Detecting Dark Energy from Supervoids and Superclusters

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Outline

1. Introduction/Cross-correlation
2. ISW from Superstructures
3. ISW from Potential Maps

Integrated Sachs-Wolf Effect

- Photons passing through changing gravitational potentials are becoming slightly hotter or colder
- The effect is linear if $\Omega \neq 1$
- If the universe is flat (e.g., from CMB), linear ISW effect signals Dark Energy
- Caviat: there can be a non-linear effect as well

ISW Effect and Cross-Correlation

- Galaxy catalogs and the CMB are correlated due to the ISW effect
- This is a tiny correlation compared to the CMB fluctuations, but it has been detected in several galaxy catalogs
- Combining all available data sets gives up to 4 σ result (Giannantonio etal, Ho etal)
- Evaluating the detection significance requires full knowledge of the covariances (between bins and catalogs)

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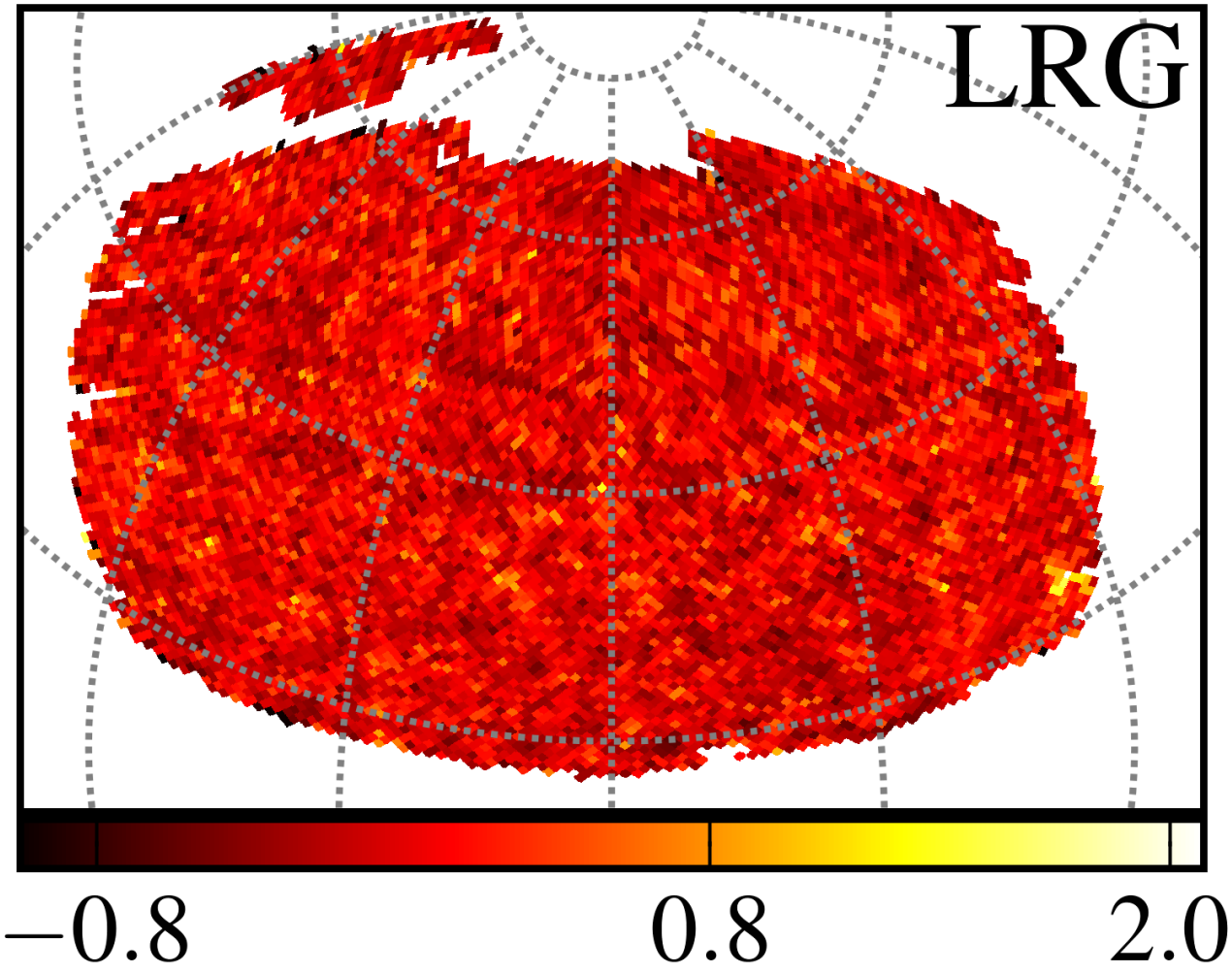
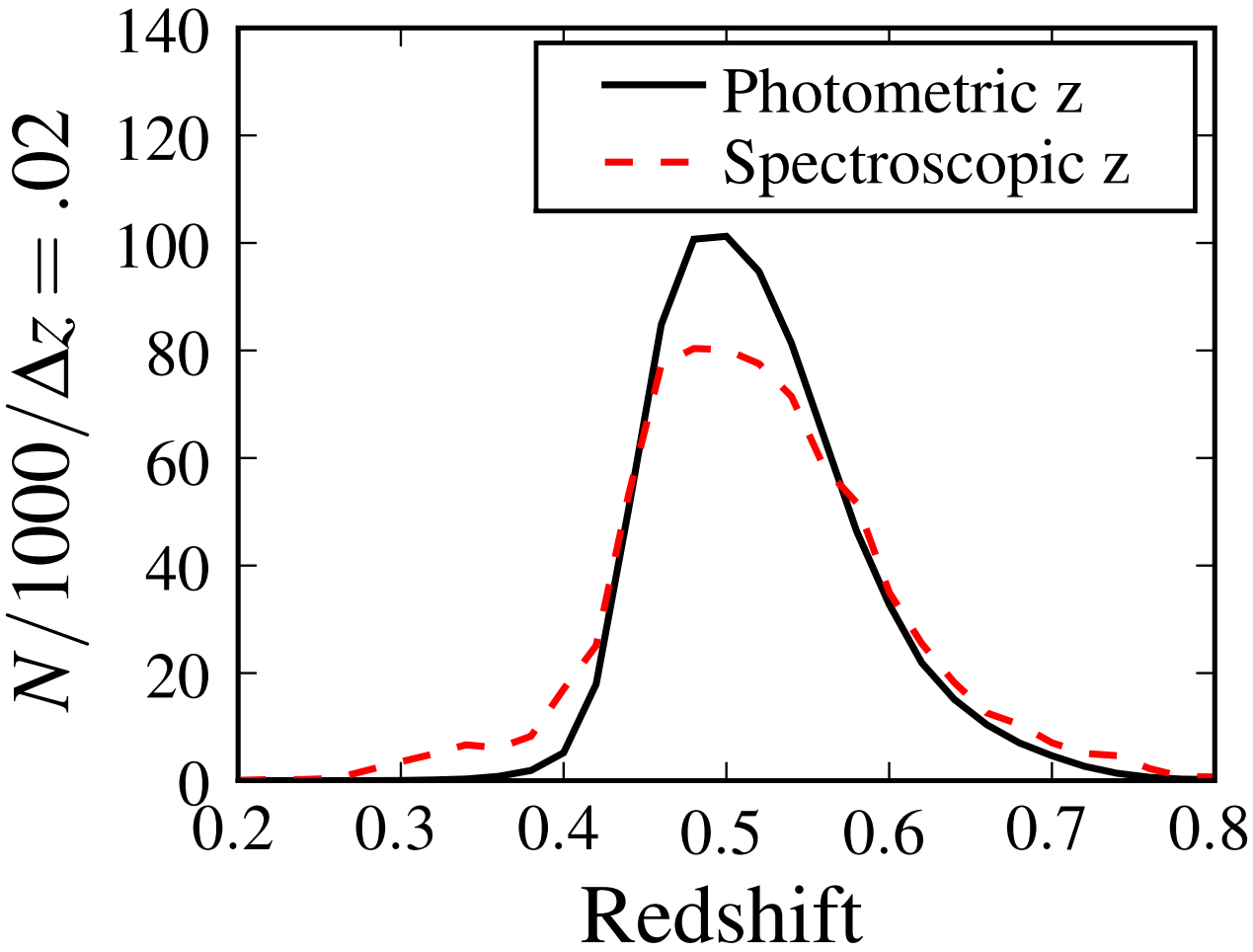
SDSS DR6 LRG

