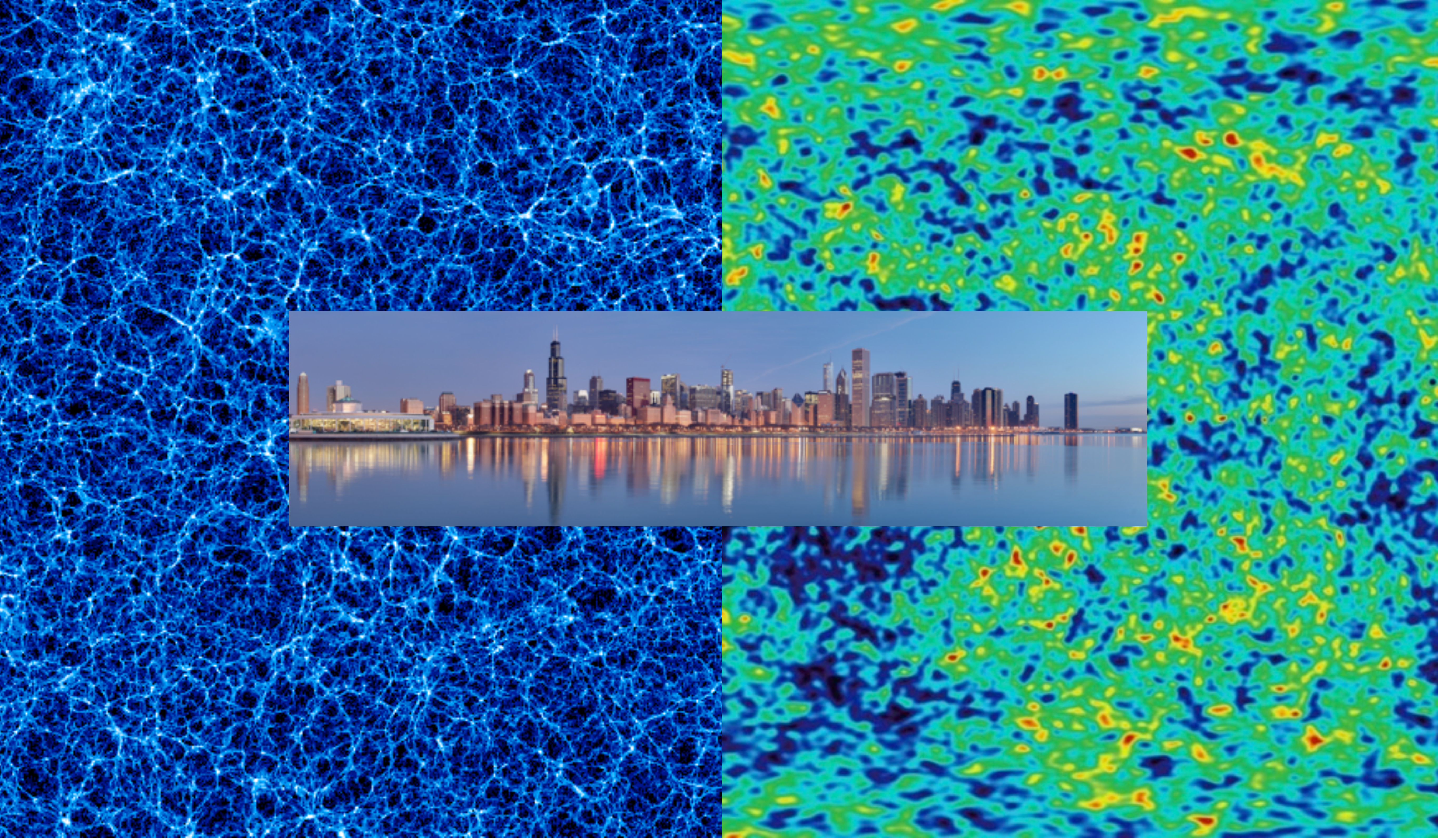

Constraining non-Gaussianity: current LSS and ISW data and outlook for the DES

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LMU Munich & Excellence Cluster

Outline

- Large-scale structure and **Primordial non-Gaussianity** (PNG)
- Scale-dependent, **non-local** bias
- LSS & correlation with the CMB: the **integrated Sachs-Wolfe (ISW) effect**
- Updates on combined LSS+ISW data: the Luminous Red Galaxies from BOSS
- Combined measurement of PNG from LSS+ISW data
- PNG with **DES** and Euclid
- Conclusions

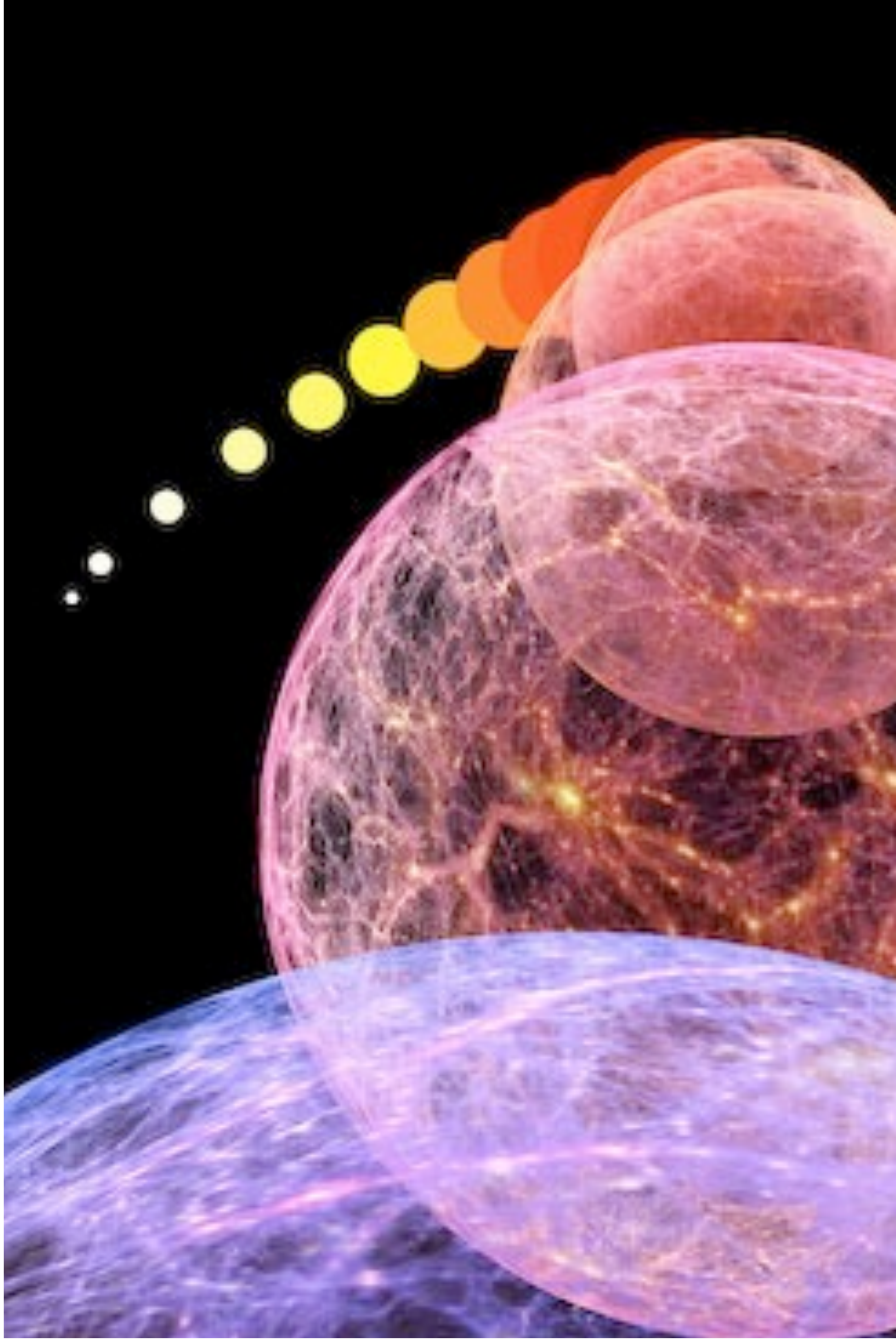
Collaborators: R. Crittenden, B. Nichol, W. Percival, A. Ross, C. Porciani, J. Weller, M. Kilbinger

Theory

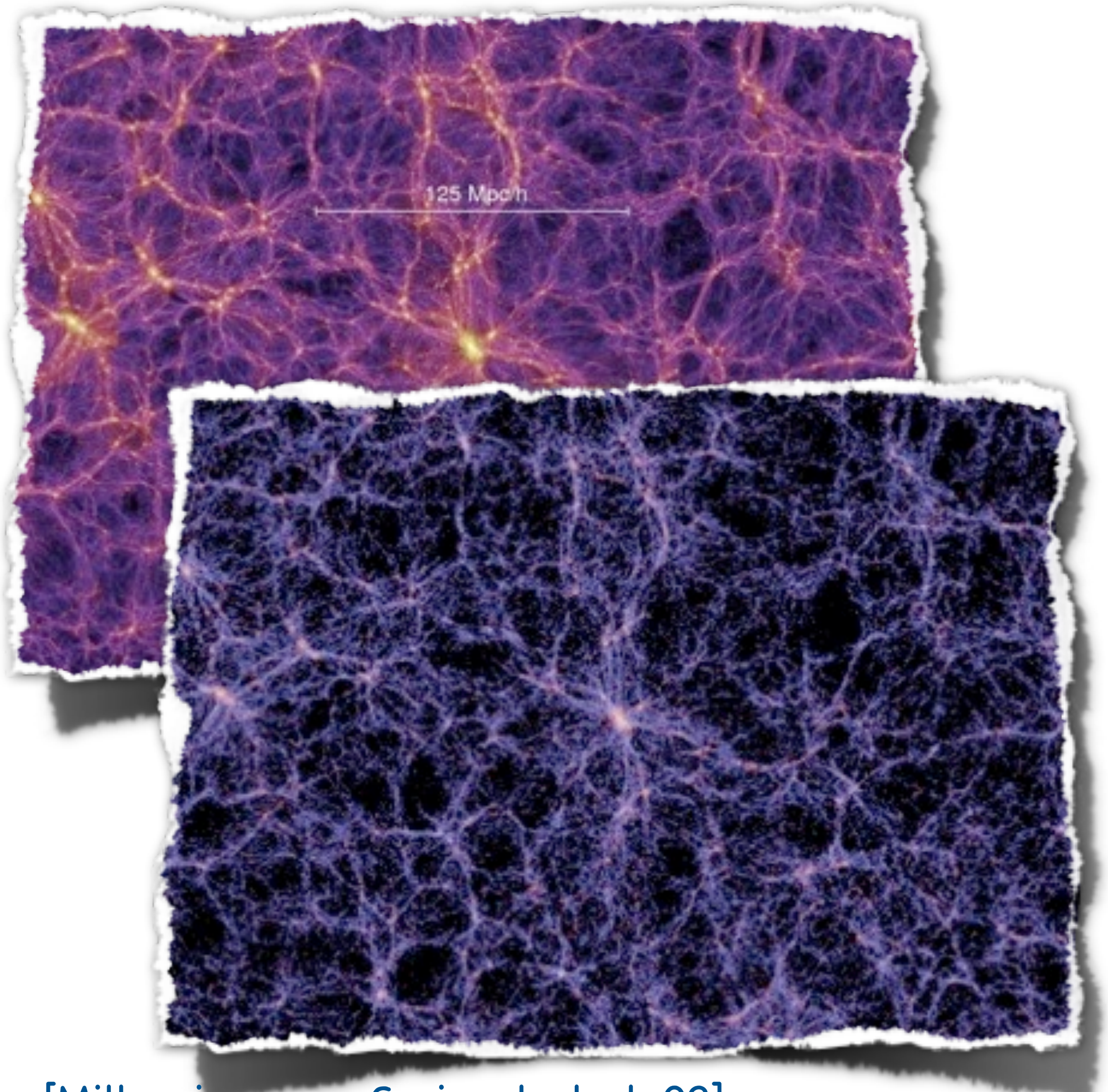
Constraining the early universe

- **Many** models available
  - single field
  - many fields
  - slow or fast decay
  - various possible kinetic terms
  - cyclic/ekpyrotic models...
- Simplest models predict:
  1. near-flatness ✓
  2. nearly scale-invariant power spectrum ✓
  3. curvature perturbations only ~ [Valiviita & TG 09]
  4. nearly Gaussian distribution ?
- Other models: many configurations: kernel W. Φ: primordial potential; φ Gaussian. Amount of NG: $\mathbf{f_{NL}}$

$$\Phi(\mathbf{x}, z_*) = \varphi(\mathbf{x}, z_*) + (f_{\mathrm{NL}} * W * \varphi * \varphi)(\mathbf{x}, z_*)$$



Non-Gaussianity and the LSS

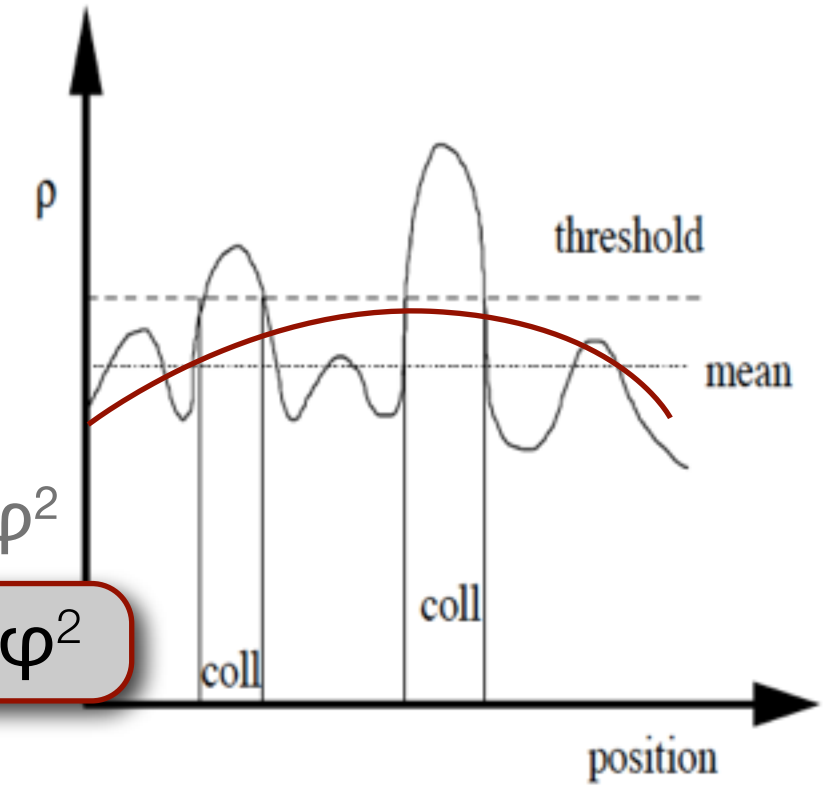


[Millennium run, Springel et al. 09]

- Dark matter perturbations δ_m > d.m. haloes δ_h > galaxies δ_g
  - halo mass function:
    halo bias, $\delta_h = b_h \, \delta_m$
  - halo occupation distribution:
    galaxy bias, $\delta_g = b_g \, \delta_m$
- PNG: strongly scale-dependent b
- Spectra ‹gal-gal› ~ b^2 and ‹gal-CMB› ~ b: constraints on PNG! [Slosar et al 08, ...]
- Also small effect on P_{matter} from bispectrum [Taruya et al 08]

Scale-dependent, non-local bias

[Dalal et al 07, Slosar et al 08, Verde et al 09, TG & Porciani 09...]



