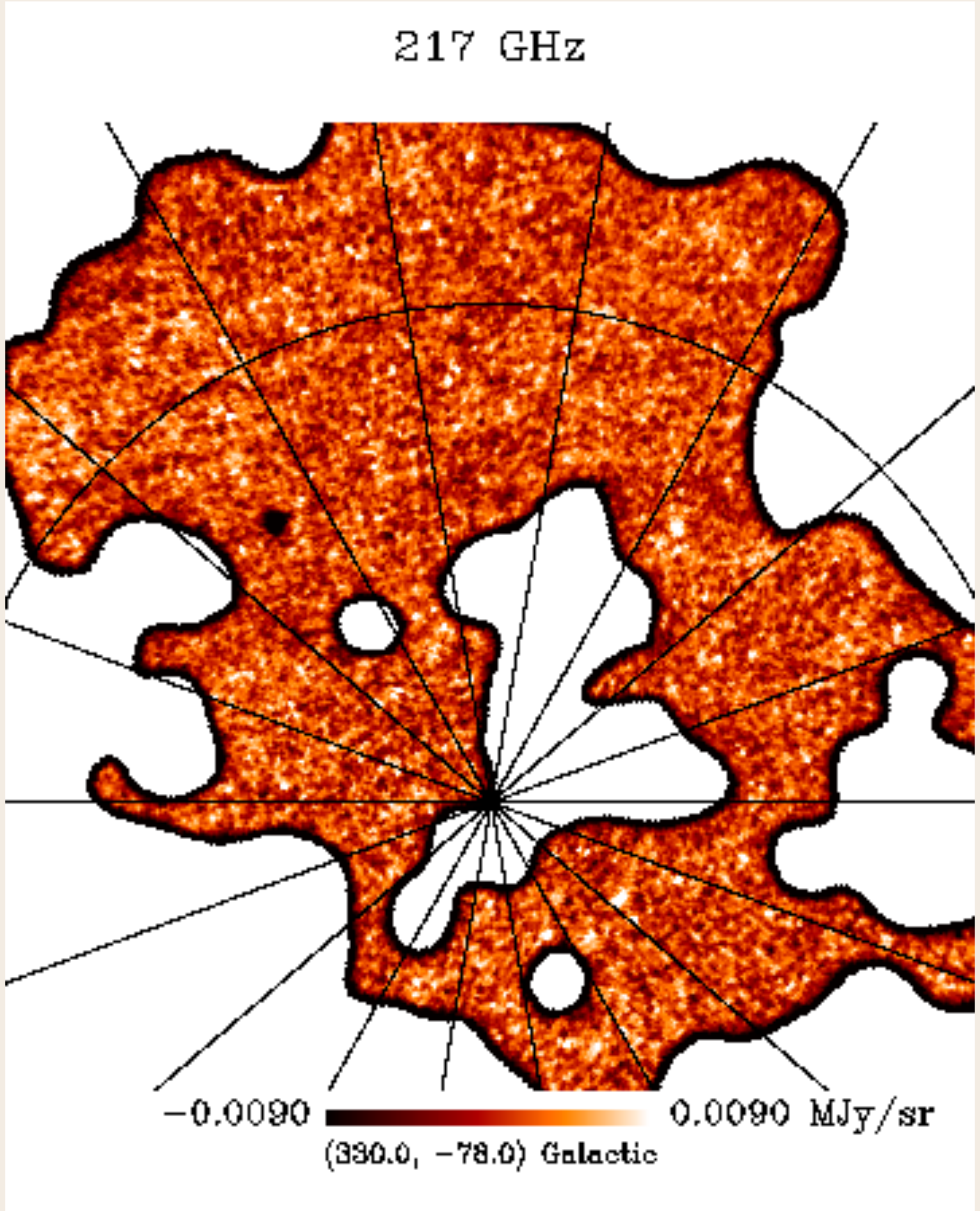
- Galactic dust substraction

(model based on external HI data)

- Galactic and point-sources mask
- estimated CIB map



$f_{SKY} = 10\%$



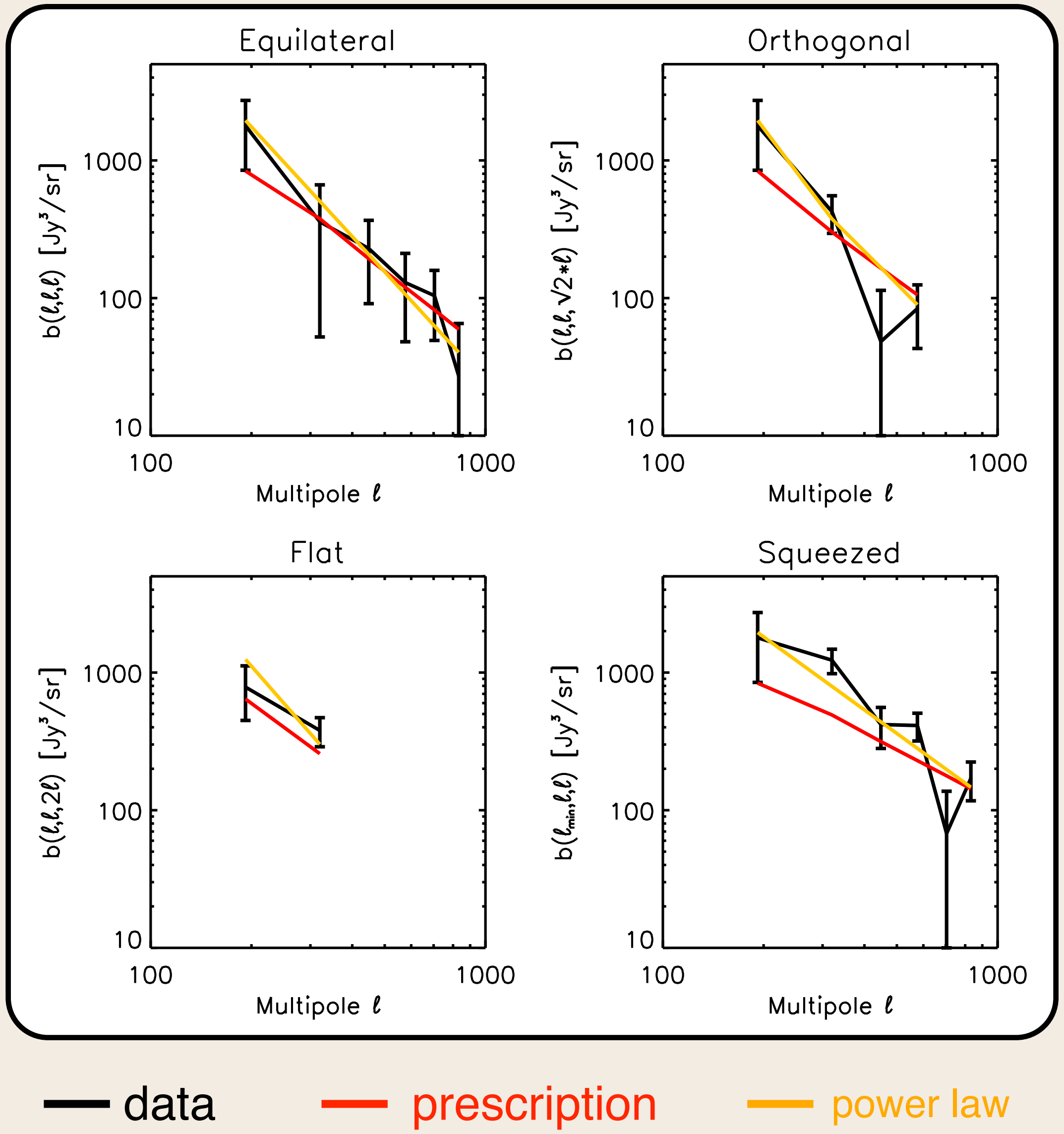
Planck Collaboration XXX 2013

B. CIB : *Planck* bispectrum

- all configurations/triangles
- mask effect : optimisation (linear term) and debiasing (by simulations)
- correction of the tSZ leakage (due to 100 GHz)

ν [GHz]	SNR moyen par config	SNR total
217	1.24	5.83
353	2.85	19.27
545	4.59	28.72

353 GHz



First detection of the CIB bispectrum per configuration and per frequency

Planck Collaboration XXX 2013

B. CIB bispectrum : teaching and perspectives

- frequency dependence consistent with spectrum
- high S/N → information there to extract
- data fit better by power law than by prescription or by previous model (from Lacasa et al. 2013, Pénin et al. 2013)
- necessity of a new model
cf Aurélie Pénin's talk

