

# Cross-Correlation of WMAP7 and WISE Full Data Release

A story about stars and stripes and cosmic variance...

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# Outline

- 1 Introduction
- 2 Measurements

# Integrated Sachs-Wolfe Effect

- Photons passing through changing gravitational potentials are becoming slightly hotter or colder

$$\Delta T_{\text{ISW}} \simeq \int d\tau \frac{d\Phi}{d\tau},$$

- where

$$\frac{d\Phi(\mathbf{x})}{d\tau} = \frac{\Phi(\mathbf{x})}{(1+z)} \frac{d}{d\tau} [(1+z)D_1(z)]$$

# Linear ISW as a Signature of DE

- In a flat, matter dominated universe  $D_1 = 1/(1+z)$ ,
- There is a linear effect if  $\Omega_M \neq 1$ , e.g.,  $\Lambda$ CDM
- If the universe is flat (e.g., from CMB), linear ISW effect signals Dark Energy
- Cross-correlation between CMB and LSS

$$C_l^{gT} = T_{CMB} \frac{3\Omega_m H_0^2}{c^2} b_g \frac{2}{\pi} \int k^2 dk P_k \times \int k^{-2} \frac{d(1+z)D_1(z)}{dz} j_l(kr) dr \int r'^2 \phi(r') j_l(kr') dr'$$