- Split $\varphi = \varphi_{short} + \varphi_{long}$ + PNG definition: $\Phi = \varphi + f_{NL}\,\varphi^2$
  - Φ_l , Φ_s, Φ_{mixed} ← coupling from double product in φ^2
- Halo formation:
  - collapse when: $\delta_s\,(1 + 2\,f_{NL}\,\varphi_l) > \delta_c$
  - with r.m.s.: $\sigma_{NG} = \sigma\,(1 + 2\,f_{NL}\,\varphi_l)$

With PNG, extra bias from the potential!

- Halo density perturbation: $\delta_h^L = \dfrac{n(M) - \bar{n}}{\bar{n}}$, $n \propto f\,[(\delta_c - \delta_l) / \sigma_{NG}]$
- Taylor-expanded in both variables!

$$\delta_h^L(\mathbf{q}) = \sum_{j,m=0}^{\infty} \frac{b_{jm}^L}{j!\,m!}\,\delta_l^j(\mathbf{q})\,\varphi_l^m(\mathbf{q})$$

1st order:

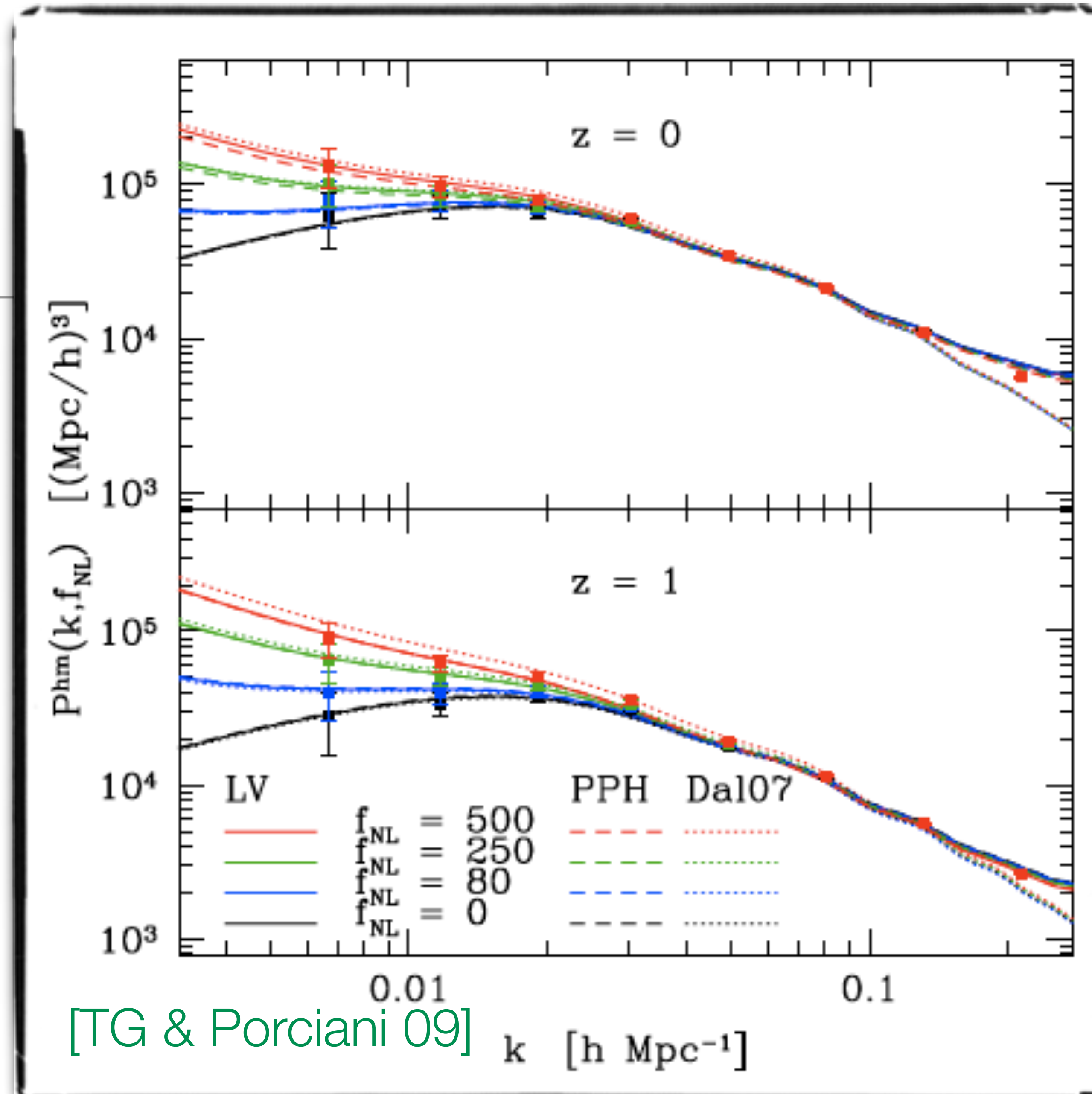
$$\delta_h^L = b^L_{10}\,\delta_l + b^L_{01}\,\varphi_l$$

- δ_l, φ_l related by Poisson eq, but **non-local**

Power spectra and Effective bias

- b_{ij}: from NG halo mass function (e.g. LoVerde et al.)
  - 1st order: $\delta_h^L = b^L_{10}\,\delta_l + b^L_{01}\,\varphi_l$
  - $b^L_{01} \propto b^L_{10}\, f_{NL}$
- Fourier space:
  - $\varphi(k) \to \delta(k) / \alpha(k)$

$$\boxed{\alpha(k) = \frac{2k^2 T(k) D(z)}{3\Omega_m H_0^2}}$$



[TG & Porciani 09]

- Power spectra: $P_{hm}(k) = \langle\delta_h(k)\,\delta(k)\rangle$

$$b(k, f_{NL}) = b_{Gaus} + \delta b(f_{NL}) + \Delta b(k, f_{NL})$$

$$\Delta b(k, f_{NL}) \propto \mathbf{f_{NL}}(b_{10} - 1)\,\mathbf{k^{-2}}$$

not $\propto b_{20}\sigma_R$ as in local approach!

- Effective $b = P_{hm} / P_{mm}$

Physical meaning: large-scale δ_h traces φ, not δ!

Current data: LSS & ISW

LSS tomography & Correlation with the CMB: The ISW effect [Sachs & Wolfe 67]

- Integrated Sachs-Wolfe: Secondary effect on the CMB:

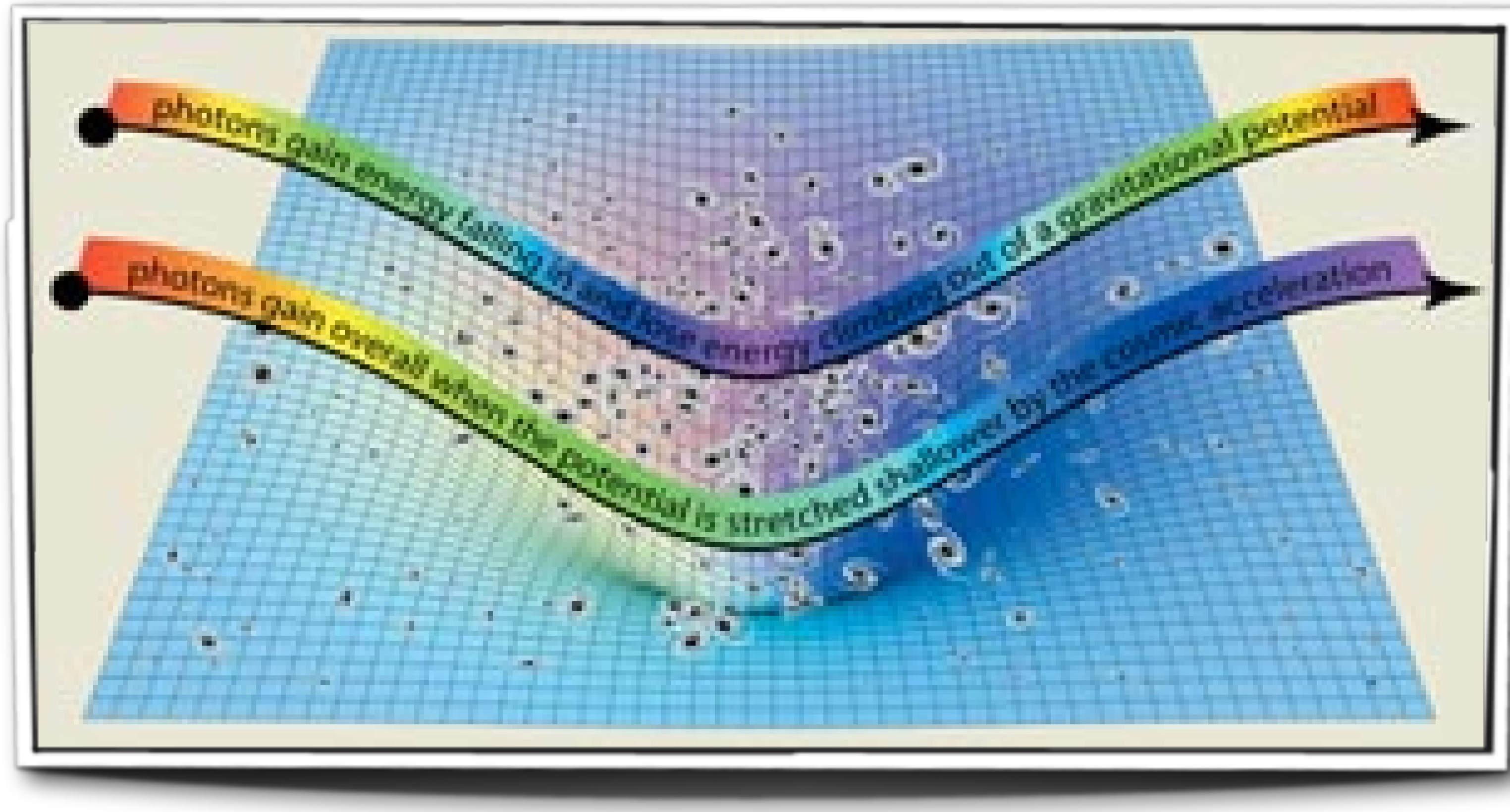
$$\frac{\delta T}{T} = 2\int_\gamma \dot{\Phi}[r(t),t]dt$$

- No effect in matter domination as

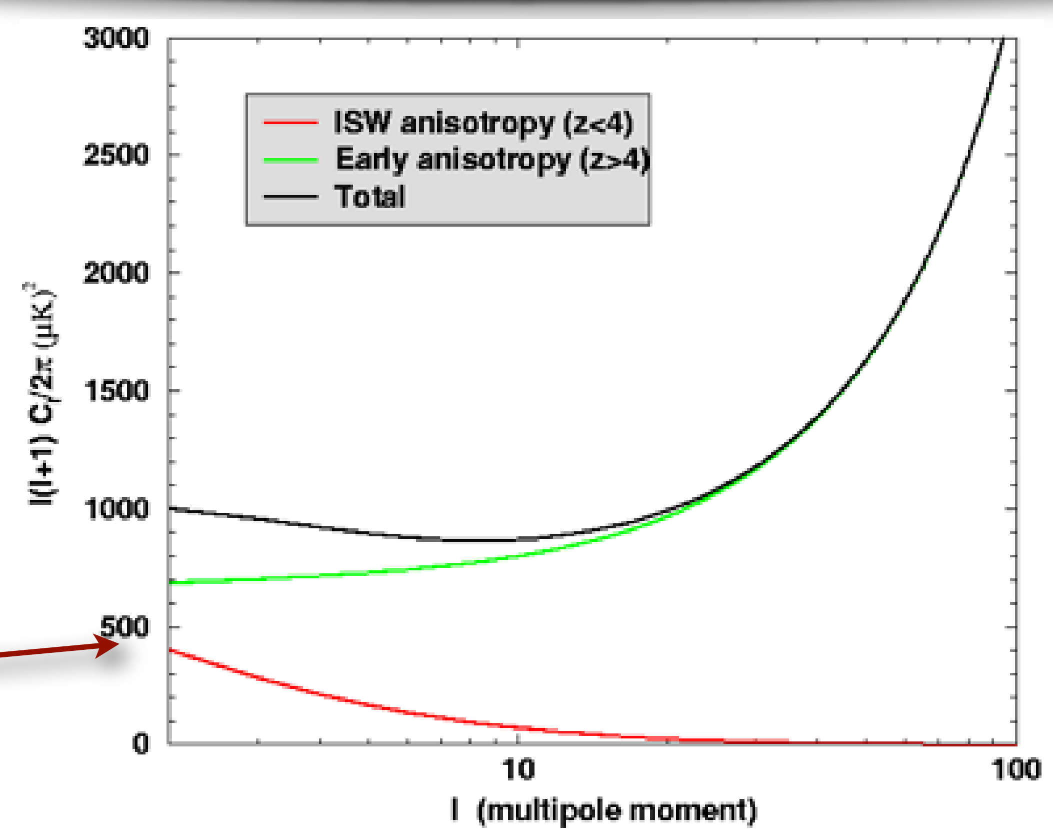
$$\delta_m \propto a \quad \Rightarrow \quad \dot{\Phi} = 0$$

