Using large-scale structure tracers and CMB to reconstruct a map of the ISW effect

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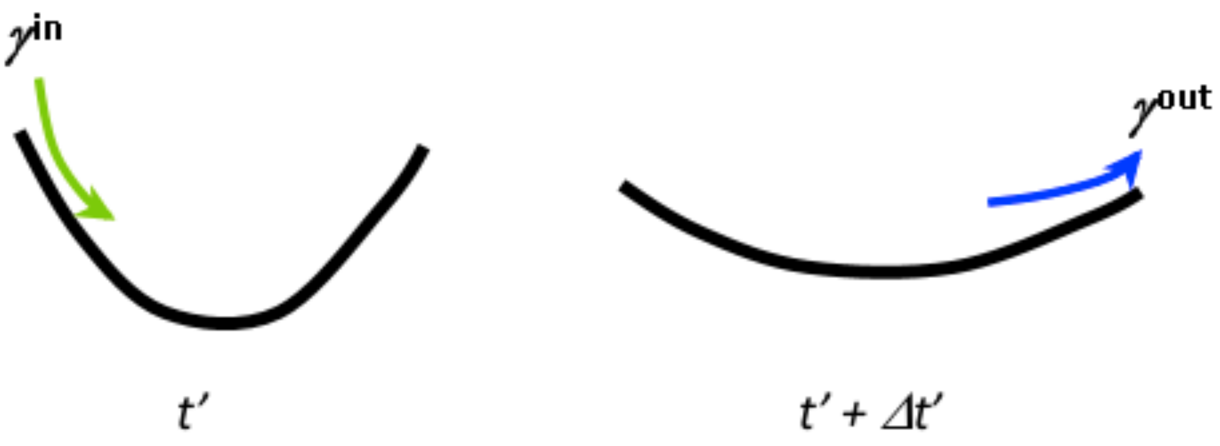
ISW effect

- ✓ CMB photons are blu- (red-) shifted when fall into (out of) gravitational potetial wells
- ✓ An evolution of the gravitational potential during the photon crossing implies a net change in the photon energy
- ✓ Very week signal that can be detected through cross-correlation with Large Scale Structure surveys (tracers of the gravitational potential)



Methodology

Linear Covariance-Based (LCB) filter by Barreiro et al., 2008: CMB (T) + LSS tracer

L Cholesky of **C**

LSS tracer

CMB map

$$\hat{s}(\ell,m) = \frac{L_{12}}{L_{11}} g(\ell,m) + \frac{L_{22}^2}{L_{22}^2 + C_\ell^n} \left(d(\ell,m) - \frac{L_{12}}{L_{11}} g(\ell,m) \right)$$

CMB signal without ISW

Bonavera et al., in prep.: CMB (T+P) + *n* LSS tracers

$t = n+1$

$$\hat{s}(\ell,m) = \sum_{i=1}^{n} \left[L_{it} \left(\sum_{j=1}^{n} (L^{-1})_{ij} g_j(\ell,m) \right) \right] + \frac{L_{tt}^2}{L_{tt}^2 + C_\ell^n - \frac{(C_\ell^{TE})^2}{C_\ell^{EE}}}$$

$$\times \left\{ d(\ell,m) - \sum_{i=1}^{n} \left[L_{it} \left(\sum_{j=1}^{n} (L^{-1})_{ij} g_j(\ell,m) \right) \right] - t_E(\ell,m) \right\}$$

