

Redshift

0 0.1 0.5 1 2 1100

# Improved PNG constraints with Galaxy Clustering and ISW

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# Outline

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- Introduction
- **Data**: Galaxy clustering and correlation with CMB (ISW effect)
- **Systematics** analysis
- **Results** on PNG
- Extension to galaxy clusters
- Conclusion

TG, Ross et al., arXiv:1303.1349

Mana, TG et al., arXiv:1303.0287

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B. Nichol, J. Weller, M. Kilbinger, A. Mana, G. Hütsi

# An open window onto the early universe

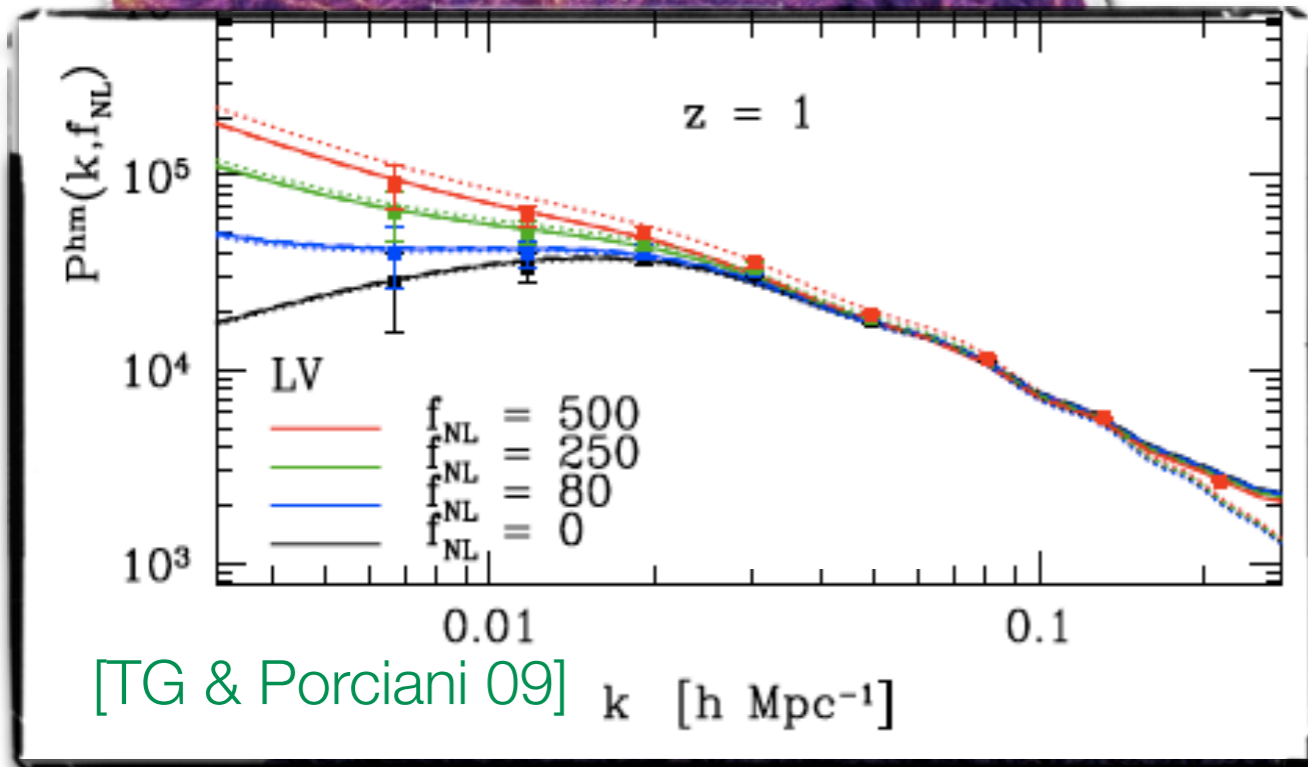
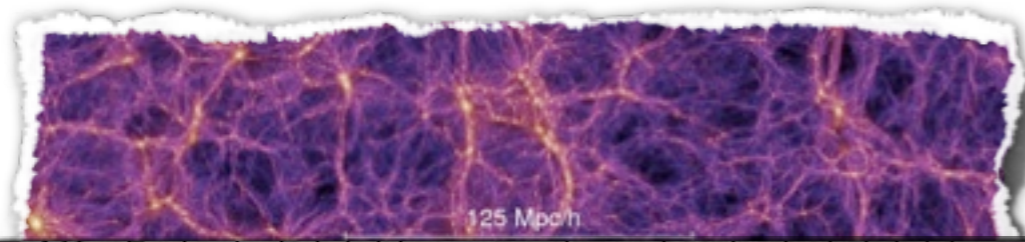
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- **(Too) many inflation models** available:
  - single / many field
  - slow or fast decay, what kinetic terms?
- Simplest single-field models predict:
  1. near-flatness ✓
  2. nearly scale-invariant power spectrum ✓
  3. curvature perturbations only ~ [Valiviita & TG 09]
  4. nearly Gaussian distribution ?  
Constraints by Planck
- Other models:  
 $\Phi$ : primordial potential;  $\phi$  Gaussian.  
Departure from Gauss:  $f_{\text{NL}}$ ,  $g_{\text{NL}}$

$$\Phi = \phi + f_{\text{NL}} \phi^2 + g_{\text{NL}} \phi^3$$



# Primordial Non-Gaussianity and the LSS



[Millennium run, Springel et al. 09]

- Dark matter  $\delta_m$ ; haloes  $\delta_h$ ; galaxies  $\delta_g$
- At linear level:
  - halo bias,  $\delta_h = b_h \delta_m$
  - galaxy bias,  $\delta_g = b_g \delta_m$
- With local Primordial Non-Gaussianity: scale-dependent, **non-local**  $b$  [Dalal+07, Matarrese&Verde08,++]
- **Measure:** Spectra  $\langle \text{gal-gal} \rangle \sim b^2$  and  $\langle \text{gal-CMB} \rangle \sim b \rightarrow \text{PNG}$  [Slosar+08, Afshordi&Tolley08, Xia+10, 11, Ross+12, TG+13]

$$b(k, f_{\text{NL}}, g_{\text{NL}}) \approx b_{\text{Gauss}} + \beta_f \mathbf{f_{NL}} / \mathbf{k^2} + \beta_g \mathbf{g_{NL}} / \mathbf{k^2}$$