- Caviat: there can be a non-linear effect as well

# Cross-correlation has been measured

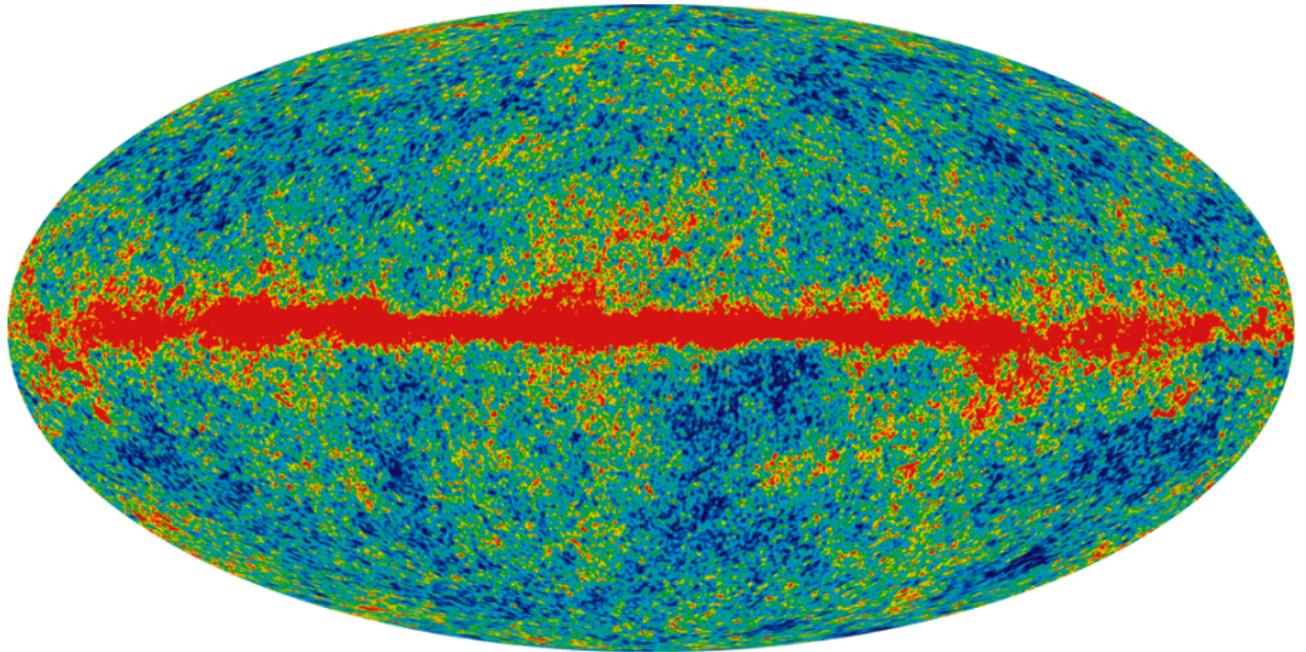
WMAP+other surveys

- optical: Scranton et al. (2003); Fosalba et al. (2003); Padmanabhan et al. (2005); Granett et al. (2008); Papai et al. (2011)
- infrared: Afshordi et al. (2004), Francis & Peacock (2010)
- radio Nolta et al. (2004); Raccanelli et al. (2008)
- X-ray background: Boughn and Crittenden (2004)
- combination: Ho et al (2008), Gianantonio et al (2008)
- WISE: Goto et al (2012), Kovacs et al (2012, this work)

# Data

## WMAP7 and WISE Full Data Release

- WMAP 7 Year Q,V,W foreground removed maps
- 71% of sky Galactic mask
- Wide Infrared Survey Explorer survey
- WISE Full Data Release 3.4, 4.6, 12, 22  $\mu\text{m}$  source catalogs
- b-cut 10, 15, 20
- Healpix maps with  $n_{\text{side}}=128$  (27.5 arcminute pixels)

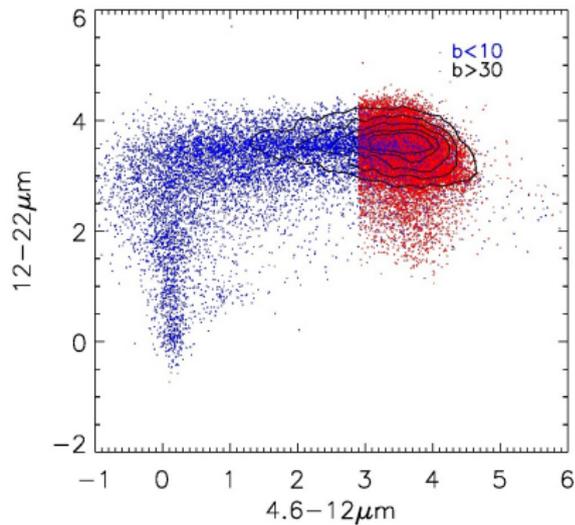
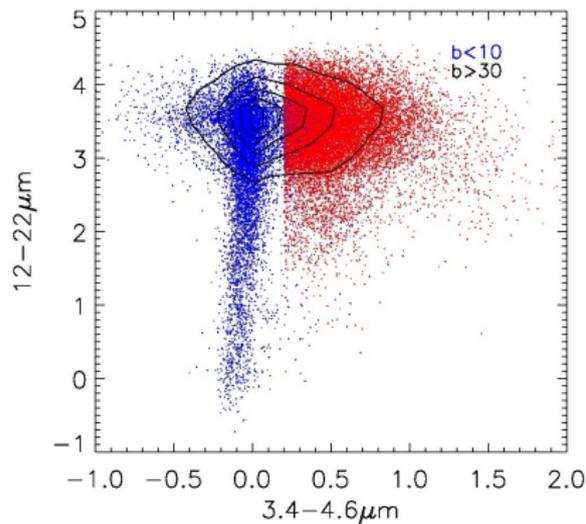


# WISE galaxy catalog

- Star-galaxy separation with colors
- $W1-W2 > 0.2$
- $W2-W3 > 2.9$
- bright selection  $W1 < 15.2$ : uniform catalog
- data quality flags are used to filter data (bright stars, ghost images, etc)