C. thermal Sunyaev-Zel’dovich NG

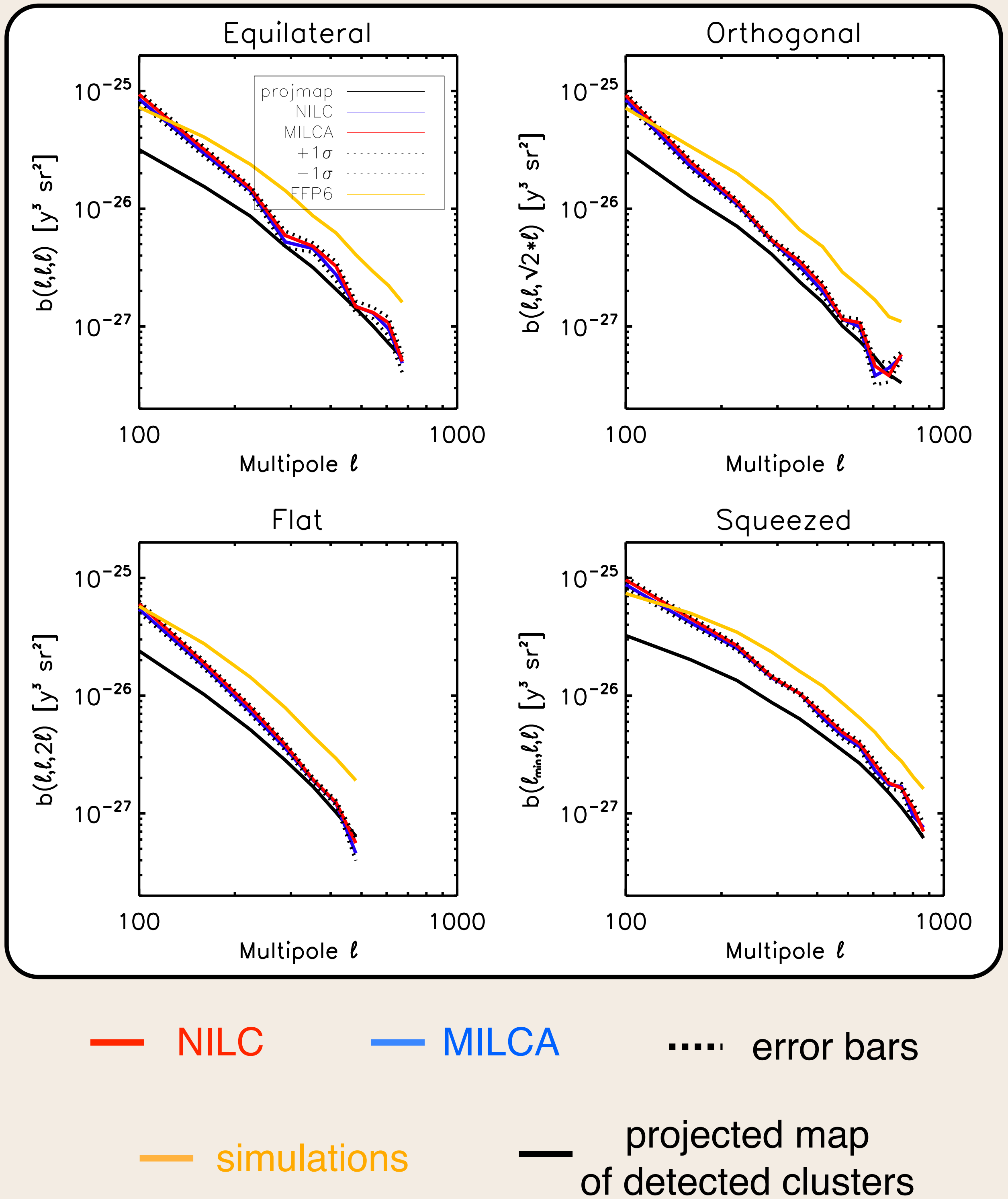
• tSZ traces ionised gas in clusters

• *Planck* can map it.
2 methods used : NILC and MILCA (resp. Remazeilles et al. 2011 and Hurier et al. 2013)

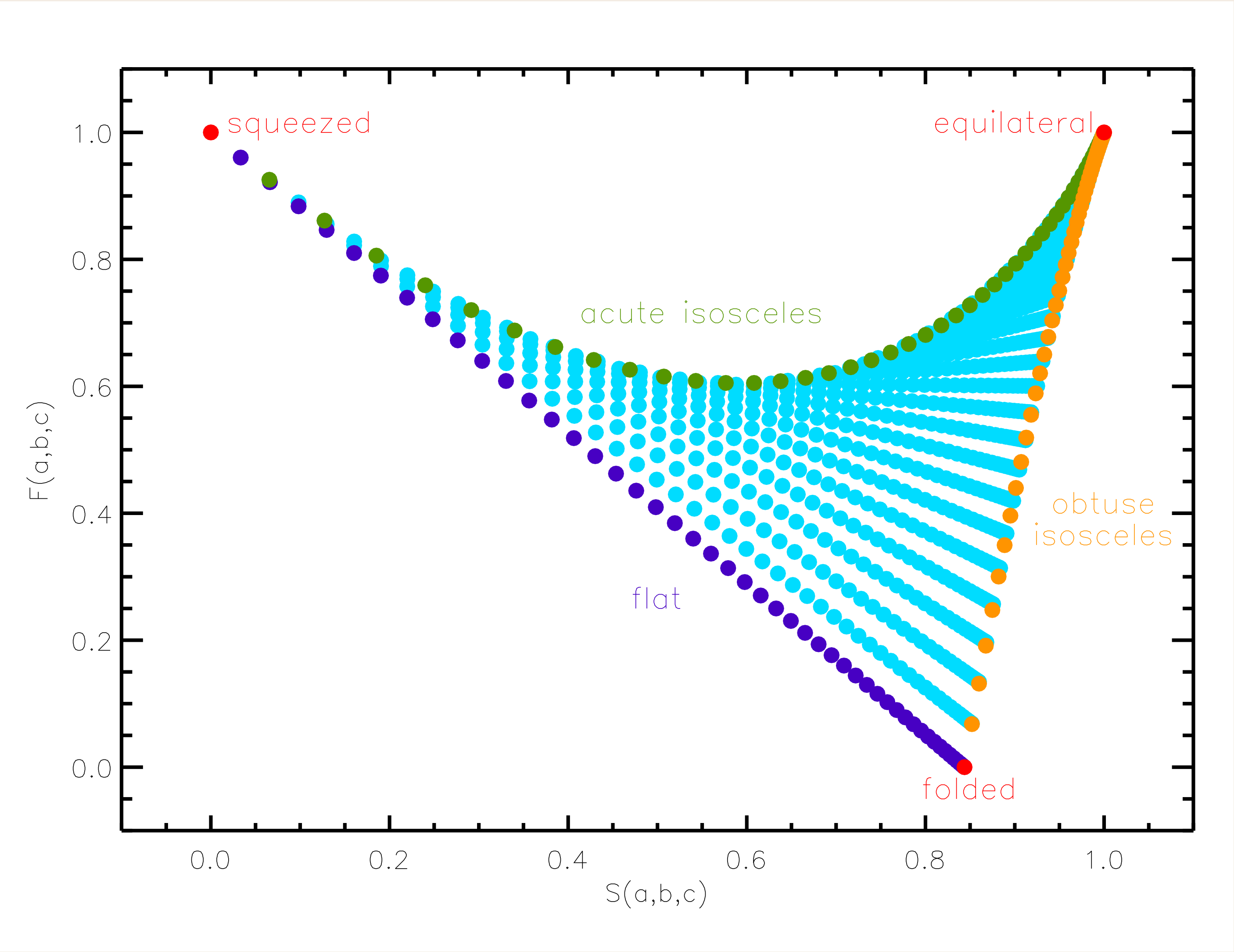
• Bispectrum estimated with ~60% of the sky

• Correction of the mask effect with a mean ratio computed on simulations

Planck Collaboration XXI 2013



C. Interlude II : parametrisation to plot a bispectrum



All triangles of a given perimeter

(in a parameter space related to symmetric polynomials)

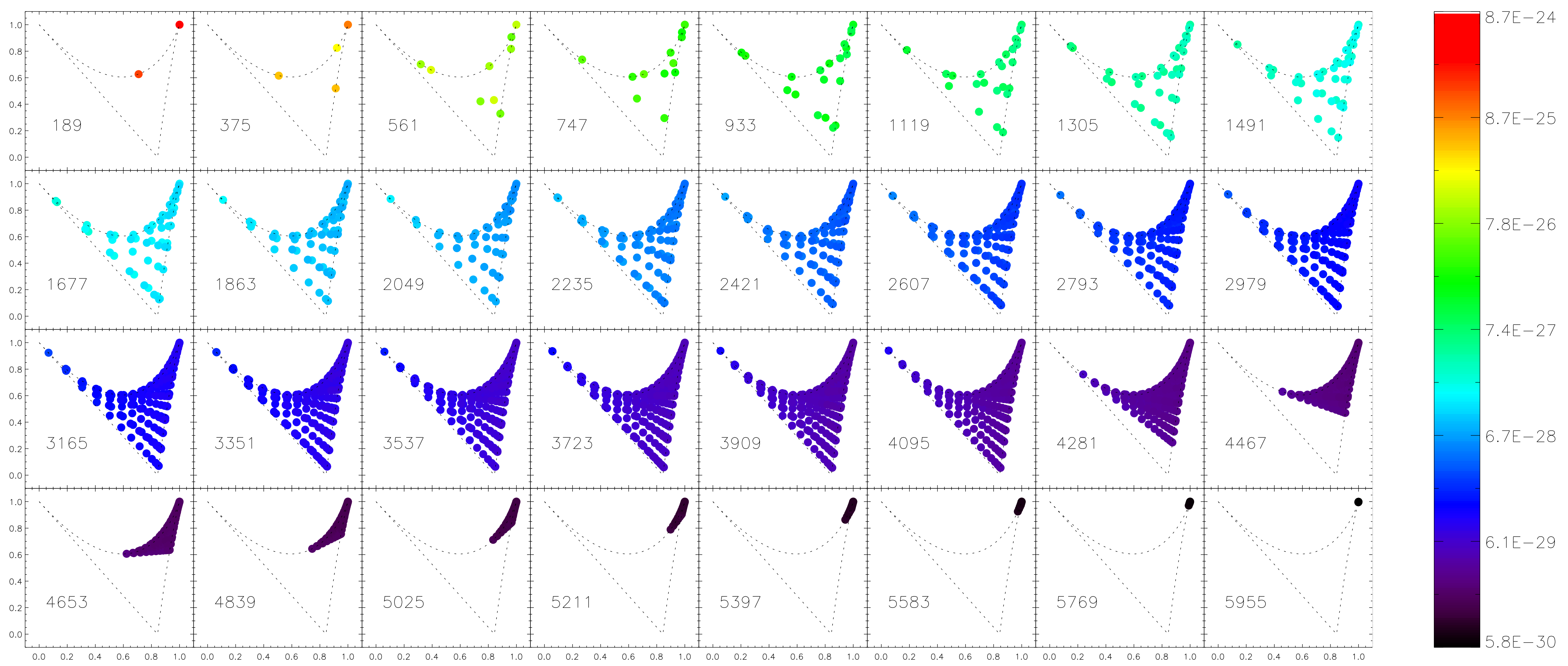
Lacasa et al. 2011

Allows to represent efficiently a bispectrum :