$\frac{C_\ell^{TE}}{C_\ell^{EE}} e(\ell,m)$

Simulated maps

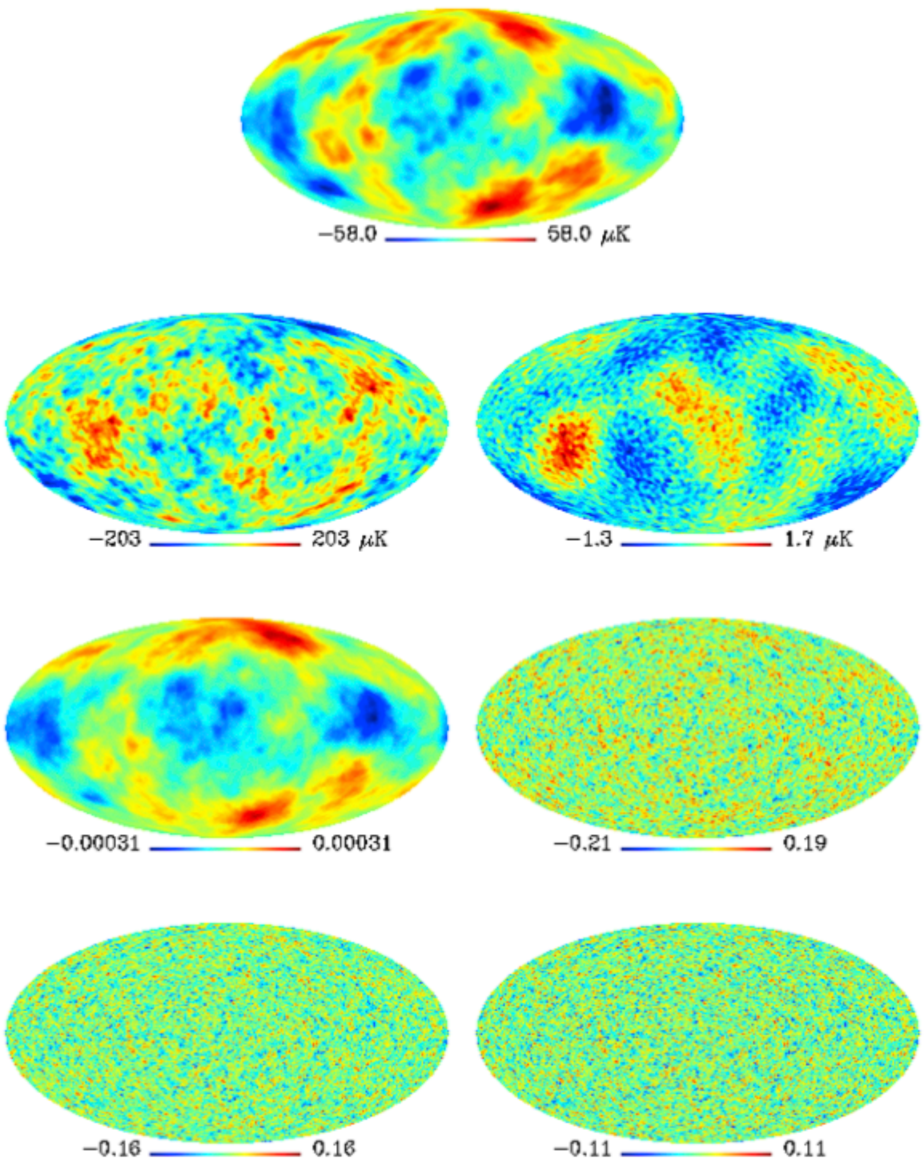


Figure 3. Reference simulated maps for the ideal case (i.e., full-sky and without noise). Top: ISW signal. Left column (from top to bottom): CMB temperature map (including the ISW contribution), lensing potential map, survey with density distribution peaking at intermediate redshift. Right column: E-mode CMB map, low- and high-z peaking distribution surveys. CMB (intensity and polarization) and ISW maps are in units of μK while the other maps are dimensionless. The survey maps represent the galaxy density number fluctuations.

Coherent Gaussian simulations:

- Planck fiducial ΛCDM model
- Power spectra calculated with CAMB
- 10000 simulation @ nside 64
- CMB related maps with beam=160 arcmin
- 3 different LSS tracer with $dn/dz \propto (z/z_0)^{\alpha} e^{-\alpha z/z_0}$

Noise:

- Poissonian noise for surveys
- Gaussian white noise amplitude for P given by Planck Collaboration 2005
- Gaussian noise with Planck amplitude for lensing

