Lensing autospectrum

Autospectrum current state-of-the-art

Also: SPTpol (Story+ 2015)
PolarBear (2015)

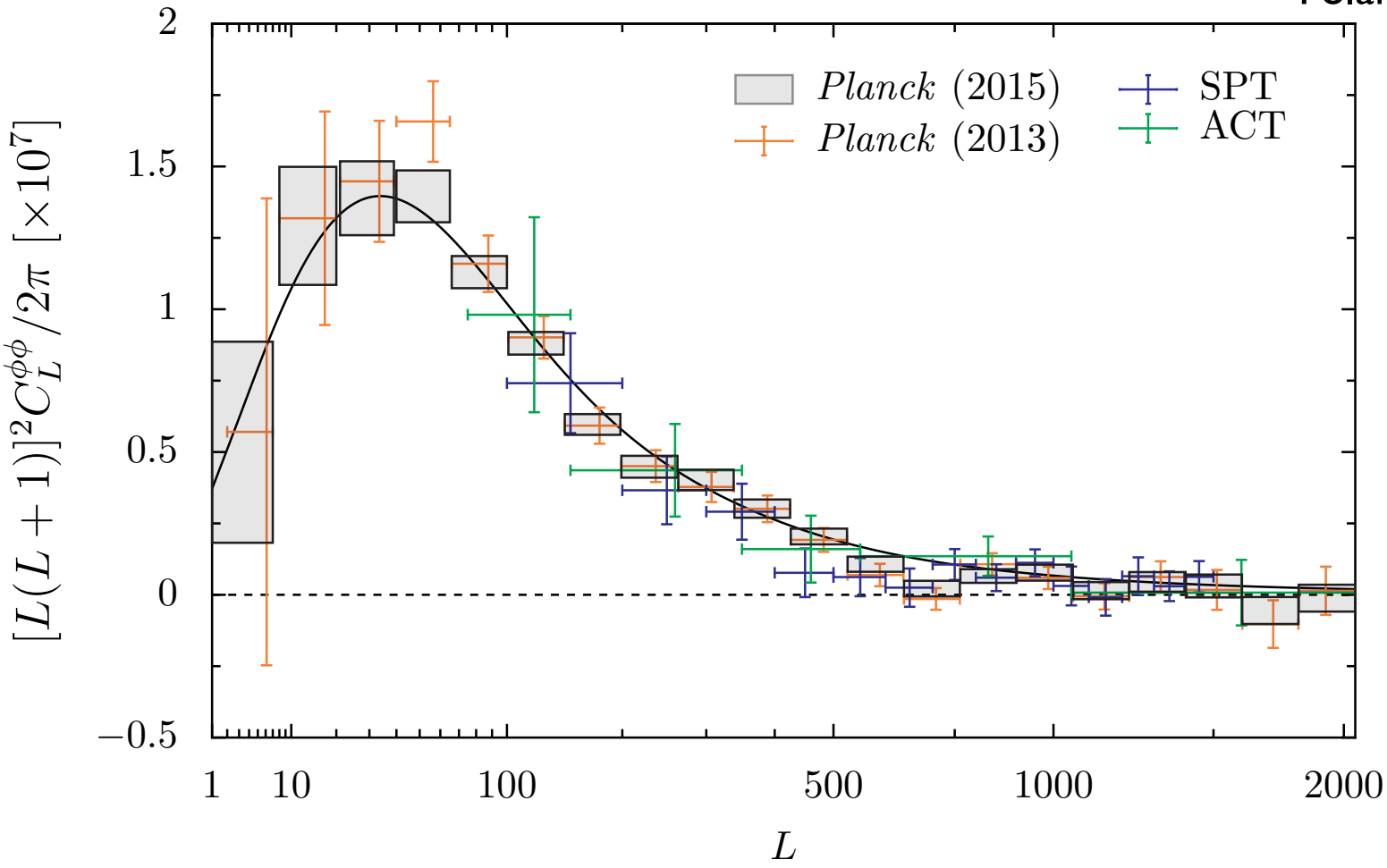
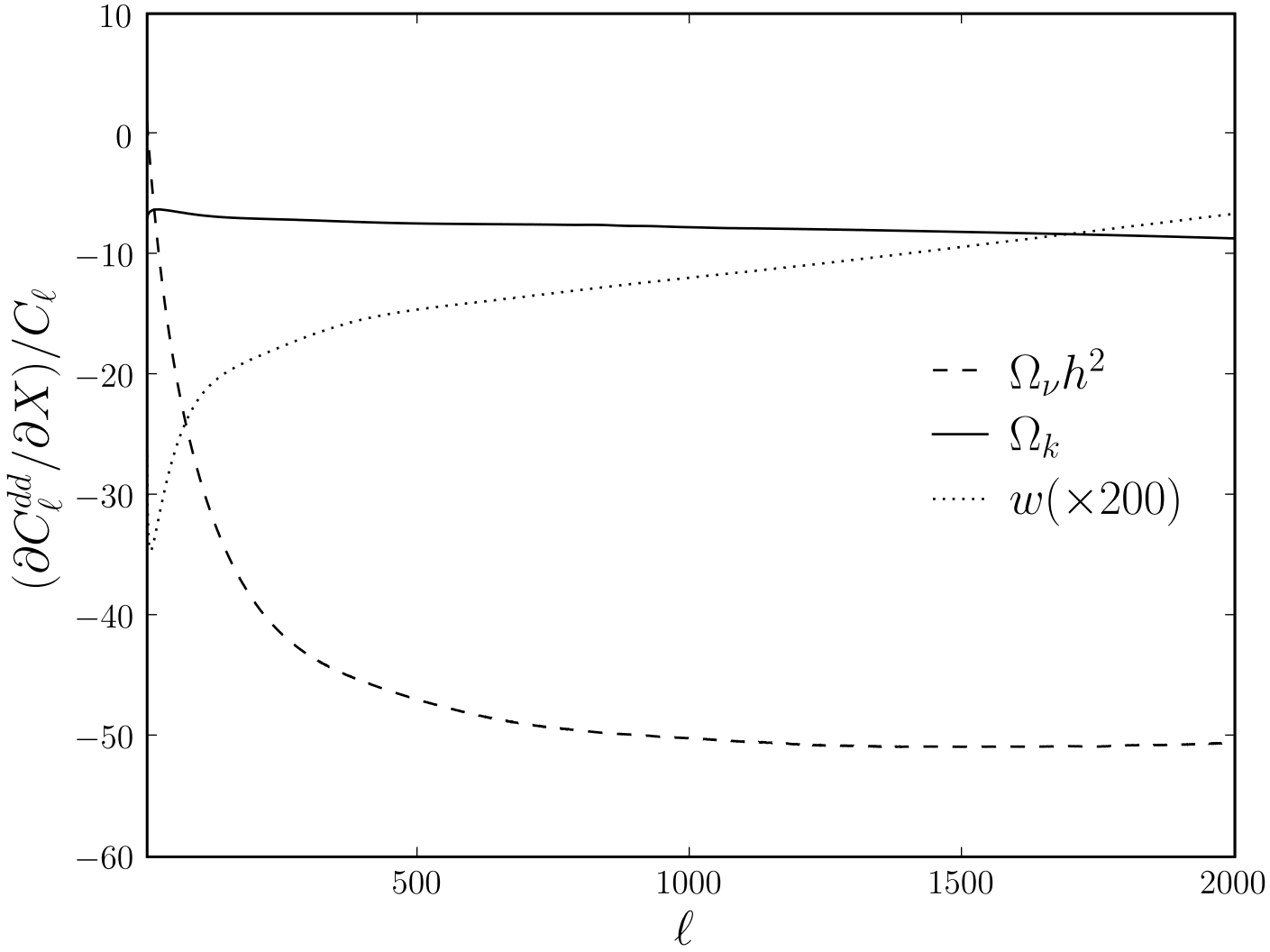