- **Late** ISW if dark energy dominates

- Probe of Dark Energy

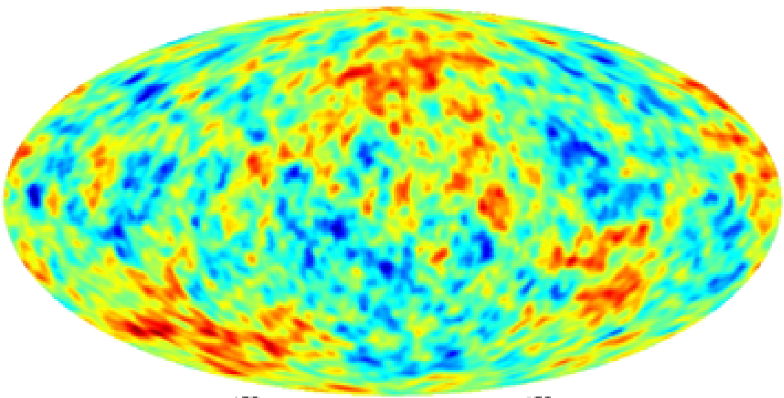


BUT: signal is small! ~10% of primary CMB <TT> spectrum

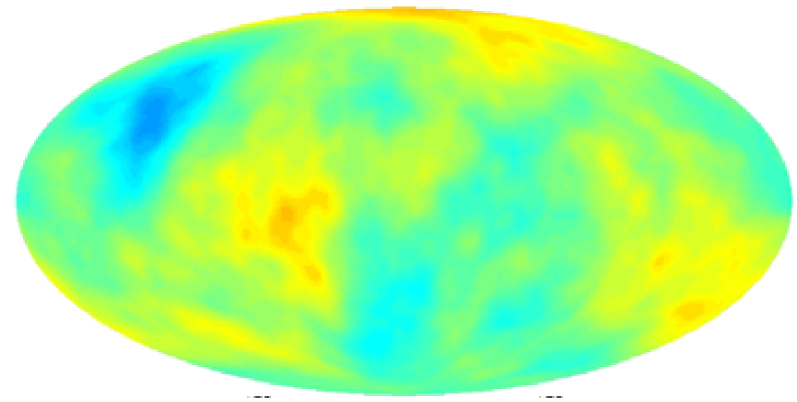


The cross-correlation method [Crittenden & Turok 95]

- **Total** observed CMB: sum of **primary** + **secondary**



Noise! $z = 1100$



Signal! $z < 3$

- **Primary**: **uncorrelated** with large-scale structure, z too high!
- **ISW**: **highly correlated** through the gravitational potential Φ

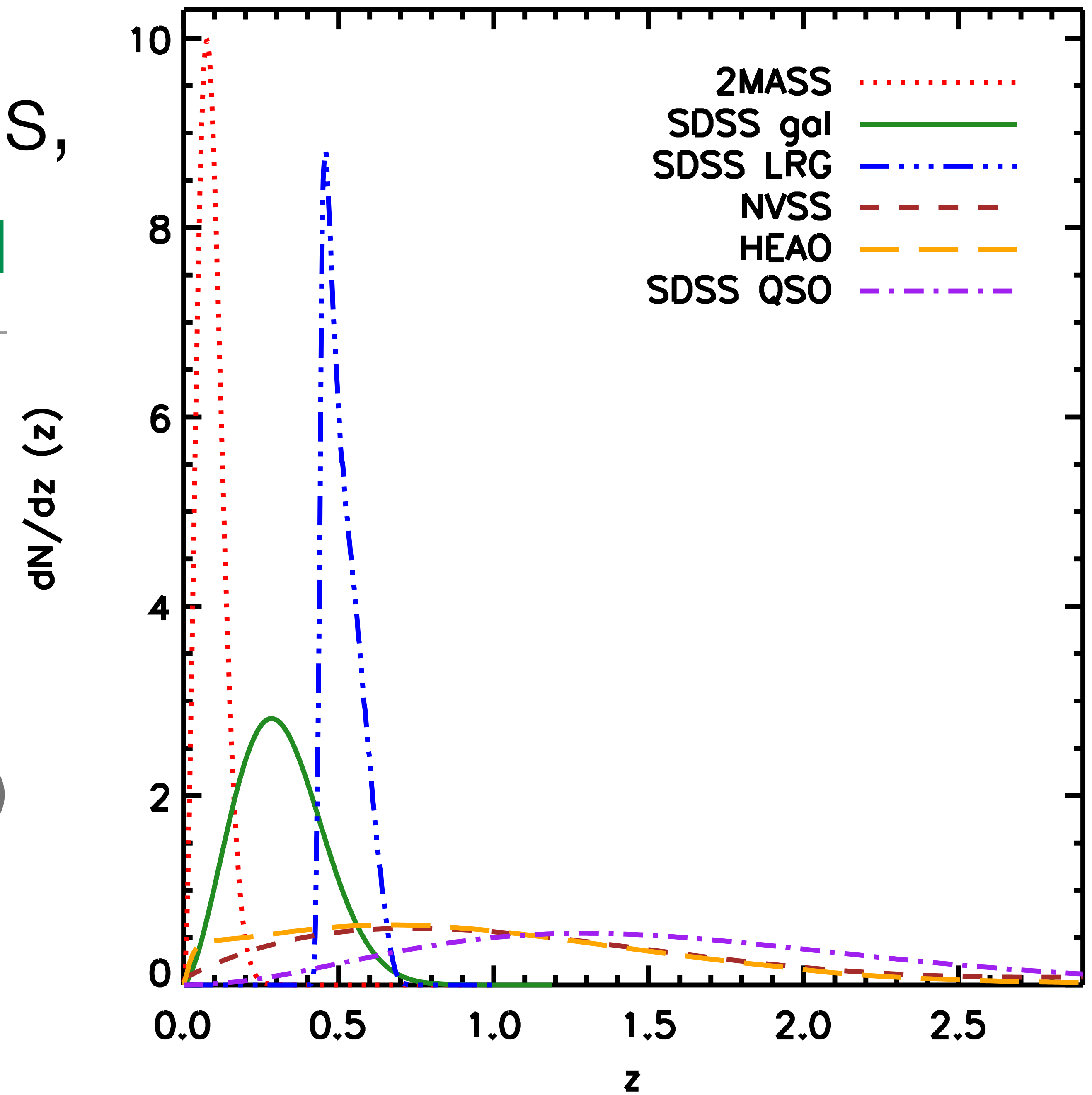
ISW signal: Detectable cross-correlating <CMB x LSS>

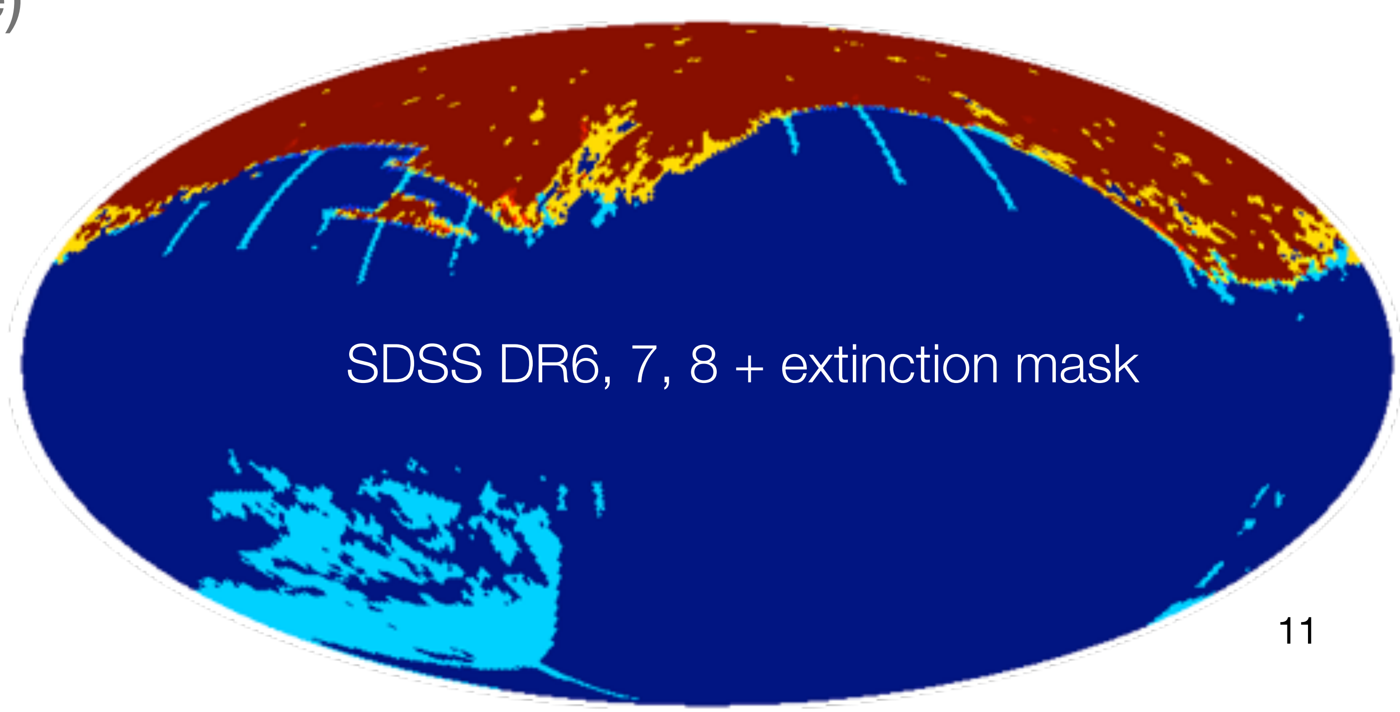
- linear, large-scale effect: need wide and deep density maps
- non-zero signal ONLY with dark energy (or K)

Observations match LCDM, low S/N ~ 2: **combine**! [TG et al 08, Ho et al, 08]

Combined LSS+ISW analysis, updated [TG 08, TG 12 et al, submitted]

- **data maps**, pixellated resolution = 0.9 deg
  - density: 6 galaxy catalogues: **2MASS**, **SDSS** (main gal **DR8**, LRG DR7-8, QSO DR6), **NVSS**, **HEAO**
  - temperature: now WMAP7 (ILC, Q, V, W)
- **masks**
  - survey geometry (DR8: 24% increase)
  - foregrounds:
    - extinction, galactic plane cut + bright sources (NVSS, HEAO)



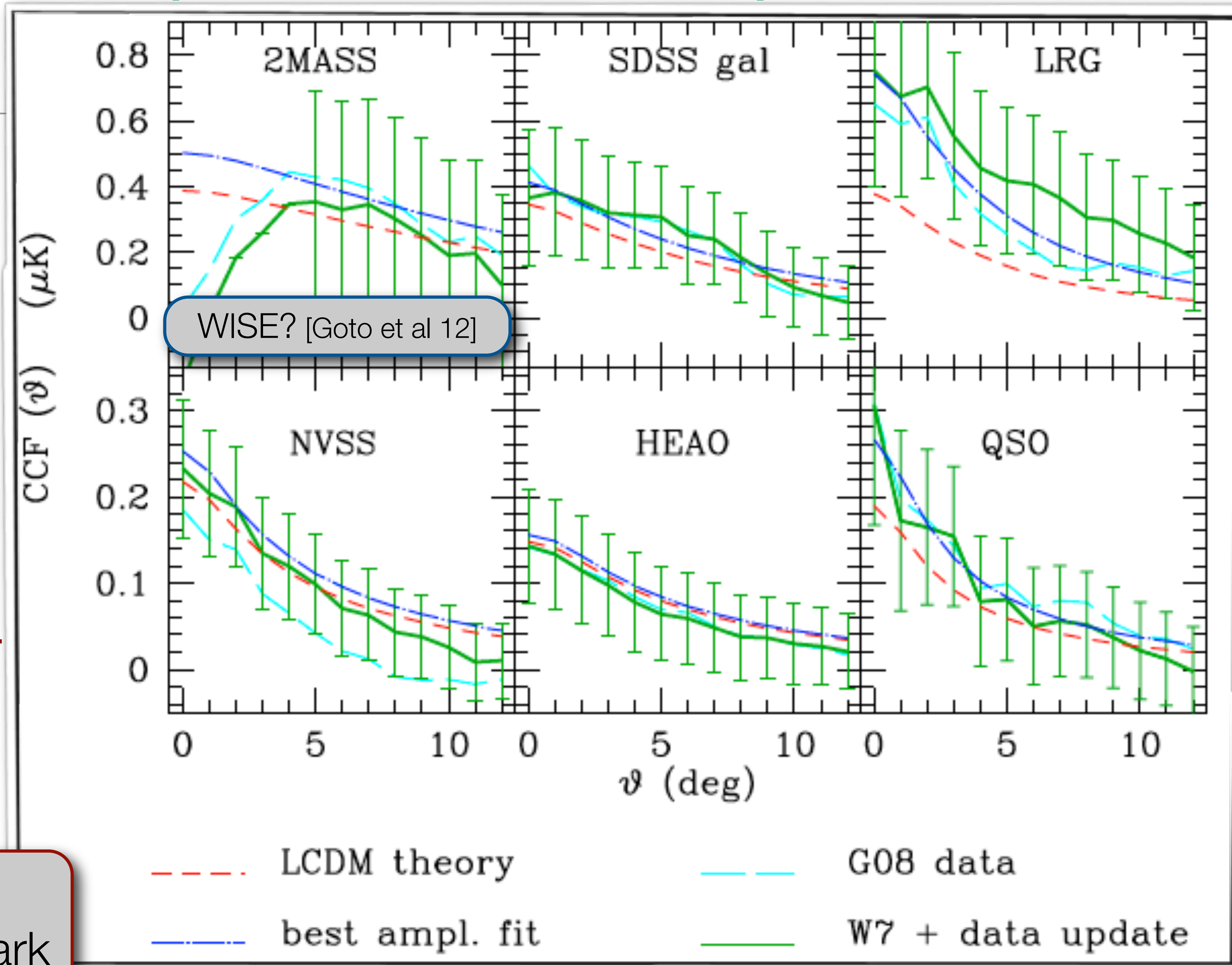


Measured correlations

- Covariance: Monte Carlos
- highly correlated
- mostly agreeing with older data
- **Total S/N = 4.4 σ (± 0.3)** (single amplitude fitting LCDM template)