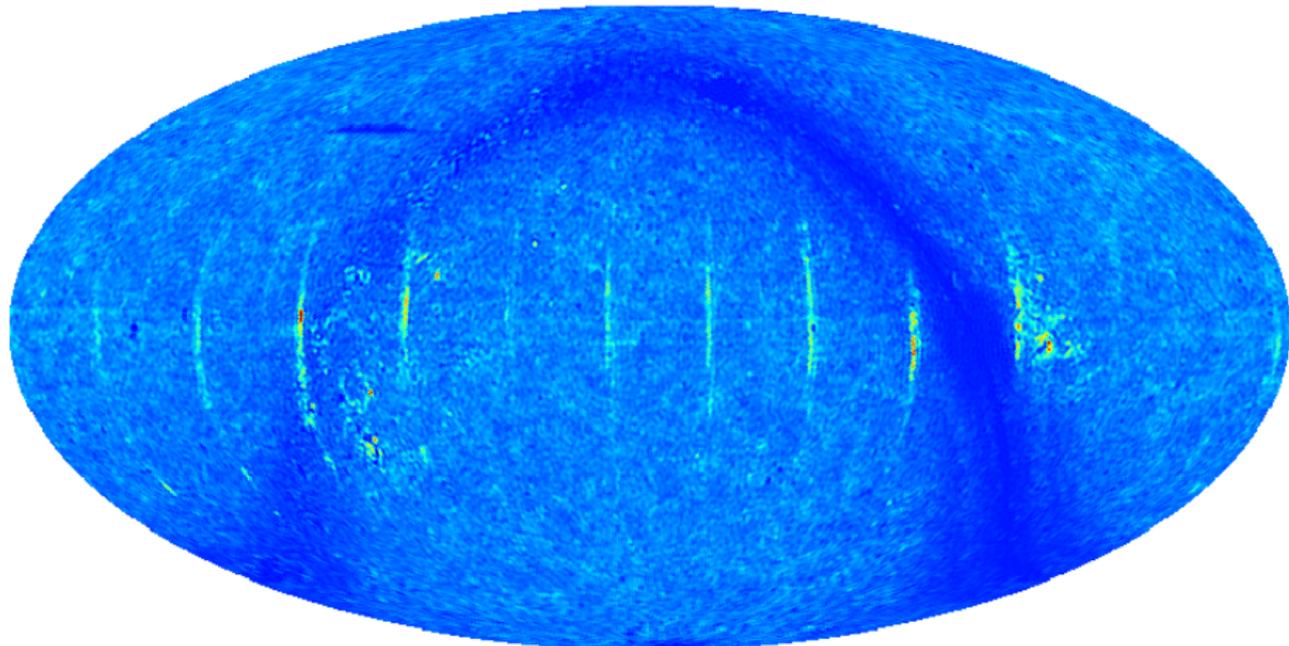
# Star-Galaxy Separation

Goto et al (2012)