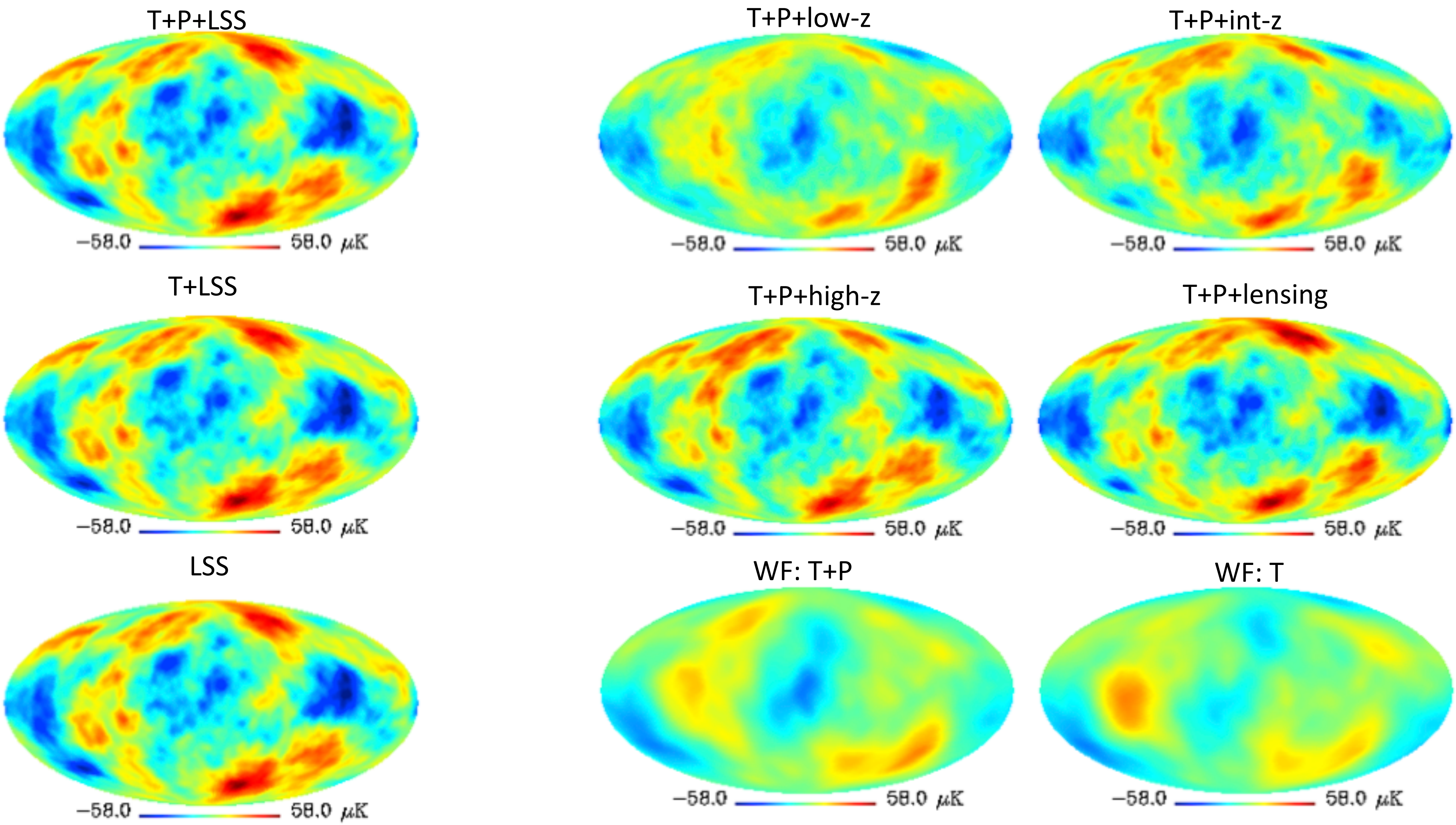
Masks:

- Galactic cut for low- and int.-z
- NVSS mask by Marcos-Caballero et al. for high-z
- WMAP 9-yr pnt src catalogue mask for CMB and lensing

		f_{sky} (%)	Noise	z_0	α
	CMB (T)	78.2	-	-	-
	CMB (P)	78.2	3.3×10^{-4}	-	-
	lensing	78.2	1.7×10^{-4}	-	-
Near gal.	low	50	2.0×10^{-7}	0.3	0.4
Luminous gal.	intermediate	50	1.1×10^{-7}	0.6	1.0
NVSS	high	70.4	6.7×10^{-6}	0.9	1.8

Table 1. Summary of the characteristics of the simulated maps. From left to right: fraction of the sky available after masking, amplitude of noise (dispersion for lensing, amplitude of power spectrum for surveys) and the z_0 and α parameters of the redshift distribution function of each survey.

Results: full-sky noiseless case



- Main contribution from the cross-correlation between ISW and LSS tracers
- Best reconstruction with all the surveys included
- Good reconstruction with lensing due to its strong correlation
- Good recostruction with high-z due to its more suitable redshift coverage
- LCB filter superior to WF of CMB
- Polarization contribution very modest (more important for WF)

Results: full-sky case

average weighted correlation coefficient → $\bar{\rho}$; average relative error → e_r

	$\bar{\rho}$			e_r		
	T+P	T	no CMB	T+P	T	no CMB
Noiseless						
3surveys+lens	1.00	1.00	1.00	0.04	0.04	0.04
3surveys	0.96	0.95	0.95	0.29	0.29	0.29
low	0.63	0.59	0.42	0.76	0.80	0.90
int.	0.78	0.76	0.72	0.62	0.63	0.69
high	0.94	0.94	0.94	0.32	0.33	0.33
lensing	0.94	0.94	0.93	0.34	0.34	0.35
Wiener filter	0.54	0.47	-	0.83	0.87	-
Noisy						
3surveys+lens	0.81	0.80	0.77	0.58	0.59	0.63
3surveys	0.79	0.78	0.74	0.60	0.61	0.66
low	0.62	0.58	0.41	0.77	0.80	0.90
int.	0.76	0.74	0.69	0.64	0.66	0.71
high	0.55	0.50	0.20	0.82	0.85	0.97
lensing	0.63	0.60	0.48	0.76	0.79	0.87
Wiener filter	0.53	0.47	-	0.83	0.87	-