Independent evidence for Dark Energy at >4σ

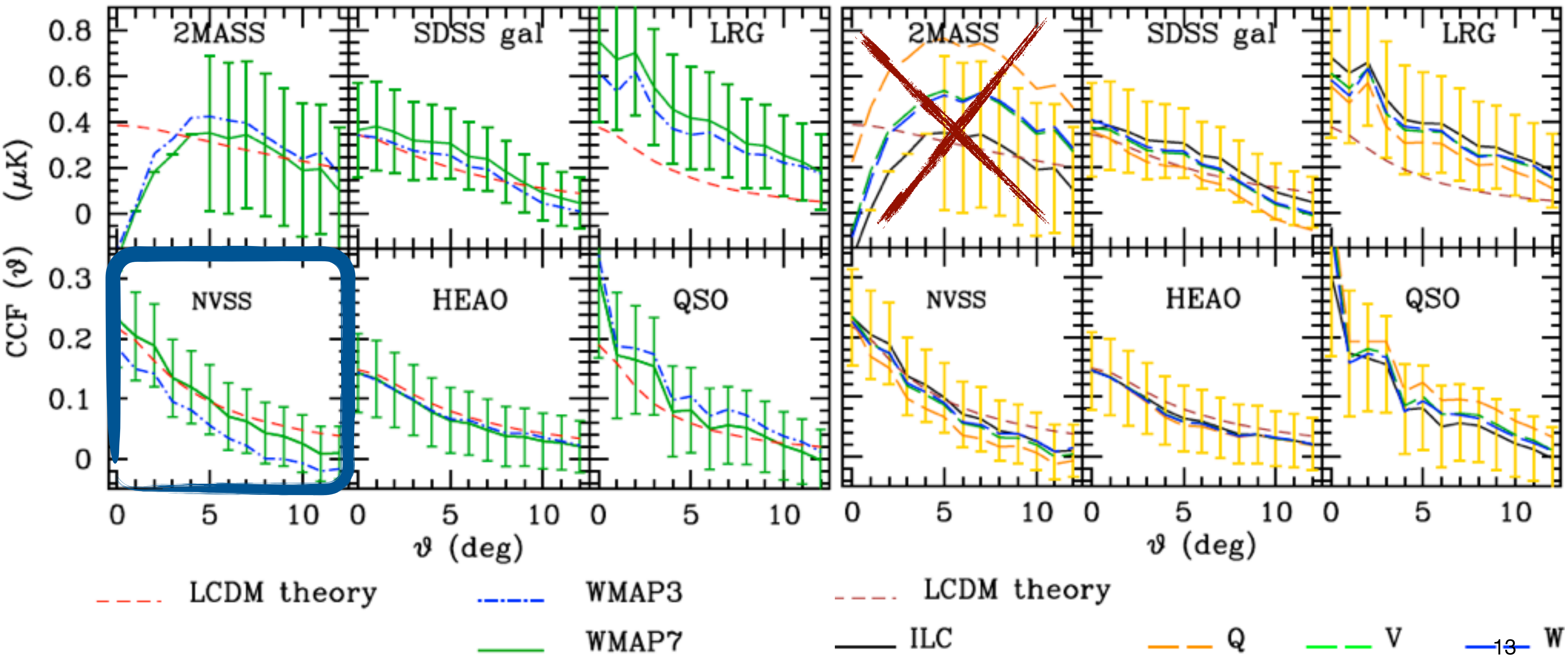
[TG et al. 12a, MNRAS submitted]



WISE? [Goto et al 12]

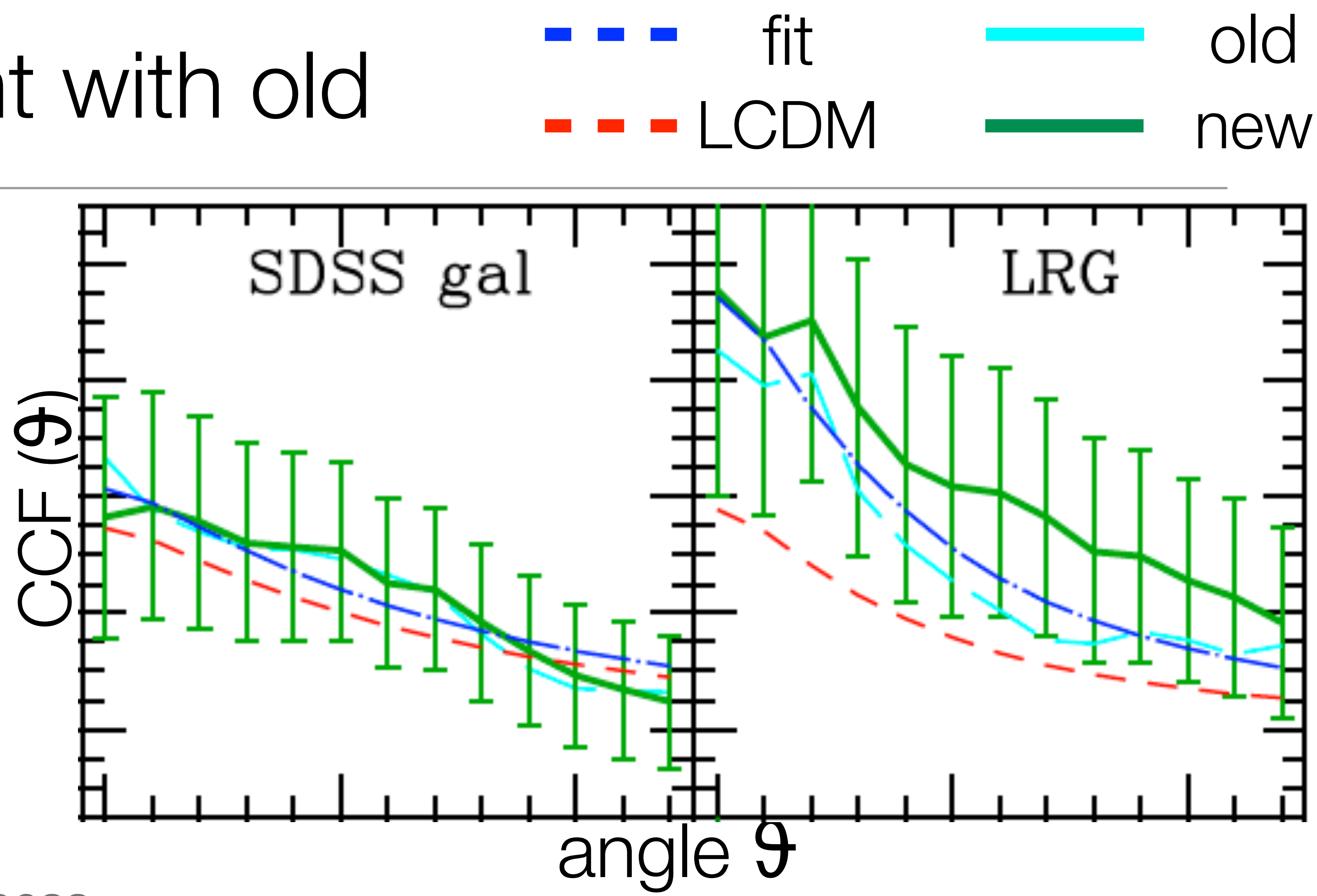
Systematics [TG et al. 12a, MNRAS submitted]

- **WMAP3 → 7**: little change, NVSS closer to LCDM
- CMB-**Frequency** independent: no evidence for contamination, SZ, etc.

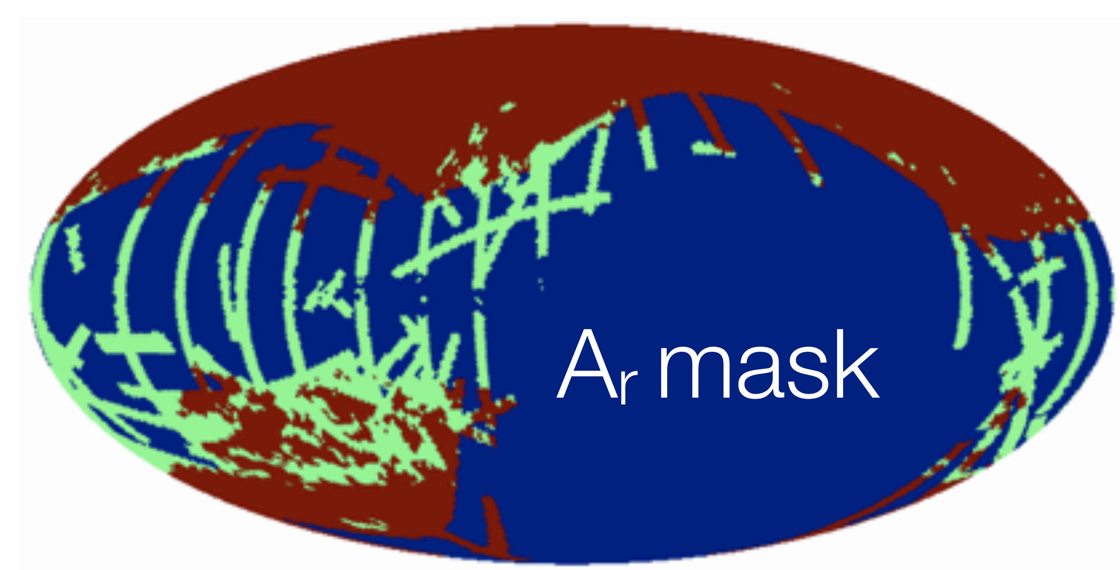


[TG et al. 12a, MNRAS submitted]

New data: consistent with old



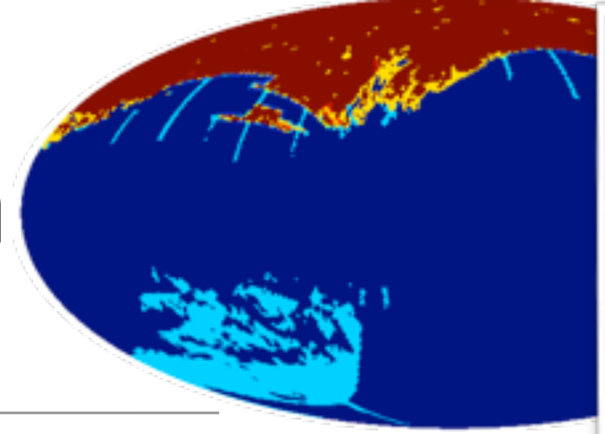
- **Main galaxies** SDSS DR8:
  - 24% extra sky area, in S
  - $0.1 < z < 0.9$; $\sigma(z) < 0.5\,z$
  - $18 < r < 21$
  - Now ~40 Million gals!
  - Reddening mask $A_r > 0.18$
  - no difference in CCF
- **LRG** [Thomas et al. 10] DR7: more excess
  - 10% area increase
  - completeness cut: $i < 19.8$
  - Star-gal separation: $\delta_{sg} > 0.2$
  - 1.4 Million LRGs, some difference in large-scale CCF (mostly due to change in WMAP and **mask**)