Fig. 6 *Planck* 2015 full-mission MV lensing potential power spectrum measurement, as well as earlier measurements using the *Planck* 2013 nominal-mission temperature data (Planck Collaboration XVII 2014), the South Pole Telescope (SPT, van Engelen et al. 2012), and the Atacama Cosmology Telescope (ACT, Das et al. 2014). The fiducial ΛCDM theory power spectrum based on the parameters given in Sect. 2 is plotted as the black solid line.

Planck 2015

Parameter dependence



Smith+ 2014

What is possible with S4?

Noise per Fourier mode in reconstructed lensing field

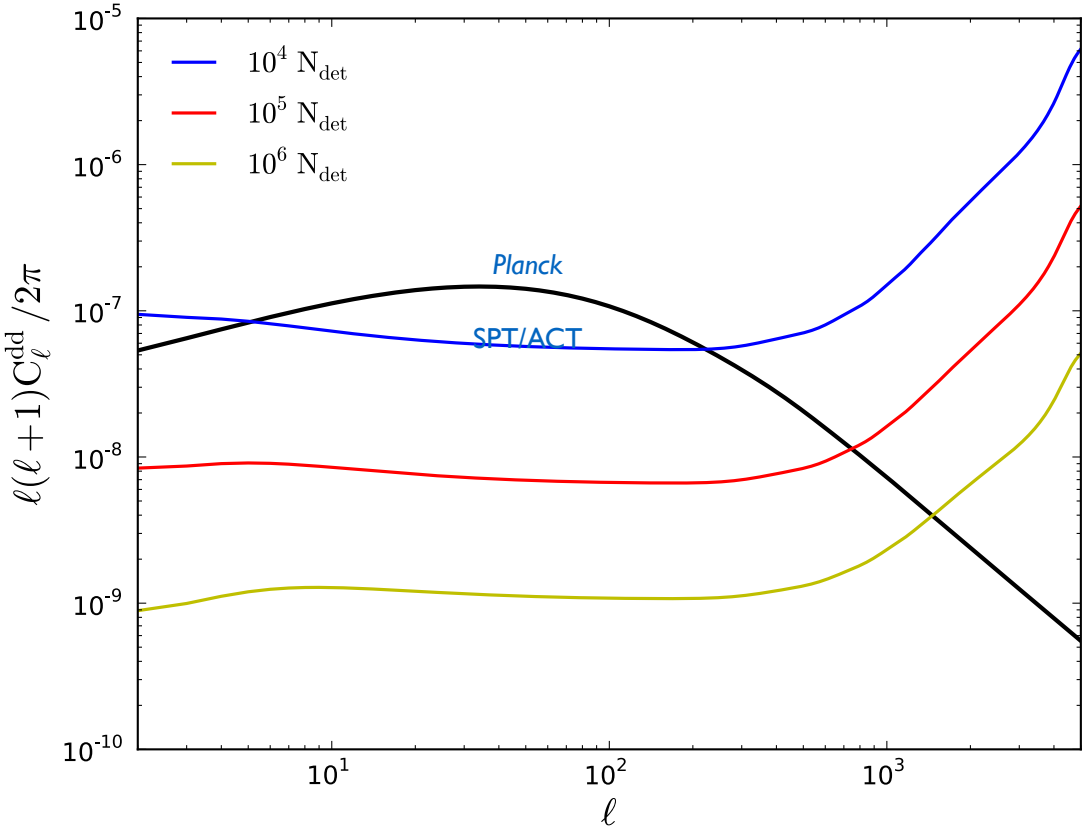


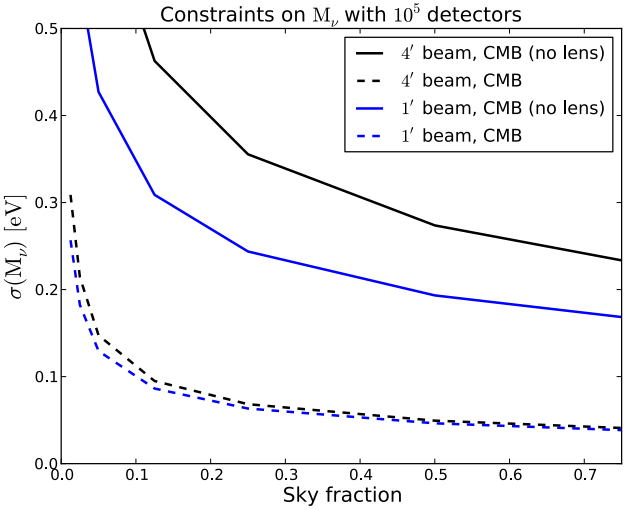
Figure 1: N_ℓ^{dd} for three $N_{\rm det}$ at $f_{sky} = 0.75$ and $1'$ beam size. The deflection angle spectrum C_ℓ^{dd} is shown in black as reference. C_ℓ^{dd} is related to the lensing power spectrum $C_\ell^{\phi\phi}$ by $C_\ell^{dd} = \ell(\ell+1)C_\ell^{\phi\phi}$.