Mean residual dispersion map

$$\bar{\sigma}_i = \frac{1}{N_s}\sum_{j=1}^{N_s}\sqrt{\langle r_{i,j}^2\rangle - \langle r\rangle_{i,j}^2}$$

pixel (i); simulation (j); residual map: $\hat{s}-s$ (r)

Weights maps

$$\omega_i = \frac{1/\bar{\sigma}_i^2}{\sum 1/\bar{\sigma}_i^2}$$

Weighted correlation coefficient

$$\rho = \frac{\sum_{i=1}^{N_p}\omega_i(s_i - \langle s\rangle)(\hat{s}_i - \langle\hat{s}\rangle)}{\sigma_s\sigma_{\hat{s}}}$$

weighted dispersion (σ_s, $\sigma_{\hat{s}}$)

$$e_r = \frac{\bar{\sigma}_r}{\bar{\sigma}_s}$$

average weighted dispersion of the residual map ($\bar{\sigma}_r$)

average weighted dispersion of the input map ($\bar{\sigma}_s$)

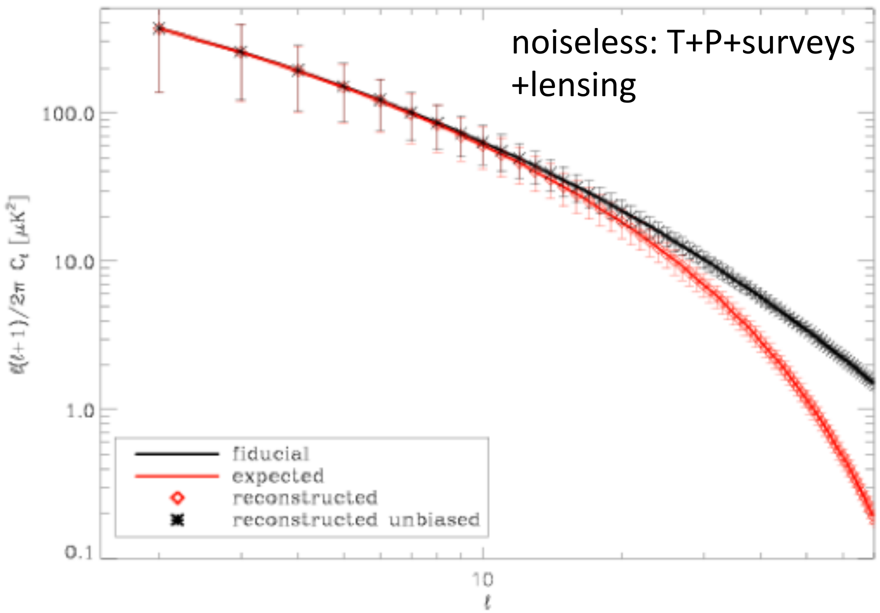
Noiseless:

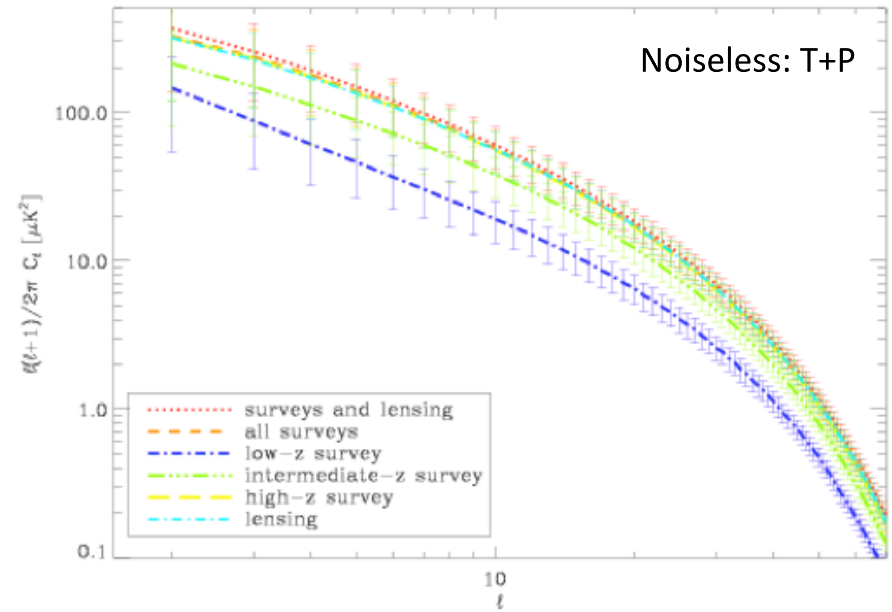
- Good reconstruction can be obtained
- CMB+one survey degrades the reconstruction:high-z or lensing are the best cases
- CMB more important when less info about LSS is available
- P more important for WF (15% improvement)

