Next frontiers of CMB: ISW and KSZ

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Agenda

-Motivations

-General Formalisms

ISW

a) Methods

b) Data:

Preparation,

Analysis

c) Results (preliminary)

KSZ

a) Methods

b) Data: Preparation, Analysis

c)Predictions with ACT and ADEPT

Motivations

- ISW: To understand the evolution of the gravitational potential in the Universe!

  -> especially useful in constraining dark energy
- KSZ: To understand the evolution of electron density throughout the universe. (in gas phase)

  -> missing baryon problem (Fukugita, Peebles et al. 1998)

Motivations and the physics!!

–Cosmic Microwave Background has been offering a wealth of information for cosmology:

–>the positions of the acoustic oscillations in the angular power spectrum gets us the curvature of the universe

–Careful modeling of power spectrum combined with other probes (large scale structure, SN, etc) gives us precise measurement of parameters of LCDM model.)

Motivations and physics

–CMB temperature fluctuations are sourced by

1)density fluctuations at the last scattering surface

2) interaction of photons with hot electrons in the galaxies and clusters (thermal Sunyaev–Zeldovich (TSZ) and kinetic–SZ (KSZ) effect)

3) the gravitational potential along their propagation path (Integrated Sachs–Wolfe (ISW) effect and gravitational lensing)

Motivations and physics:

- In particular:
- ISW:

  a) ISW results from the red-(or blue-) shifting of CMB photons as they propagate through the potential wells.

  b)If the potentials did not evolve, then the blueshift gain (falling) cancels out the redshift loss (emerging from well). Therefore evolving potentials spoil this cancellation.

  c) teaches us the evolvement of potentials in the universe.

$$\frac{\delta T}{T} = -2\int_0^{y_0} dy\, \dot{\phi}(y, y\hat{n})$$

Motivations and physics:

–KSZ:

1)electrons in velocity bulk flows interact with the cmb photons

2)since the electrons in the same bulk motion gives rise to a incre/decrement of the photon energy depending on the direction of the bulk flow velocities.

3) the velocities correlates positively to the temperature fluctuations of the cmb photons at small scale

4) –> understand the amount of ionized electrons: thus baryon fraction in the universe.

$$\frac{\delta T_{ksz}}{T_{cmb}} = -\int n_e \sigma_T \left(\frac{\vec{v}}{c} \cdot \hat{n}\right) dl$$

General formalisms

- Both signals are really small and hard to detect!
- Need to cross correlate them with suitable tracer populations
- Estimating the cross correlation:

(for any cross correlation between a cmb temperature map and a tracer of density)

$$C = \begin{pmatrix} C^{TT} + N^{TT} & C^{gT} \\ C^{gT} & C^{gg} + N^{gg} \end{pmatrix}$$

$$C_{ij}^{ab} = \sum_{lm} C_l^{ab} Y_{lm}^{*}(\hat{n}_i^a) Y_{lm}(\hat{n}_i^b)$$

where C is the covariance matrix, N^{xx} is the pixel noise matrix

General formalisms

- And we can parametrize C_l^{ab} as a sum of bandpowers
- Which is a sum of step function (since the shape of the power specturm is unknown)

$$C_l^{ab} = \sum_i c_i \tilde{P}_{i,l}$$

- We form quadratic combinations of the data:

$$q_i = \frac{1}{2} x^t C^{-1} \frac{\partial C}{\partial c_i} C^{-1} x$$

- Where x is a single data vector combined (for more than one datasets: we have x = $(x_i, x_{2,\ldots} x_T)$ where each of these x_i are the quantity we are trying to correlate per pixel.

General Formalisms

- And the estimated c_i are related to the estimators by fisher matrix F

$$\hat{c}_i = \sum_j (F^{-1})_{ij} q_j$$

$$F_{ij} = \frac{1}{2} C^{-1} \frac{\partial C}{\partial c_i} C^{-1} \frac{\partial C}{\partial c_j}$$

Covariance matrix of the c_i is the inverse of the Fisher matrix if the fiducial power spectra and noise used correctly describes the data,

Thus the $\hat{c}_i$ are good approximationsto the maximum likelihood estimators of the c_i

Now let's dive into each of these effects separately

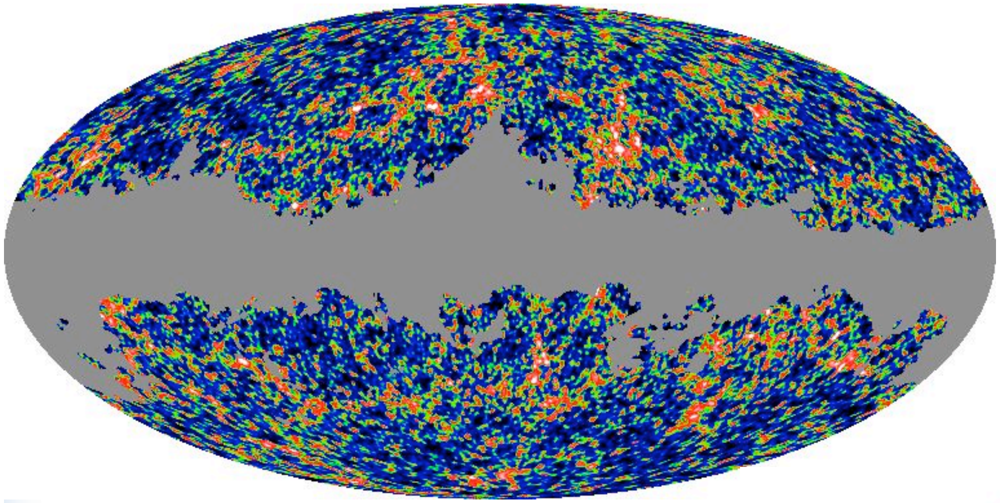
ISW: data

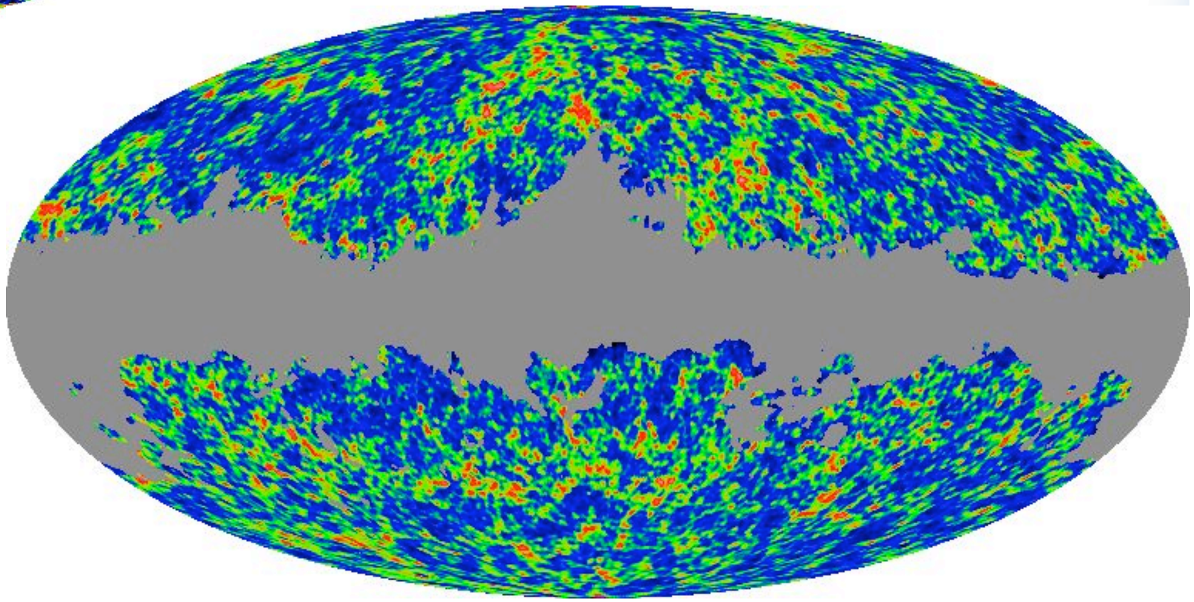
- WMAP: using Ka, Q, V, W bands
- Adding up from different DAs by weighting according to the inverse variance
- Mask with kp0 point source mask
- Taking into account of the pixel window function and the beam transfer function.