- no redundancy
- separates geometric and scale dependence

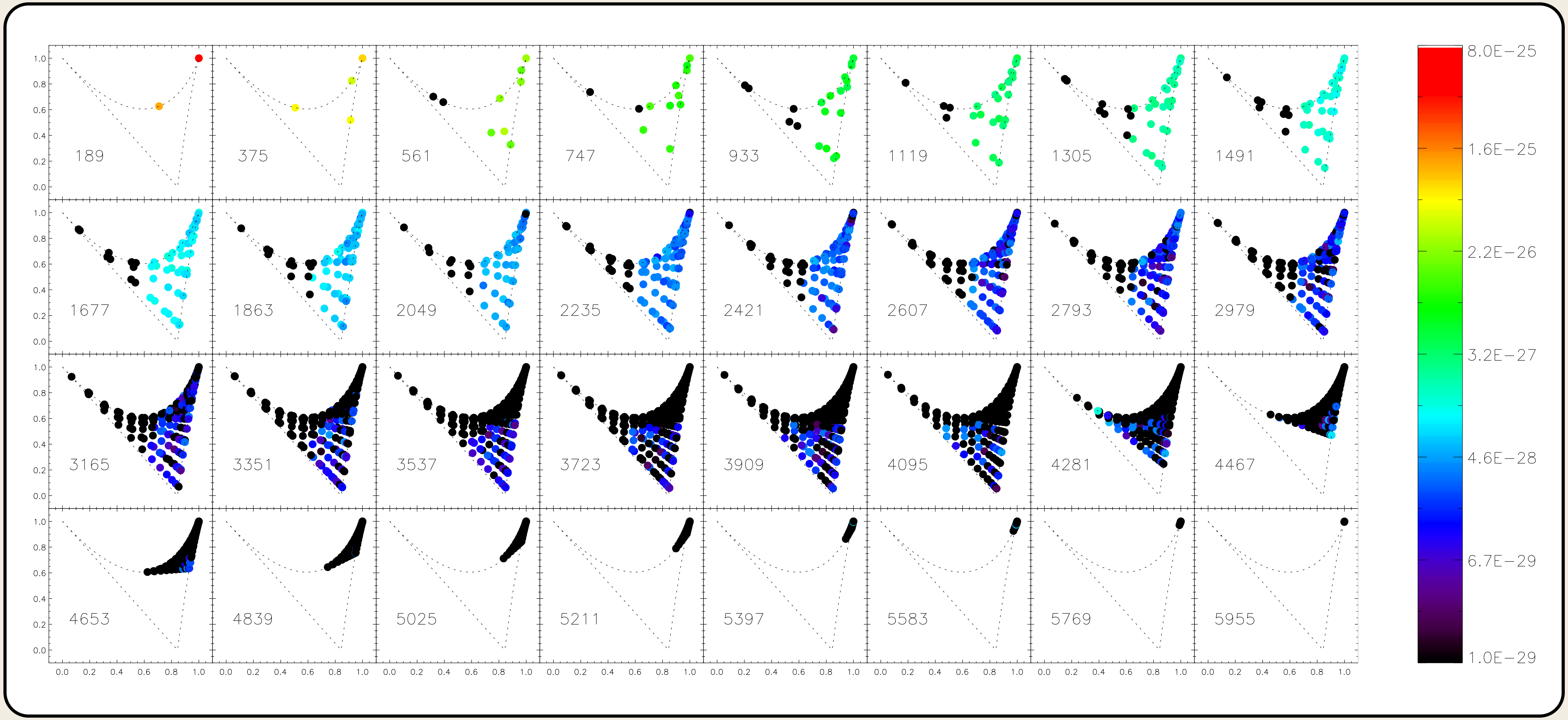
C. tSZ bispectrum in the parametrisation : simulations

Planck simulations



C. tSZ bispectrum in the parametrisation : NILC

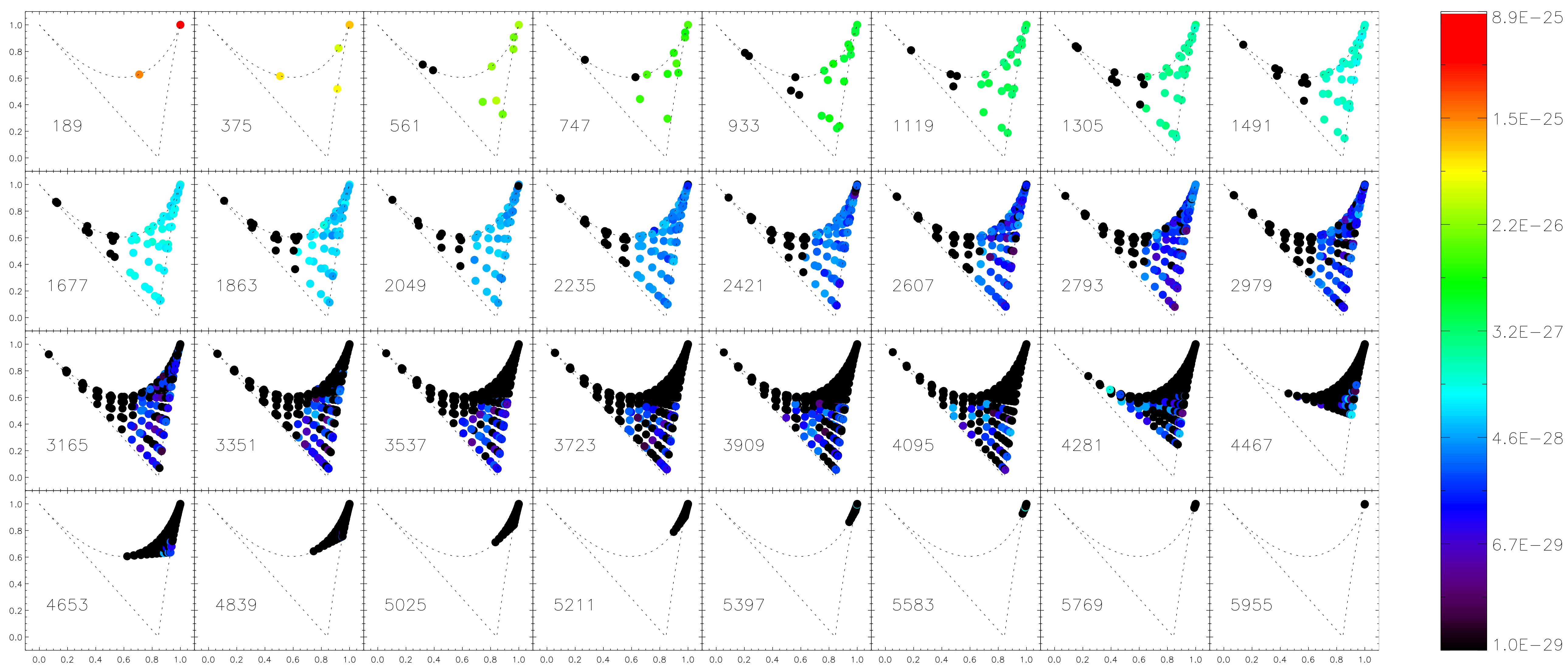
Planck 2013 results



Black points : configurations discarded conservatively to avoid systematics (foregrounds, mask effect)

C. tSZ bispectrum in the parametrisation : MILCA

Planck 2013 results



C. *Planck* tSZ bispectrum : conclusions/perspectives

- high consistency of the measurement :
  - internally : NILC/MILCA
  - externally : with simulations
- high detection signal-to-noise

there is valuable information to extract

- ‘2014’ results to come. Better, stronger
- improvements are even possible
- necessity of a model

C. tSZ bispectrum : model

Aim : a model predicting both the tSZ power spectrum and bispectrum

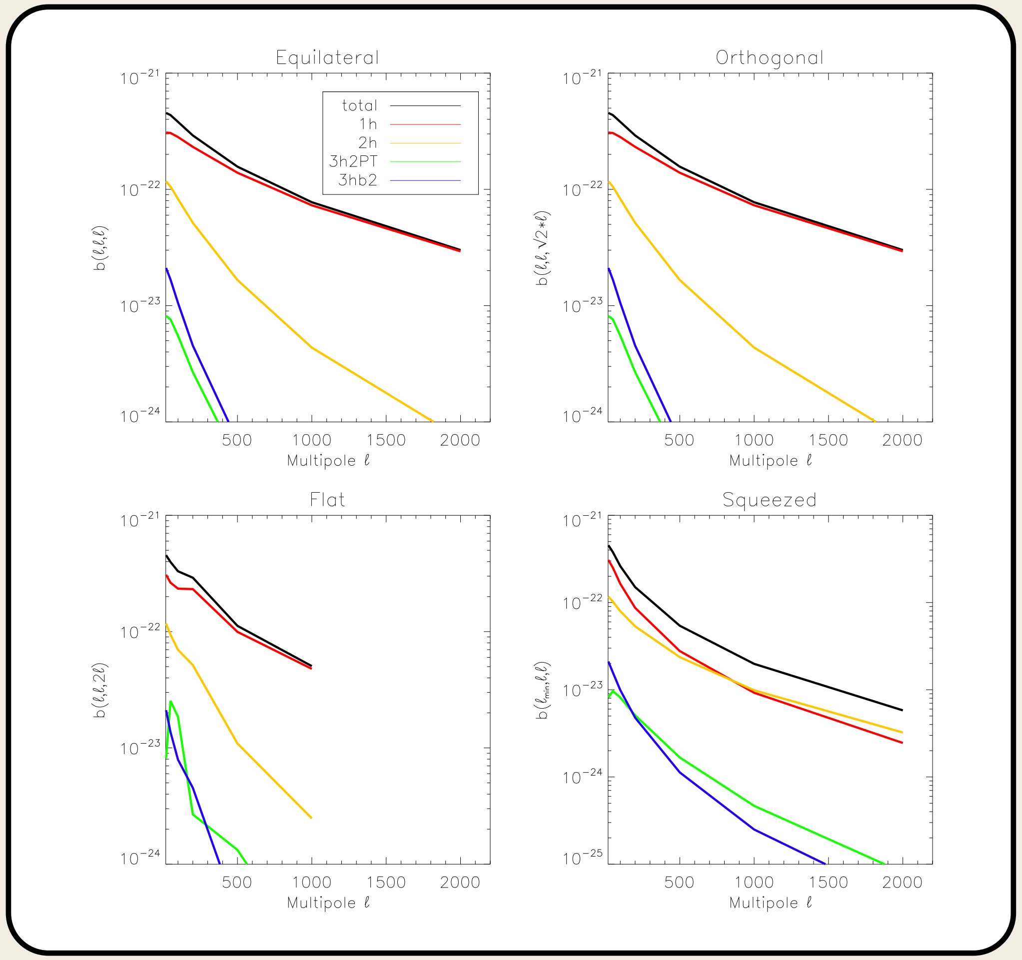
and later on their covariance matrix, to constrain tSZ physics and cosmology : σ_8 and Ω_m (possibly also neutrinos, MG, f_{NL})

Preliminary results

including 1-halo, 2-halo an 3-halo terms

Find that 1h dominates, except on large scales and in squeezed triangles

Consistent with expectations from power spectrum



in progress...