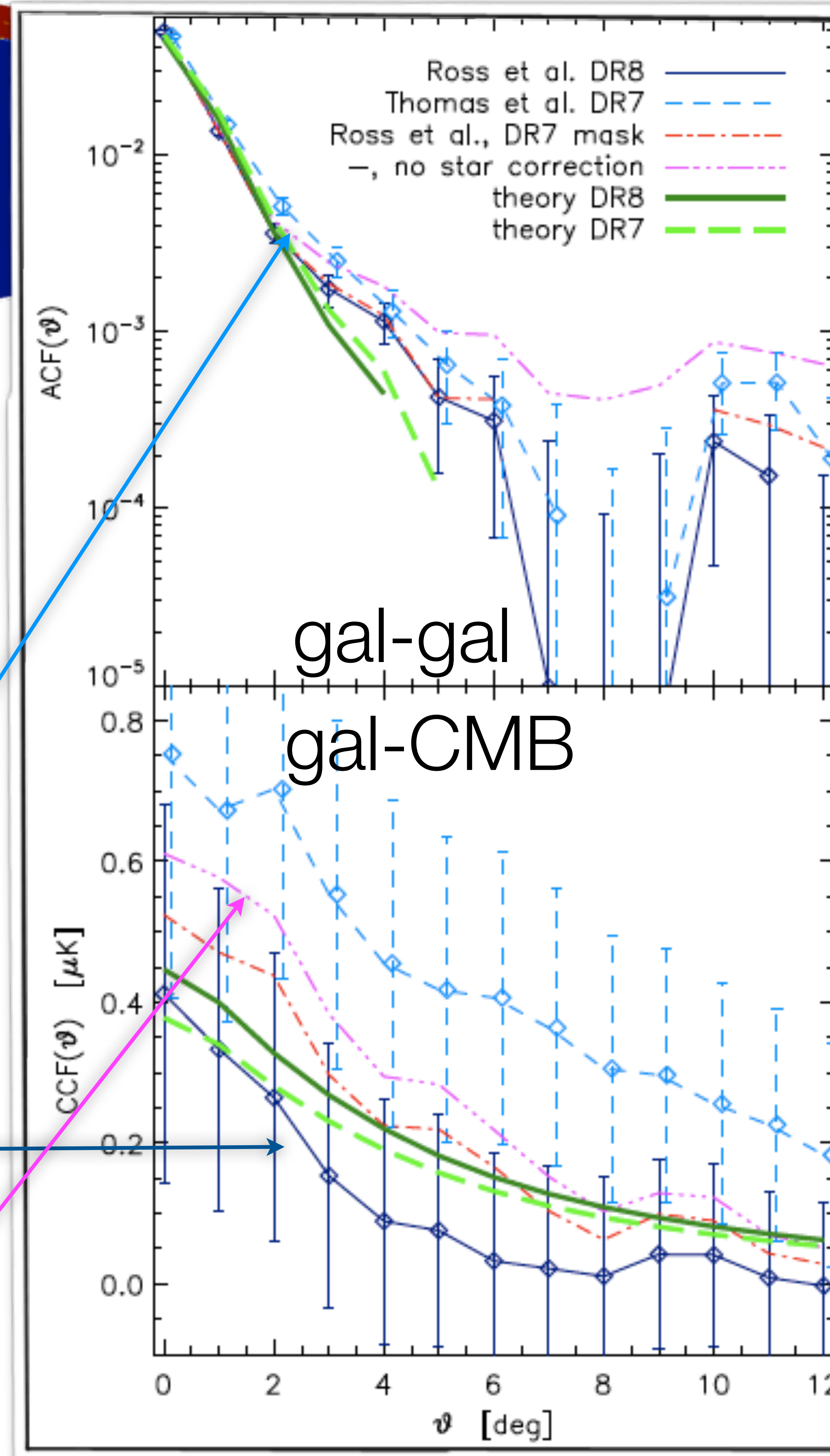
- Even better **LRG** data [Ross et al. 11] DR8...

LRG comparison

[TG et al. 12b, in prep.]



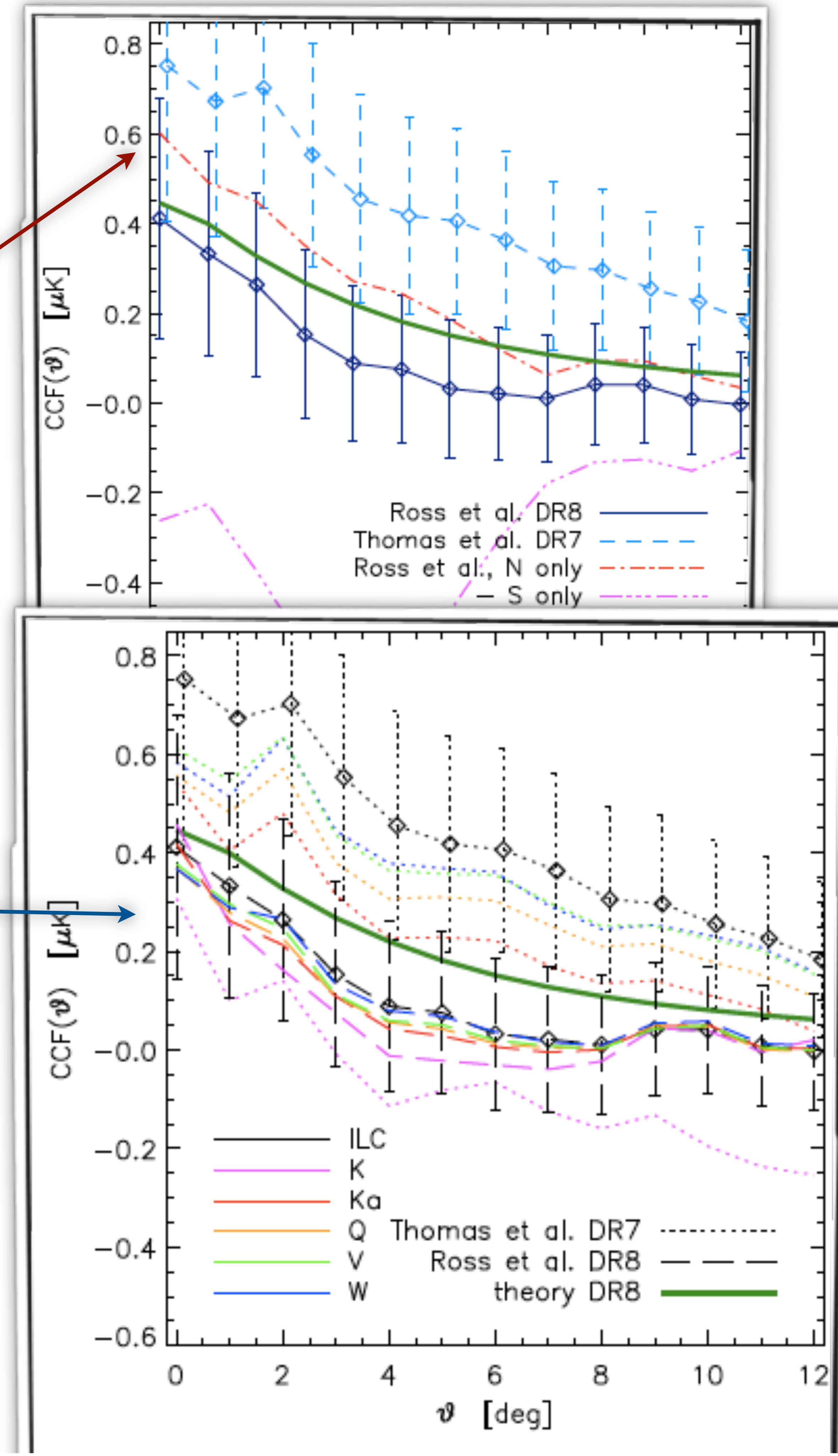
- Thomas et al. 10 **MegaZ** vs Ross et al. 11 SDSS DR8 **CMASS**
- Similar redshift range, Ross et al. South coverage (DR8)
- Ross et al.: correction for stellar systematics!
  - Fewer galaxies observed where lots of stars!
  - Large proportion (15%) with BOSS spectra
- **ACF**: Thomas et al. show more excess power on large scales --> stars?
- **CCF**: Ross et al. lower, in agreement with LCDM! :-)
- If no star correction, same area: higher CCF



LRG systematics

[TG et al. 12b, in prep.]

- N/S divide
  - Ross et al. in N: higher CCF
  - possibly statistical fluke
  - (S alone too noisy)
- Frequency independence:
  - Very stable CCF, with all WMAP bands!
  - Evidence for superior quality of Ross et al. data
  - Stellar contamination negligible

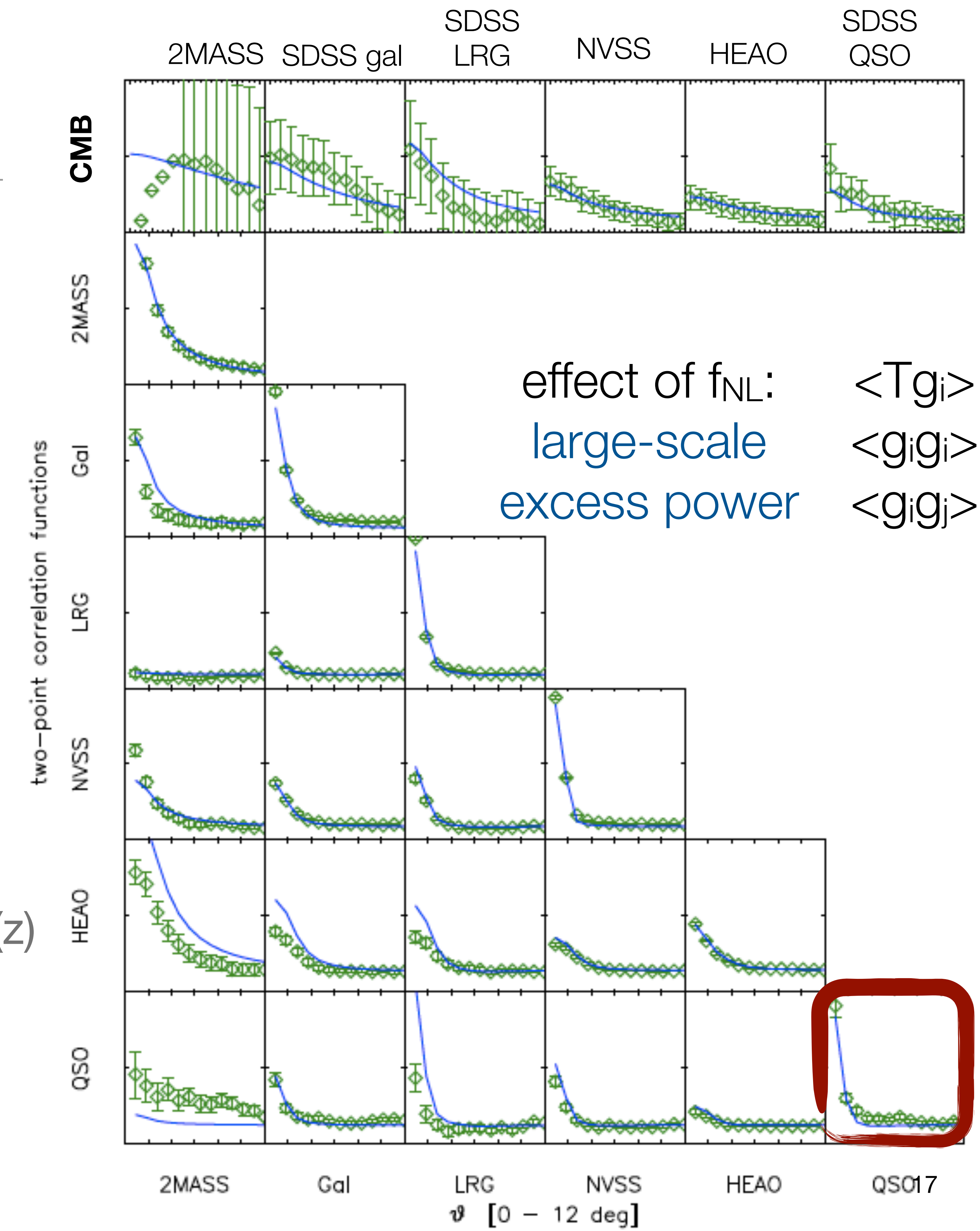


Total ISW S/N down to **4.1**;
even better agreement with LCDM

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

- Measure (local) **f_{NL}** via b
- Not only **‹Tg›** $\propto$ b, but also ALL **‹gg›** $\propto$ b^2 correlations
- **Data**: all 27 2-pt functions!
- For each catalogue we model
  $b_i(k,z) = b_{i0}(z) + \Delta b\,(k,z)$
- Several models for Gaussian b_0:
  - constant $\quad b_i\,(z) = b_{0i}$
  - evolving $\quad b_i\,(z) = 1 + (b_{0i} - 1) / D(z)$

nuisance parameters



effect of f_{NL}: large-scale excess power

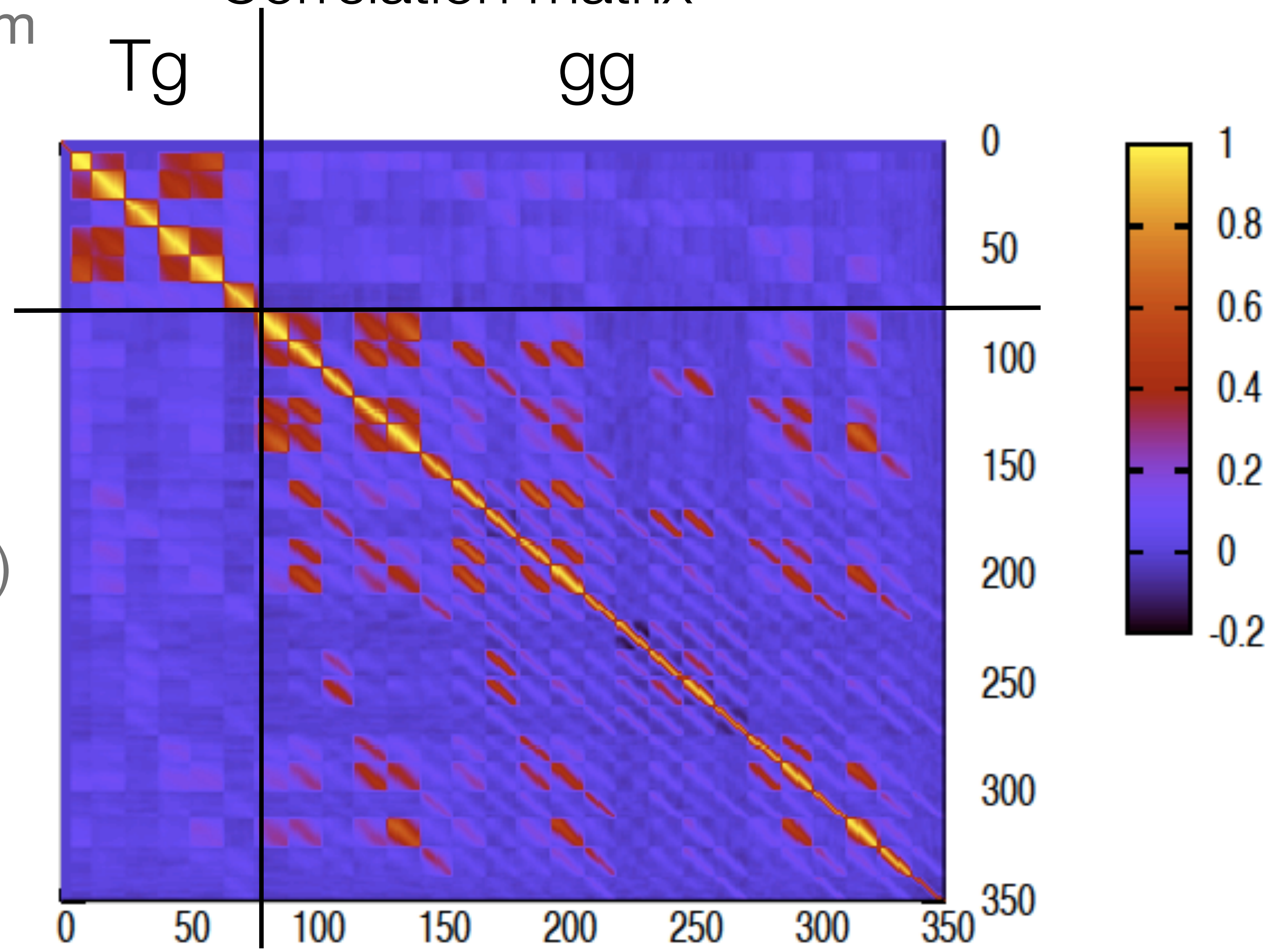
$<Tg_i>$
$<g_ig_i>$
$<g_ig_j>$

Monte Carlo likelihood analysis

[Preliminary]

- Full Covariance Matrix (351x351) from 10,000 Monte Carlo mocks
- Theory models: with modified Camb code
- **Monte Carlo** likelihood analysis, marginalising over (nestled sampling)
  - cosmology (7 params)
  - 6 nuisance parameters b_{0i}
  - 3 nuisance parameters κ_i: **stellar contamination**

Correlation matrix =



- **Results:** (mostly from QSO ACF: high b)

preliminary, **16 < f_{NL} < 60** @ 95% c.l.