# Combined LSS+ISW data, updated [TG+ 08, 12, 13]

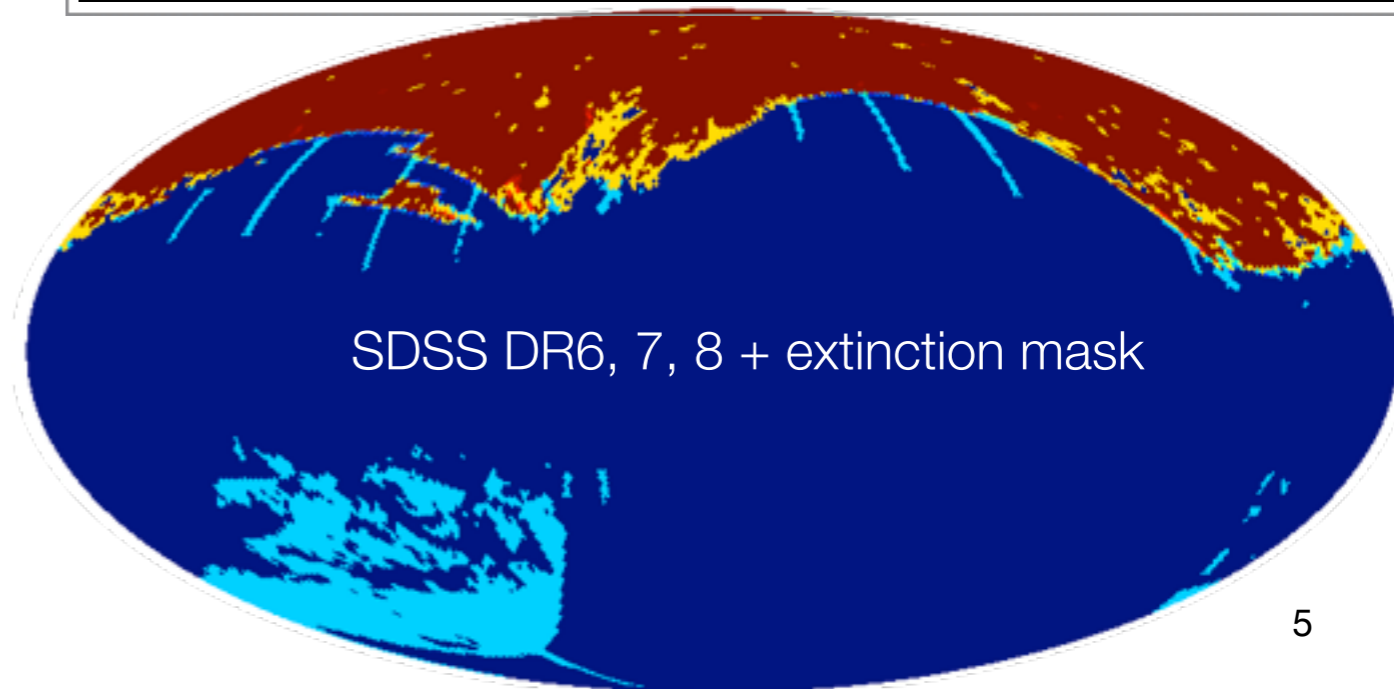
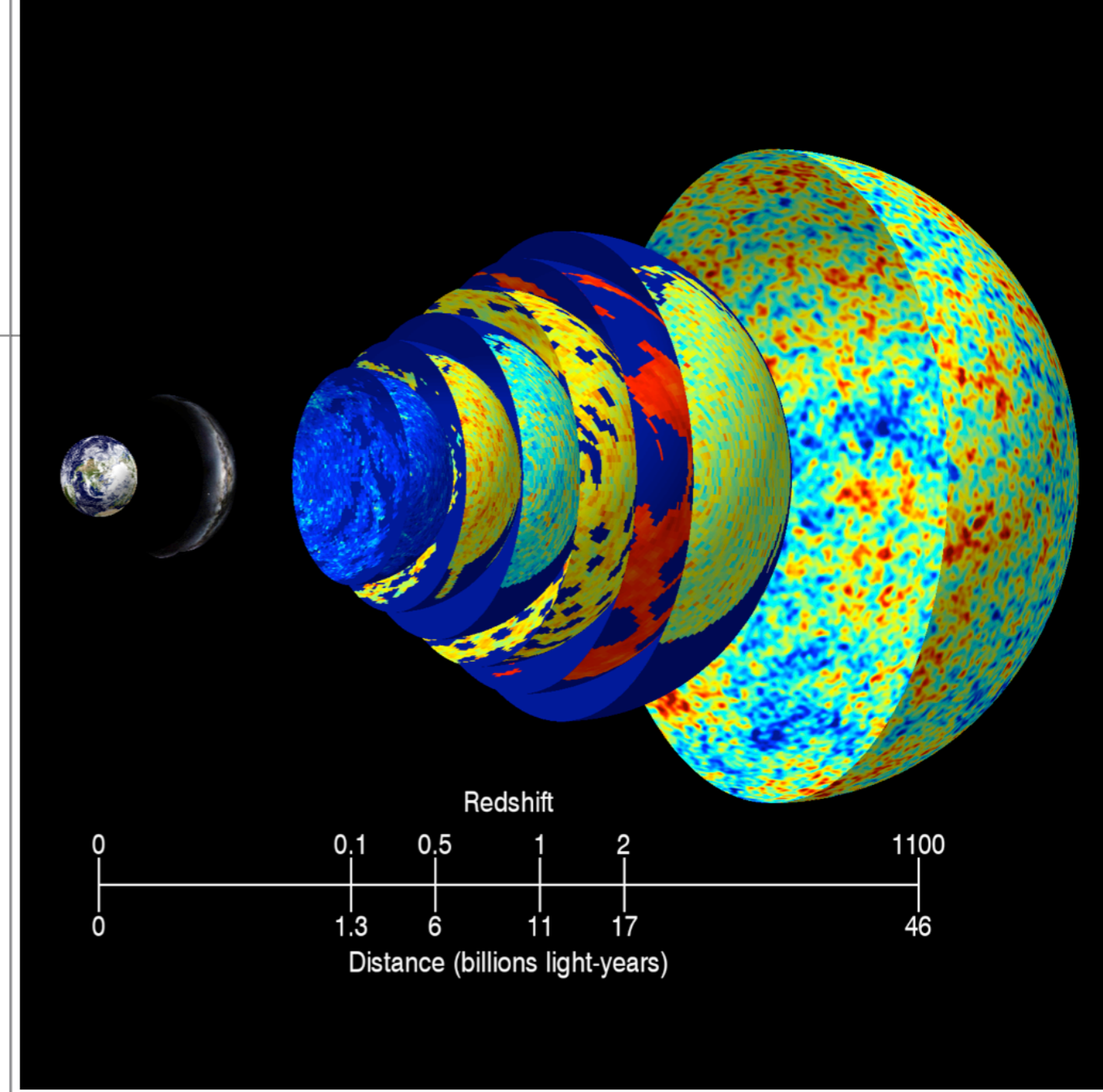
- **Data maps**

- **density**: 6 galaxy catalogues:
  - infra-red **2MASS**
  - optical **SDSS DR8**: (main galaxies, luminous red **LRG**, DR6 quasars)
  - radio **NVSS**
  - X-ray **HEAO**