- 7500 square degree
- 2SLAQ cuts
- 746962 objects
- $0.45 < z < 0.75$ with median $z = 0.52$
- median photo-z errors $\sigma_z \simeq 0.04$

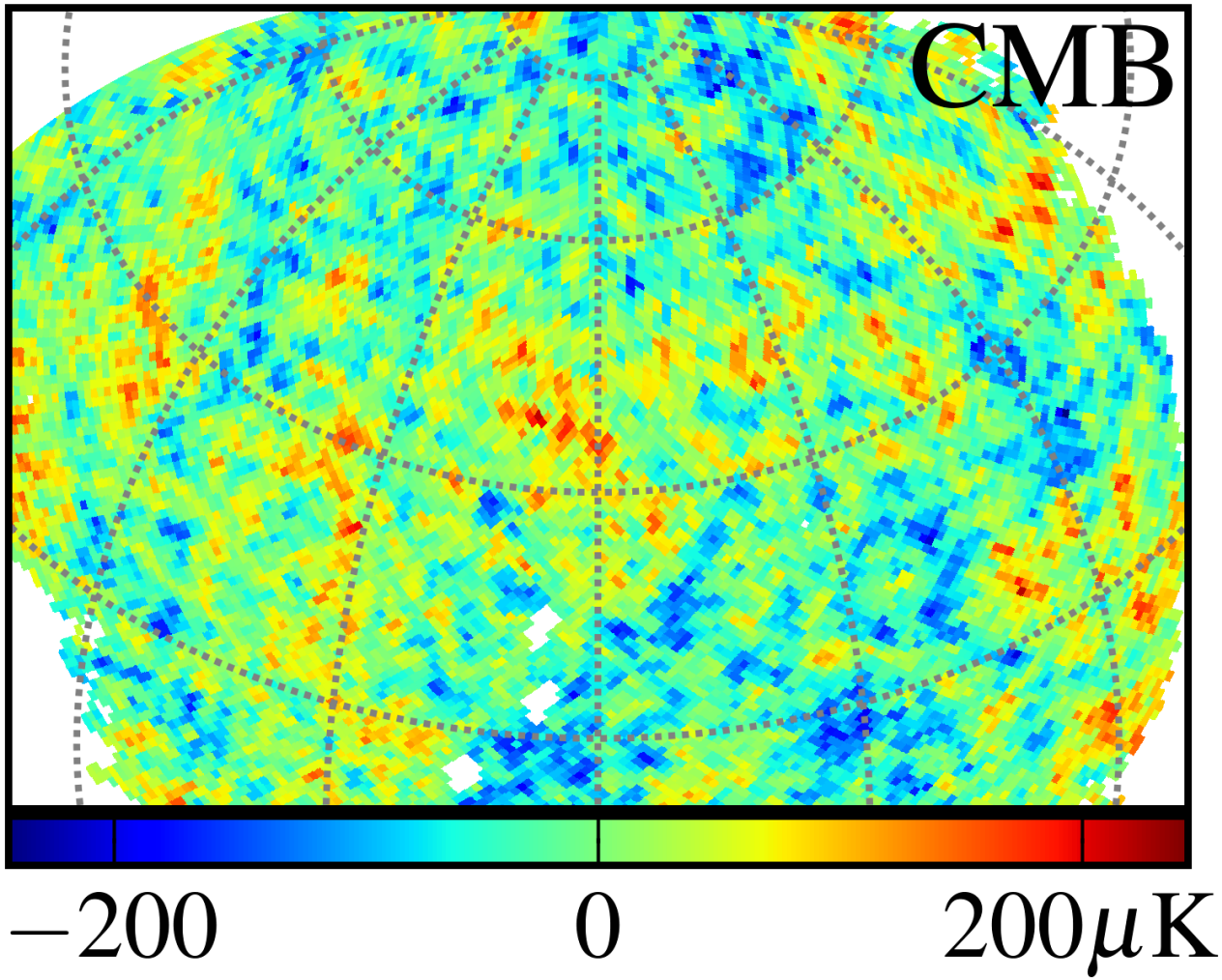
The SDSS DR6 LRG catalog



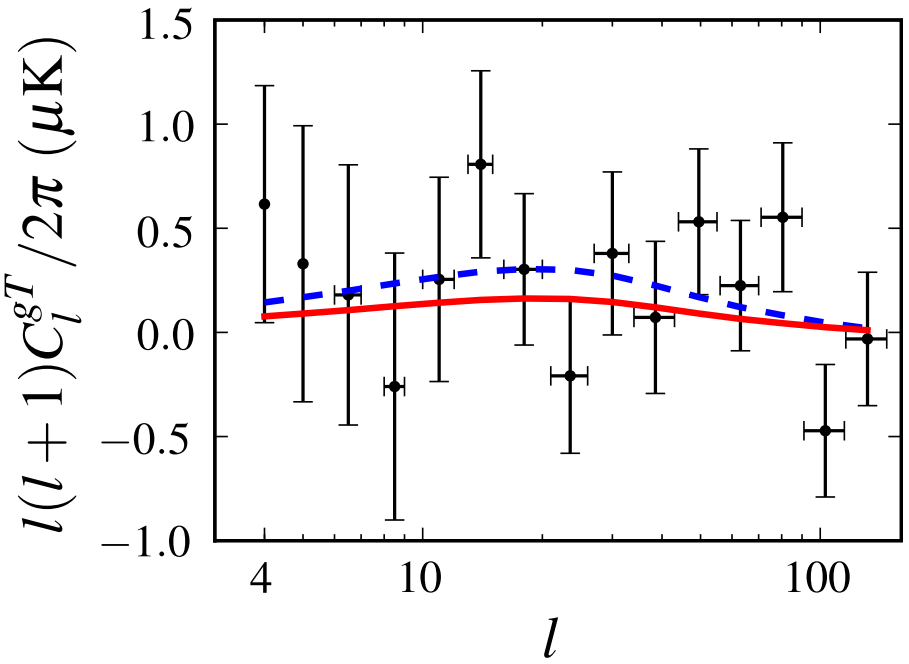

Photometric z
Spectroscopic z
$N/1000/\Delta z = .02$
140
120
100
80
60
40
20
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Redshift

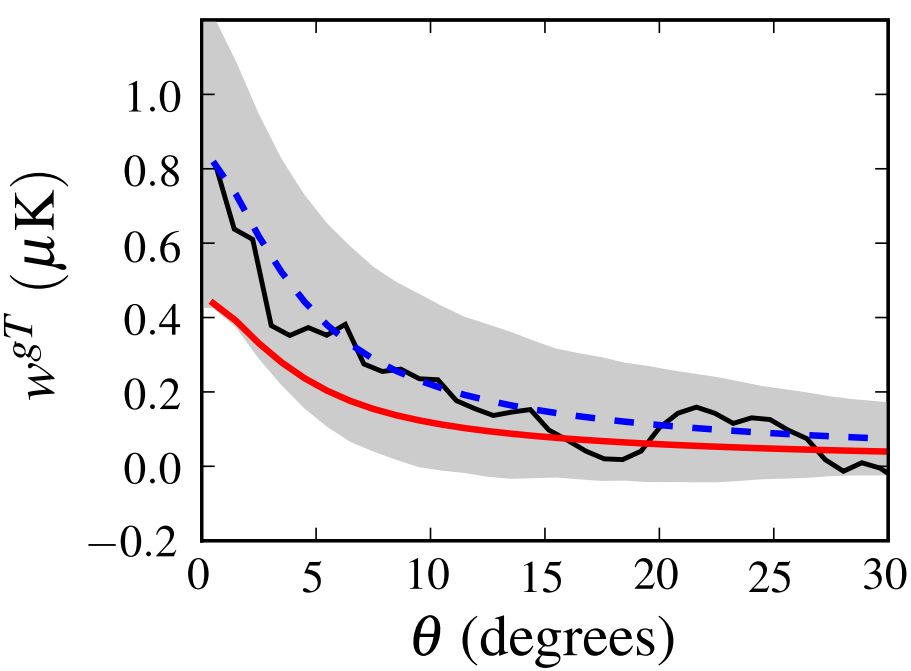
WMAP 5-year data set

- co-added Q,V,W
- ILC map
- MCMC map (joint fit to temperature, polarization and foregrounds)
- KQ75 galactic foreground masks
- maps are smoothed to 1°FWHM resolution
- Healpix $N_{side} = 64$ maps, or 55 arcminute resolution