Systematics!

[Preliminary]

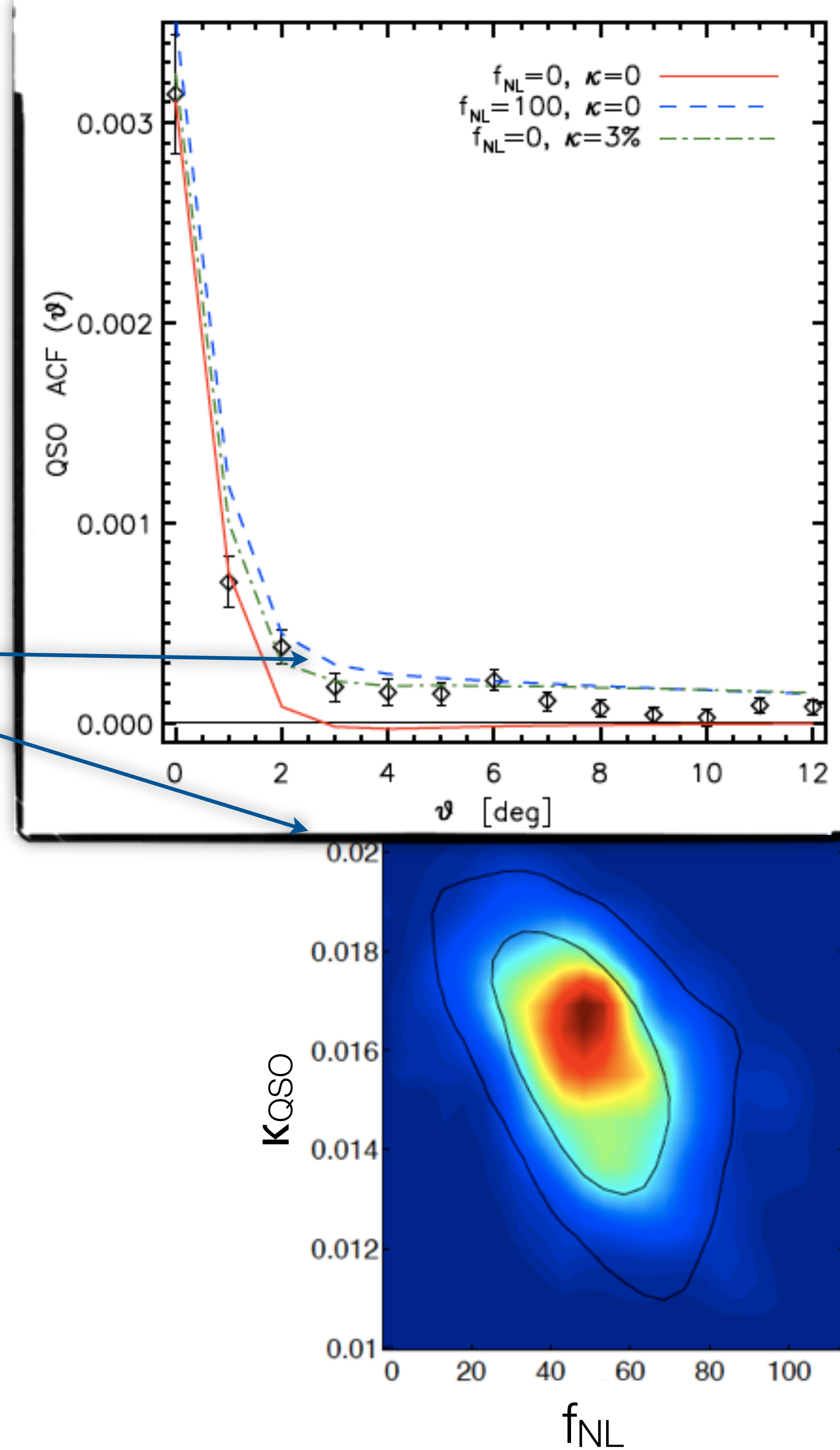
- **Stellar contamination** fraction κ (in SDSS samples)

$$\tilde{\xi}^{gg}(\vartheta) = (1-\kappa)^2\,\xi^{gg}(\vartheta) + \kappa^2\,\xi^{\rm star}(\vartheta)$$

  - Severe degeneracy: in plateau

f_{NL} = 100 ~ κ = 3 %

  - forcing κ = 0 %, **60 < f_{NL} < 98**
  - forcing κ = 2 %, **-6 < f_{NL} < 37**
  - Cleaner, high-bias data needed! e.g. à la Ross et al 11



- Uncertainties in dN/dz
  - 15 extra nuisance parameters b_{ij}:

$$\xi_{\rm obs}^{g_i g_j}(\vartheta) = b_{ij}\,\xi^{g_i g_j}(\vartheta)$$

  - Weaker bounds: **-2 < f_{NL} < 186**

Forecasts

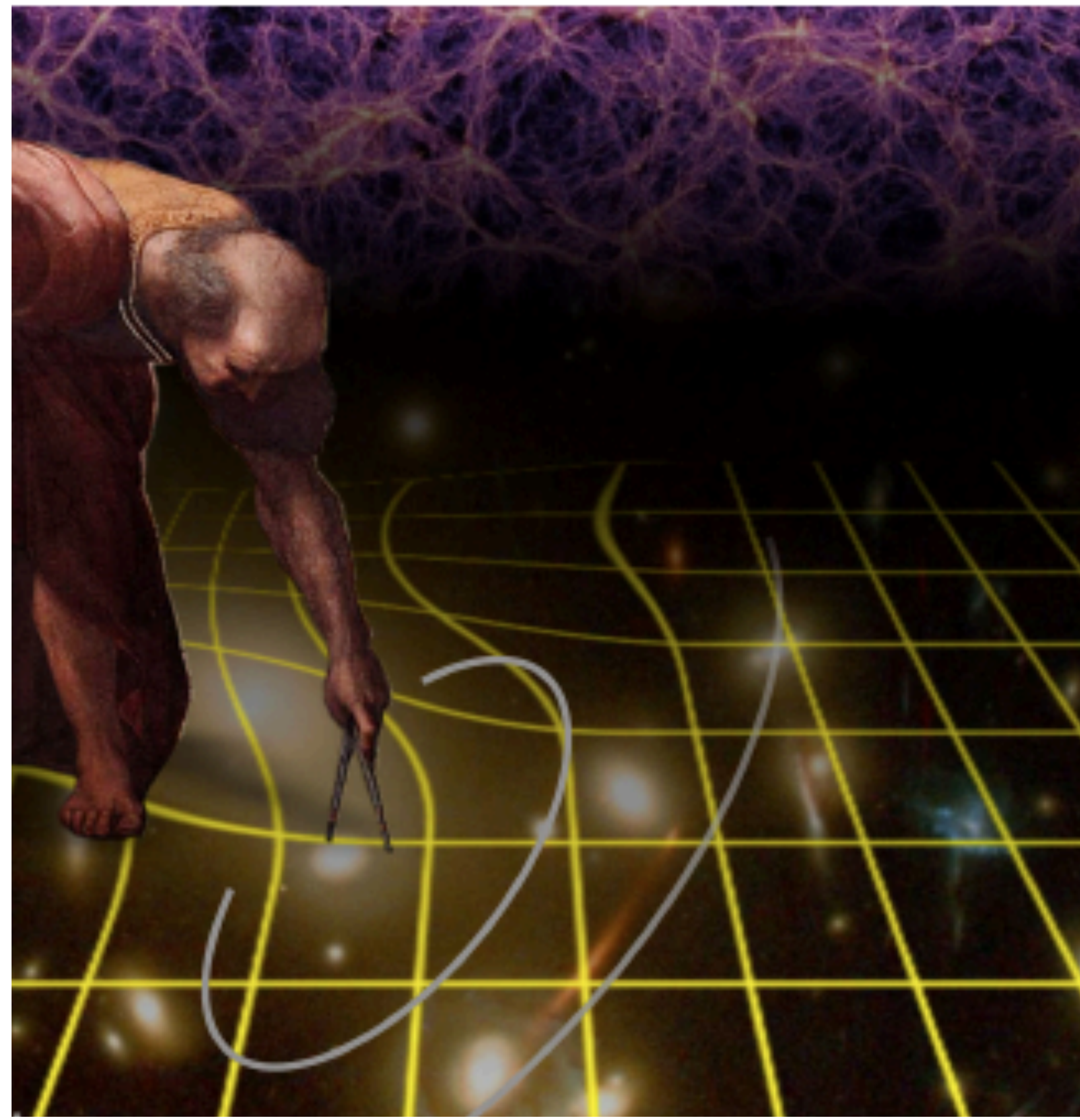
Primordial NG with DES and Euclid

[TG et al. 11]

Euclid

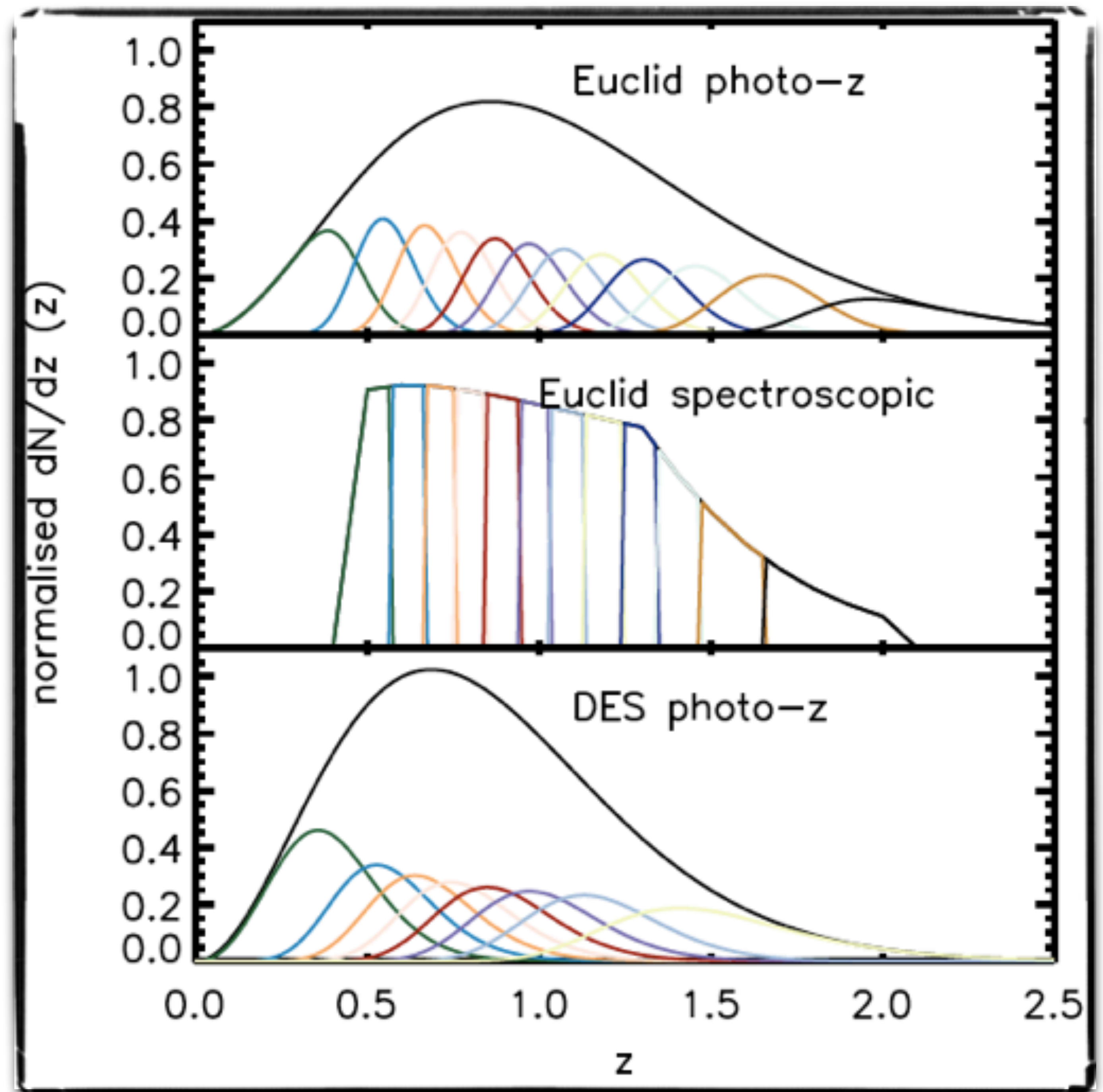
Mapping the geometry of the dark Universe

- Combining: lensing + galaxy clustering
- Following Hu & Jain 04
- Including primordial non-Gaussianity
  - **DES**:
    - Starting soon!
- **Euclid**: future ESA mission
  - In L2 orbit, launch ~2019
  - Imaging (vis+IR) + spectra
  - Measure w_0 to few %!