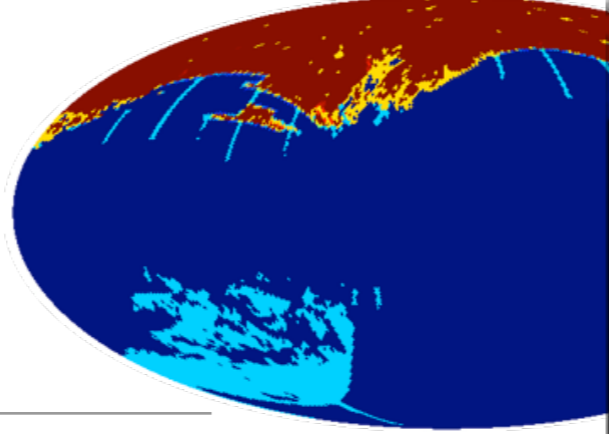
- **CMB temperature**: WMAP7

- **Masks**

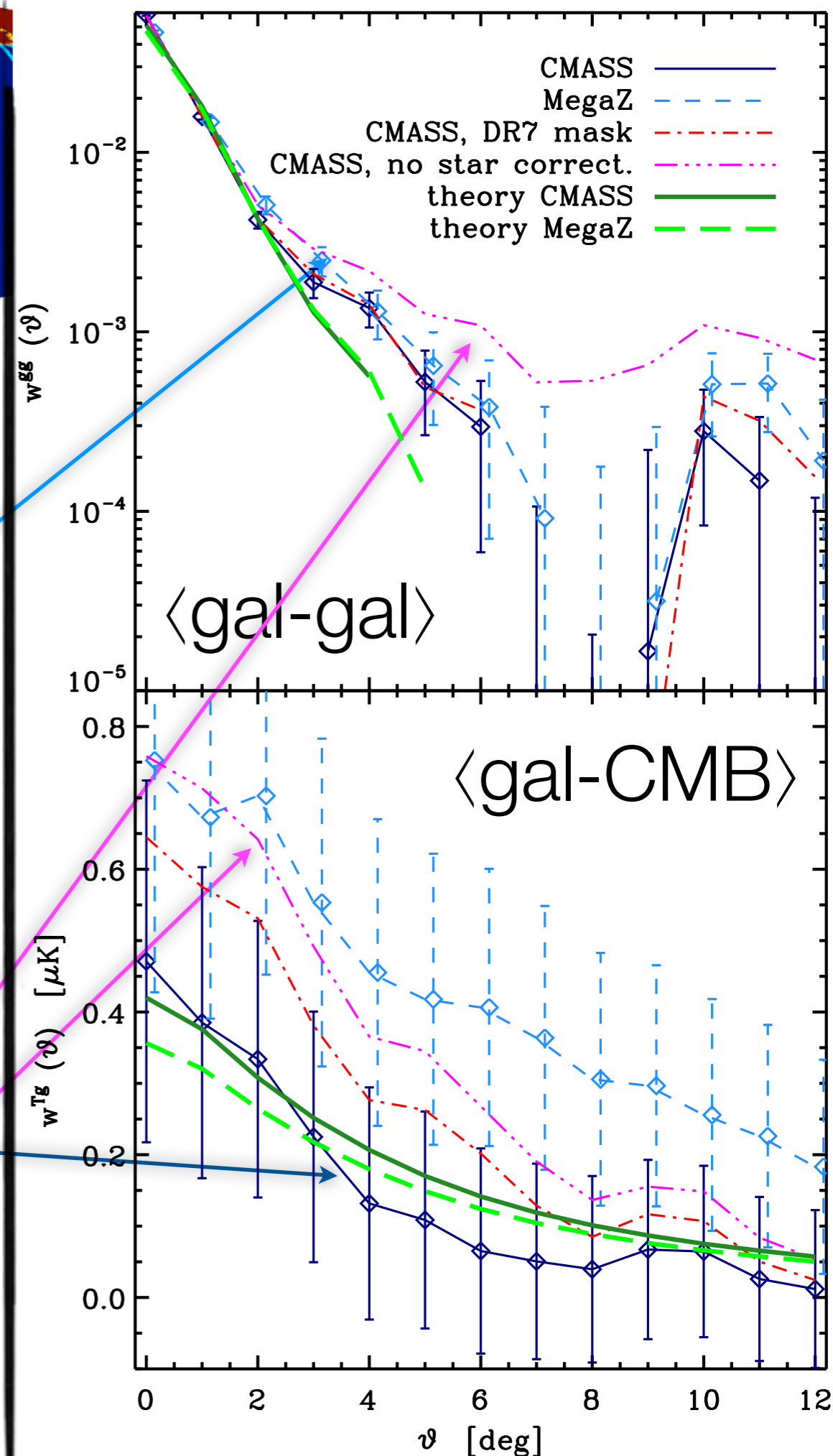
- survey geometry
- (galactic) foregrounds - **extinction**