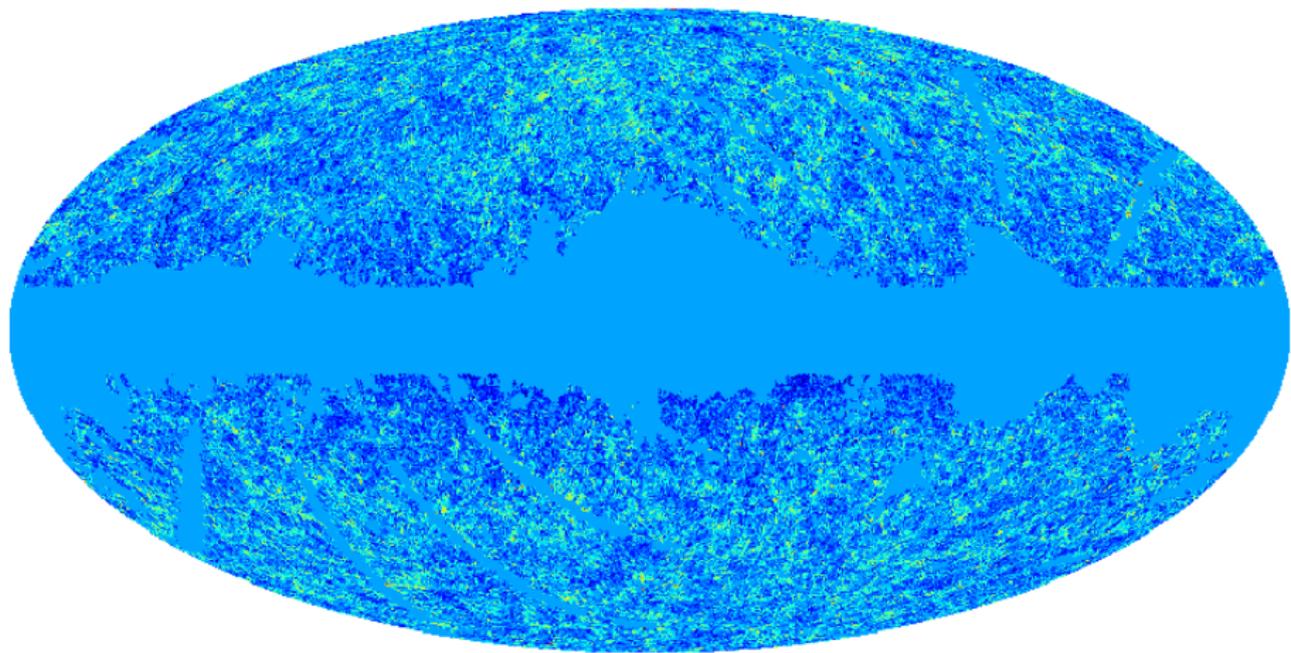
# Stars and Stripes

Mollweide view



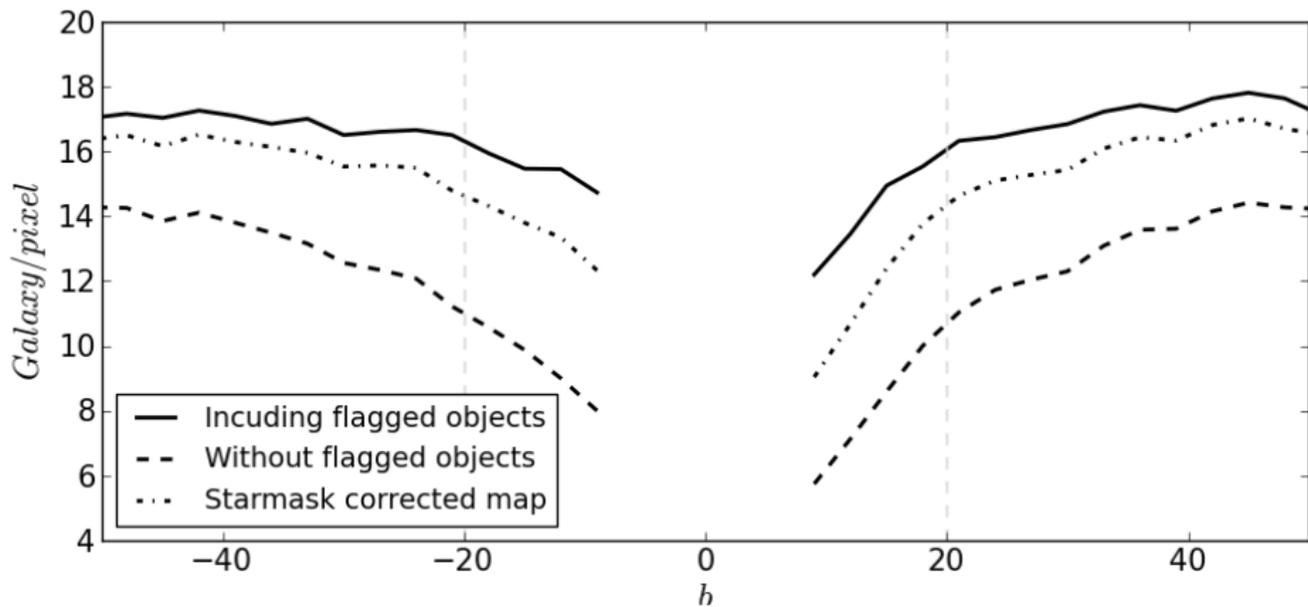
# WISE Mask

- stripes originating from the Moon
- Moon contamination flag is used to create mask
- 'moonlev' > 3 in any band is masked out
- This effectively removed the stripe pattern
- We tested that 14.9 magnitude cut further reduced residual effects but did not change final results/significances