Combining probes for *DES*

A. Covariance of the galaxy spectrum and cluster counts

Cluster count is the monopole of the halo density field

$$\hat{N}_{\rm cl}(i_M, i_z) = \overline{N}_{\rm cl}(i_M, i_z) + \frac{1}{\Omega_S} \int dM\, d^2\hat{n}\, dz\, r^2 \frac{dr}{dz} \frac{d^2 n_h}{dM\, dV}\, \delta_{\rm cl}(\mathbf{x}, z|M, z)$$

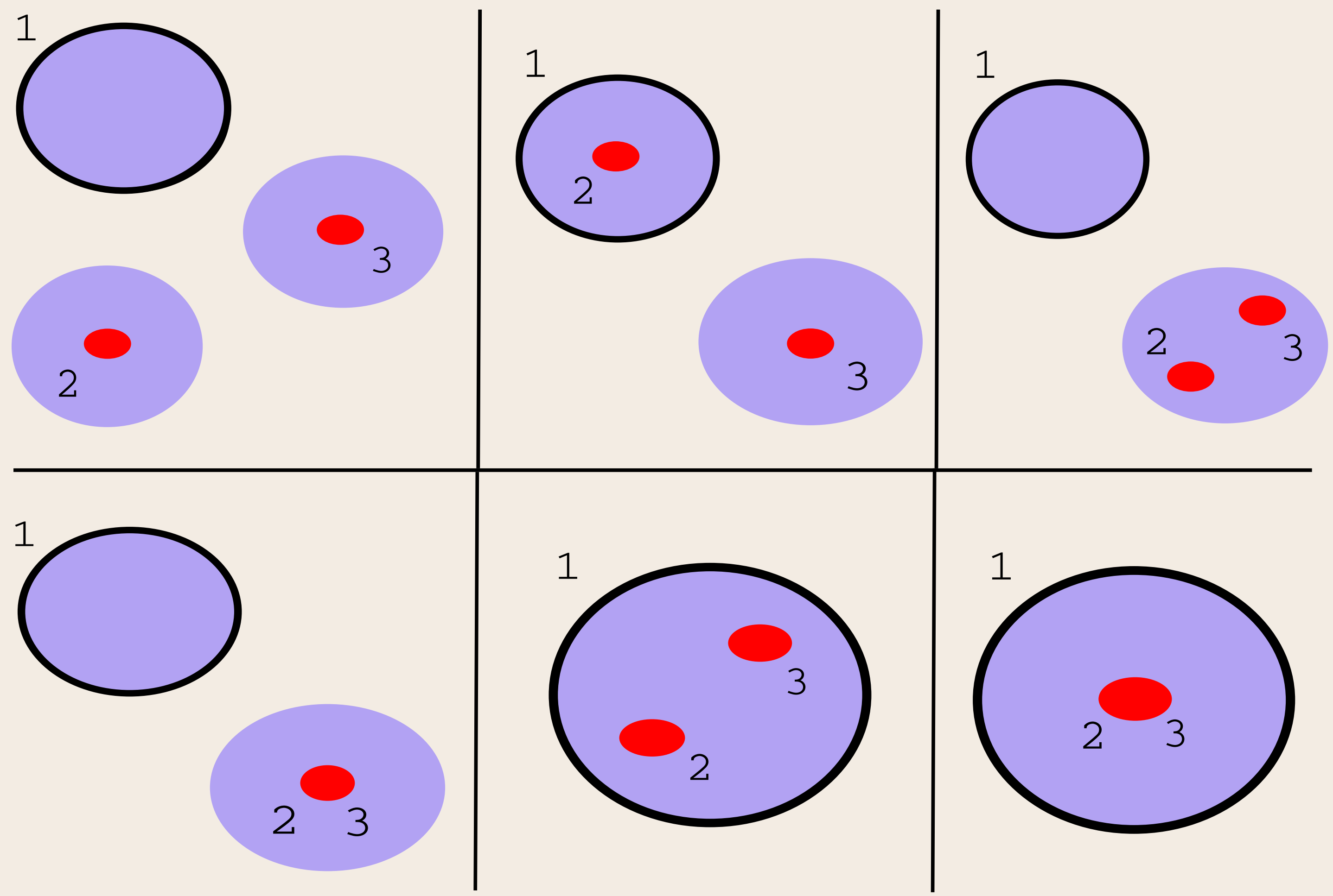
$$\mathrm{Cov}\left(\hat{N}_{\rm cl}(i_M, i_z), \hat{C}_\ell^{\rm gal}(j_z, k_z)\right) = \int \frac{dM_1\, dz_{123}}{4\pi} \frac{dV}{dz_1} \left.\frac{d^2 n_h}{dM\, dV}\right|_{M_1, z_1} b_{0\ell\ell}^{\rm hgg}(M_1, z_{123})$$

Galaxy angular power spectrum between two redshift bins

Cluster count in a bin of mass (i_M) and redshift (i_z)

Halo-galaxy-galaxy angular bispectrum

A. Diagrammatic method for the hgg bispectrum

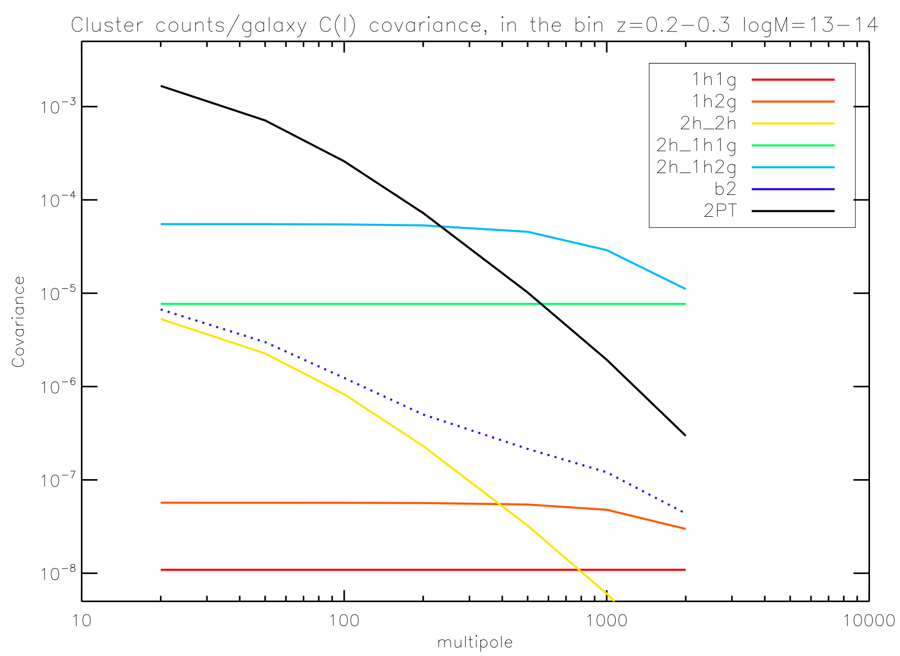


Ex: $$B_{\rm hgg}^{2h-1h2g}(k_{123}|M_1,z_{123}) = \frac{\delta_{z_2,z_3}}{\overline{n}^2_{\rm gal}(z_2)}\int dM\,\frac{d^2n_h}{dM\,dV}\langle N_{\rm gal}(N_{\rm gal}-1)(M)\rangle\,u(k_2|M)\,u(k_3|M)\,P_{\rm halo}(k_1|M_1,M,z_1,z_2)$$

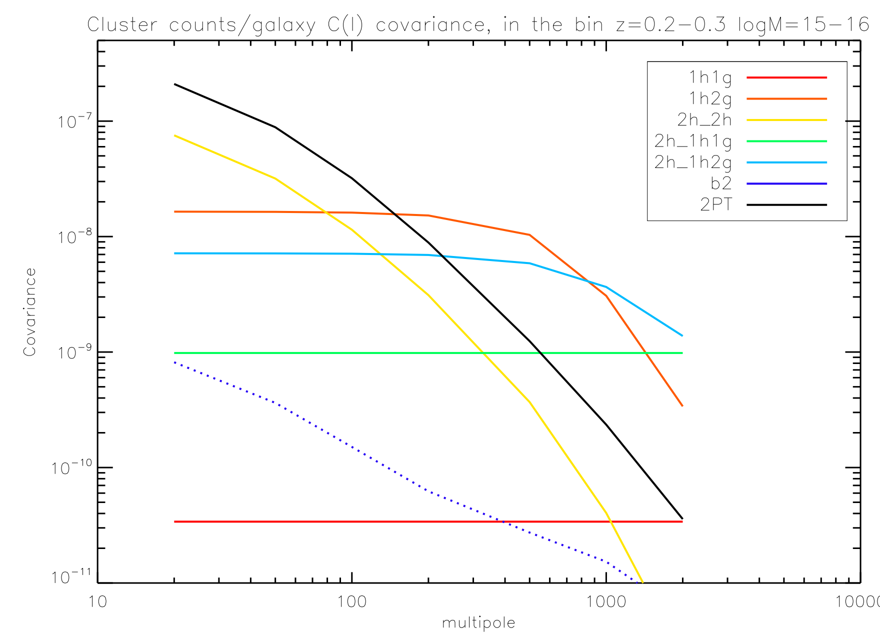
Ingredients : cosmology, halo model, Halo Occupation Distribution (HOD)