# LRG systematics



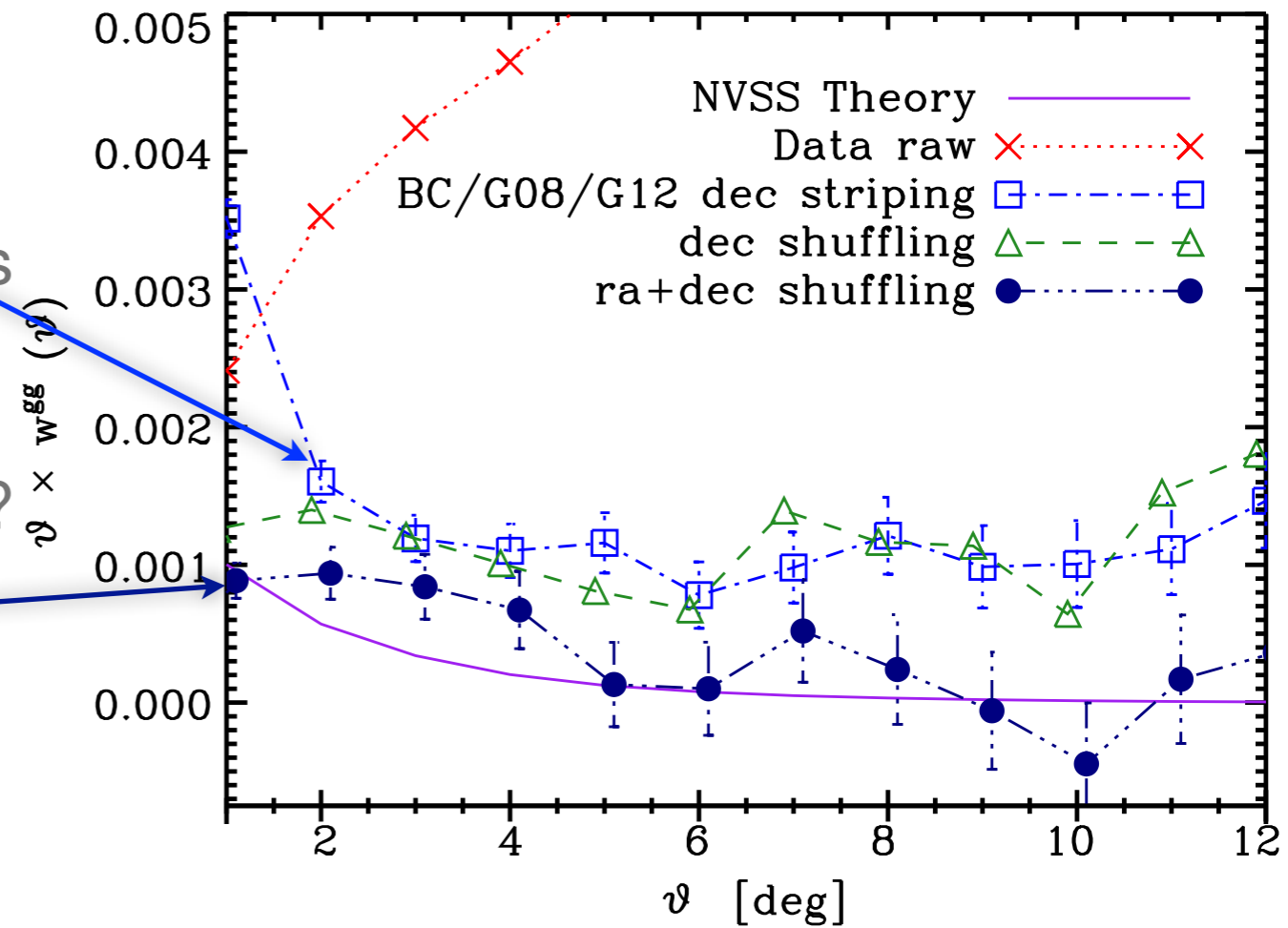
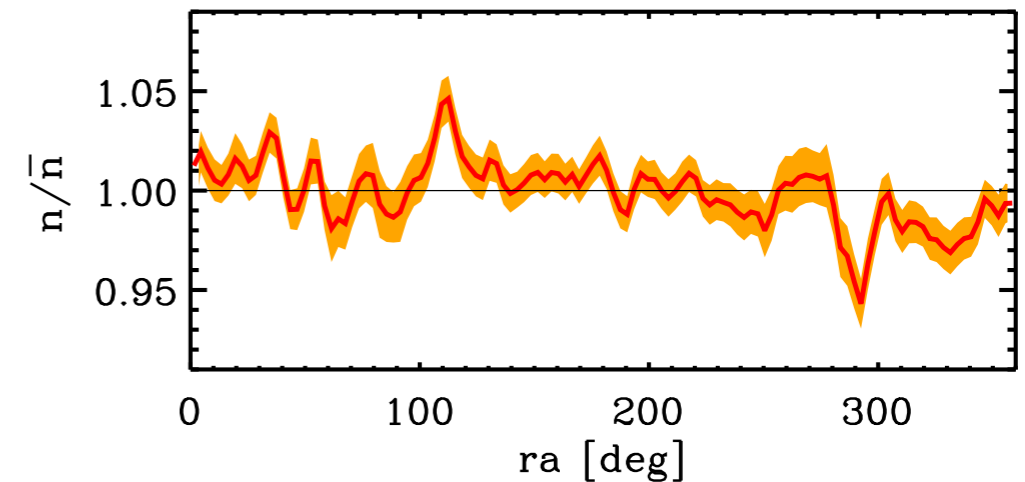
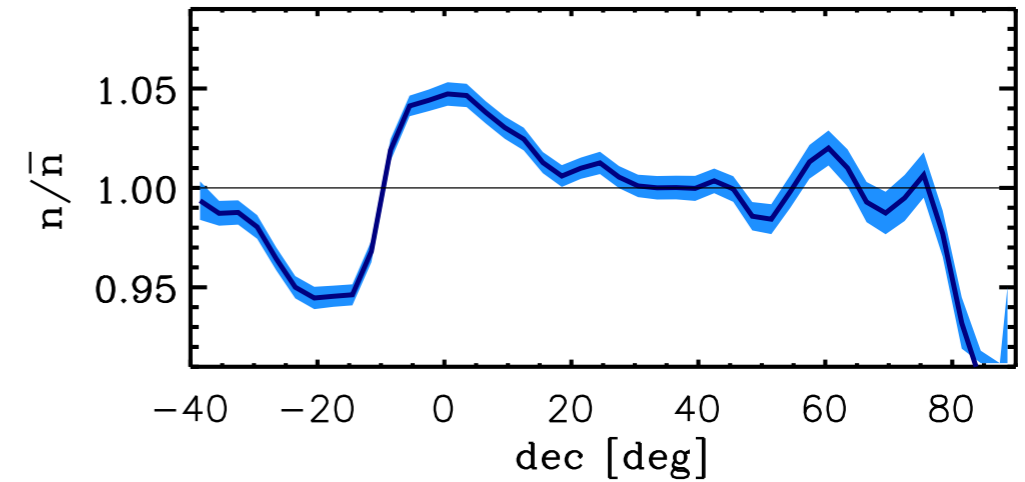
- Thomas et al. 10 **MegaZ** vs Ross et al. 11 SDSS DR8 photometric **CMASS**
- Similar redshift, CMASS South coverage
- **CMASS**: correction for stellar systematics
  - 15% with BOSS spectra
- **ACF**: **MegaZ** more power on large scales: stars or primordial?
- **CCF**: **CMASS** lower, in agreement with LCDM also **CMB frequency independent**
- If no star correction: higher ACF/CCF



CMASS suitable for  $f_{\text{NL}}$  analysis

# NVSS systematics

- Known problem: number density changes in dec & smaller r.a. effect
- Large effects on ACF. Corrections:
  - ‘Striping’ in dec bands and rescaling n density [Boughn&Crittenden01, Smith+ 08, TG+ 08, 12]
  - Cut Flux < 10 mJy [Blake+04, Xia+10, 11]
  - Give infinite variance to  $m = 0$  modes [Smith et al. 07]
- Arbitrary, results vary! Discard this ACF?
- ‘Shuffling’ Get r.a., dec modulating mask by randomly reassigning ra, dec