Noisy:

- Noise degrades the reconstruction
- High-z and lensing most affected by noise
- CMB contribution more significant

Results: full-sky case



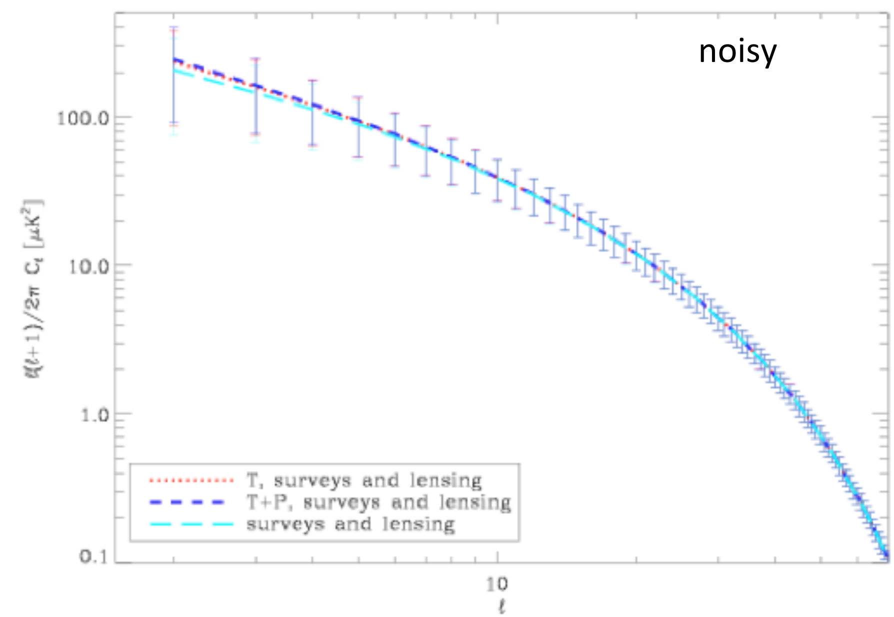


Noiseless:

- ✓ Unbiased Cls agree with fiducial model
- ✓ T, T+P or LSS only give similar results

Noisy:

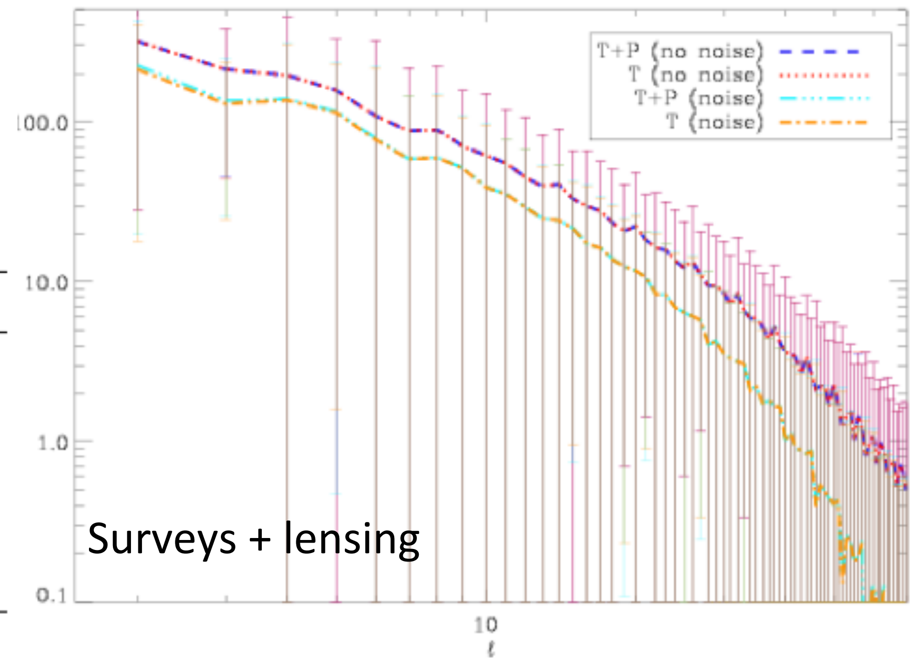
- ✓ CMB inclusion reduces the bias at large scales
- ✓ P slightly reduces the bias at smallest multipoles