Specifications

- **Euclid photometric**: **Shear** & **gal 2D** spectrum
  - 15,000-20,000 sq. deg
  - shapes of 2 bn galaxies to z = 2
  - median z = 1, $\sigma_z < 0.05\,(1+z)$
  - density 40 / arcmin^2
- **Euclid spectroscopic** (slitless): **also 3D spectrum + RSD + Alcock-Paczinsky**
  - H_α range 1000 - 2000 nm: 0.5 < z < 2
  - 80 M galaxies
  - median z = 1.1, $\sigma_z < 0.001\,(1+z)$
  - density ~ 1 / arcmin^2
- **DES: photometric: Shear & gal 2D spectrum**
  - **5,000 sq. deg**
  - **shapes of 300 M galaxies to z=2**
  - **median z = 0.8, $\sigma_z < 0.1\,(1+z)$**
  - **density 12 / arcmin^2**



Results
[TG et al. 11]

Critical assumpion for f_{NL}: $b_{fiducial}$ (z) ~ $(1+z)^{1/2}$, similar to Orsi et al. 09.

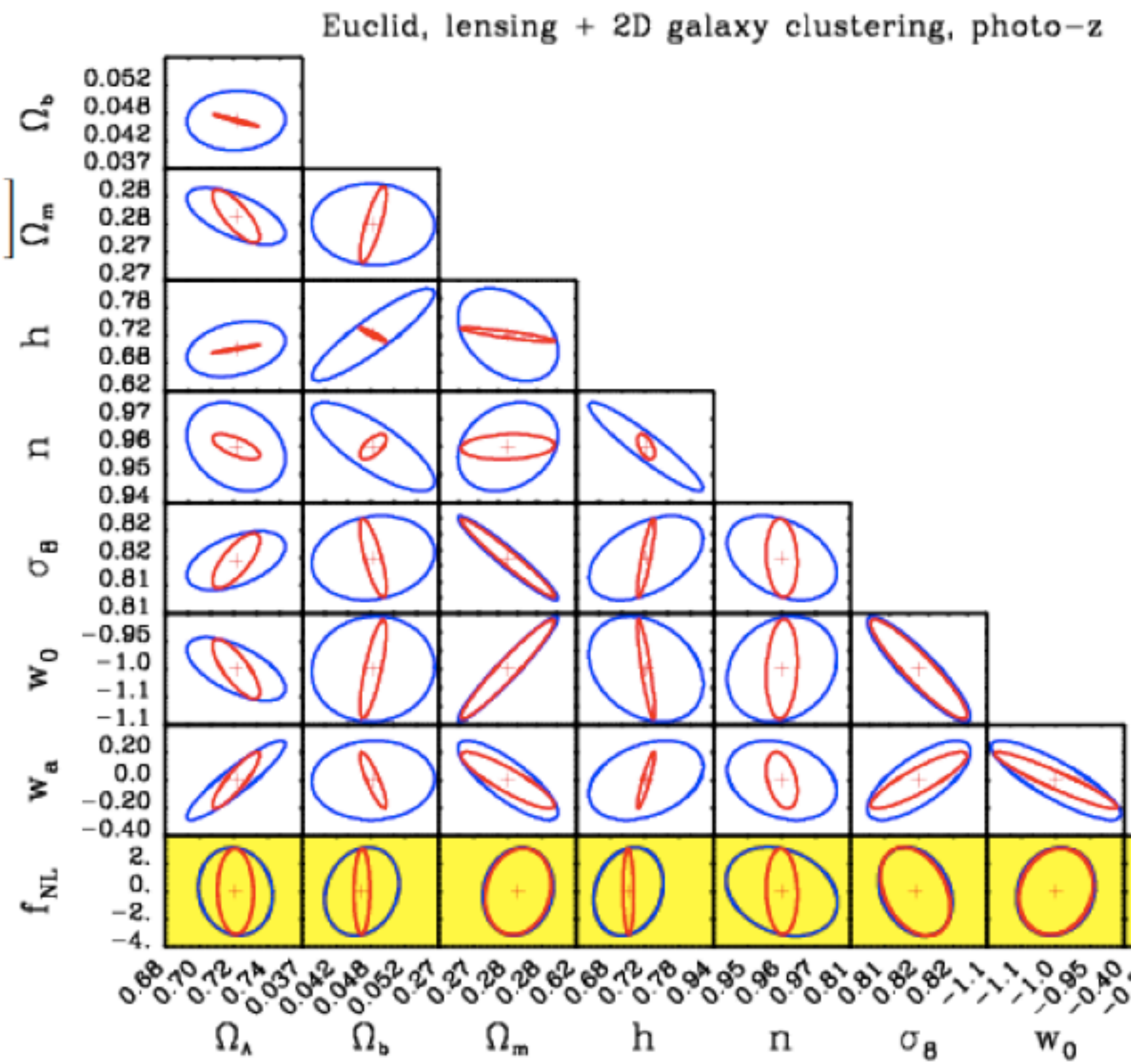
- **Combined** lensing + 2D gal spectrum Fisher forecast:

$$C_l^{\epsilon_i\epsilon_j} \qquad C_l^{g_i g_j} \qquad D_{l\alpha}^{\epsilon_i\epsilon_j} = \frac{\partial C_l^{\epsilon_i\epsilon_j}}{\partial\vartheta_\alpha}$$

$$F_{\alpha\beta}^x = f_{\rm sky}\sum_{l=l_{\rm min}}^{l_{\rm max}}\frac{(2l+1)}{2}\,{\rm Tr}\left[\mathbf{D}_{l\alpha}^x\,(\tilde{\mathbf{C}}_l^x)^{-1}\,\mathbf{D}_{l\beta}^x\,(\tilde{\mathbf{C}}_l^x)^{-1}\right]$$

[Hu & Jain 04]

- includes <lens-gal> spectrum
- Red: with Planck TT priors
- Euclid accuracy on local f_{NL}: ±3
- **For DES: accuracy on f_{NL} ~ ±8**
- Running: n_{fNL} ~ ±0.12 if f_{NL} = 30
- lens+gal matrix sum: worse



Conclusions & Future Work

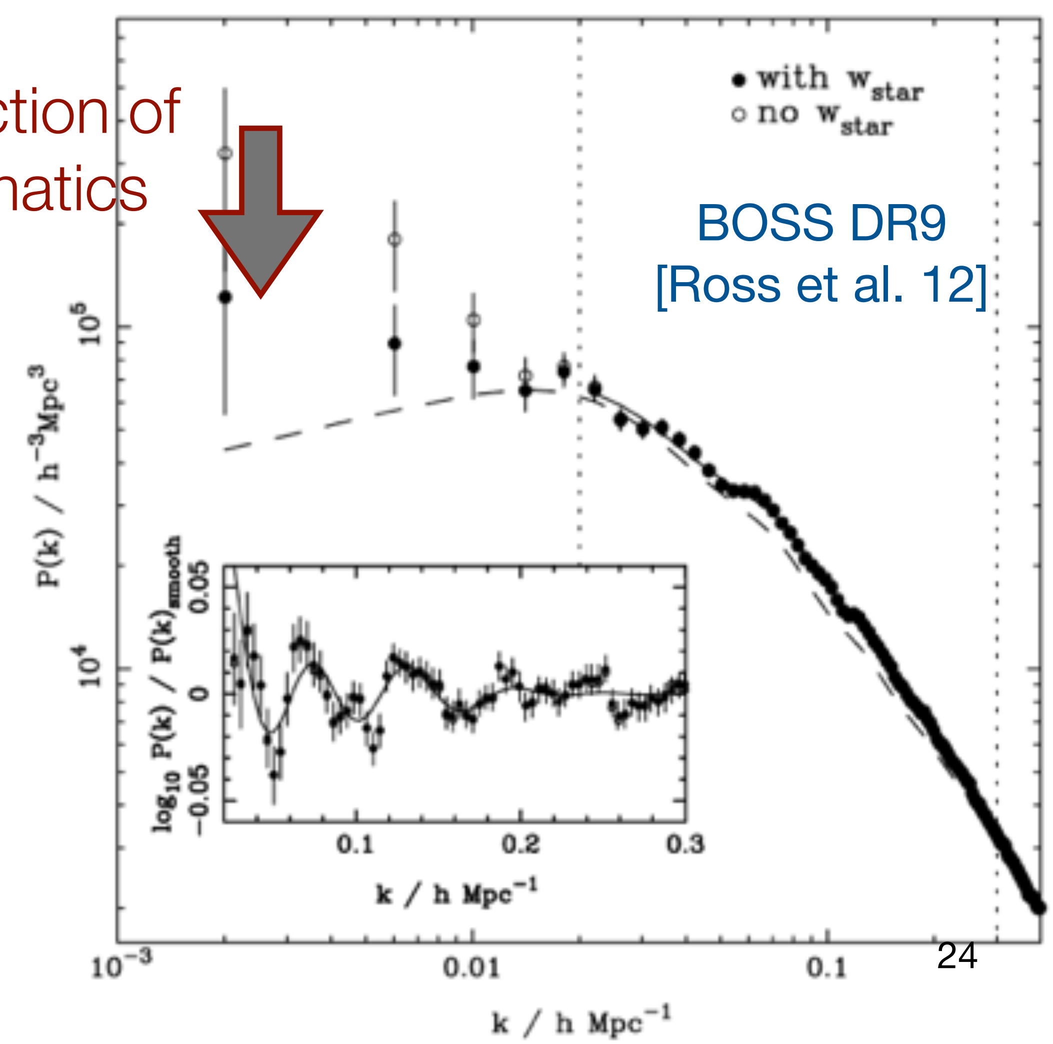
- LSS+ISW updated: consistent with older data, still **S/N > 4**
- Now better systematics control (stars, rotations, ...)
- Likelihood analysis: now better use of ACF (full covariance) and bias (marginalization)
- Non-Gaussianity: **16 < f_{NL} < 60 @ 95% c.l.**, *but* stars are a **big issue**

- **BOSS**: better systematics control
  - DR8 QSO
  - LSS+ISW analysis with **3D clustering** (DR9, DR10)

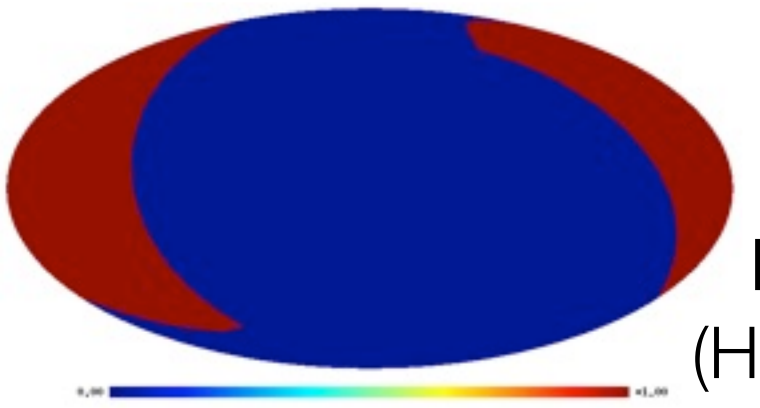
- **DES**: $f_{NL} \pm 8$
  gal-gal, CMB-gal, CMB-shear