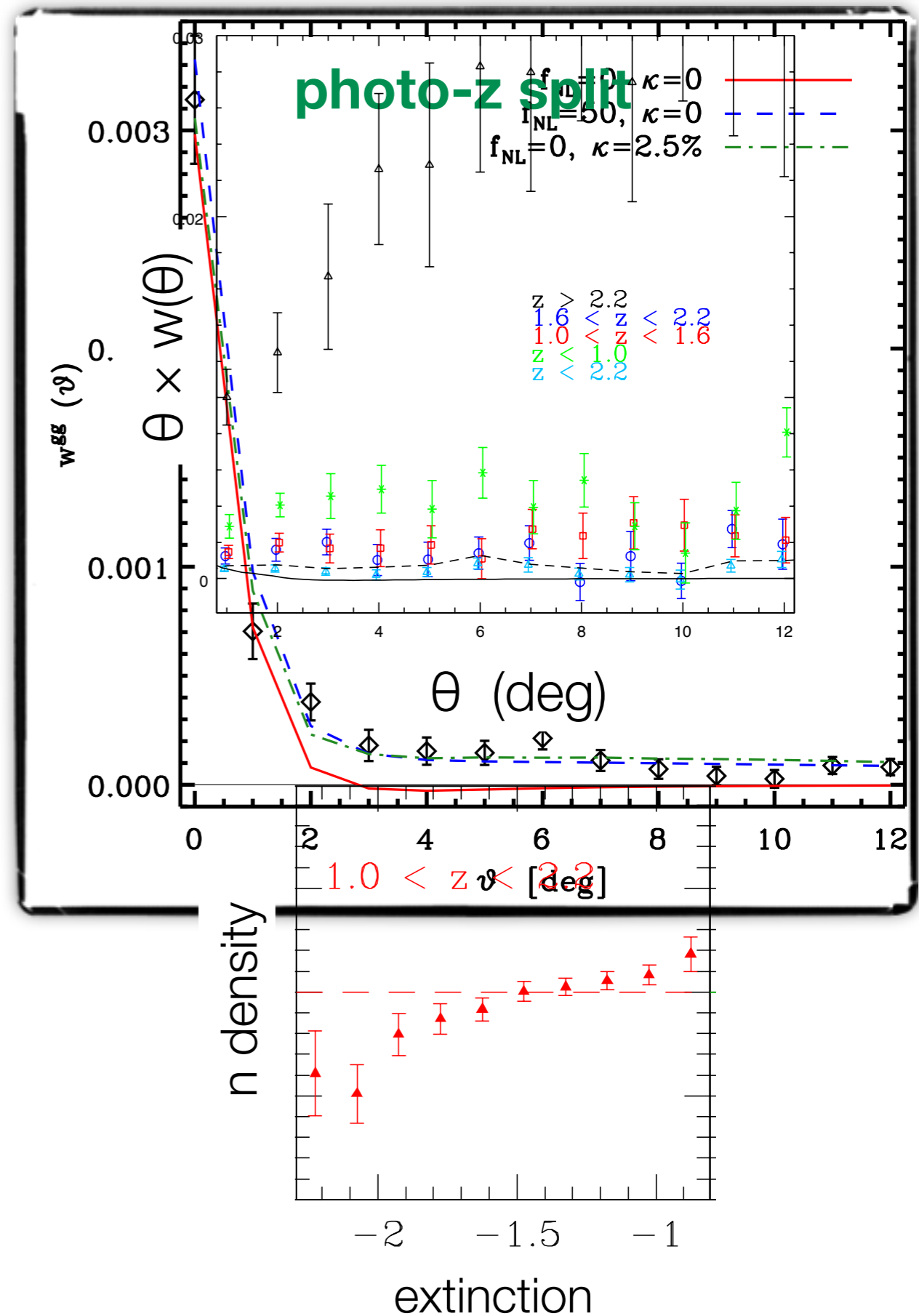


# Quasar systematics

- **Excess power at large angles**
- **Stellar contamination** fraction  $\kappa$
- Prior from  $\langle \text{qso-stars} \rangle$  correlation: does not solve (only  $\sim 1\%$ )
- Splitting by **photo-z** or **i-mag**: ACF unstable at large angles
- Splitting causes **correlation density-extinction and other systematics!**
- Remaining systematics

$$f_{\text{NL}} = 50 \sim \kappa = 2.5 \%$$

[Pullen & Hirata 12, Leistedt et al. 13]

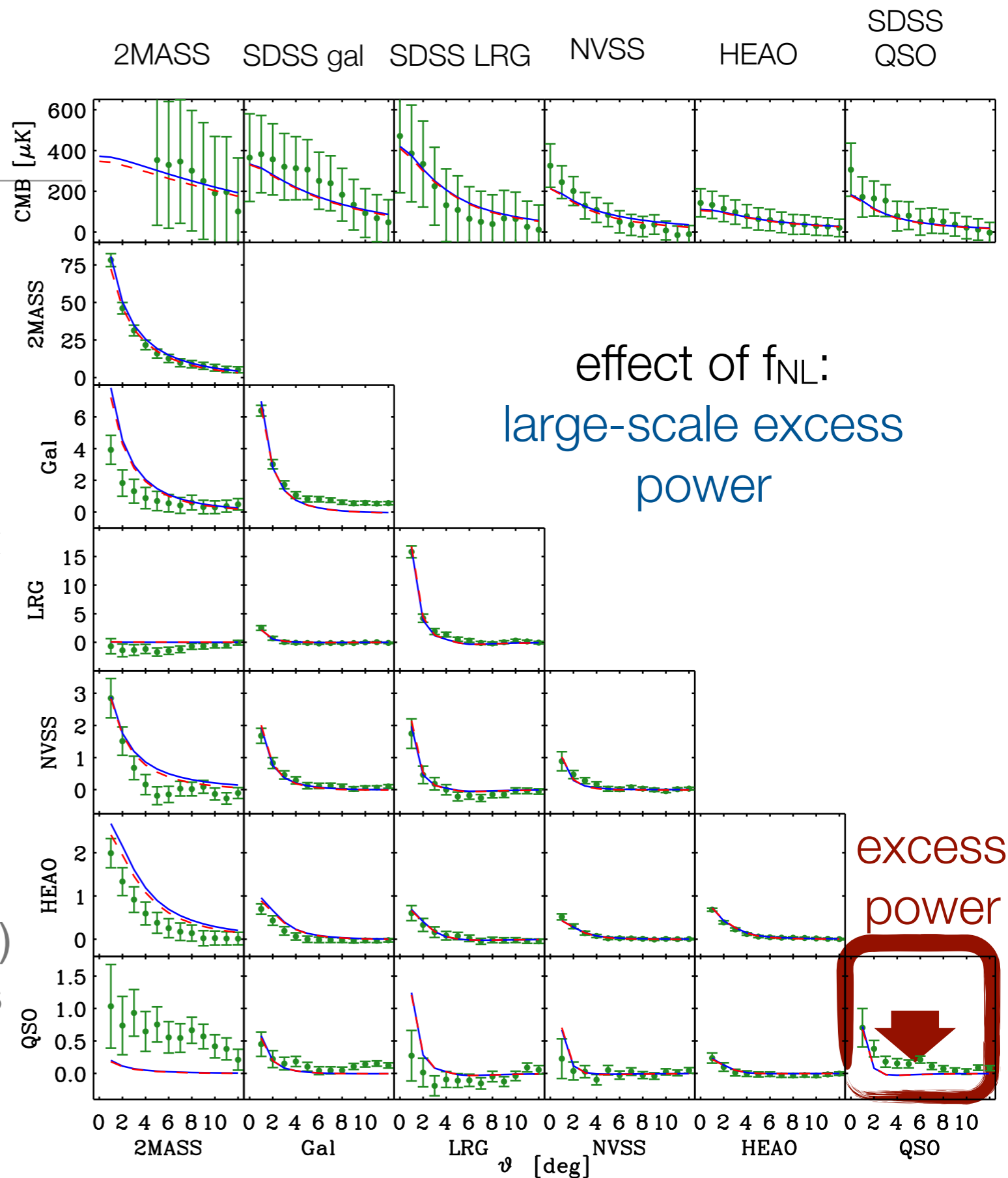


Discard quasar ACF



# Full bias analysis of LSS + ISW data & $f_{NL}$

- Measure (local)  $f_{NL}$  via (linear)  $b$
- All 27 2-pt functions
- $\langle Tg \rangle \propto b$ ,  $\langle gg \rangle \propto b^2$
- Gaussian bias:  $b_1^i(z) = 1 + \frac{b_0^i - 1}{D^{\gamma_i}(z)} 1000 \times w(\vartheta)$
- Nuisance parameters:  $dn/dz$  uncertainty, stars
- Full Covariance Matrix (351x351) from 10,000 Monte Carlo mocks
- Nested sampling: Multinest [Feroz et al. 09]



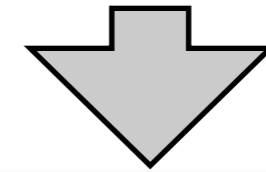
# What can we trust?