Results: incomplete sky case

	$\bar{\rho}$			e_r		
	T+P	T	no CMB	T+P	T	no CMB
Noiseless						
surveys+lens.	0.98	0.98	0.98	0.20	0.20	0.21
surveys	0.90	0.90	0.89	0.41	0.41	0.42
low^3	0.61	0.57	0.41	0.77	0.79	0.89
int.	0.75	0.73	0.68	0.64	0.65	0.71
high	0.89	0.89	0.89	0.44	0.44	0.46
lensing	0.93	0.93	0.93	0.34	0.35	0.36
Wiener Filter	0.46	0.52	-	0.87	0.84	-
Noisy						
surveys+lens.	0.79	0.77	0.74	0.59	0.60	0.64
surveys	0.76	0.74	0.70	0.62	0.64	0.68
low^3	0.60	0.57	0.41	0.77	0.80	0.89
int.	0.73	0.71	0.65	0.65	0.67	0.73
high	0.53	0.48	0.19	0.83	0.86	0.97
lensing	0.62	0.59	0.48	0.77	0.79	0.87
Wiener Filter	0.46	0.51	-	0.87	0.84	-

Apodised masks
Quantities computed with union mask, monopole and dipole subctraction



Noiseless:

- Mask slightly degrades the recostruction outside the union mask
- Lensing survey gives the maximum contribution
- P slightly improves the reconstruction

Noisy:

- Noise degrades the reconstruction (like fullsky)
- Relative contribution of the survey modified with respect to noiseless case
- P more important