# Bright Star Correction

- Ticho2 star catalog
- $V < 14$  mag
- Star Halo Radius =  $9.52 - 0.74V$  arc min
- WISE objects within the halo are removed
- Galaxy counts corrected to lost area



## Catalog Properties

Mask	Area[deg <sup>2</sup> ]	$N_{gal}^{noflag}$	$N_{gal}^{starcorr}$	$N_{gal}$
$ b  > 10$	26443	1662995	2016563	2234370
$ b  > 15$	25248	1617745	1948454	2129013
$ b  > 20$	23167	1521755	1814156	1945517
$ b  > 10$	10967	782502	976209	1057073

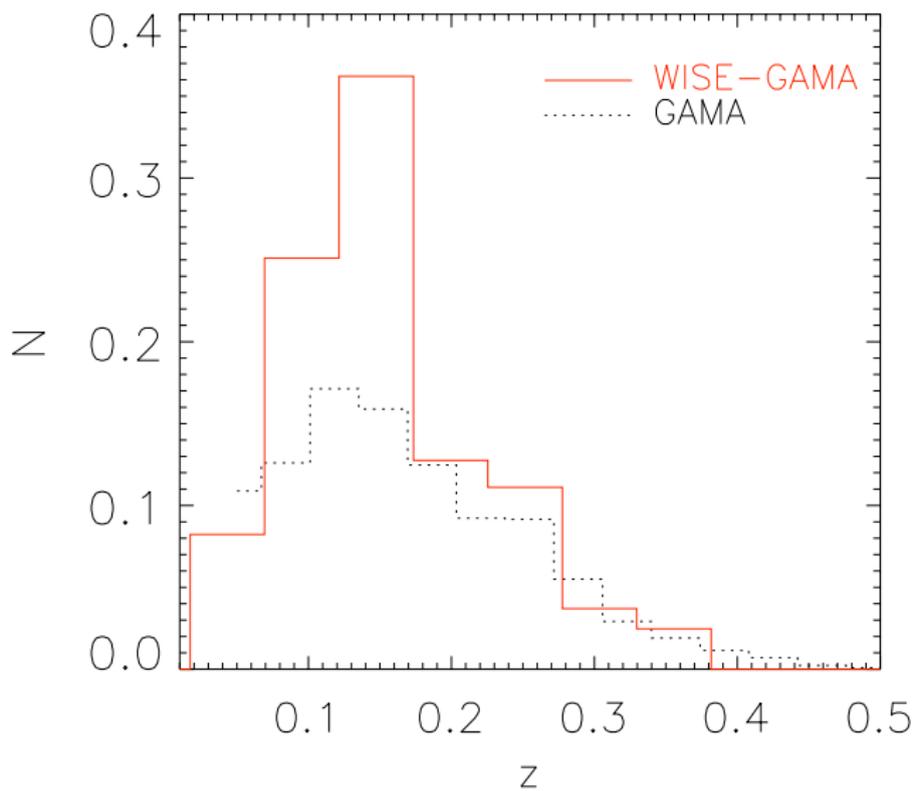
# Power spectra and bias

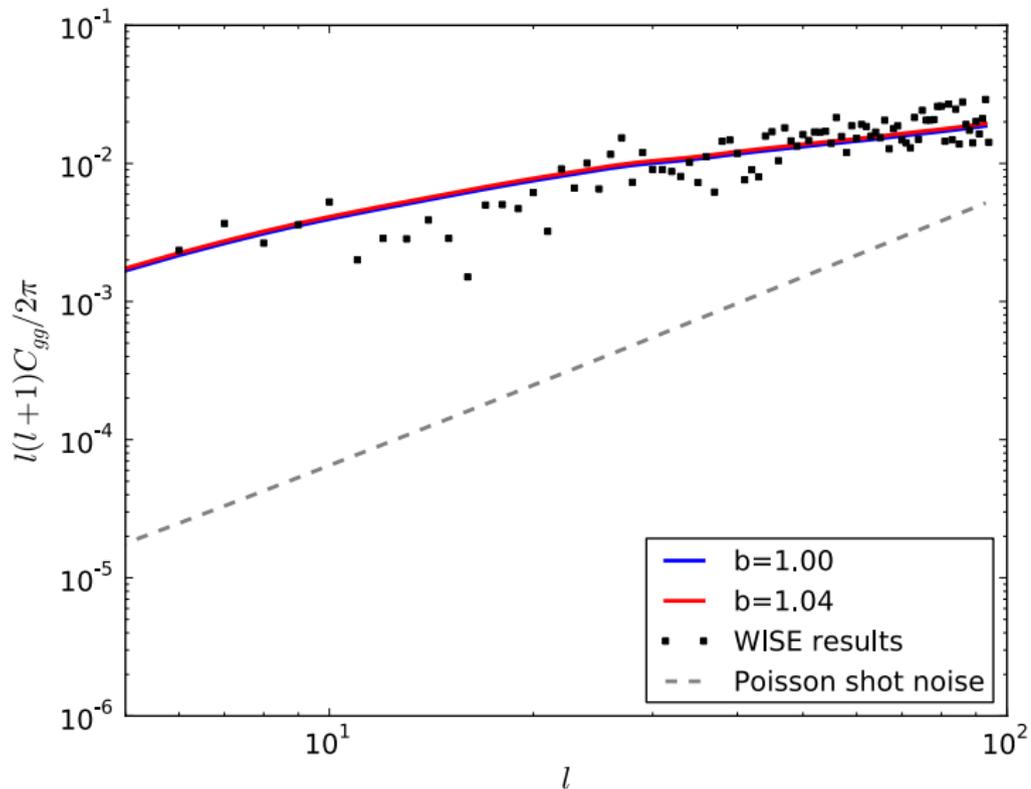
- Calculate auto and cross  $C_l$  spectra (SpICE, Planck version)



$$C_l^{gg} = b_g^2 \frac{2}{\pi} \int \left[ \int r^2 \phi(r) j_l(kr) dr \right]^2 k^2 P(k) dk,$$