- Non-zero  $f_{NL}$  driven by **quasar** auto-correlations
- Not all data equally reliable: 3 results
  - **Full data**
  - **Ultra-conservative**: drop 2MASS, main gal, and all ACF except BOSS LRGs
  - **Fair**: drop only NVSS, QSO auto-correlation
- **Cross-correlations safer** than auto-correlations, keep them

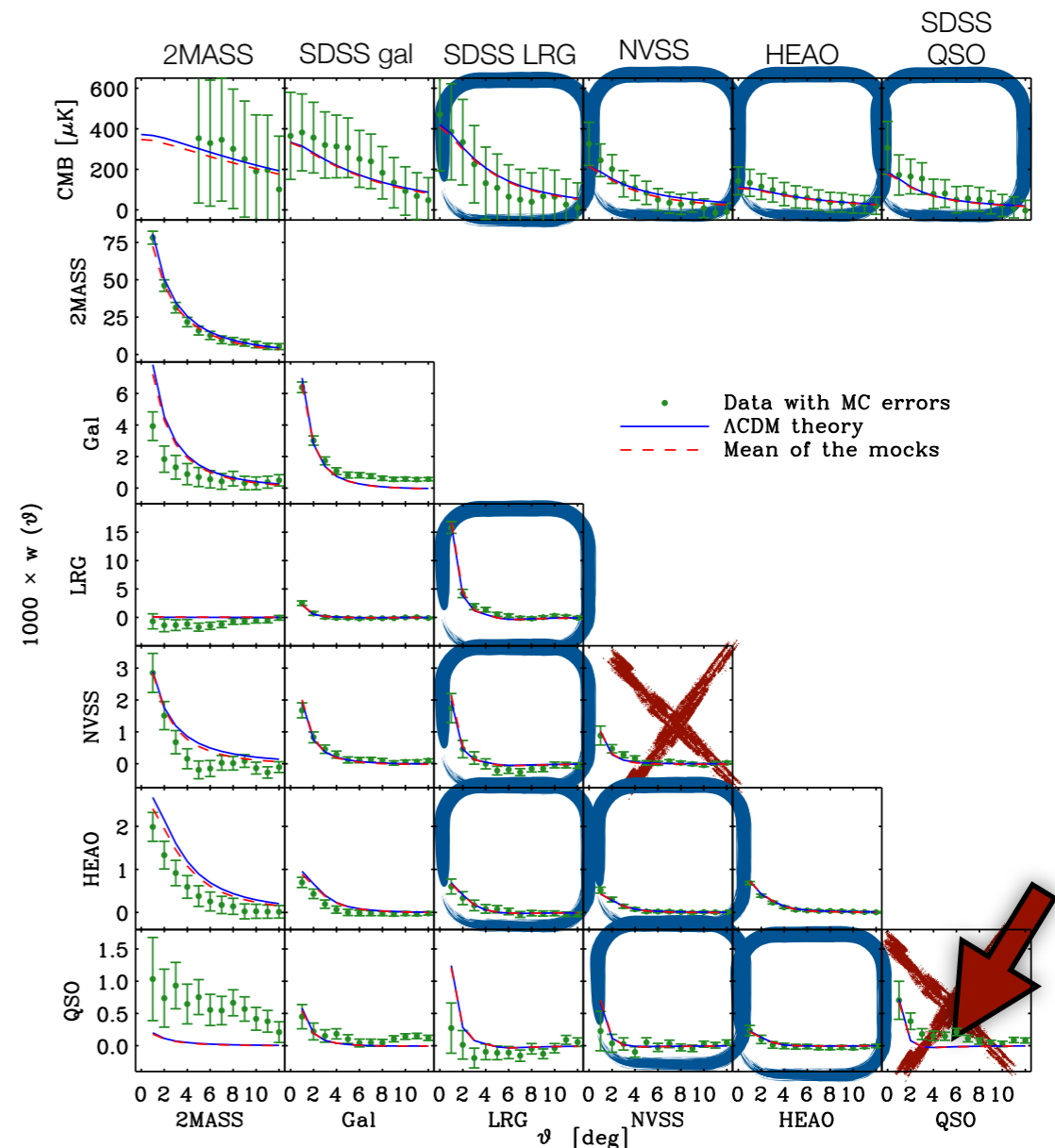
**NO evidence for non-Gaussianity!**

full, unreliable:  $30 < f_{NL} < 62$  @95%

ultra-conservative:  $-37 < f_{NL} < 25$  @95%