ISW: data

- 2MASS galaxies (2 Micron All Sky Survey: split into 4 samples (depending on K-band magnitude range)
- Peak at redshift of 0.1
- Therefore the redshift distribution of these 4 overlaps quite a bit.

2MASS

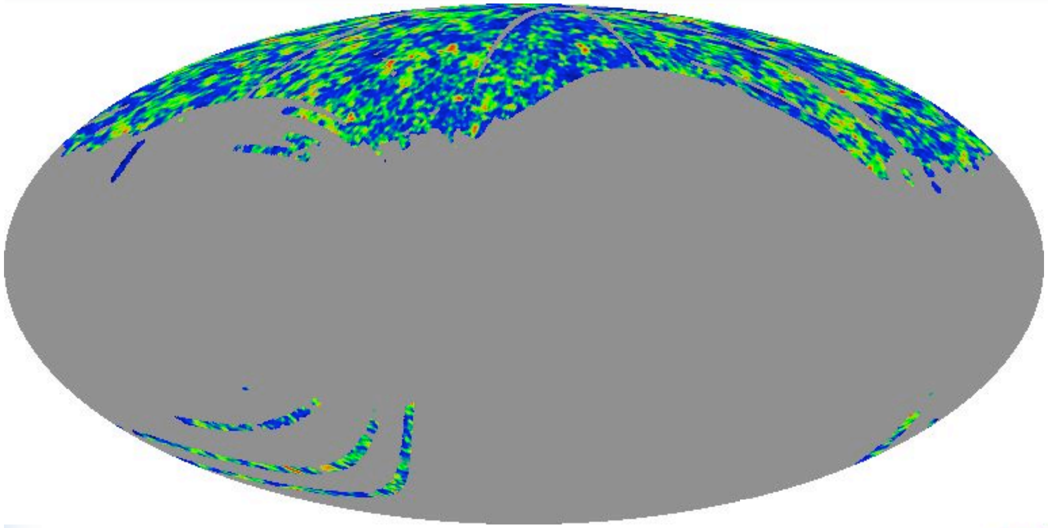


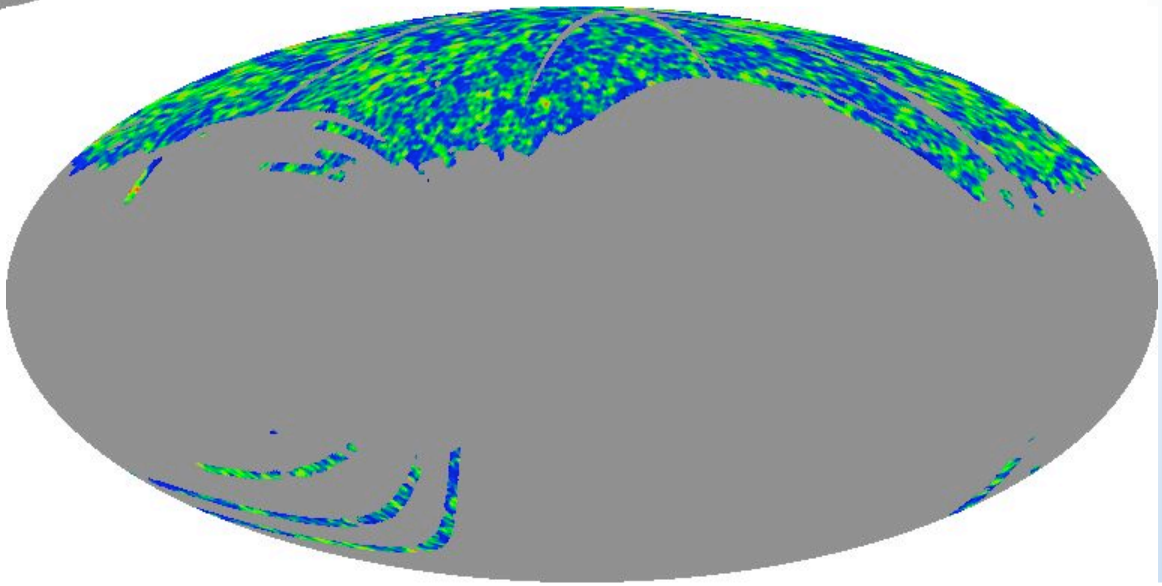


ISW: data

- SDSS – photometric LRG (DR5+)
- 1) good photoz because of 4000\AA break
- 2) still need to do regularized deconvolution of the photoz errors (refer to Padmanabhan 2004)
- 3) 2 sample: z=0.2-0.4, z=0.4-0.6

SDSS-LRG





ISW: data

- SDSS-photometric Quasars (DR5+)
- Issues:
- 1) finding out which are the quasars:

  ->finding nearest neighbors in color^4 space (matching with dr3 UVX and qso sample)

  -> description: (refer to Richards et al. 2003)

  photometric quasars are selected from a sample of UV-excess objects by looking at their colors