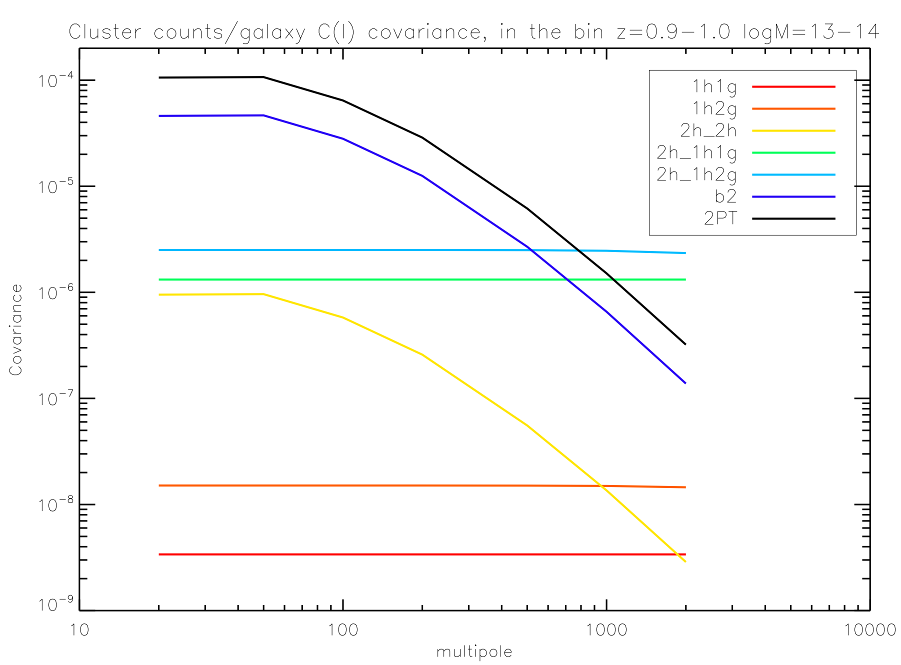
A. Ideal results I : scale dependence of the covariance

1



2





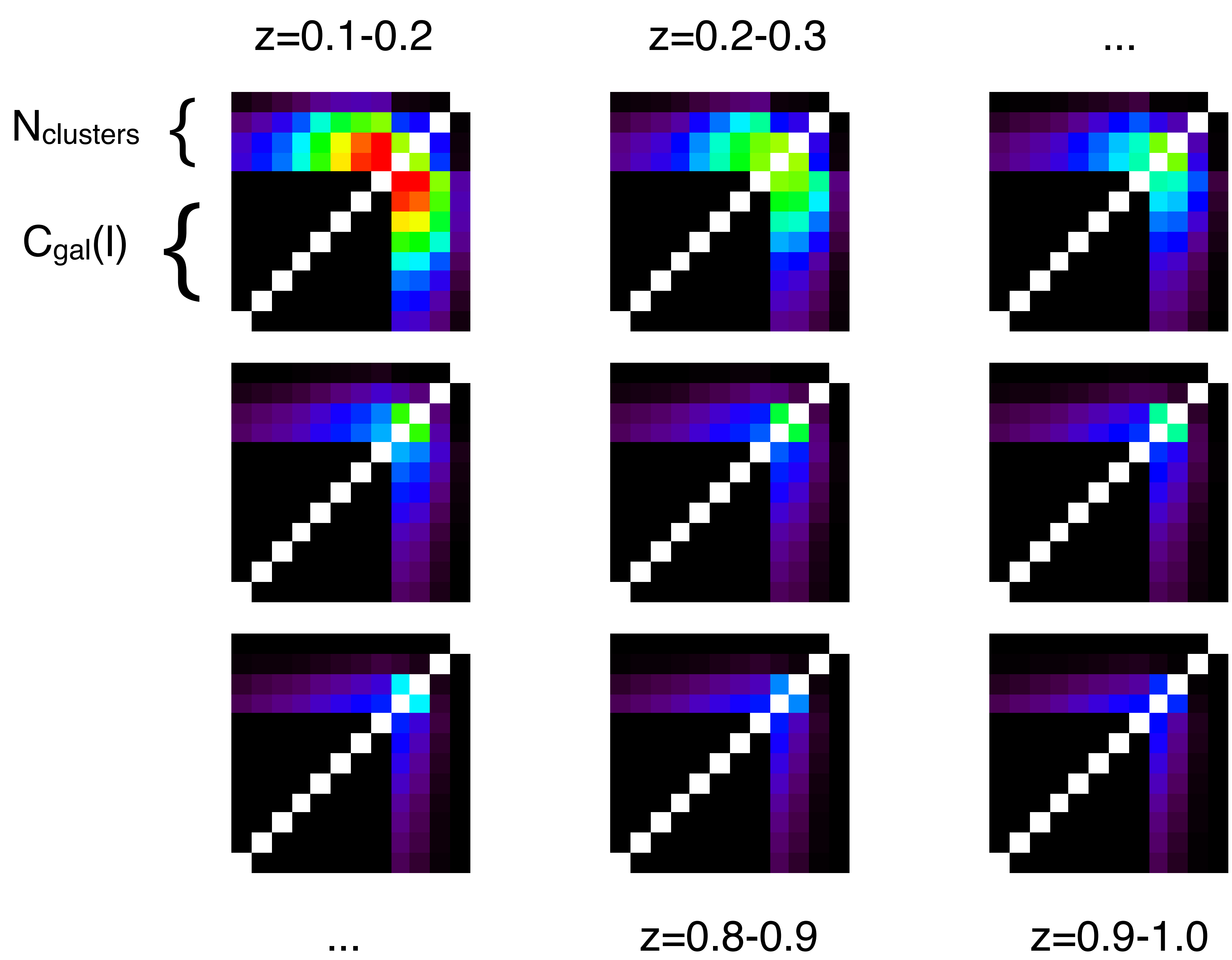
3

1 : z=0.2-0.3 and log(M/M_{sun}) = 13-14

2 : z=0.2-0.3 and log(M/M_{sun}) = 15-16

3 : z=0.9-1.0 and log(M/M_{sun}) = 13-14

A. Ideal results II : joint covariance matrix



B. Joint likelihood

Cluster counts follow a Poisson distribution
Galaxy correlation is more Gaussian

→ How to mix their likelihood ?
(cannot assume that the joint likelihood is Gaussian)

Edgeworth / Gram-Charlier expansion

$$P(x) = \exp\left[\sum_{n=1}^{+\infty} \left(\kappa_n(P) - \kappa_n(P_{\mathrm{fidu}})\right) \frac{(-1)^n}{n!} \frac{d^n}{dx^n}\right] P_{\mathrm{fidu}}(x)$$

Expand around independent case. Result :

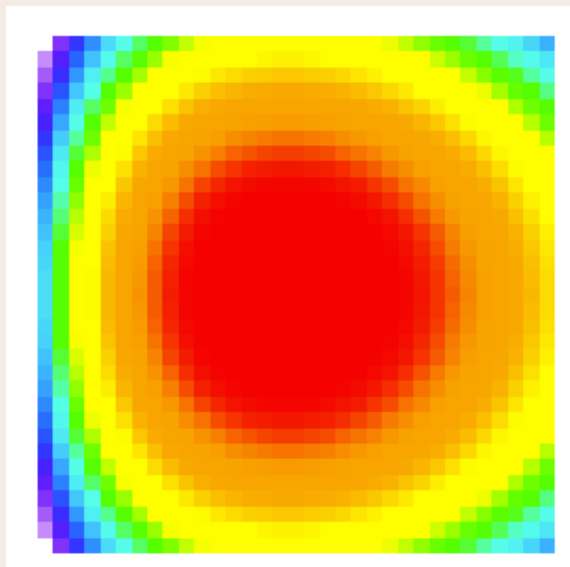
$$\mathcal{L}(\mathrm{counts}, C_\ell) = \exp\left[-\sum_{ij} \langle c_i\, C_{\ell_j} \rangle_c \left(\log \bar{c}_i - \Psi(c_i + 1)\right) \left({}^T C_\ell\, C^{-1} e_j\right)\right] \mathcal{L}(\mathrm{counts}) \mathcal{L}(C_\ell)$$

B. Joint likelihood : functional form

without correlation | with correlation

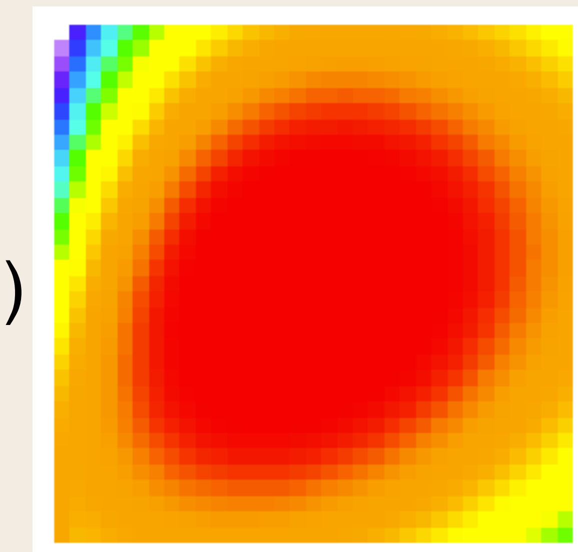
$\langle N_{clust}\rangle=16$

C(l)



0 counts 20

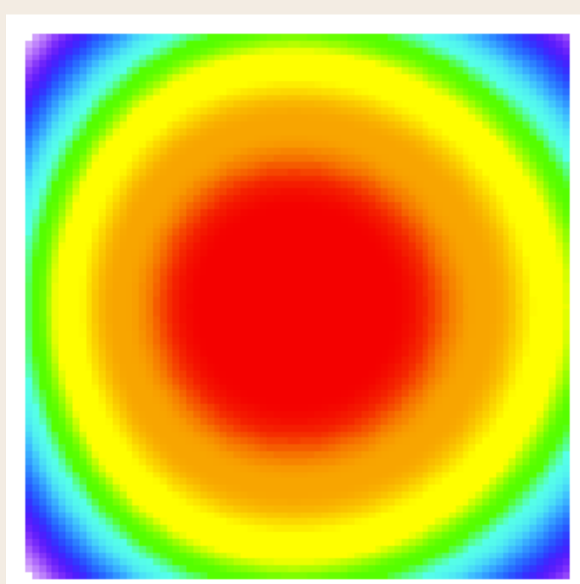
C(l)