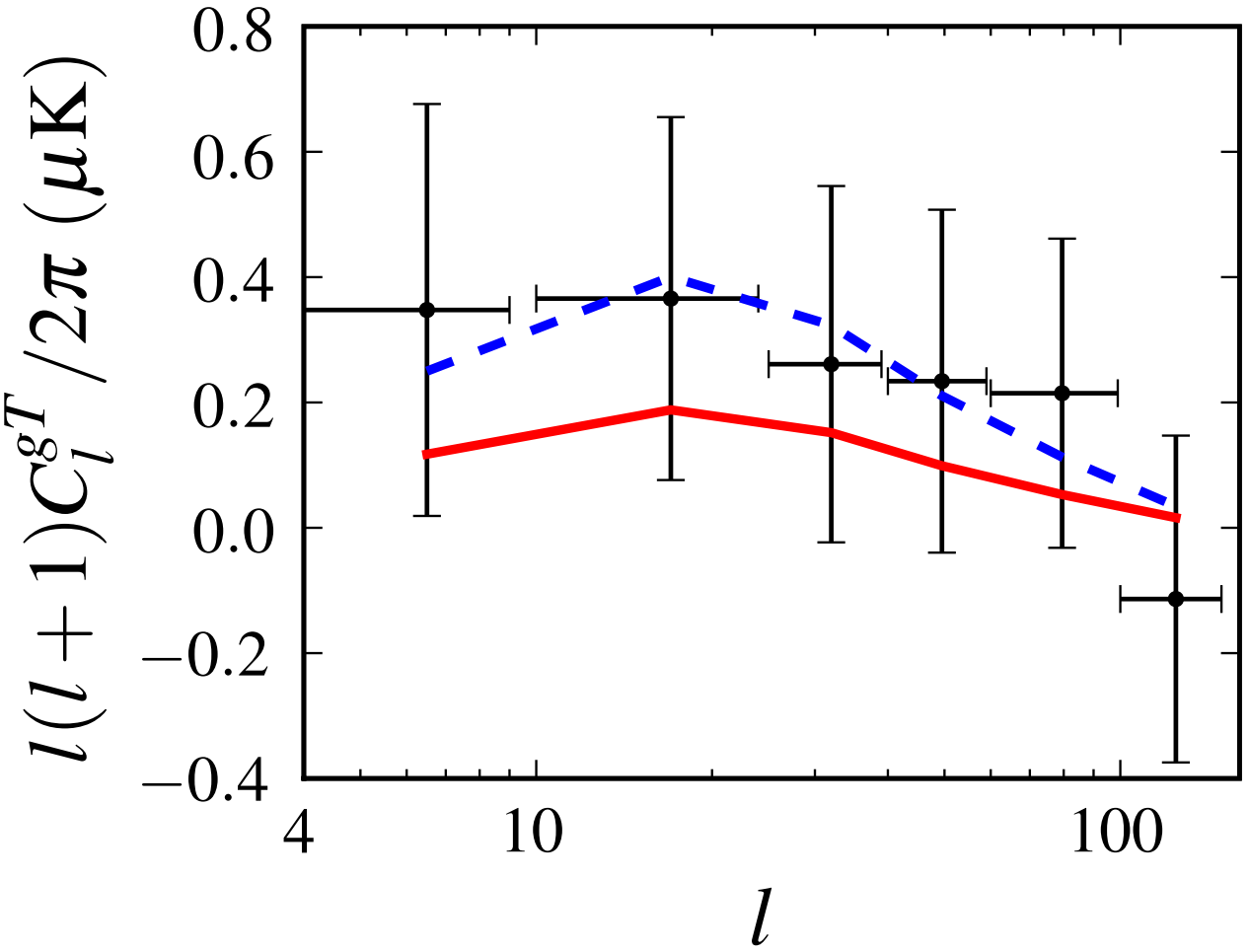

CMB
−200
0
200μK

Cross-correlation results with SpICE and MLHood





- Agreement with Giannantonio etal, Ho etal, e.g., 2.1 σ from the MCMC map..


0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
4
10
100
l
$l(l+1)C_l^{gT}/2\pi\ (\mu\mathrm{K})$

Beyond Cross-correlation

Why in the linear regime

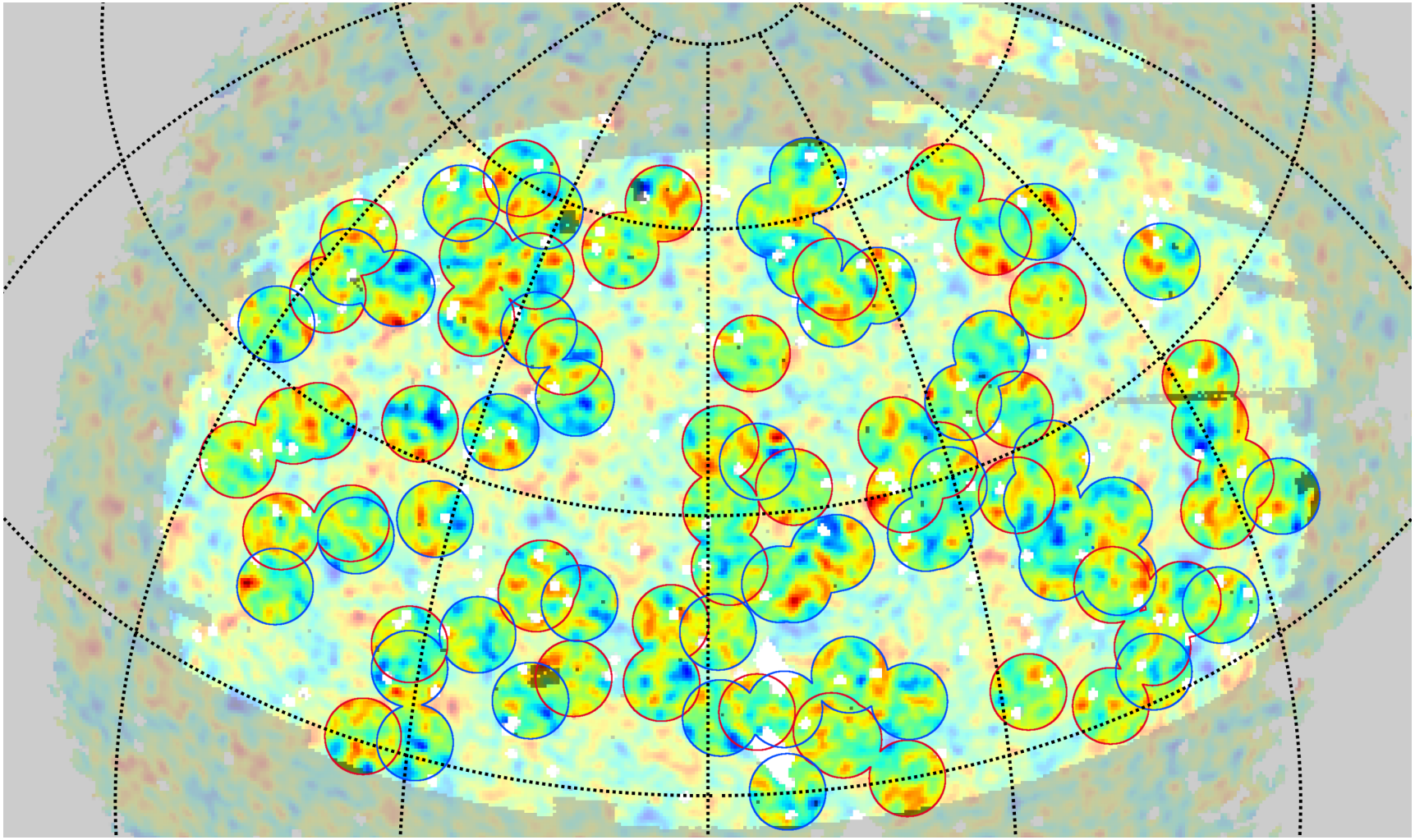
- Non-optimal weighting
- No redshift information was used
- Cosmic variance of galaxy data, even though we have access to a particular realization
- Perhaps more than linear signal
- ...