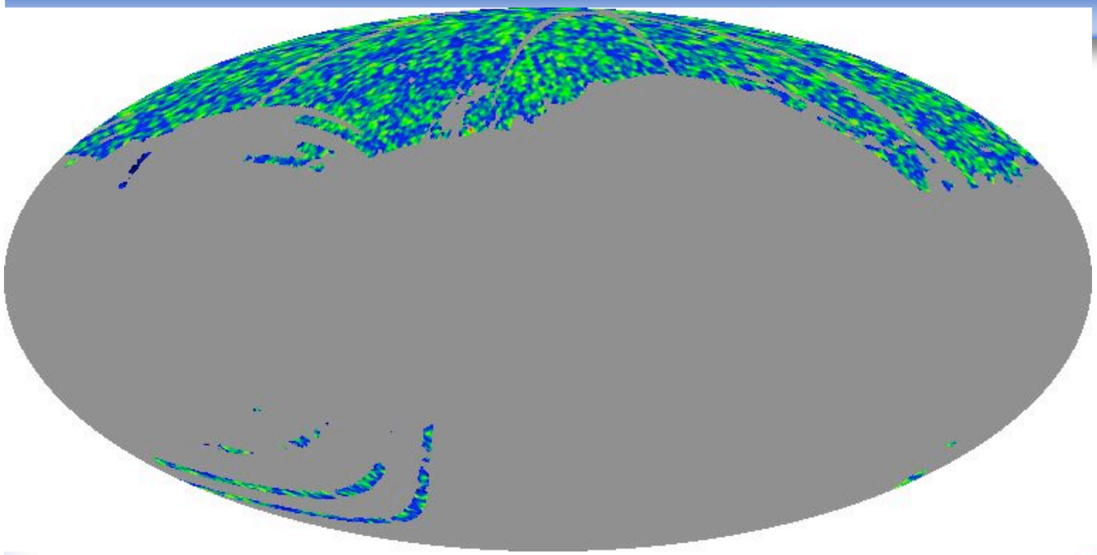
SDSS-QSOs

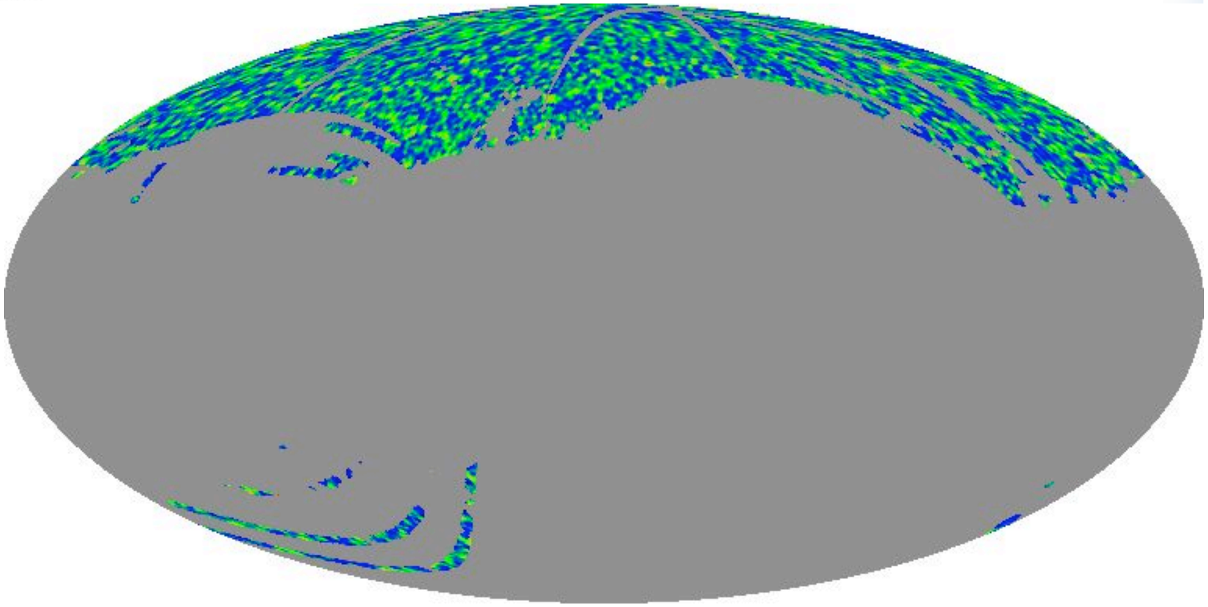
- 2) determining the redshift distribution:

  -> photoz (from the matching routine), but we need the true bias*dN/dz!! (for the correct estimation of the cosmological parameters!)

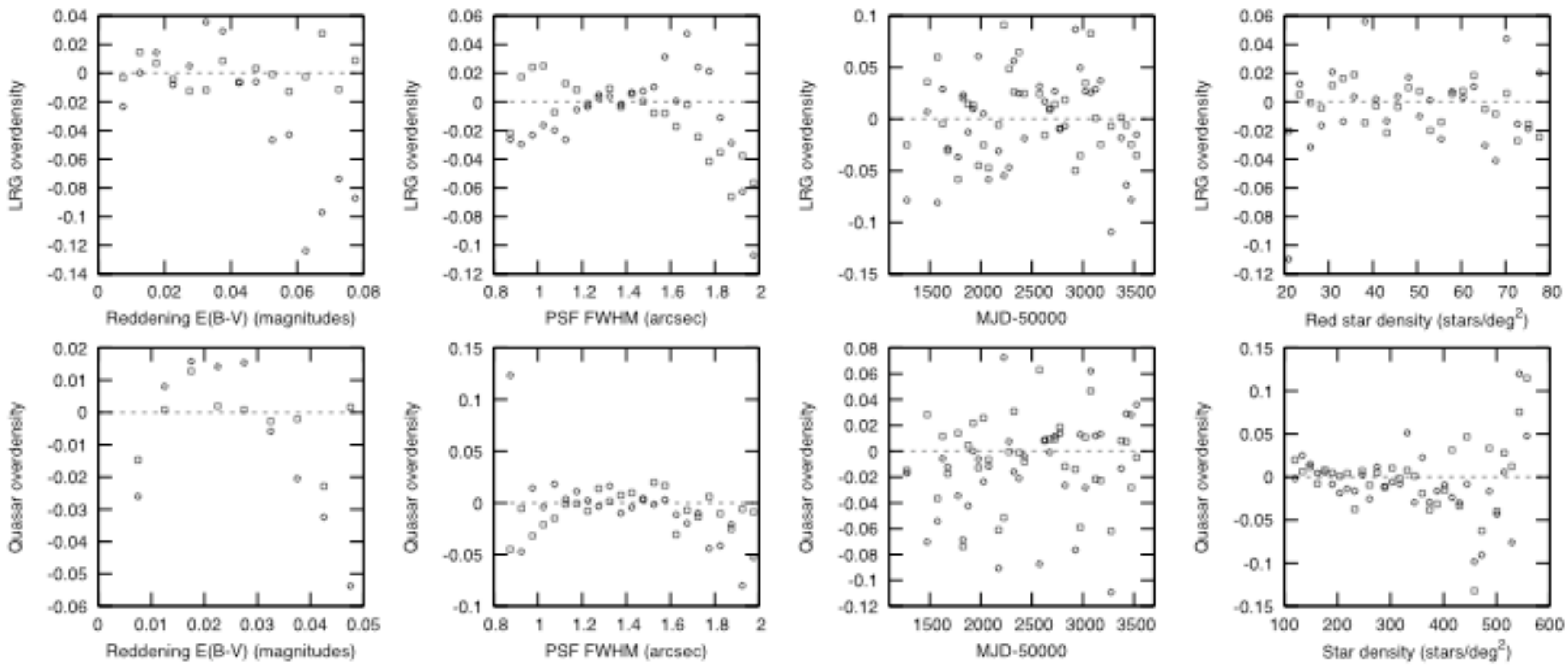
  -> cross correlating with other data sets (we need bias*dN/dz only)
- Need datasets in the same range of redshifts (approximately z = 1-2).
- Working on this now: since there is a huge degeneracies in the shapes of the bias*dN/dz when we don't really have samples that overlaps with this redshift distribution

SDSS-QSOs





LRG and QSO systematic check



SDSS: other issues:

- As we included more sky area in DR5+,
- We discover a stripe in the sky that were having problems as there are way too many LRGs and less QSOs
- And there seems to be more red stars than other spots in sky…
- This happens in only 3 runs of the survey, so we masked them out (using stellar density mask)

ISW: data

- NVSS: (**NRAO VLA Sky Survey)**
- 1.4 GHz observation of the sky: giving us mostly quasars (high redshift) and star forming galaxies (low redshift)
- Issues:
- 1)Stripping problem