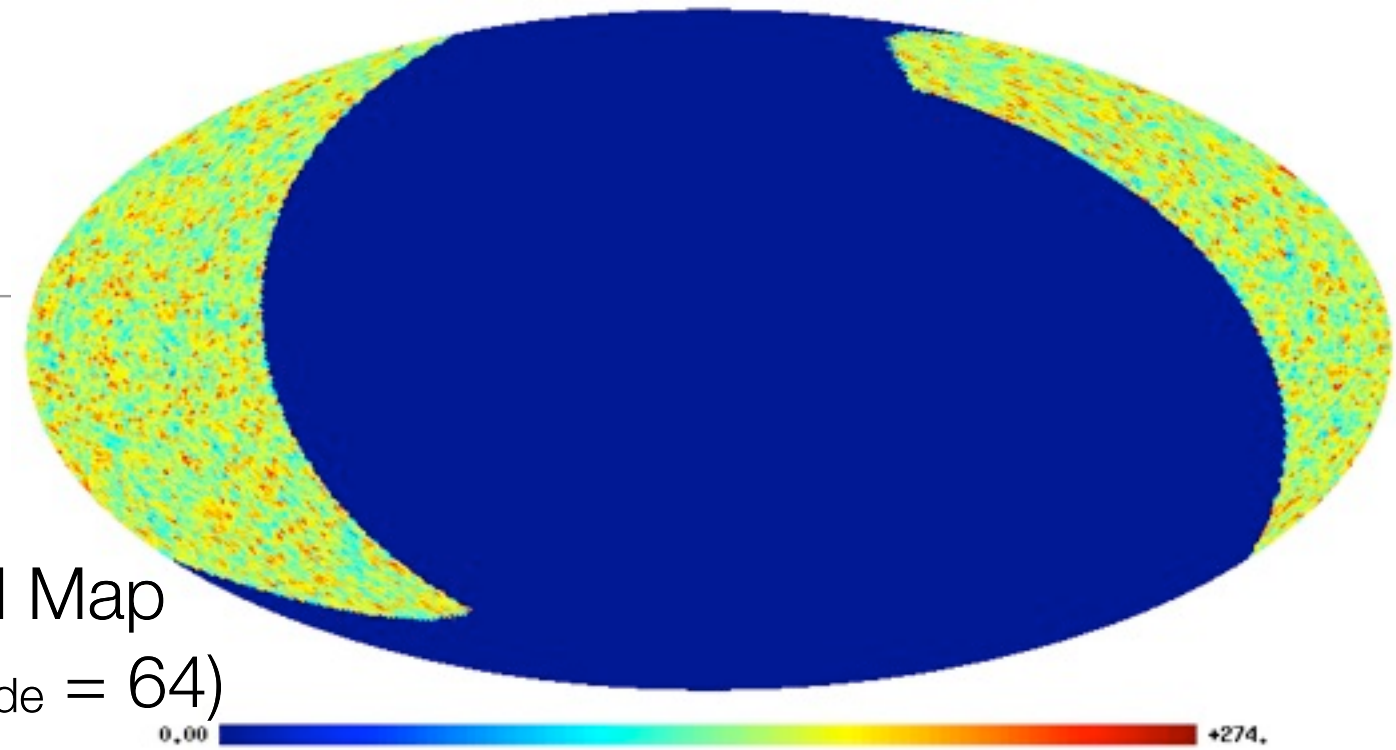
- **Euclid**: $f_{NL} \pm 3$

Subtraction of systematics

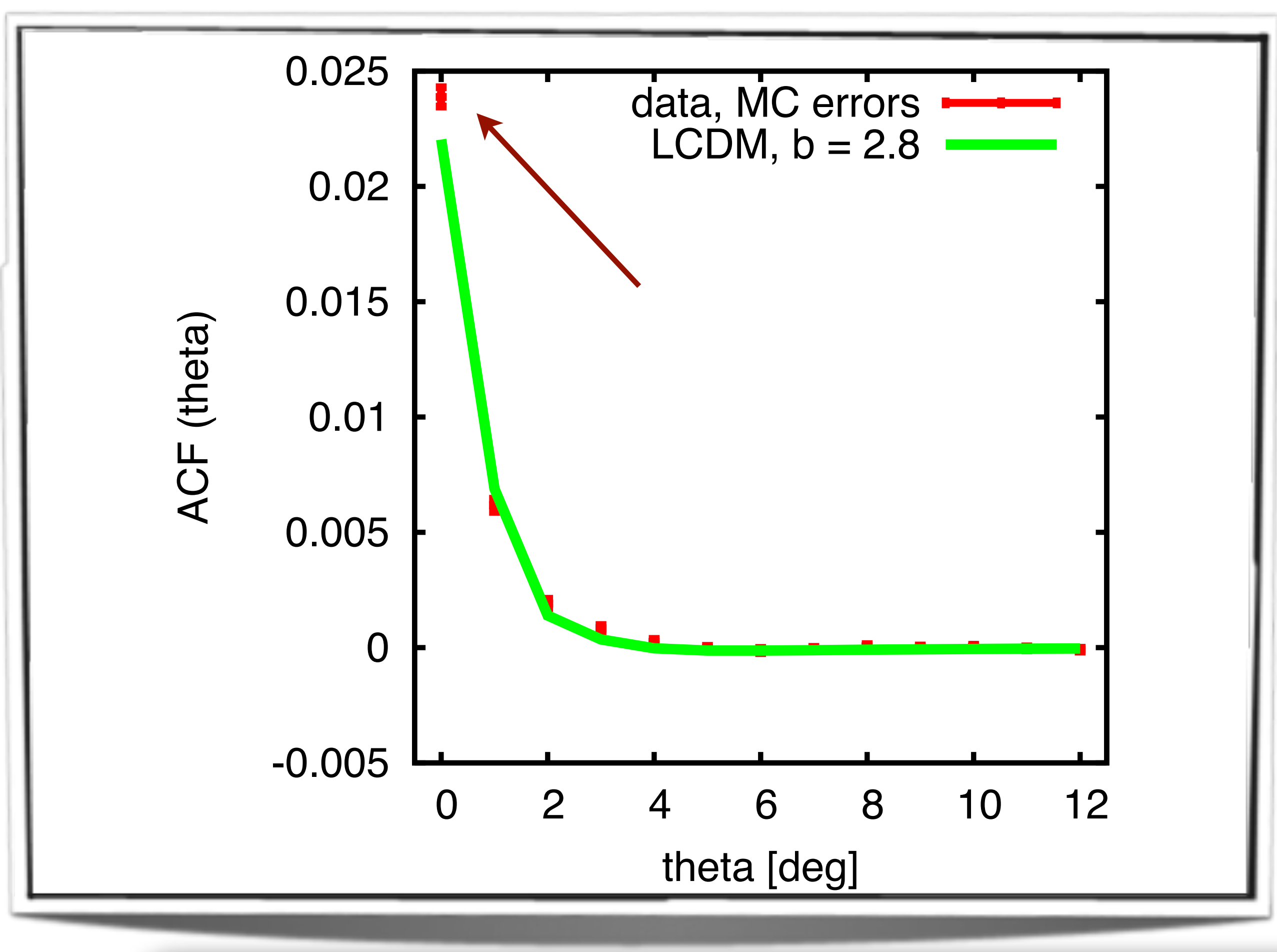


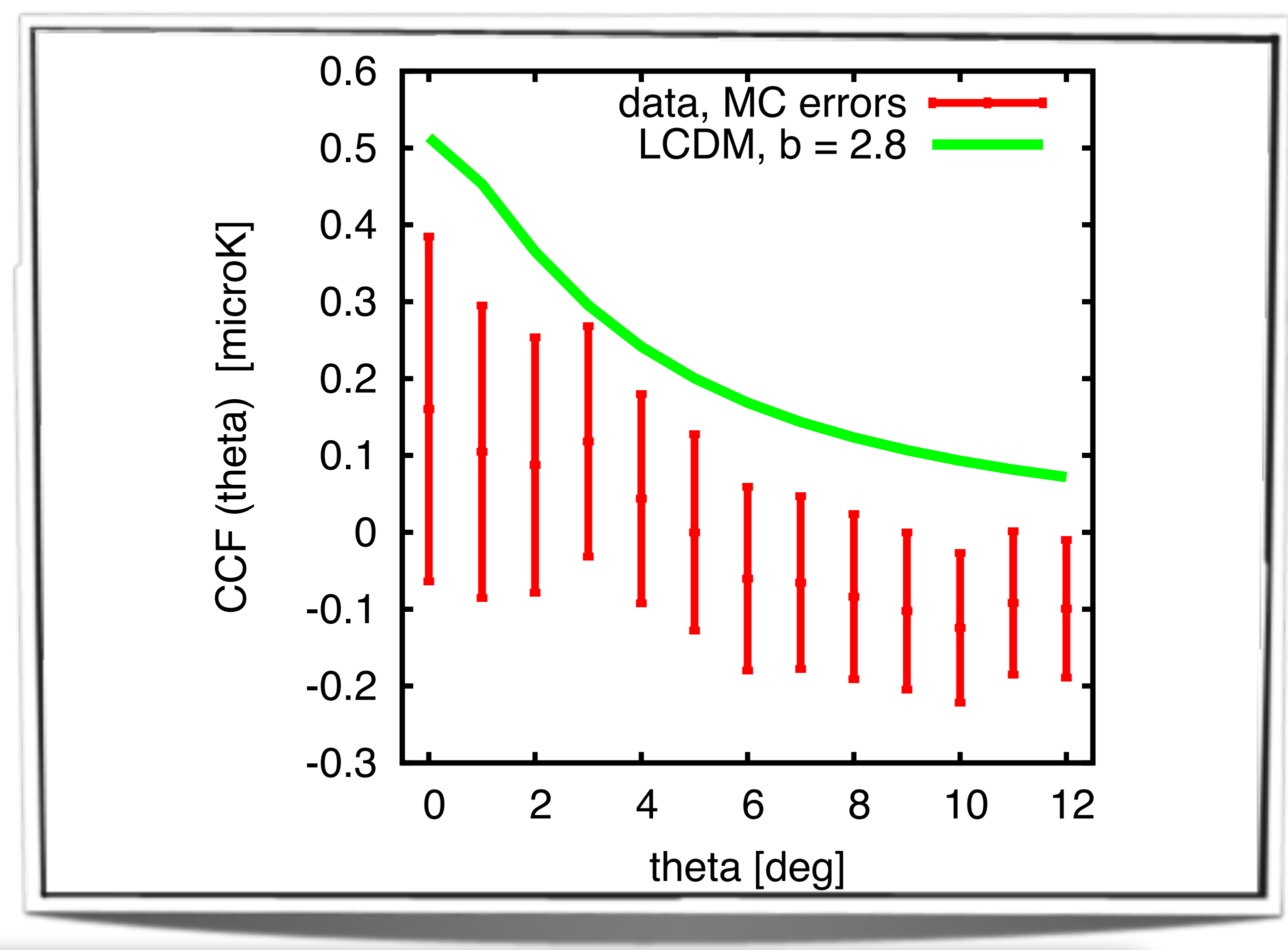
Simulation 1 analysis





Mask and Map
(Healpix N_{side} = 64)



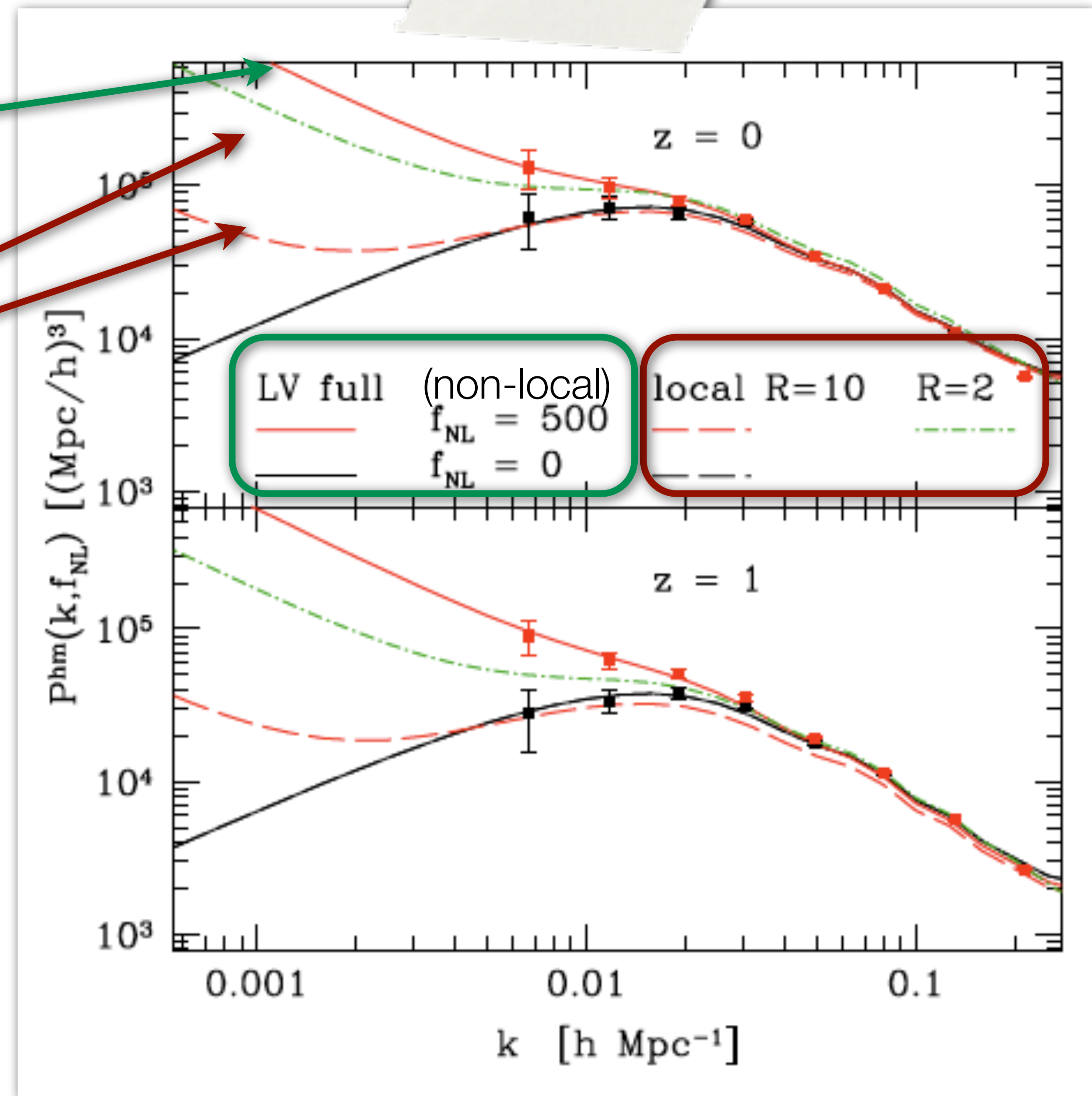


joint analysis, VERY PRELIMINARY, **margin. error on local f_{NL} ± ~20** @ 95% c.l.

Differences from local approach

Bivariate (or non-local) b vs. local b [Taruya et al. 08, Sefusatti 09]

- At linear order:
- we recover $\Delta b \propto b_{10}-1$
- No strong dependence on R smoothing at leading order
- in local approach is found $\Delta b \propto b_{20}\,\sigma^2(R)$
- This is ∝ R smoothing
    - equivalent only in particular case: Press-Schechter, high peaks ($\delta_c\, b_{10}^{L2} \sim b_{10}^{L}\, b_{20}^{L} \sim \delta_c^3$), smoothing R = halo Lagrangian R
    - but then $\sigma \sim 1$, so pert. theory problematic
- Asymptotic k-dependence identical
    - so no problem if b's are free fitting parameters, or renormalised a la McDonalds 08
- but non-local (bivariate) method needed for predictive bias theory



Physical meaning: large-scale δ_h trace φ, not δ!