0 counts 20

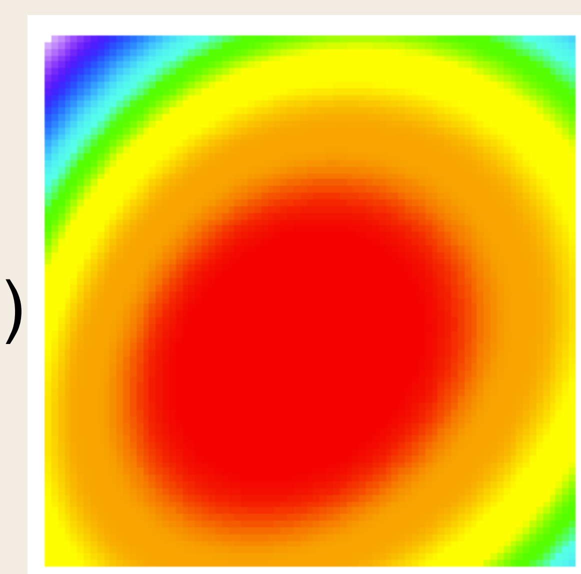
$\langle N_{clust}\rangle=100$

C(l)



60 counts 140

C(l)



60 counts 140

B. Joint likelihood : conclusions / perspectives

• large counts and small cross-covariance limit : Gaussian with correct covariance matrix

• is easily extended to include cluster sample covariance

• inclusion of Bayesian hyperparameters
→ robustness to tension and error estimates

• valid to combine any Gaussian and Poisson observables (e.g. weak-lensing/counts)

• Markov chain pipeline to be built

- for realistic forecasts
- application to *DES* data

Conclusions

• *Planck* yields high quality NG measurement for the Cosmic Infrared Background and for the thermal Sunayev-Zel'dovich effect

• Combining probes for galaxy surveys like *DES* also involves NG indirectly

• NG is an important tool to extract as much information as possible from Large Scale Structure observables in the present and for the future.

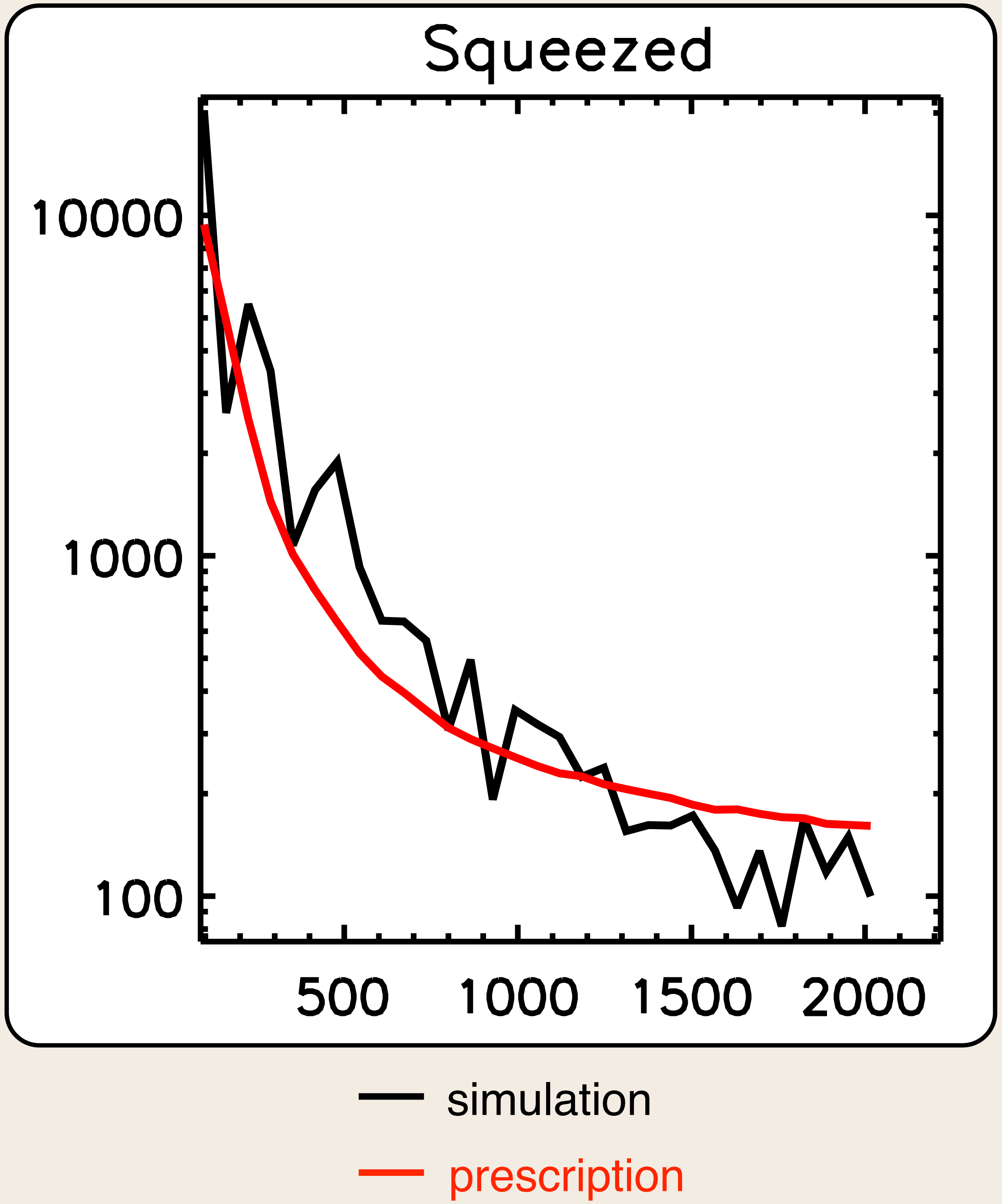
Thanks for your attention

CIB phenomenological NG prescription

- analytical prescription for clustered sources

$$b_{\ell_1\ell_2\ell_3} = \alpha\sqrt{C_{\ell_1}C_{\ell_2}C_{\ell_3}} \quad \text{avec} \quad \alpha = \frac{\int S^3 \frac{dn}{dS}\,dS}{\left(\int S^2 \frac{dn}{dS}\,dS\right)^{3/2}}$$

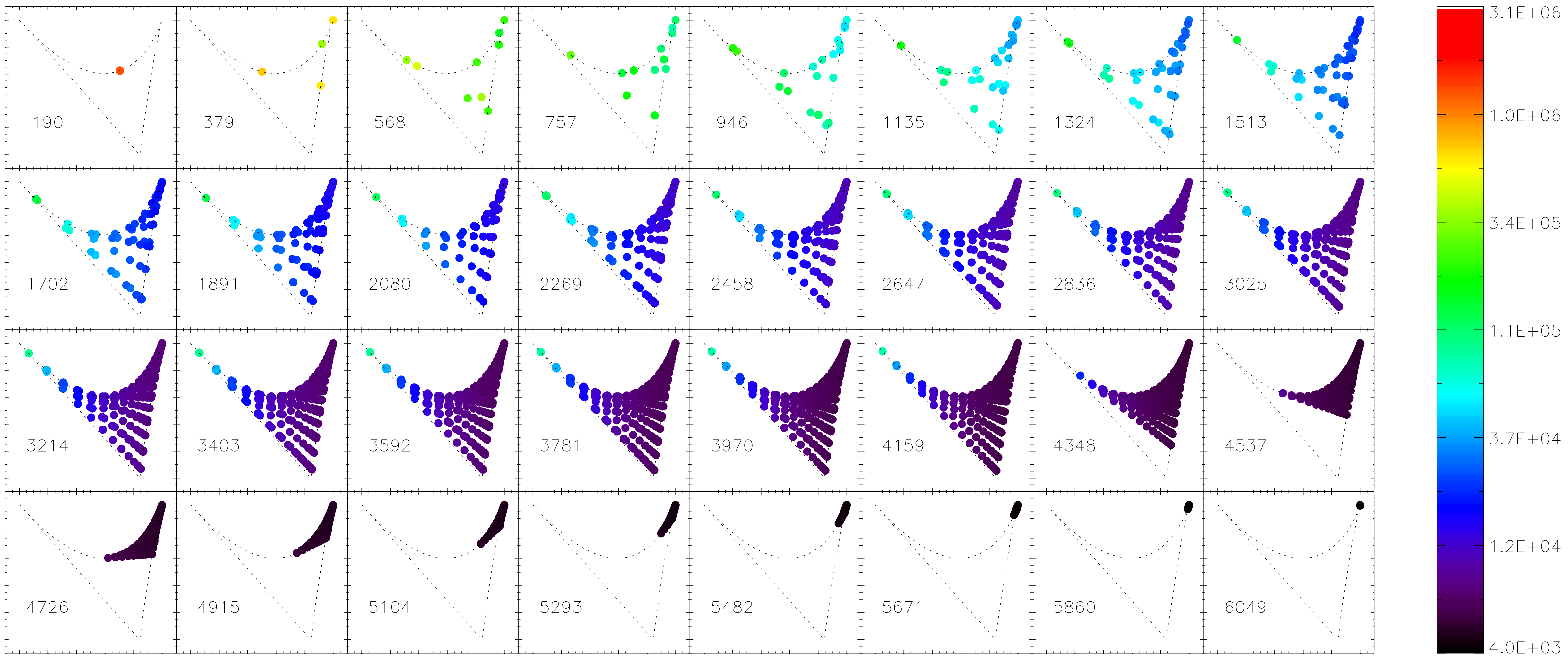
- based on moment of order 1 (counts) and 2 (spectrum)
- reproduces the CIB bispectrum on simulations (Sehgal et al. 2010)
- CIB bispectrum maximal in squeezed