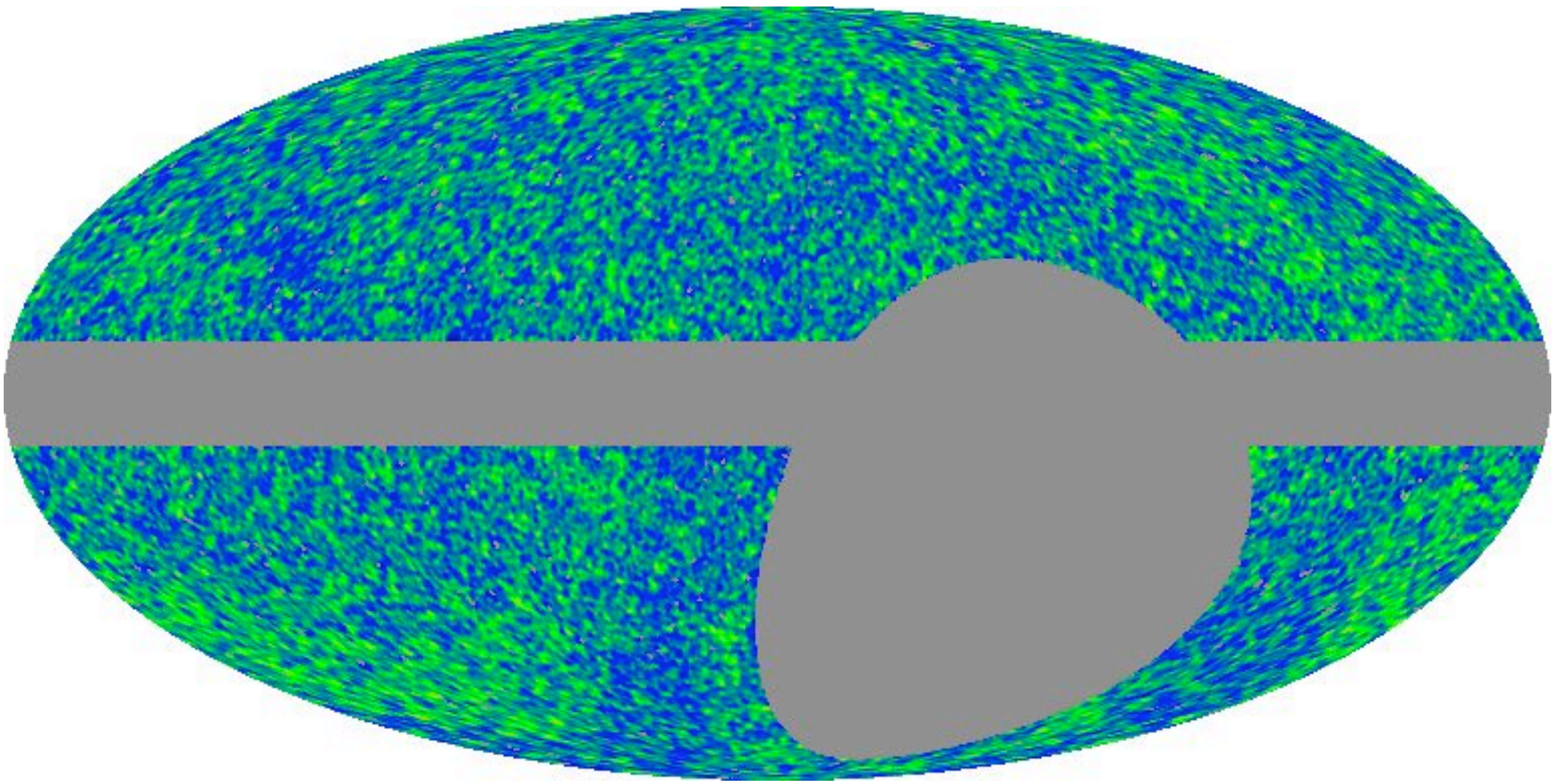
  -> impose a flux limit (2.5 mJy) to get rid of the stripes, we also mask out very bright radio sources.

NVSS: Data

->put in templates of declination rings and haslam map (synchrotron radiation) to "project out" any spurious power associated with either extinction or galactic synchrotron radiation.

- 2) redshift distribution (also solved by cross correlating it with other datasets)

NVSS:

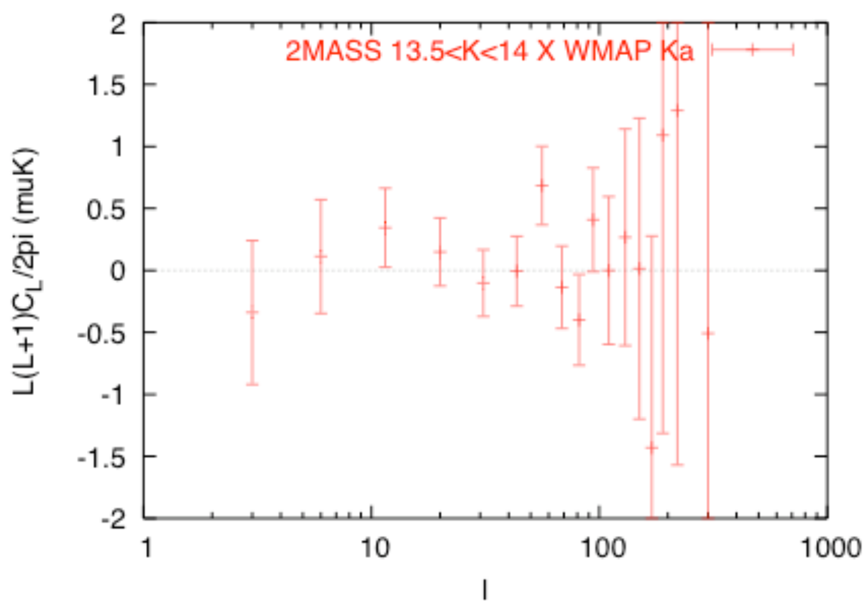


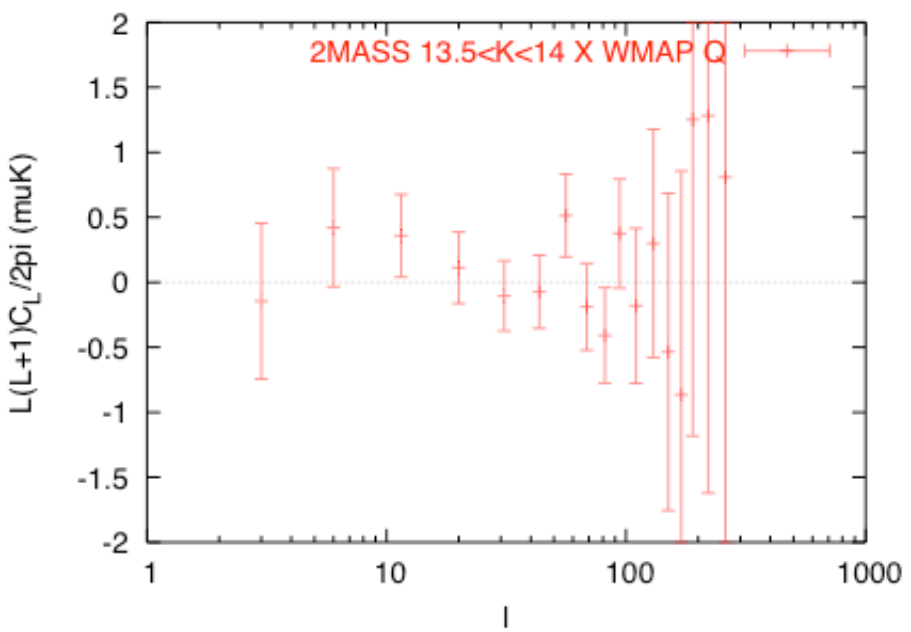
ISW: Analysis

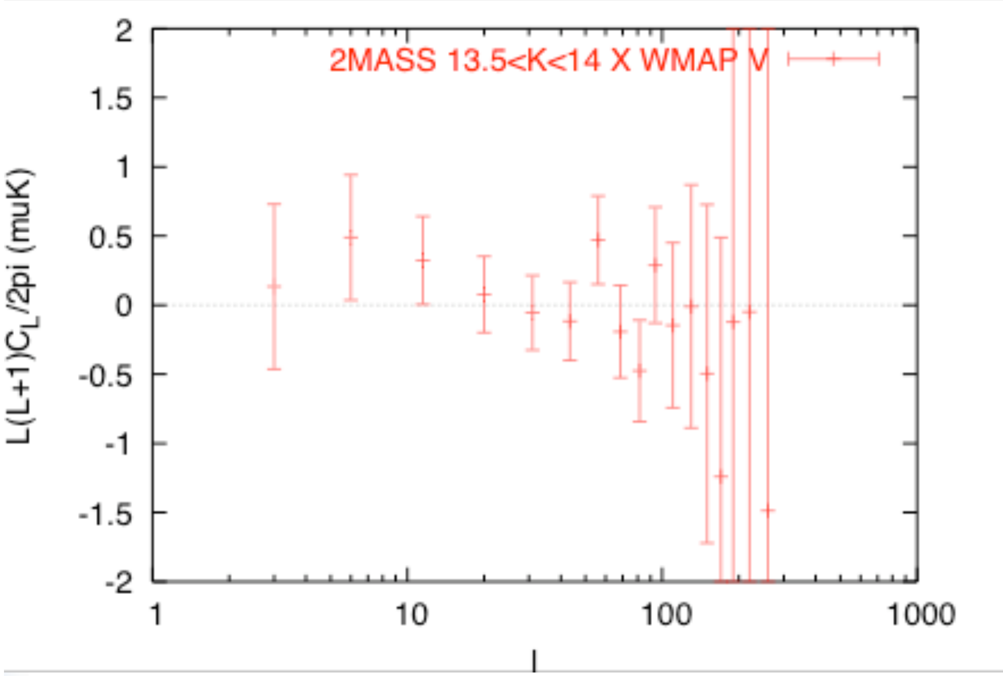
- 1) Getting all the auto-correlations to estimate the angular auto power spectrum to get correct priors for the cross correlations.
- 2) Getting all cross correlations between various samples and WMAP
- 3) Generate the covariance matrix (with all the datasets) by cross-correlating them with 1000 simulated cmb sky (using V-band)
- 4) Getting bias*dN/dz for fitting cosmological parameters
- 5) To fit for different cosmological models (next talk :))