'fair':  $-29 < f_{NL} < 31$  @95%

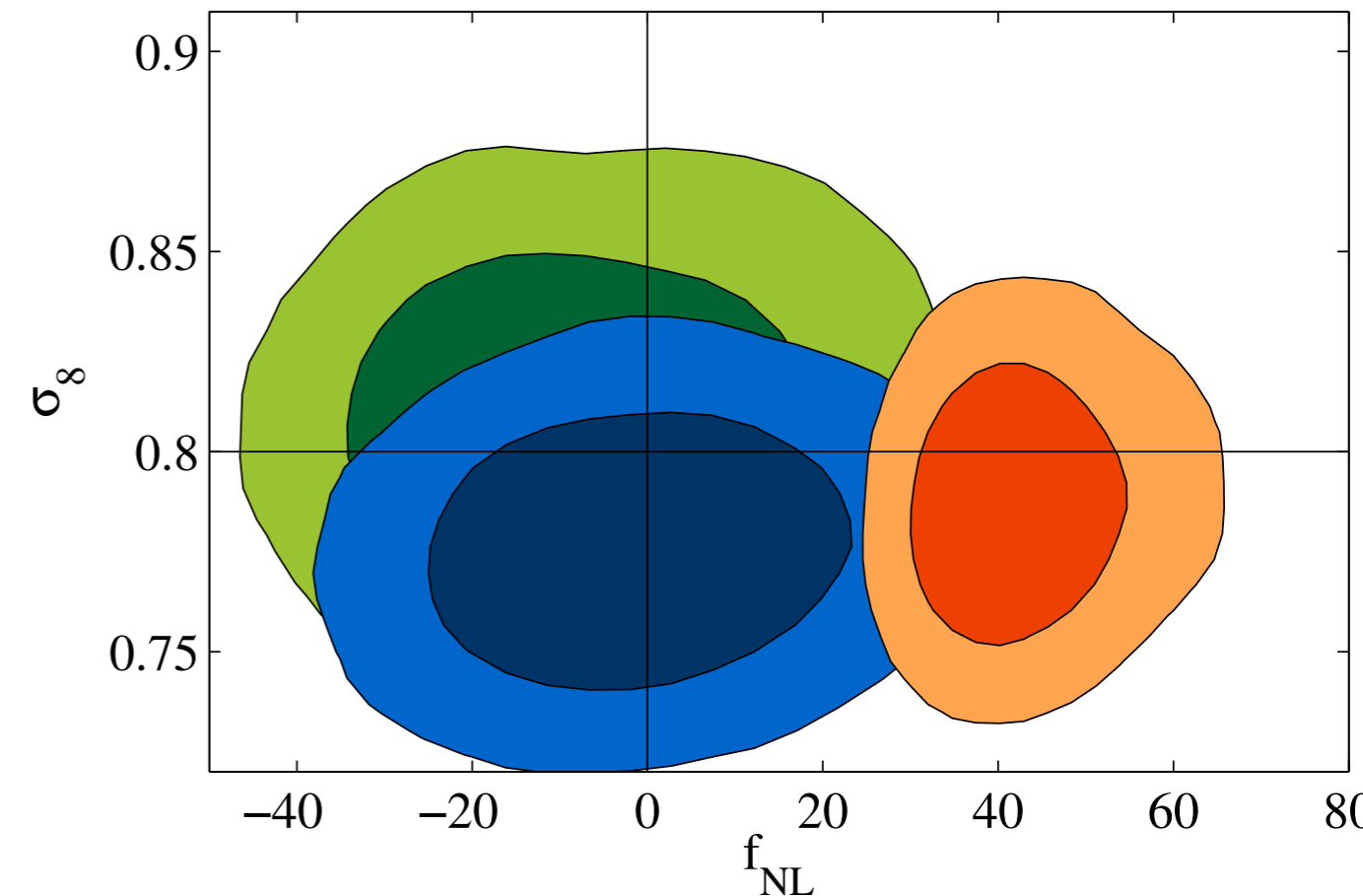
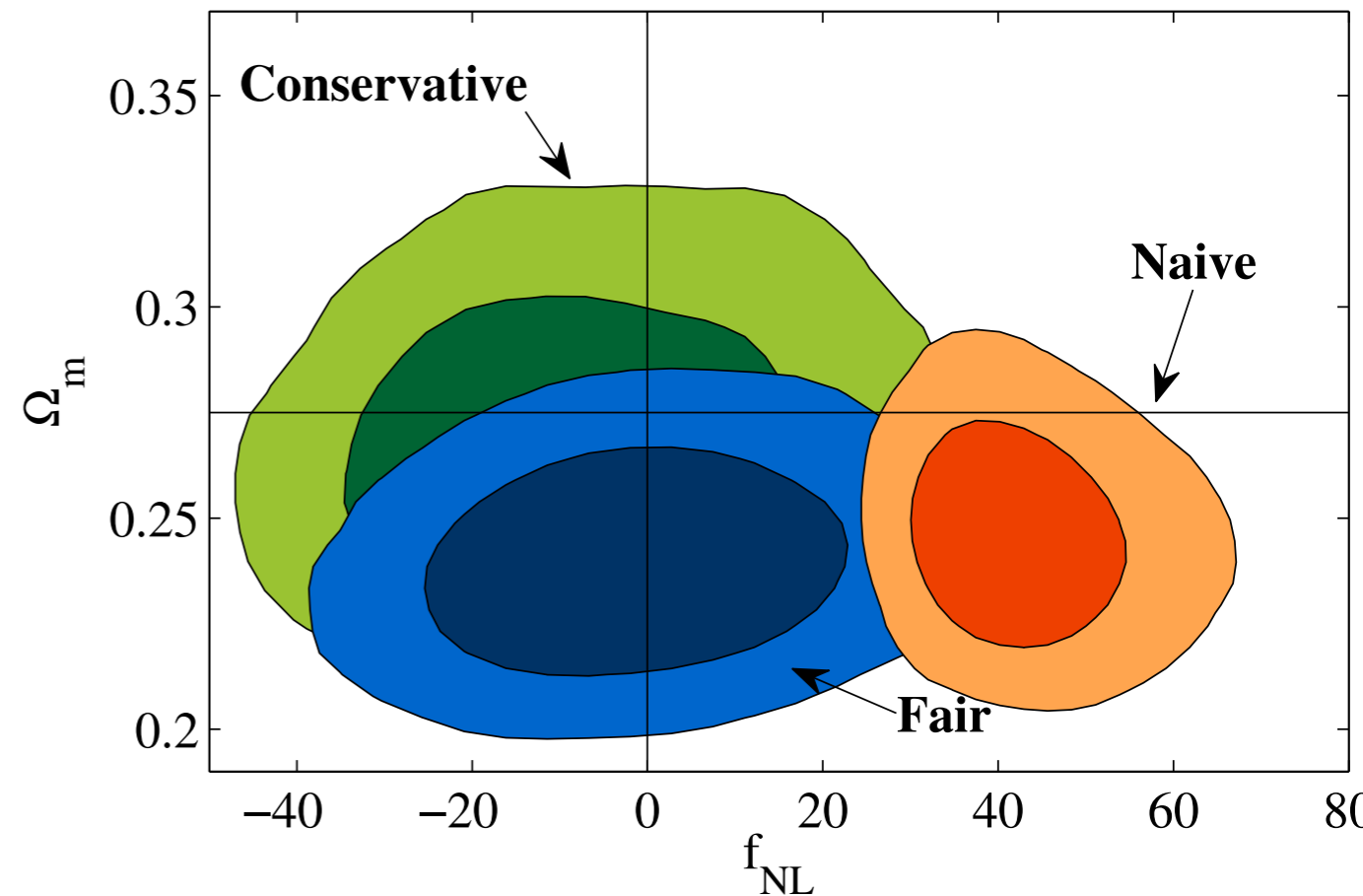


# Results

- Conservative & Fair: consistent with standard model, no PNG
- Fair data + WMAP7: prefer slightly lower matter content
- No significant degeneracies  $f_{\text{NL}}$  - other parameters

*'conservative'*:  $f_{\text{NL}} = -6 \pm 15.5$  ( $1\sigma$ )  
*'fair'*:  $f_{\text{NL}} = +1 \pm 15$  ( $1\sigma$ )

- Later confirmed by Planck:  
 $f_{\text{NL}} = +2.7 \pm 5.8$  ( $1\sigma$ )