Lacasa et al. 2012, MNRAS

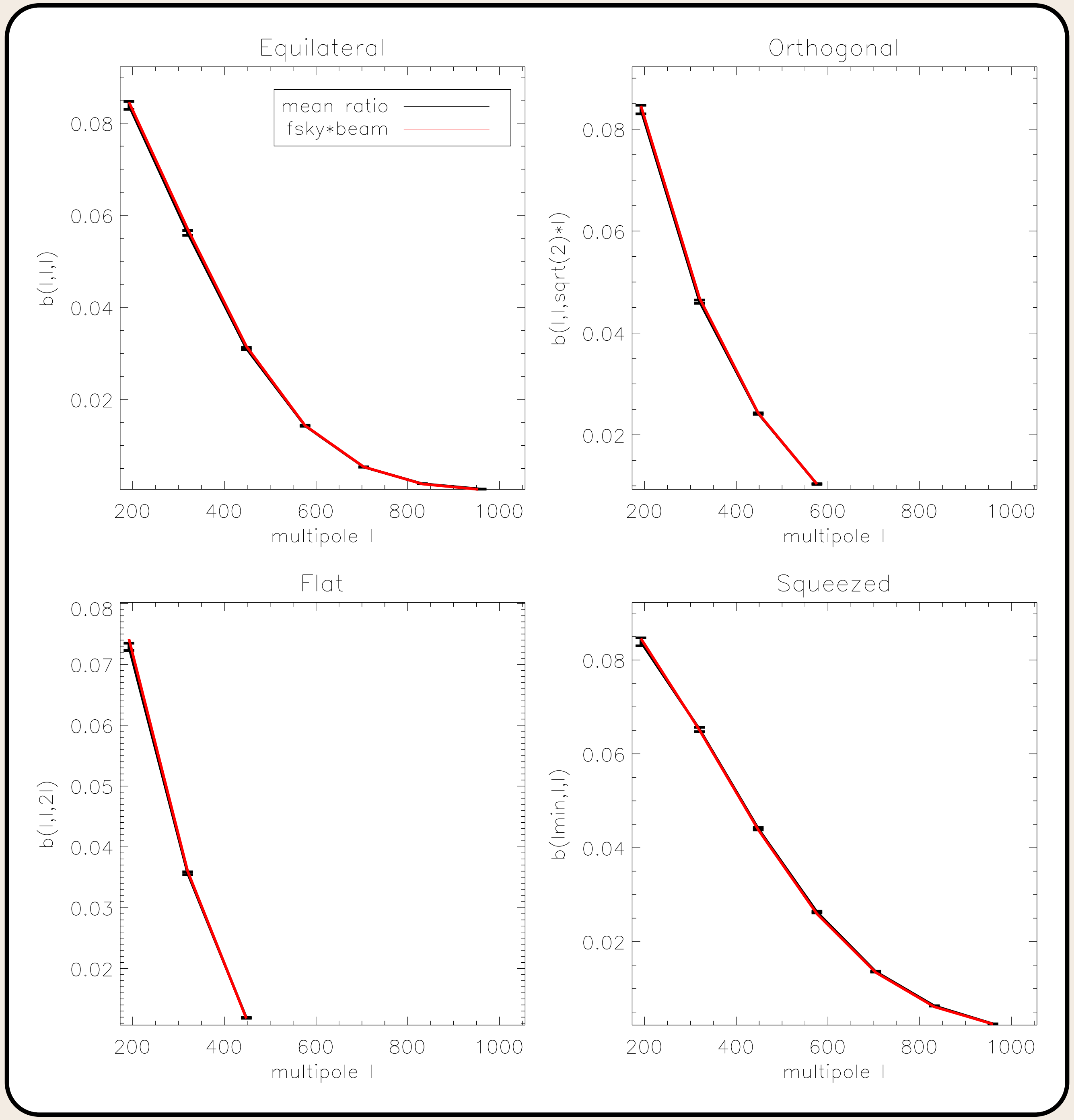
Configuration dependence of the CIB bispectrum : model

Total bispectrum



maximal in squeezed

CIB bispectrum : debiasing the mask effect

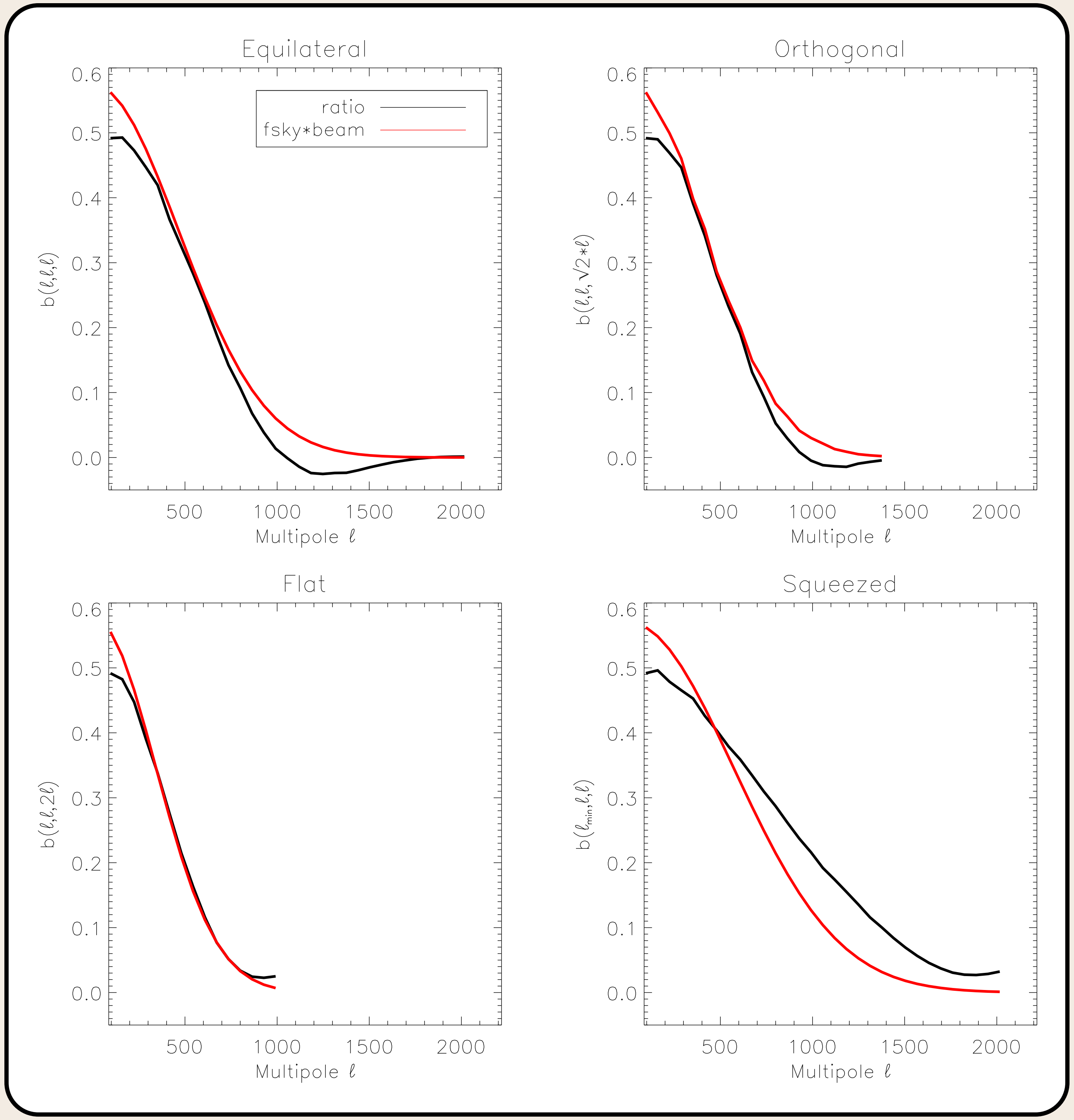


ratio full-sky bispectrum/ partial sky bispectrum on simulations with CIB prescription

simulations ratio

f_{SKY} * beam

tSZ bispectrum : debiasing the mask effect

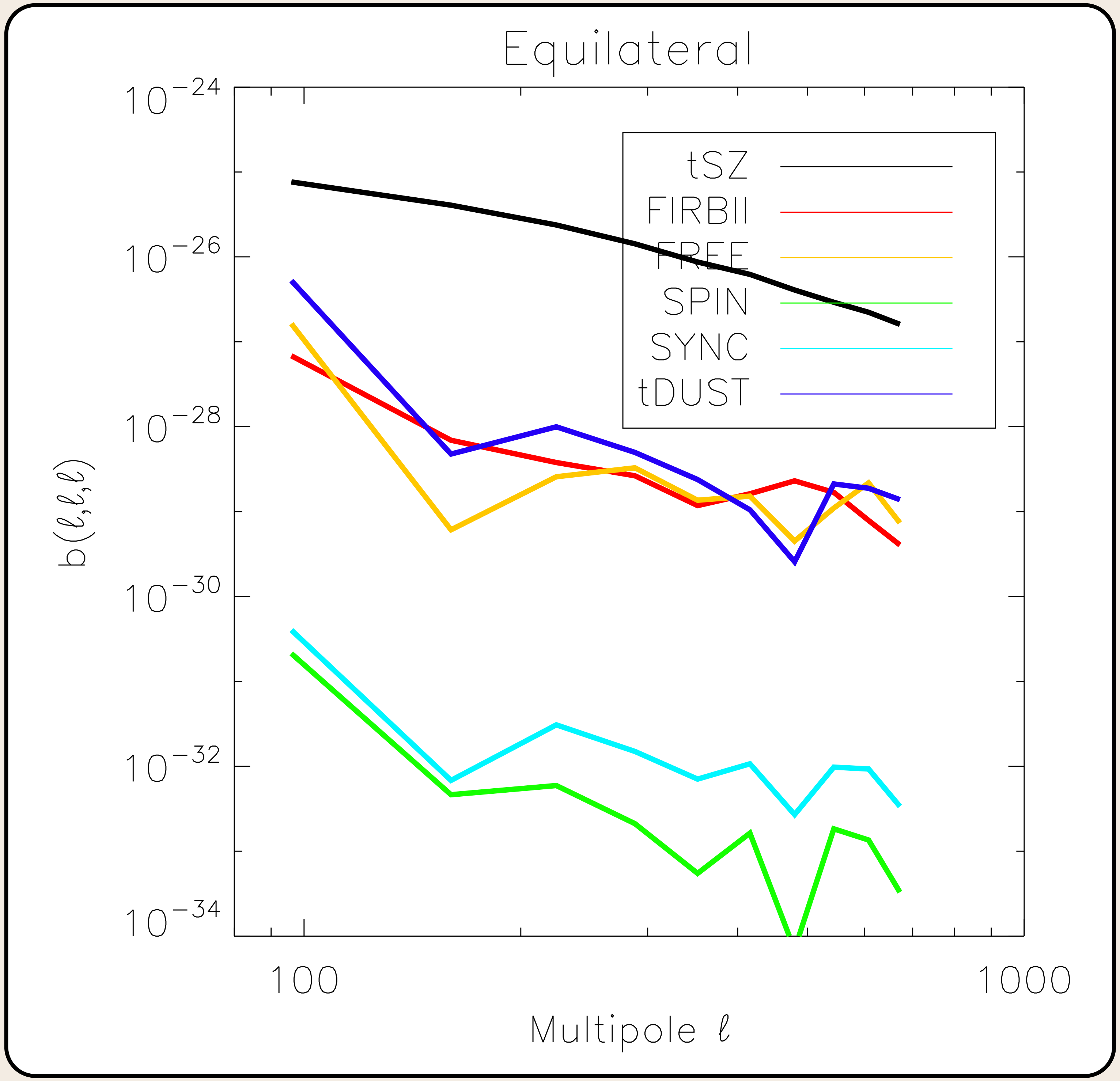


ratio full-sky bispectrum/ partial sky bispectrum on NG simulations reproducing the tSZ bispectrum

simulations ratio

f_{SKY} * beam

tSZ bispectrum : contamination by foregrounds



For MILCA :
Comparison of the tSZ bispectrum and of foreground residuals.
On *Planck* simulations