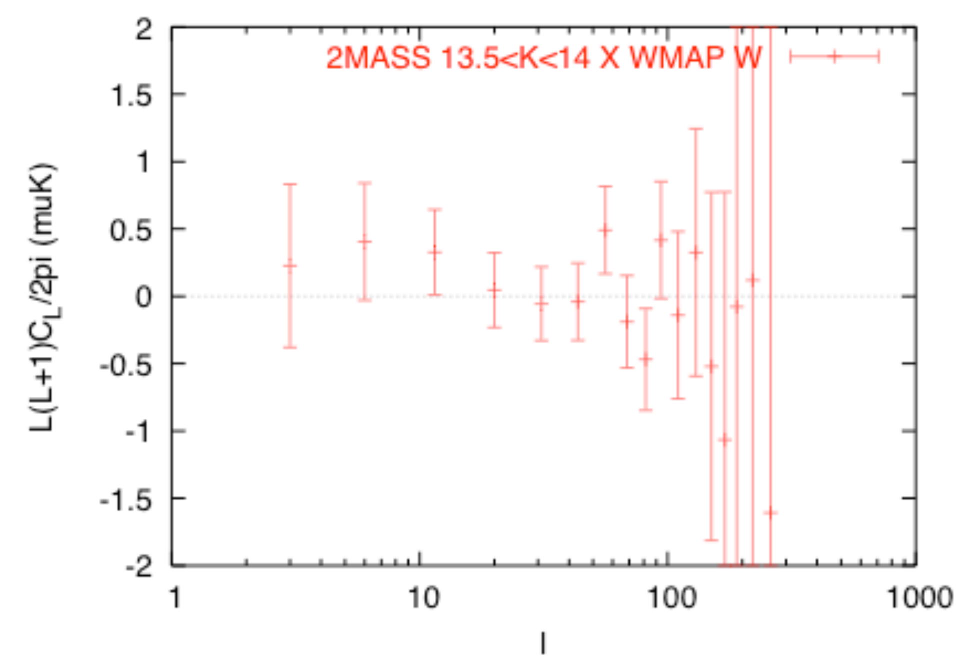
Results: (preliminary)

- 2MASS cross-correlations (Compare with Afshordi et al. 2004)



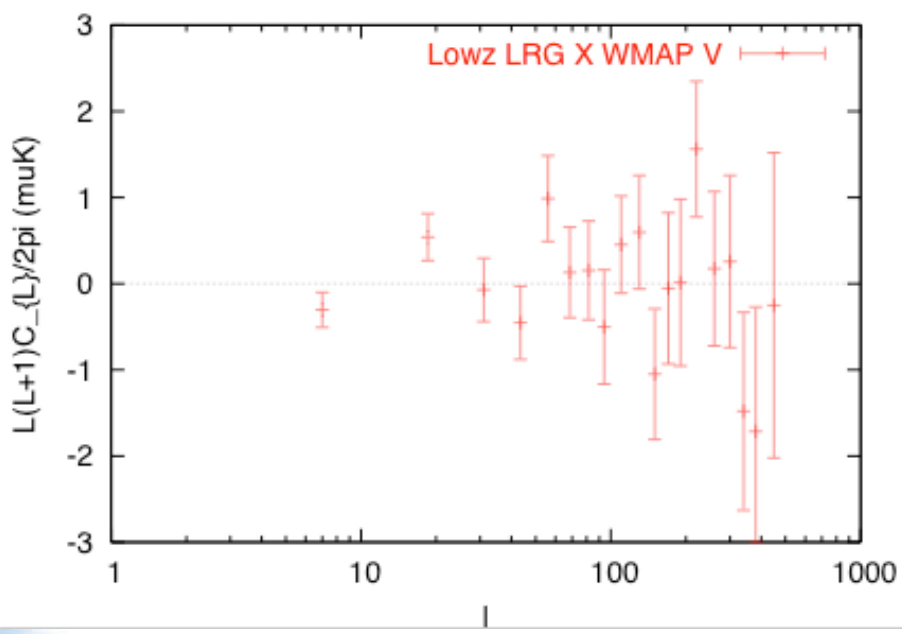


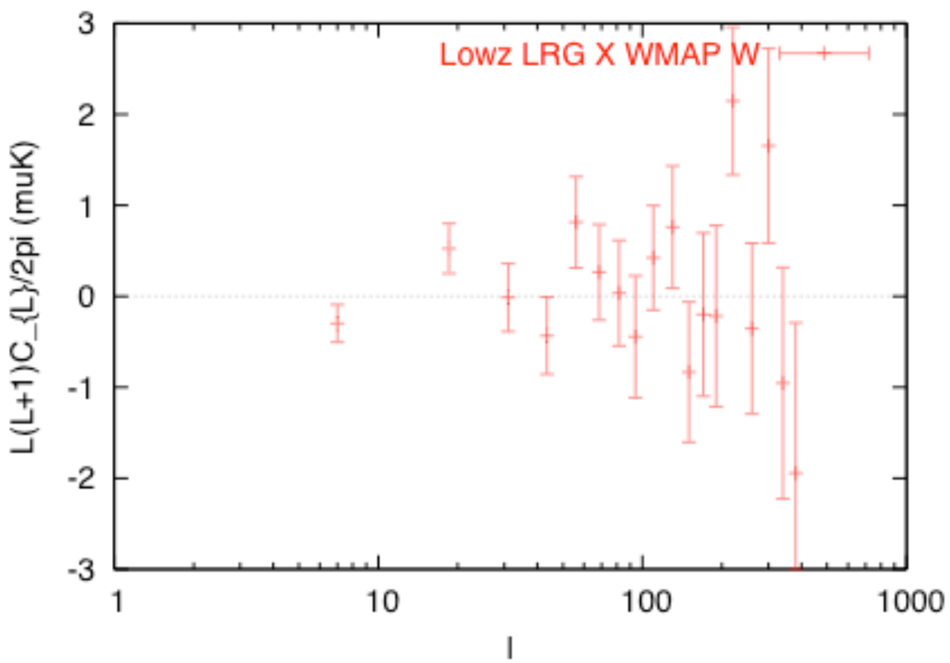

2MASS 13.5<K<14 X WMAP V
L(L+1)C_L/2pi (muK)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1
10
100
1000
l