Finding Superstructures (100Mpc scales)

The magic of Voboz

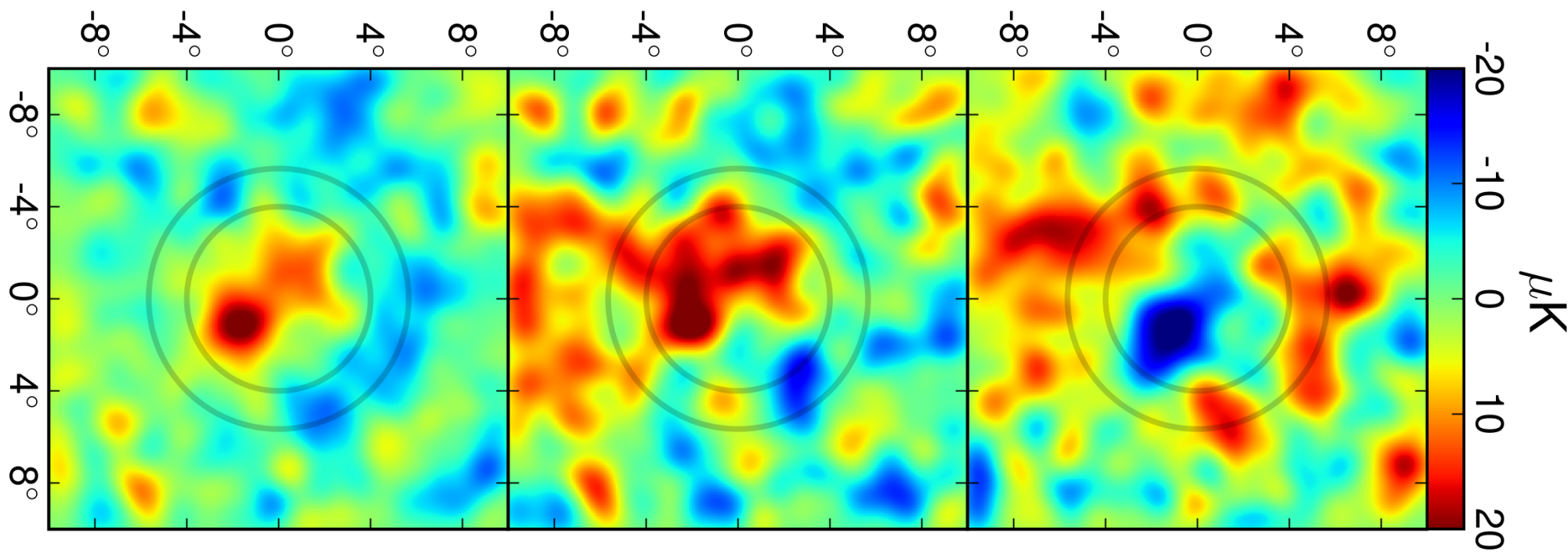
- Voboz/Zobov algorithms to find supervoids and superclusters int the LRG catalog
- Cutting out the highest signal-to-noise areas (simple weighting)
- Photometric redshift information is used
- Actual realization of the galaxy (DM) field is used
- Linear use of the data
- Possibility of localizing the signal, especially if there is a non-linear component