Planck Collaboration XXI 2013

Halo-galaxy-galaxy bispectrum : from 3D to 2D

$$b^{\rm hgg}_{0\ell\ell}(M_1, z_{123}) = \frac{\delta(z_2 - z_3)}{r_2^2 \frac{dr}{dz_2}} \frac{2}{\pi} \int k_1^2 dk_1 \, B_{\rm hgg}(k_1, k_2^*, k_2^* | M_1, z_1, z_2, z_2) \; j_0(k_1 r_1) \, j_0(k_1 r_2) \quad \text{with} \quad k_2^* = \frac{\ell + 1/2}{r(z_2)}$$

angular bispectrum

3D bispectrum

Bessel functions

Limber's approximation on k_2 and k_3

(bispectrum varies slowly compared to bessel's oscillations)

Ingredients

$$B_{\rm hgg}^{2h-1h2g}(k_{123}|M_1, z_{123}) = \frac{\delta_{z_2,z_3}}{\overline{n}^2_{\rm gal}(z_2)} \int dM \, \frac{d^2 n_h}{dM\, dV} \langle N_{\rm gal}(N_{\rm gal}-1)(M)\rangle \, u(k_2|M)\, u(k_3|M)\, P_{\rm halo}(k_1|M_1, M, z_1, z_2)$$

halo mass function
(Sheth&Tormen or Tinker)

Halo Occupation Distribution
(Tinker&Wetzel 2010)

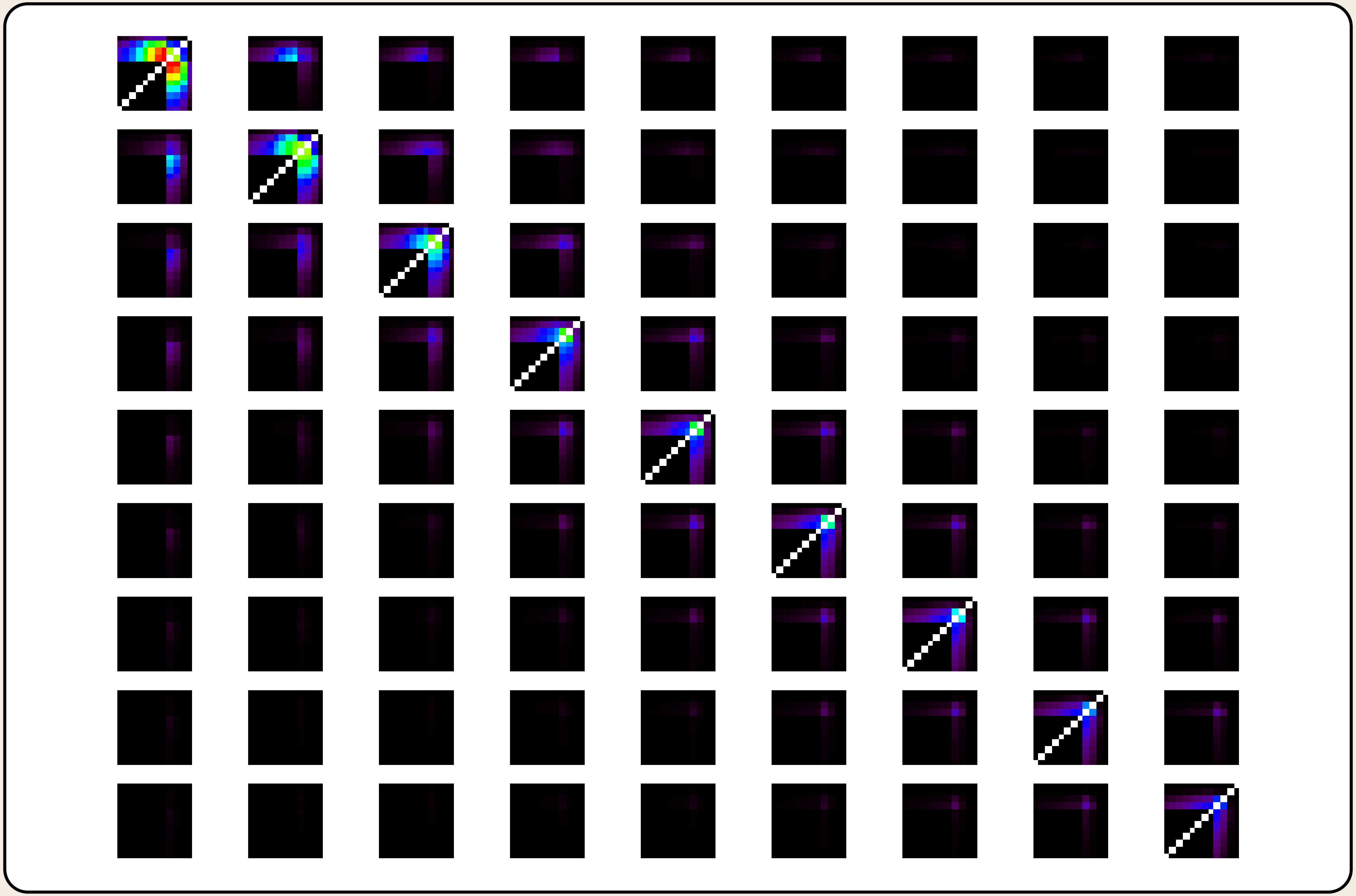
halo profile
(NFW)

halo bias
(Tinker : 1, Sheth&Tormen : 1&2)

matter power spectrum
(Eisenstein&Hu 98)

+ cosmology
(growth function, comoving volume...)

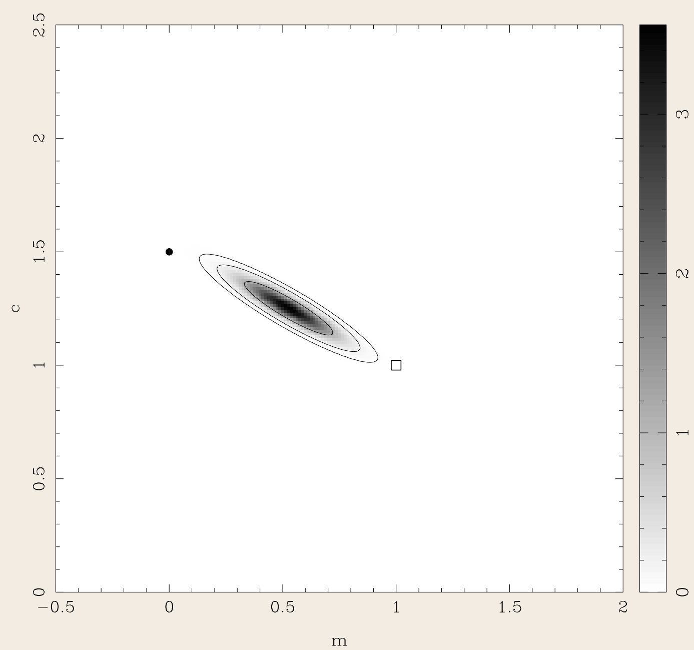
Counts - gal spectrum covariance, with cross-redshifts

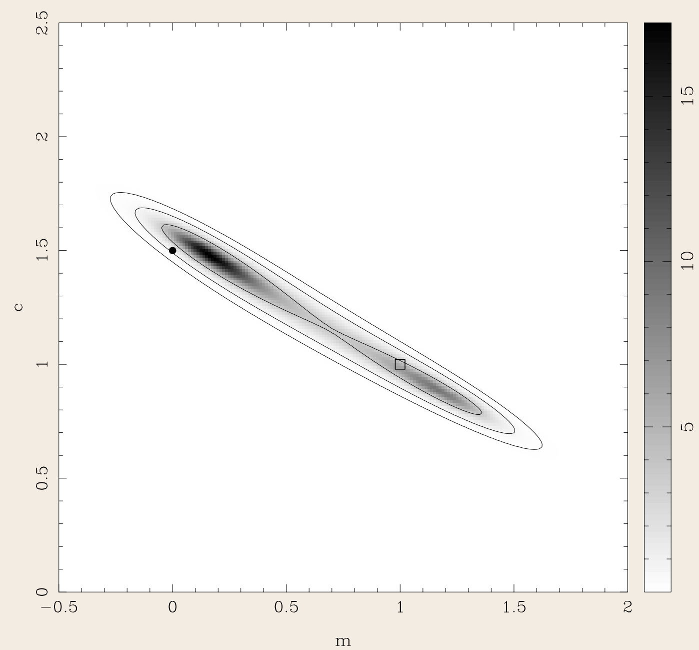


Bayesian hyperparameters

• Statistical method allowing to detect underestimation of error bars or inconsistencies between data sets

without HP





with HP

Hobson et al. 2002

• Idea : rescale error bars
one rescaling parameter per data set. These parameters are included in the MCMC exploration. Then marginalise over them.

• Only done for Gaussian distribution at the moment

Hyperparameters for a Poisson distribution

• not possible to satisfy all the properties of the Gaussian case
(i.e. keep the mean but rescale the variance)

• two possible approximate prescriptions
with a good asymptotic behaviour