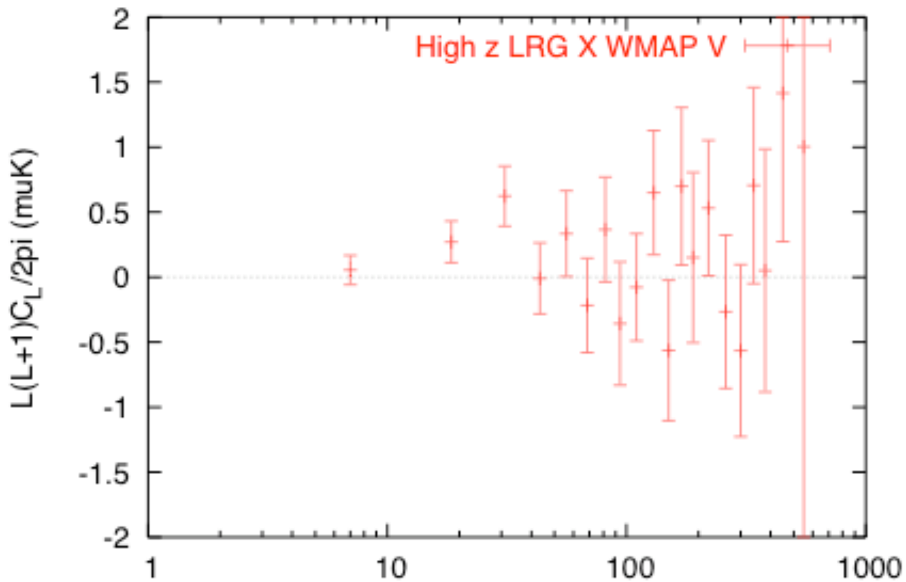

2MASS 13.5<K<14 X WMAP W
L(L+1)C_L/2pi (muK)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1
10
100
1000
l

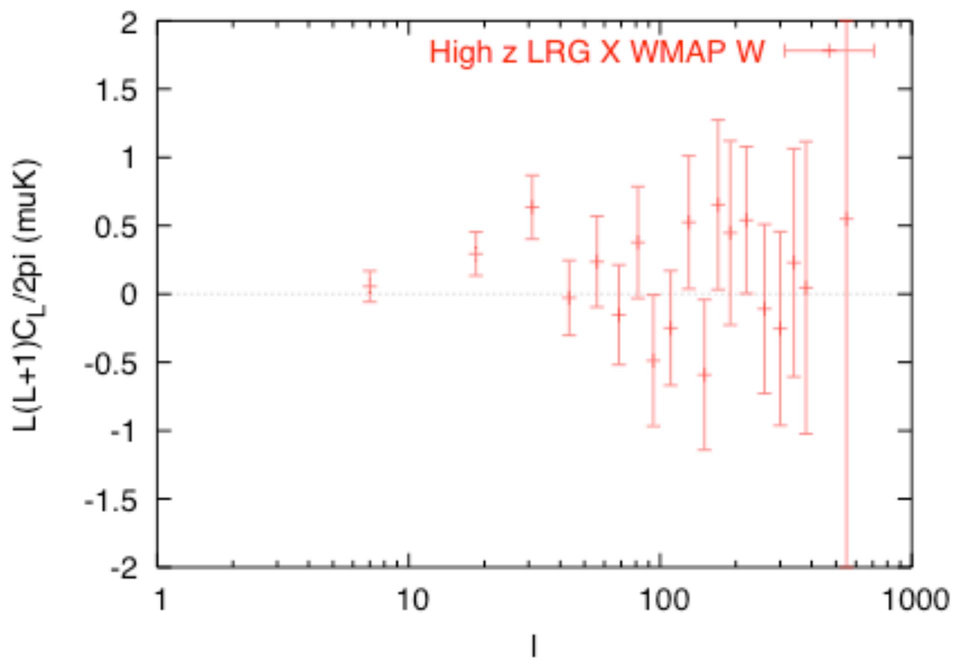
Results(continued)

- SDSS(DR5+)-LRG cross WMAP



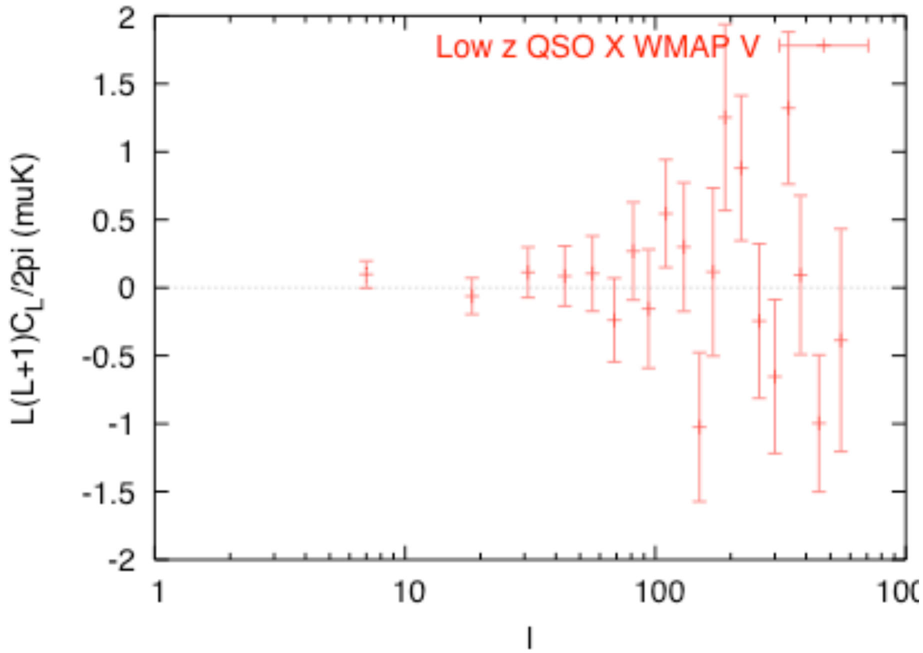


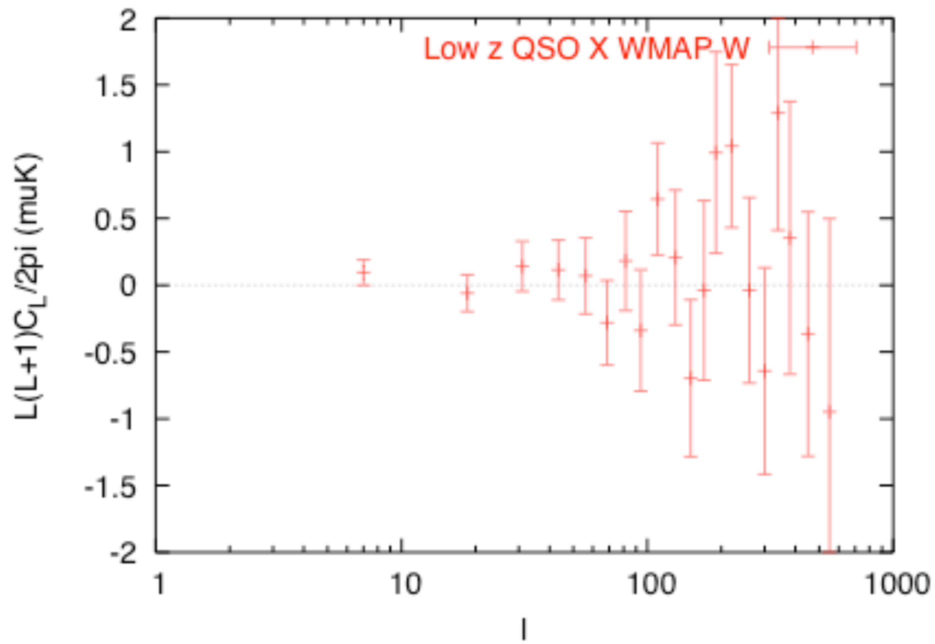

High z LRG X WMAP V
L(L+1)C_L/2pi (muK)