Supervoids and Superclusters



Back to the Basics: Image-stacking

Granett, Neyrinck, & Szapudi 2008, ApjL, 68, L99-102



- Two different Monte Carlos to determine significance: agree within 2%

Detection significance

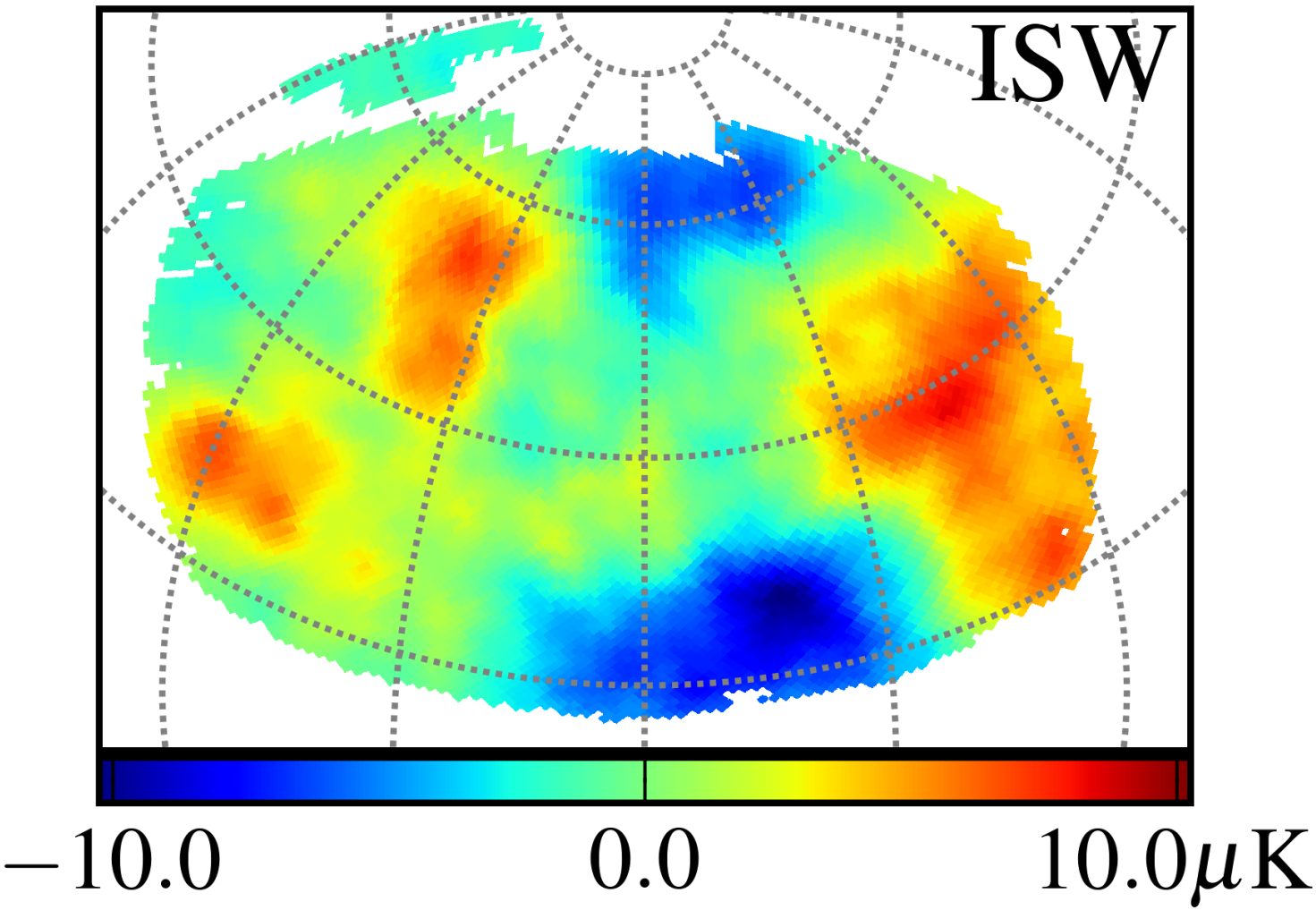
Robust against number, radius, color.

N	Radius	$\Delta T \mu K$	$\Delta T/\sigma$
30	4.0°	11.1	4.0
50	4.0°	9.6	4.4
70	4.0°	5.4	2.8
50	3.0°	8.4	3.4
50	3.5°	9.3	4.0
50	4.0°	9.6	4.4
50	4.5°	9.2	4.4
50	5.0°	7.8	3.8

Granett, Neyrinck, & Szapudi, in prep.

- What does this mean, how do we do cosmology with our results?
- Understand Voboz/Zobov or simplify technique
- Keep advantages: weighting,redshift information and realization.
- Calculate the potential from the galaxies (N-body engine)
- Raytracing, using the linear growth factor to calculate derivatives in 2 $\int \dot{\phi}$
- Use maximum likelihood to reveal the signal in the CMB data.