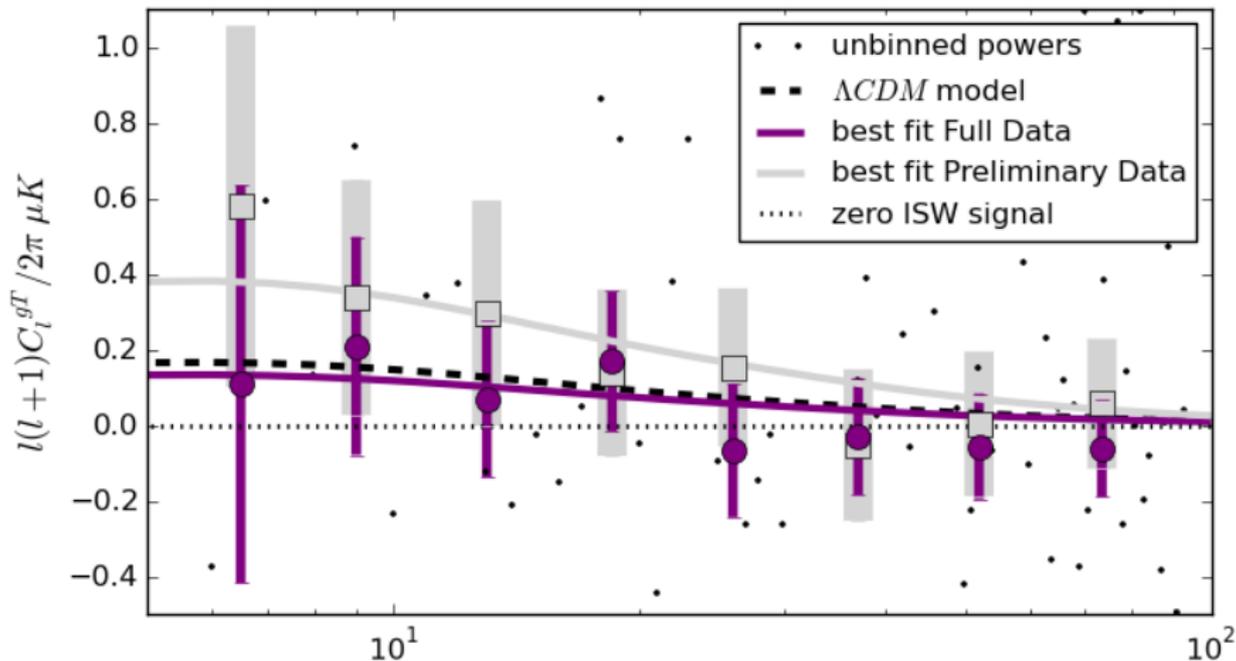
- redshift distribution from matching with GAMA (Galaxy and Mass Assembly, Driver et al 2011)
- about 200,000 galaxies to  $r_{AB} < 20.5$
- 82% match with 3" matching radius
- we fit  $b_g = 1.04$
- median  $z \simeq 0.15$
- cosmology: WMAP7