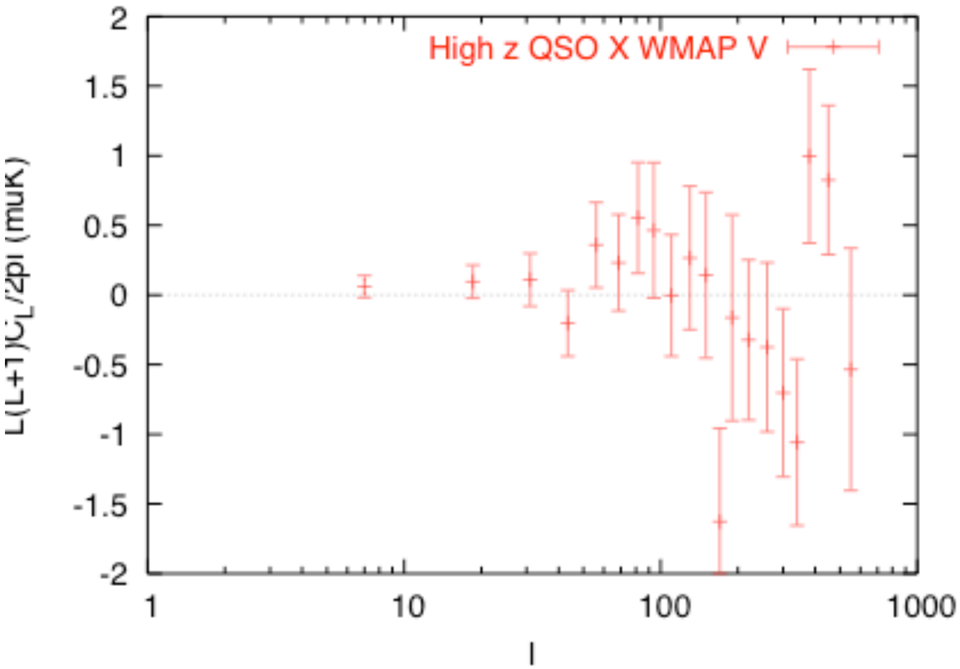

High z LRG X WMAP W
L(L+1)C_L/2pi (muK)
l

Results (continued)

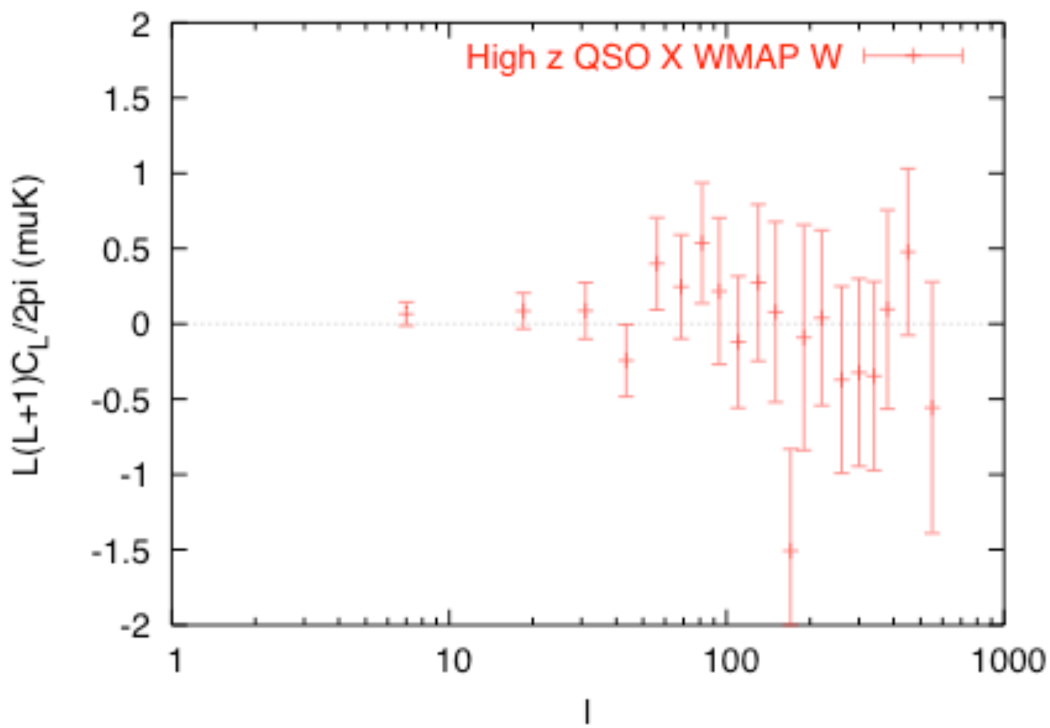
- SDSS(DR5+)-QSOs cross WMAP







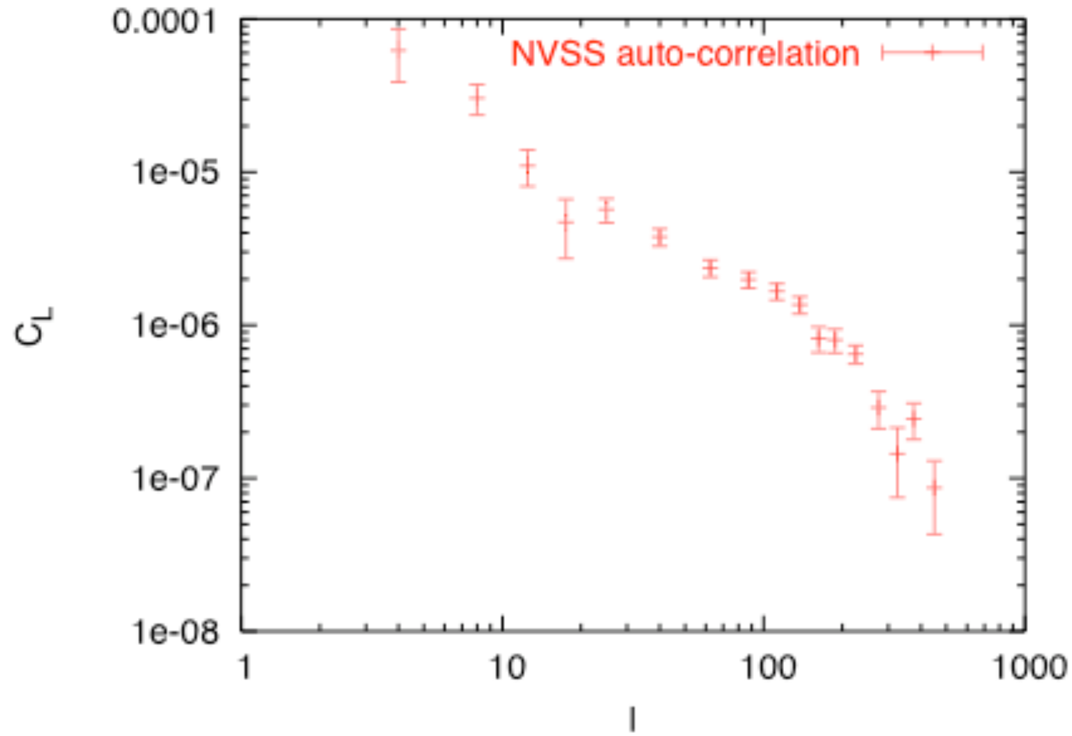
High z QSO X WMAP V
L(L+1)C_L/2pi (muK)
l



High z QSO X WMAP W
L(L+1)C_L/2pi (muK)
l

Results (continued)

- NVSS cross WMAP (next time)
- NVSS auto-correlation:



ISW: mini-conclusion

- More results to come in next couple months!
- Constraints will be put on cosmological parameters by looking at the evolution of gravitational potential.
- Now… let's switch gear to next topic!
- --> Kinetic Sunyaev Zeldovich Effect

KSZ: Method

- Very difficult to detect, but we will try this new method:
- 1) Generate velocity field from galaxy density (assuming linear theory) (refer to Davis)
- 2) Filter the cmb with a ksz filter (S/(S+N)) where S is the ksz power spectrum, N is the wmap power spectrum (including instrument noise)

  (ksz power spectrum generated from N-body simulations, assuming a lcdm cosmology)

KSZ: Method

- 3) cross correlate the ksz template with the filtered cmb map
- Since the signal is relatively weak:

->Need large survey! To beat down the noise!