Potential map corresponding to the LRG catalog

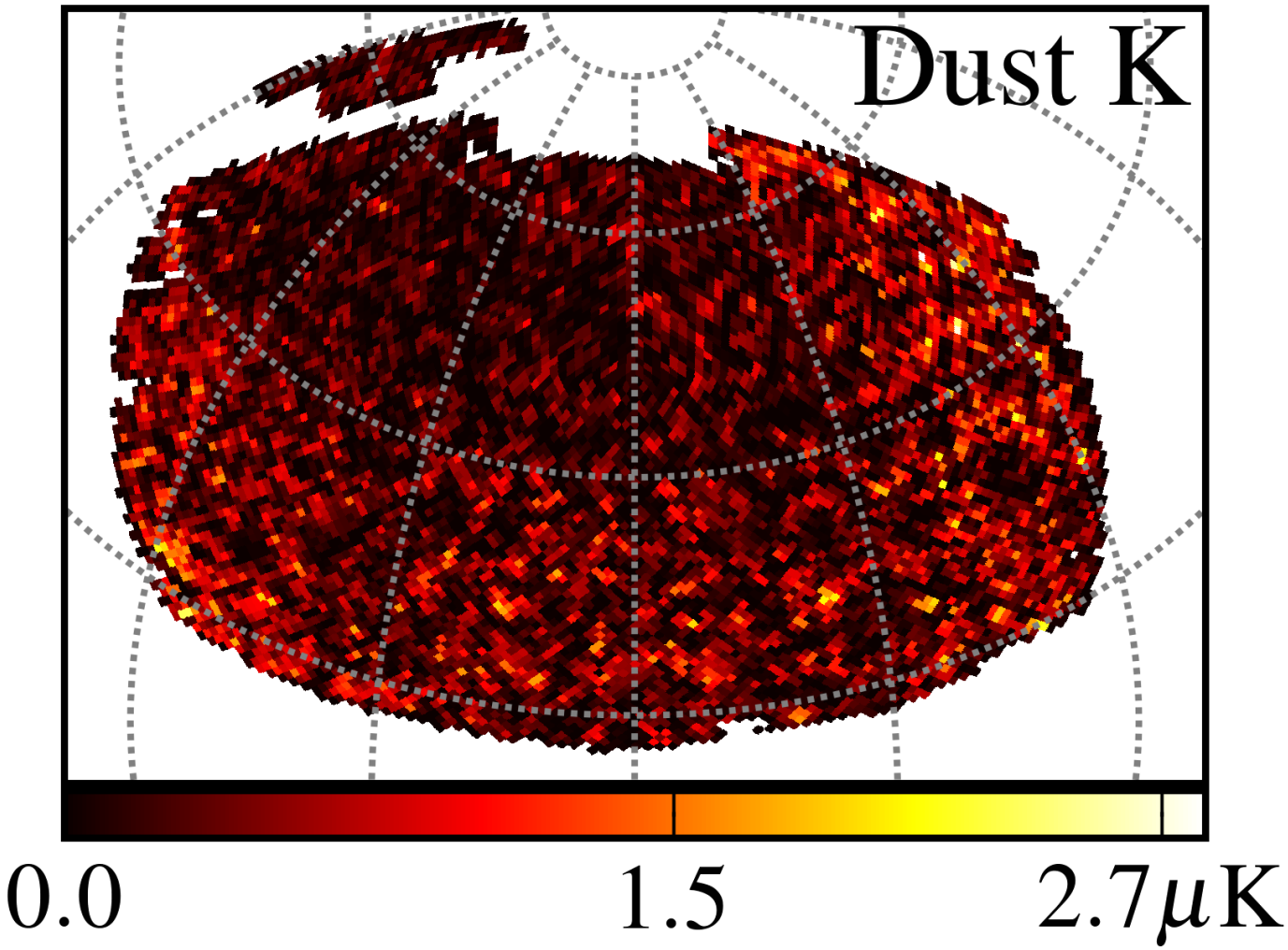


Max. Likelihood/Matched Filter

- if $Y = \lambda X$ plus some noise (here the CMB)
- Maximum likelihood gives

$$\hat{\lambda} = \frac{XC^{-1}Y}{YC^{-1}Y}, \tag{1}$$

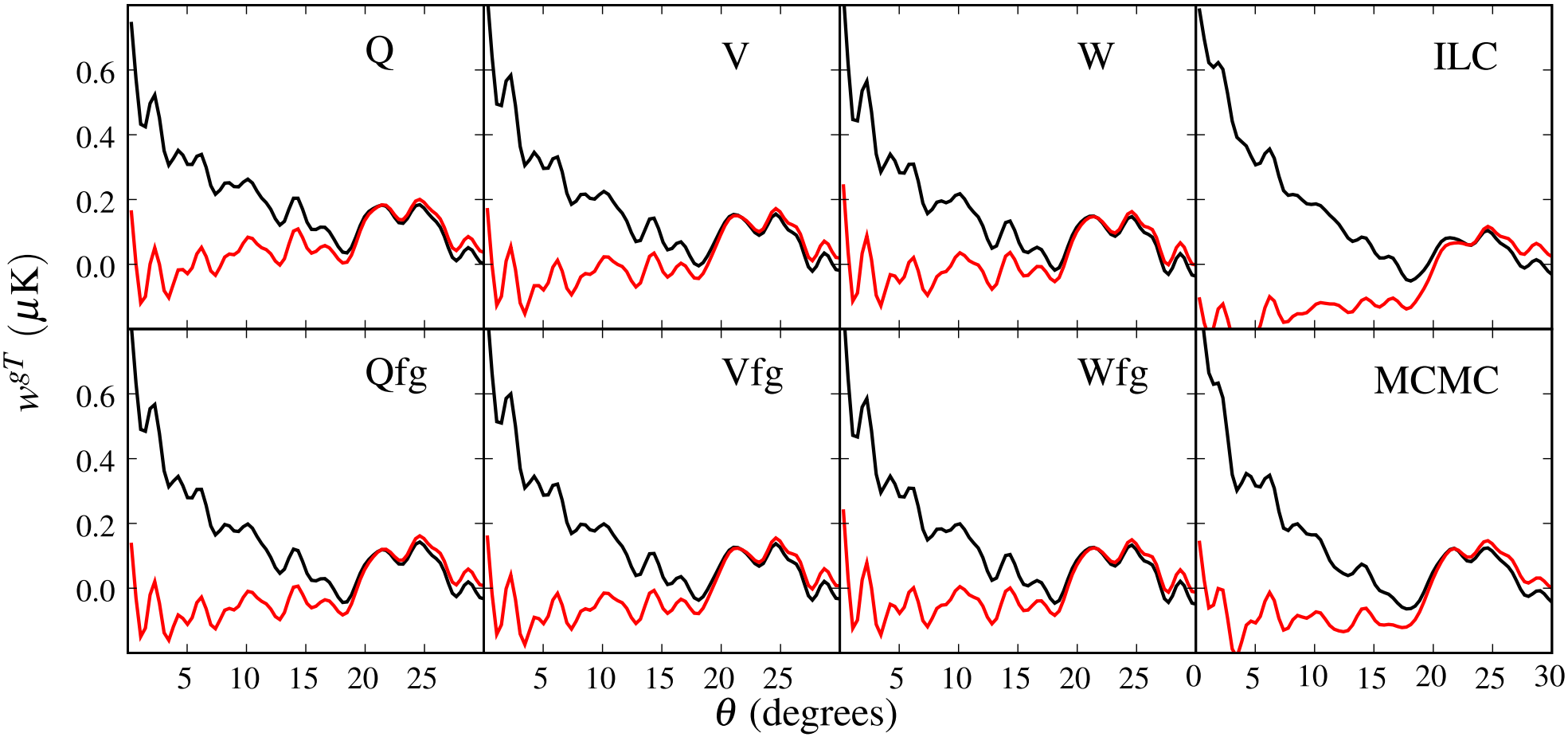
- with variance $\sigma^2 = (YC^{-1}Y)^{-1}$, where $C = \langle X_i X_j \rangle$
- λ is related to the bias (and any numerical factors missed in the prediction)
- looks like an optimal sum over a two-point quantity