Results: incomplete sky case, noiseless

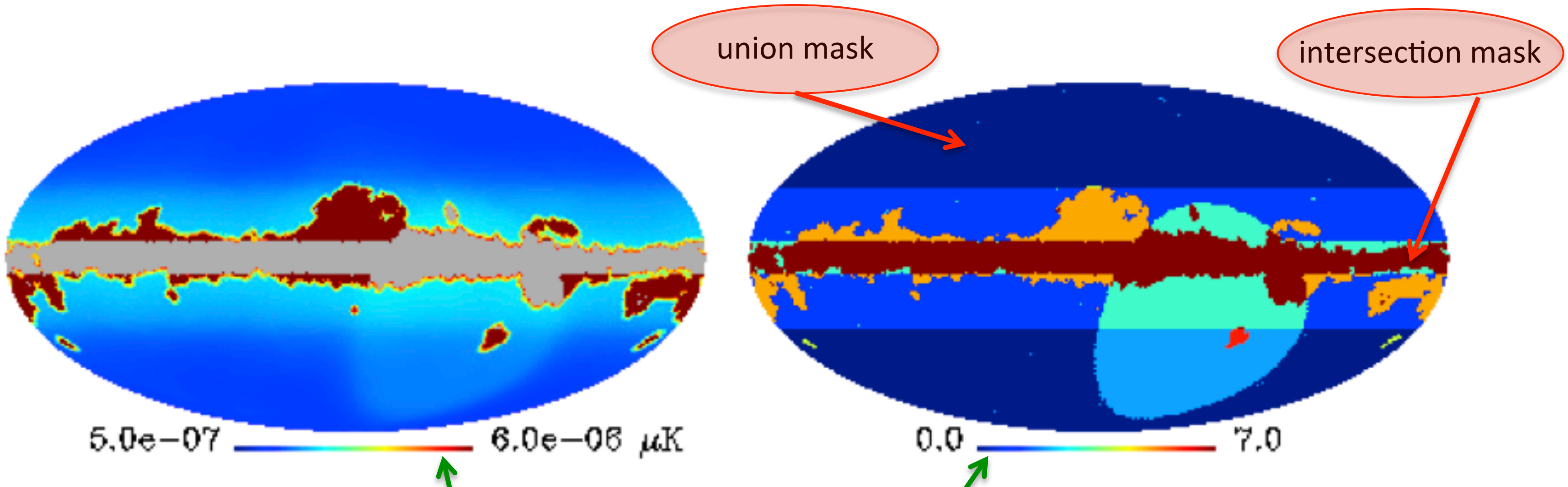
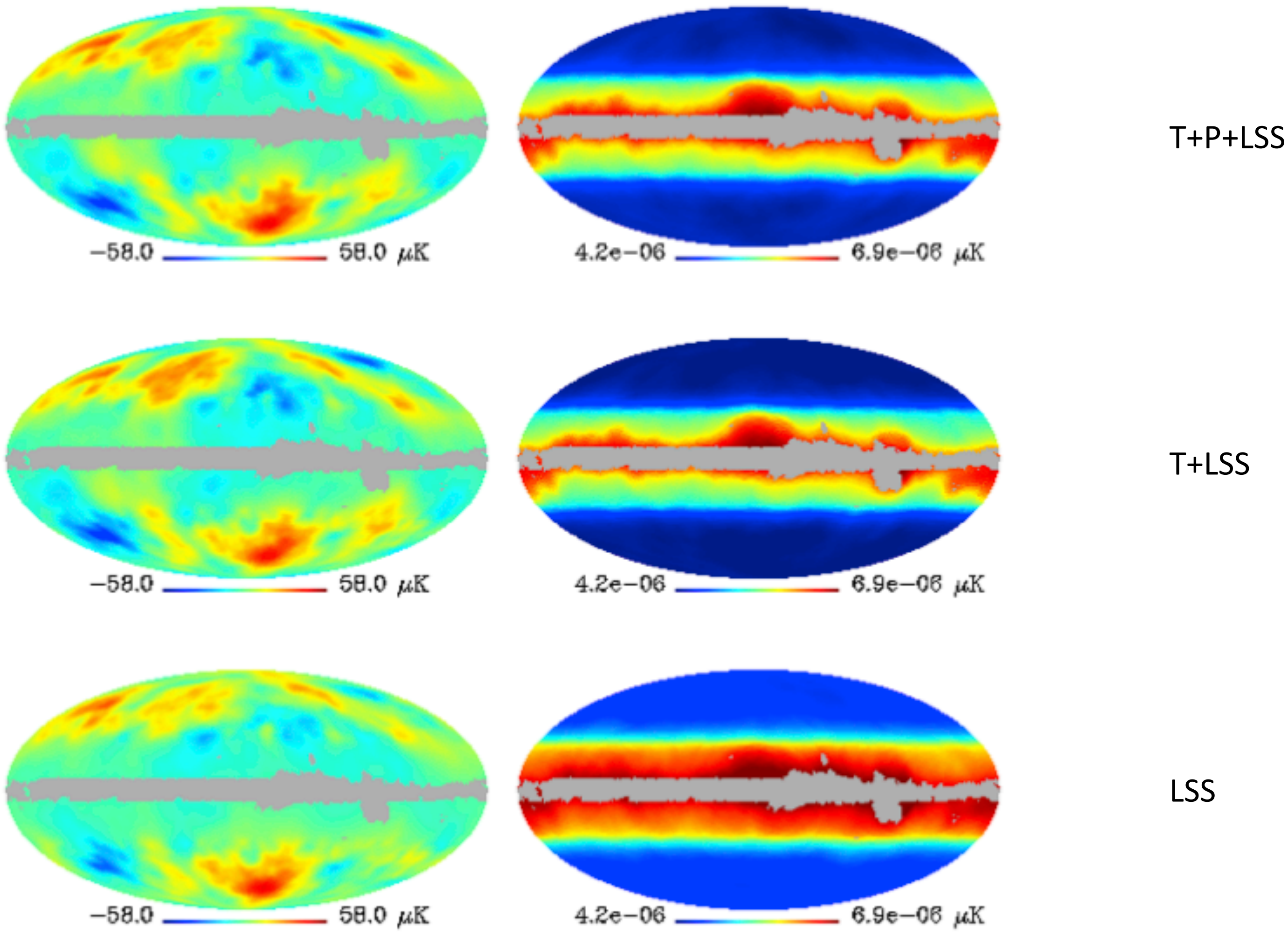


Figure 12. On the left, a map of the dispersion of the residuals for the ISW recovery at each pixel, with the intersection mask applied, is given. It has been obtained from 10000 simulations for the case with mask and without noise and using all the available information (three surveys, lensing, CMB intensity and polarization). On the right, the intersection of the masks considered for each data set is shown: 7 (dark red) stands for pixels which are not observed by any data set, 6 (red) for the pixels excluded by both NVSS and in WMAP masks, 5 (orange) for those both in the WMAP and the galactic cut masks, 4 (yellow) for the pixels that are only in the WMAP mask, 3 (turquoise) for those both in NVSS and the galactic cut masks, 2 (azure) for those covered only by the NVSS mask, 1 (blue) for the pixels masked only by the galactic cut and 0 (dark blue) for pixels present in all data sets.