-> ADEPT + ACT (applicable to other surveys such as Panstarrs and APEX?)

->SDSS + WMAP (example of what we actually have to do(dealing with cut sky and various real problems) and if it is possible to do)

KSZ: What we hope to do: ADEPT and ACT

- ADEPT: a proposed experiment to measure 10,000 sq deg using slitless spectroscopy to get about 100 million galaxies at z=1-2 (via the H-alpha emission line) at J-band.

- ACT: (Atacama Cosmology Telescope)

  we used the ACT specifications for its noise and beam size, 100 square degrees

KSZ analysis:

- We used N-body simulations (1000^3 (Mpc/h)^3, wmap 1st year parameters)

  (thanks to Ed Sirko)
- Then add in the poisson noise while getting a galaxy surface density. (Thanks to Simon Dedeo!!)
- Generate ksz template(and realizations of it)
- Cross correlate (to find out the S/N)

  < (Tcmb+Tksz,realiz)| Tksz,temp>

Caveats:

Have not put in noise term for the galaxy density except the Poisson Noise, possible issues include the failure of id-ing the galaxies, errors on dN/dz, etc.

KSZ: predicted S/N

- 100 realizations of ksz!
- 100 square degree of ACT only
- 10,000 sq deg of sky in J-band.
- ->S/N of 50!
- Promising tool for finding the missing baryons!

What we can do now: WMAP and SDSS VAGC sample

- We used the VAGC main galaxy sample and cut out a volume limited sample (a sample of which you know that the survey is complete in that region)
- Generate velocity field via linear theory:

$$\mathbf{v}(\mathbf{k}, a) \propto H(a) \frac{d \ln D}{d \ln a} \delta(k) \frac{\mathbf{k}}{k^2}$$

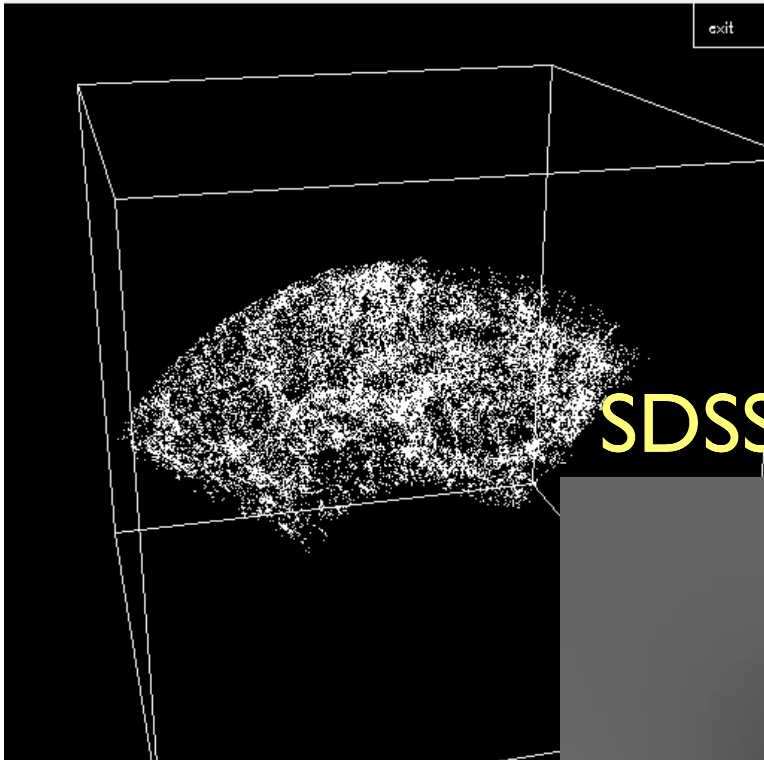
SDSS VAGC sample

- Caveats:

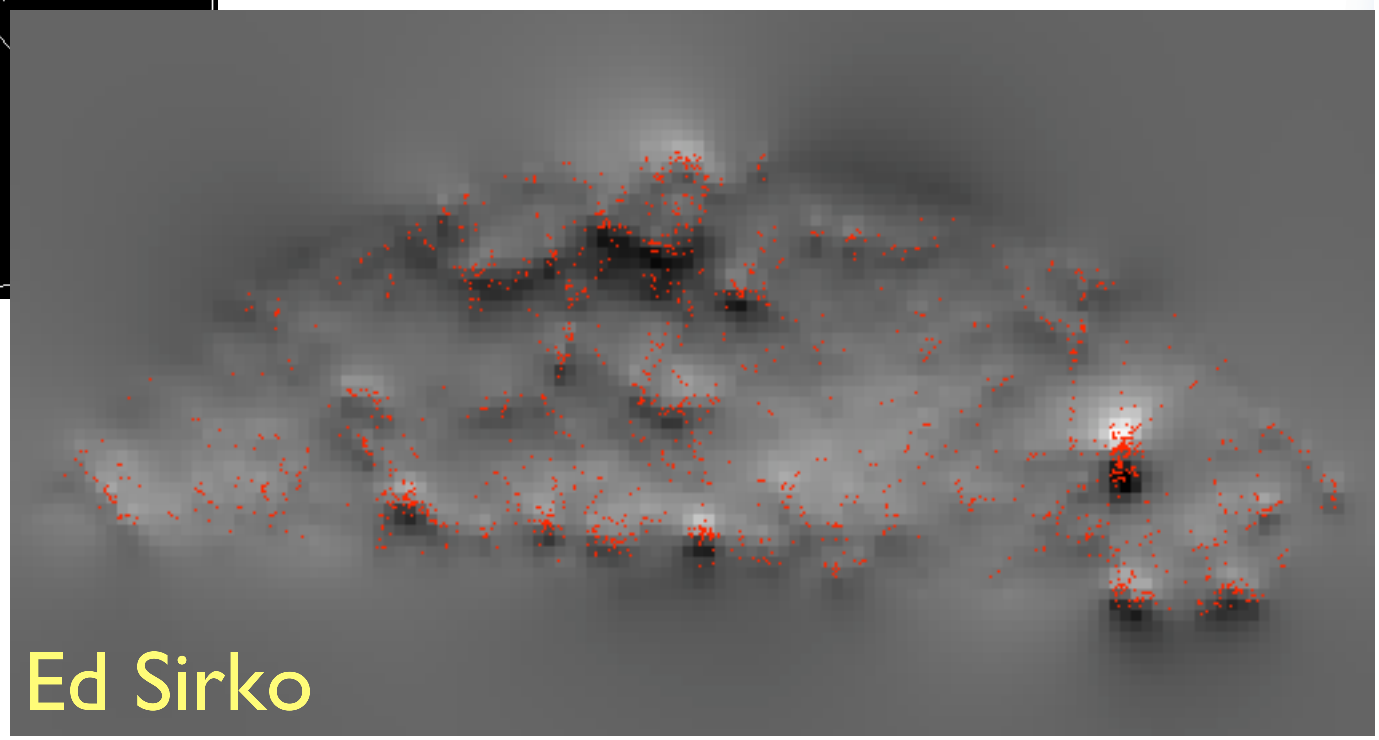
  a) Since we are assuming linear theory only (which works well in this regime, as we know that velocity field are coherent in ~30Mpc/h level),

  b) also we do not deal with redshift space distortion issues here either.

VAGC sample:



SDSS volume-limited reconstruction



KSZ: results: (SDSS cross WMAP)

- Cross correlating SDSS VAGC sample with WMAP V+W band (we weighed them according to the inverse variance), gave us a 0.5 sigma detection of the ksz effect.

Conclusions

- Results to come for constraining cosmological models that involve changing gravitational potential from ISW!
- Promising new method to get at baryons evolution via KSZ !!
- Thanks!