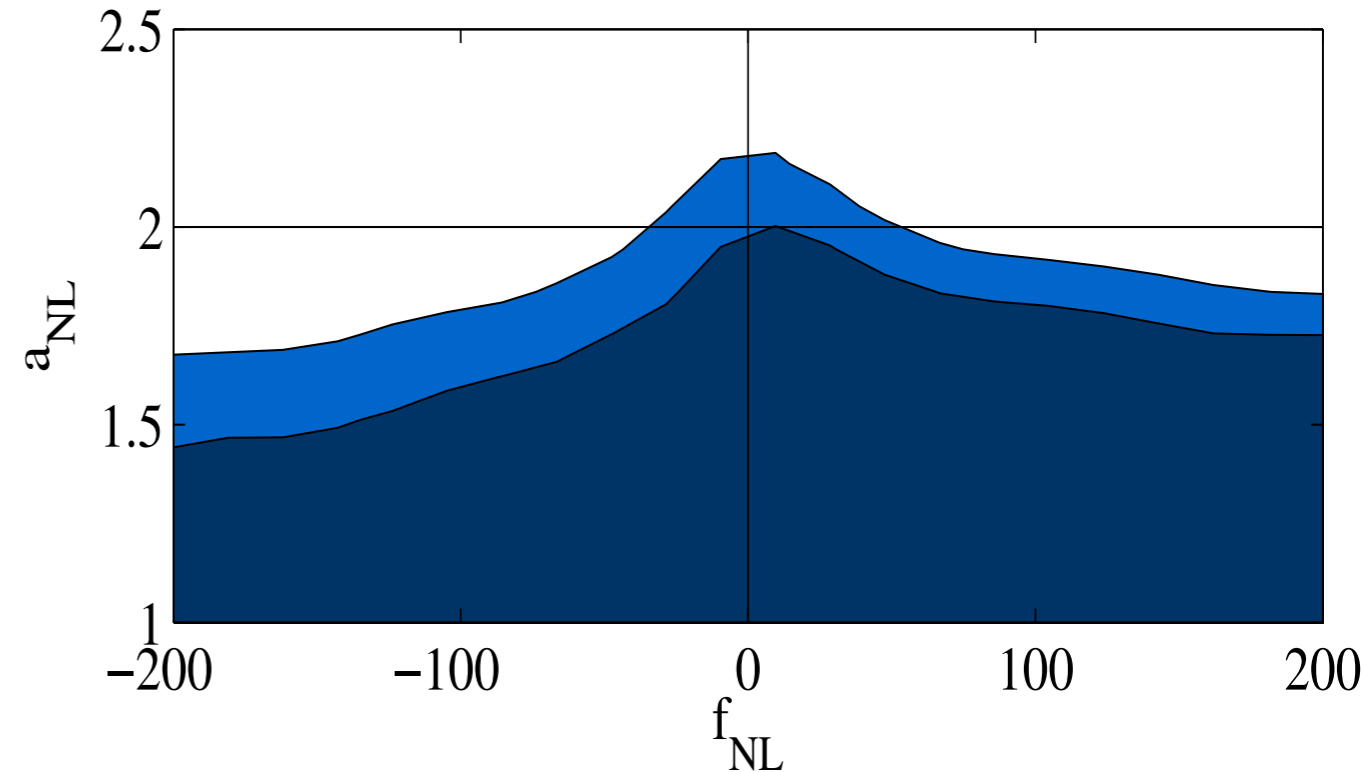
# Extended PNG

- **Variable slope** of scale-dependent bias:  $a_{\text{NL}}$ 
  - accounts for both non-local model or for local  $f_{\text{NL}}(k)$
  - $a_{\text{NL}} = 2$  if local, scale-independent

$$b(k, f_{\text{NL}}) \approx b_{\text{Gauss}} + \beta_f \mathbf{f_{NL}} / \mathbf{k^{a_{\text{NL}}}}$$

- **Kurtosis  $g_{\text{NL}}$  model**
  - assume bias fitting formula by **Smith, Ferraro, LoVerde 12, optimistic assumption**
  - marginalising over  $f_{\text{NL}}$ : (degeneracy partially broken)

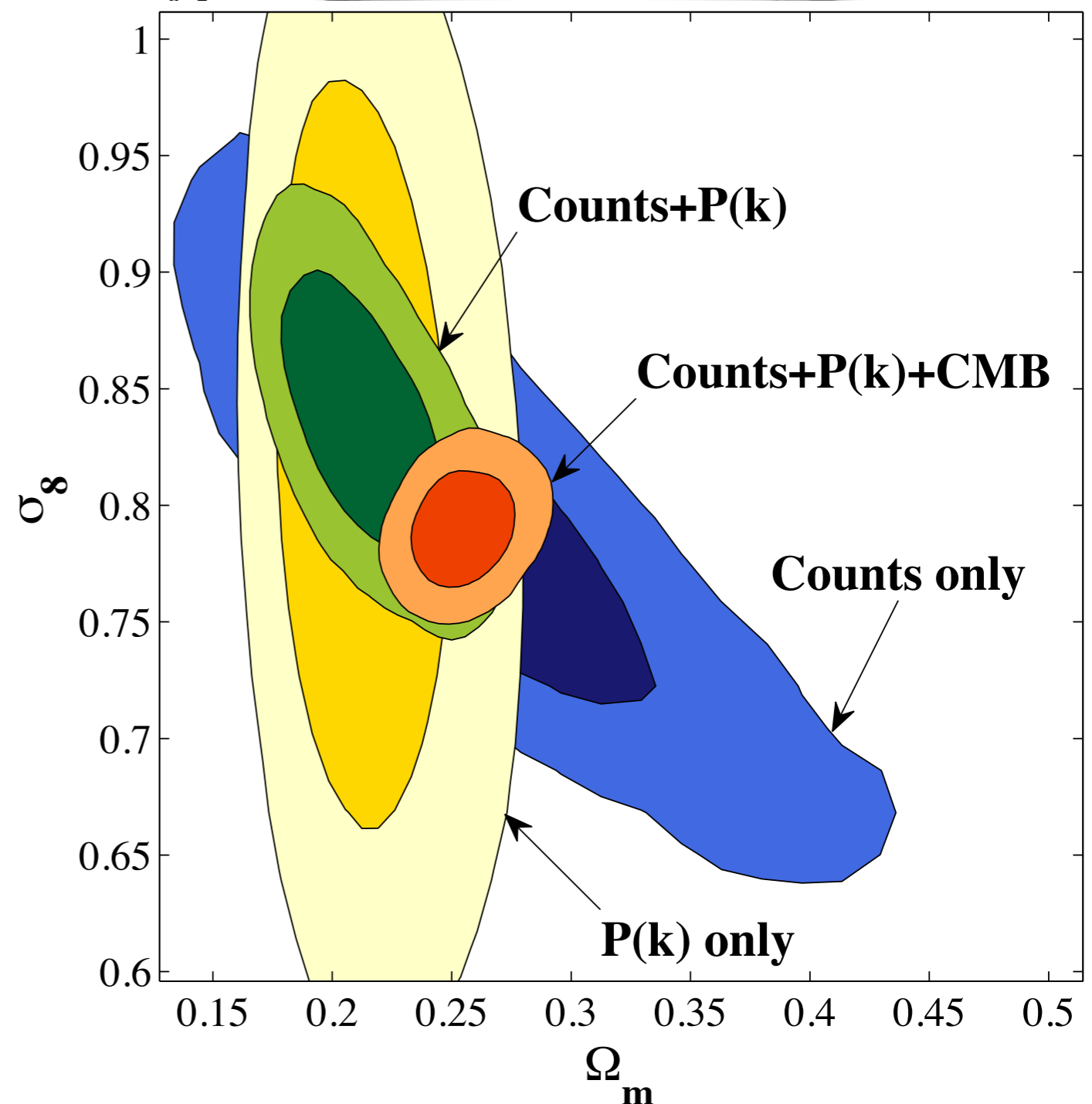
$$\mathbf{-5.8 \cdot 10^5 < g_{\text{NL}} < 1.7 \cdot 10^5 @95\%}$$



# Extension to galaxy clusters

[A. Mana, TG, et al. 13]

- Probe high-mass tail of mass function  
Tinker+10, LoVerde+08
- High bias: good for PNG
- MaxBCG: 14,000 clusters to  $z < 0.3$  from SDSS [Koester+07]
  - **Counts** in richness bins Rozo+09
  - **Masses** from weak lensing data Johnston+07
  - **Power spectrum** Huetsi 09
- MCMC analysis - 10 parameters
  - Mass function sensitive to **ALL types of PNG** [Shandera+13]



# Conclusions & outlook

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- Extended analysis of PNG with latest combined LSS+ISW data
- **NO non-Gaussianity**:  $f_{\text{NL}}^{\text{local}} = -6 \pm 15$  ( $1\sigma$ ): canonical single-field inflation OK
- **Systematics a big issue in ACFs**: any evidence of PNG should be confirmed by cross-correlations between independent data
- Proved consistent with Planck bispectrum:  
 $f_{\text{NL}}^{\text{local}} = 2.7 \pm 5.8$  ( $1\sigma$ )
- Our window gets smaller...
  - **DES**:  $f_{\text{NL}} \pm 8$  [TG, Porciani et al. 11]
  - **HETDEX**: High  $z$ : also 3-point
  - **Euclid**:  $f_{\text{NL}} \pm 3$  ... if systematics under control