- Residuals map resembles the masks map: lower residuals where more data are available

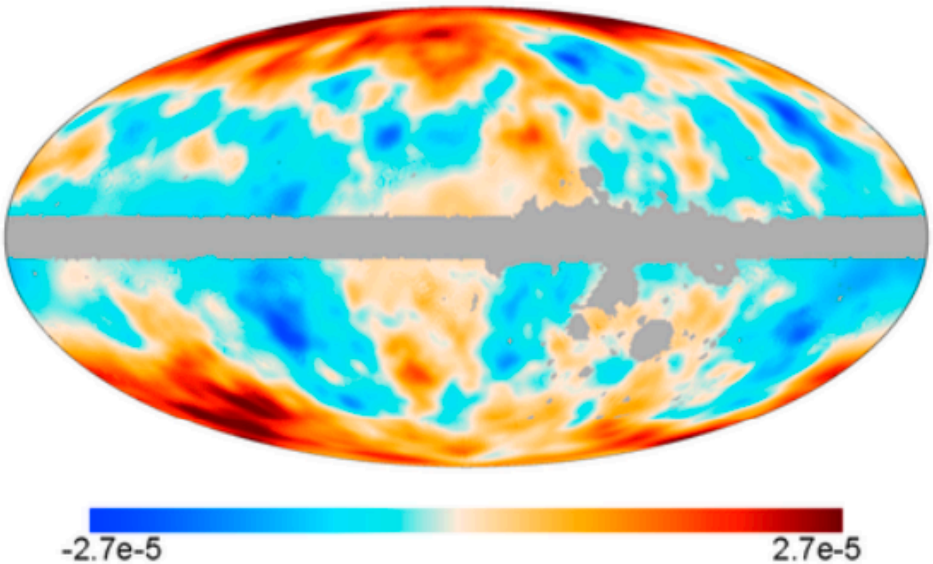
Results: incomplete sky case, noisy

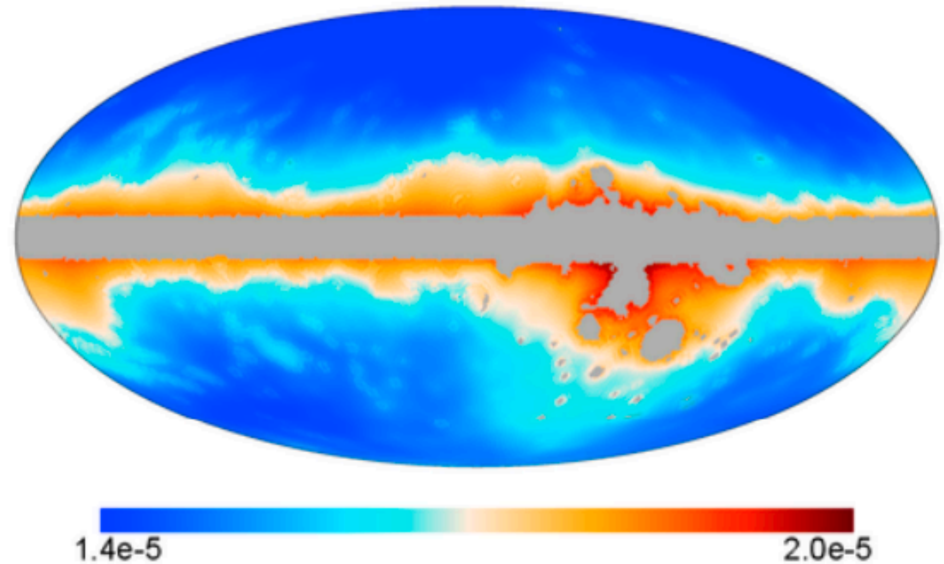


- Leaving out the CMB increases the error
- High-z survey not significant due to high noise

Results from Planck

Planck SEVEM CMB map (T) + NVSS + WISE-AGN + WISE GAL + SDSS-CMASS/LOWZ + SDSS-MphG + lensing





	Intersection mask		Union mask	
	f_{sky}	$\bar{\rho}$	f_{sky}	$\bar{\rho}$
CMB and all surveys	0.85	0.60	0.16	0.67

Summary

- ✓ Extension of the LCB filter: several LSS and CMB polarization
- ✓ Tested with 10000 coherent simulations whose fiducial power spectra are obtained with a modified version of CAMB: CMB, 3 surveys peaking at different z and lensing

Full-sky noiseless case:

- Main contribution from LSS tracers
- Including CMB slightly improves the reconstruction
- CMB more important when less info on LSS are available
- High-z is the most suitable survey for the ISW reconstruction
- Lensing has similar effect as high-z

Full-sky noisy:

- Quality of recostruction degraded
- CMB more important (mainly at largest scales)
- Relative contribution of each LSS tracer changes (different levels of noise for each survey)
- Intermediate-z (lower noise) major contribution to the reconstruction

Incomplete sky:

- Quality of reconstruction slightly degraded by the mask
- Different amount of degradation where observations are not available for some of the data sets