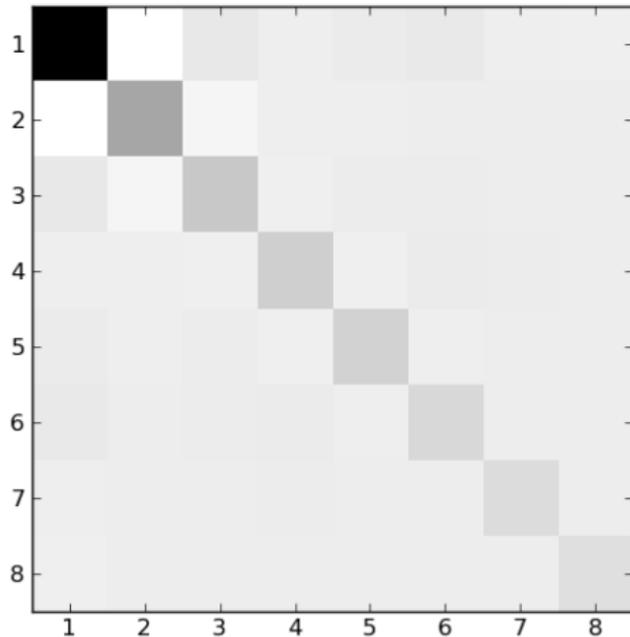




# Main Result

## Angular Cross Power Spectrum of WMAP and WISE





## Significance tests

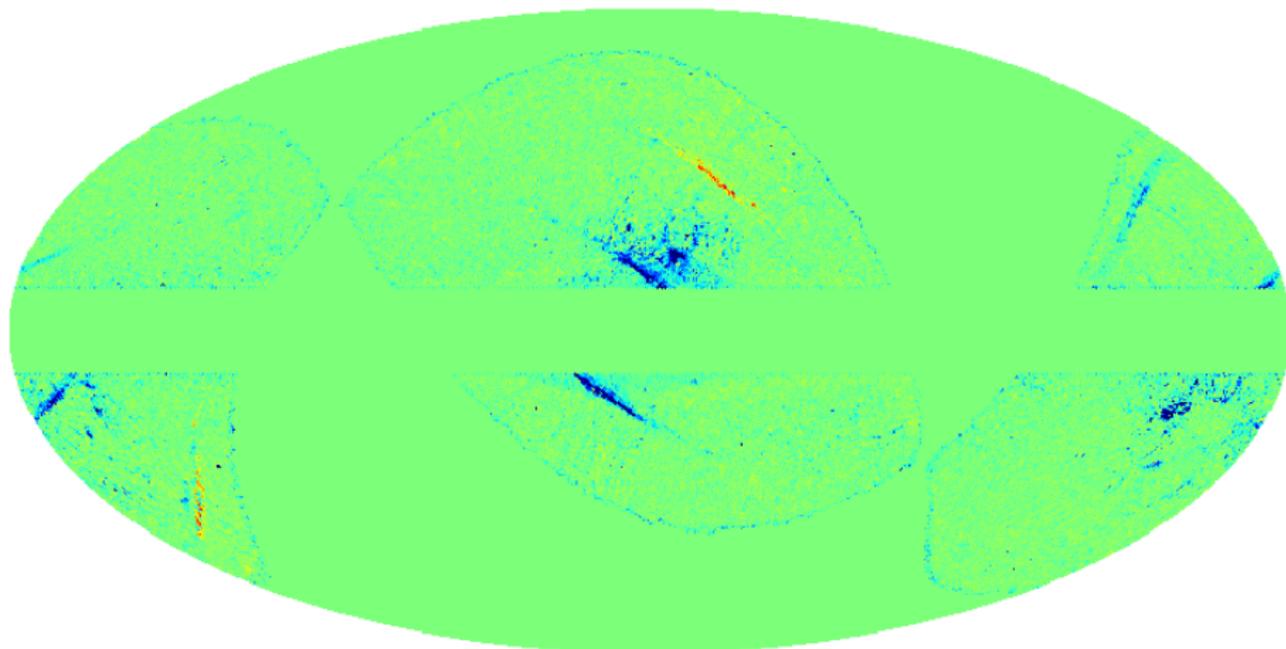
Mask	ISW Model	$\chi^2$	$\Delta\chi^2$	Amplitude	$\sigma$
$ b  > 10$	Zero	3.07	-		
	Best-fit	2.20	0.87	$0.8 \pm 0.9$	0.9
	$\Lambda$ CDM	2.26	0.81		
$ b  > 15$	Zero	2.71	-		
	Best-fit	2.13	0.58	$0.7 \pm 0.9$	0.9
	$\Lambda$ CDM	2.27	0.44		
$ b  > 20$	Zero	2.32	-		
	Best-fit	1.63	0.69	$0.8 \pm 0.8$	1.0
	$\Lambda$ CDM	1.74	0.58		
preliminary area only	Zero	5.64	-		
	Best-fit	2.91	2.73	$2.3 \pm 1.2$	1.9
	$\Lambda$ CDM	3.74	1.90		

# Comparison with Goto etal 2012

## Differences

- Full vs pre-release data
- 71% mask vs 78%
- 2.4 times more area
- flagged objects are omitted
- MOONLEV mask vs hand drawn masks
- Tycho2 star catalogue vs phenomenological correction

# Pre-Release – Final Release



# Comparison with Goto etal 2012

## Results

- changing to pre-release data increases signal by about 10%
- $C_\ell$ 's and errorbars agree well
- Nevertheless the significance in the pre-release area is only about  $2\sigma$  vs  $3\sigma$  for Goto etal (except when individual  $C_l$ 's are used)
- The results appear to be robust against the slight changes in methods
- Nevertheless no perfect agreement is expected from a ground up new analysis with new data
- Cosmic variance is responsible for a large part of the difference

# Summary

- We cross correlated WMAP with WISE final release
- non-significant correlation for the full sky
- now consistent with LCDM
- much larger signal in preliminary area: consistent with cosmic variance
- Goto et al higher significance: stars and stripes and cosmic variance...
- no color dependence Q, V, W
- robust for b-cut (10,15,20)
- Final release is consistent although slightly lower than pre-release
- future: pushing to higher z, super structures, galaxy power spectrum