Dust K
0.0
1.5
2.7μK

Detection Significance from Potential Map

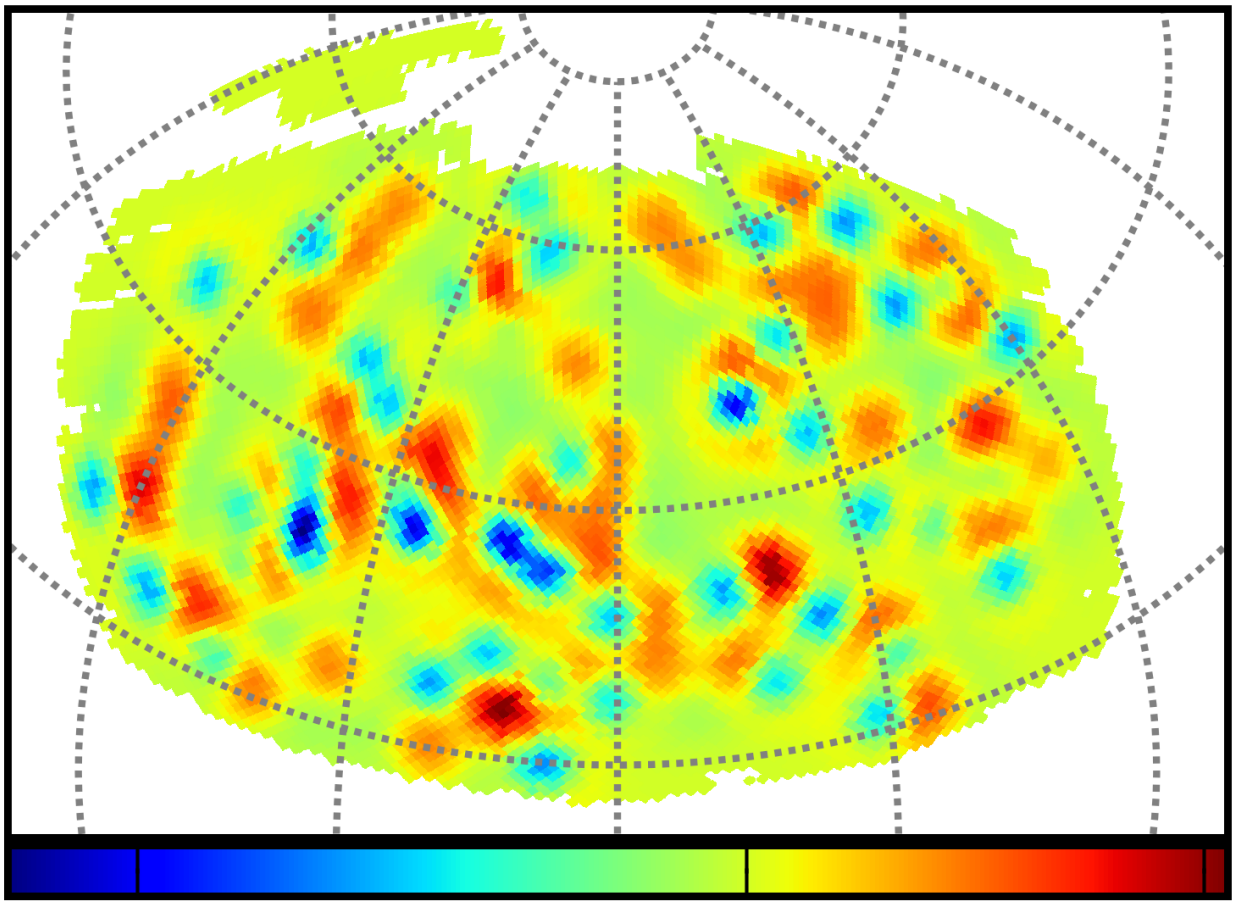
Map	Amplitude	σ
Q Coadd	2.96 ± 1.71	1.7
V Coadd	3.33 ± 1.71	1.9
W Coadd	3.01 ± 1.71	1.8
Q FG reduced	3.43 ± 1.71	2.0
V FG reduced	3.52 ± 1.71	2.1
W FG reduced	3.20 ± 1.71	1.9
MCMC	3.75 ± 1.71	2.2
ILC	4.33 ± 1.67	2.6

Disappearing the cross-correlations



Potential + Superstructures

Formally a 5.3 σ signal



Summary

www.ifa.hawaii.edu/supervoids for more

- Over 2σ detection of the linear ISW from cross-correlation and (marginally better) potential maps from the LRG's
- Cross-correlation disappears when the best fit ISW map is subtracted
- Signal from superstructures over 4σ very robustly
- This appears to be in addition to the linear ISW signal
- Potential + Superstructures 5.3σ!
- The nature of the signal from superstructures is yet to be determined (astrophysical, non-linear, or...?)
- Pan-STARRS will be able to confirm all these measurements with overwhelming statistical significance: 6σ for linear ISW.
- Theoretical investigations of the non-linear ISW are on-going.