Wu+ 2014

Mnu constraint vs. Beamsize

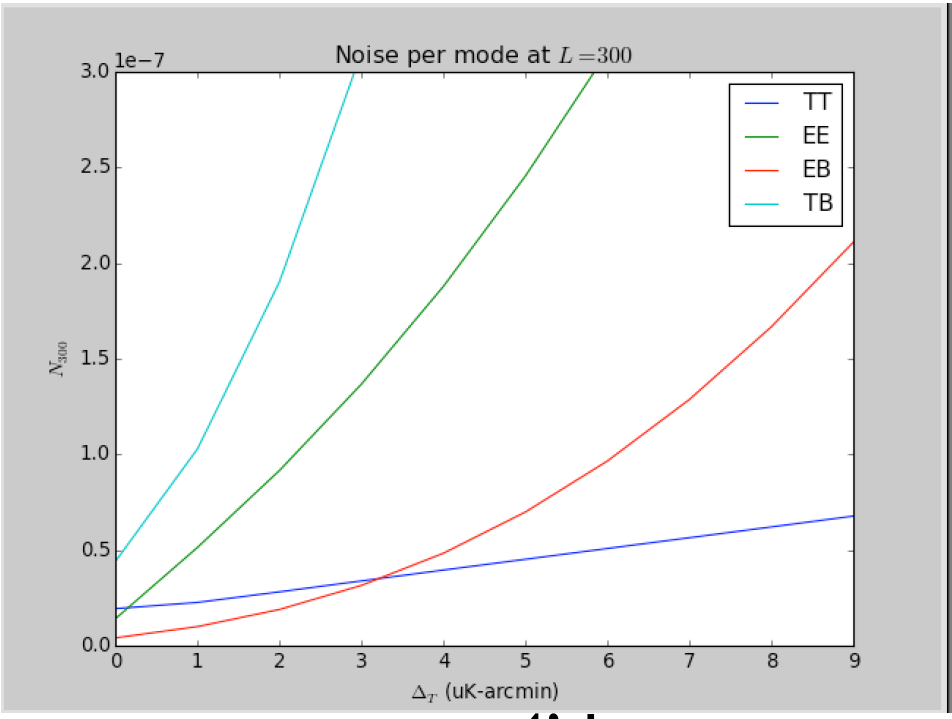
	CMB				CMB+BAO			
	$1'$	$2'$	$3'$	$4'$	$1'$	$2'$	$3'$	$4'$
10^4 detectors								
$f_{sky} = 0.25$	71.7	72.8	74.4	76.6	22.8	23.0	23.4	23.9
$f_{sky} = 0.50$	54.7	55.7	57.2	59.2	20.6	20.9	21.3	21.9
$f_{sky} = 0.75$	48.1	49.0	50.5	52.5	20.1	20.4	20.9	21.5
10^5 detectors								
$f_{sky} = 0.25$	63.3	65.2	66.7	68.3	19.7	19.8	19.9	20.1
$f_{sky} = 0.50$	46.4	47.2	48.2	49.4	16.9	17.0	17.1	17.2
$f_{sky} = 0.75$	38.5	39.2	40.0	41.0	15.7	15.8	15.9	16.0
10^6 detectors								
$f_{sky} = 0.25$	54.9	58.1	62.2	64.7	19.1	19.2	19.3	19.4
$f_{sky} = 0.50$	40.8	42.7	45.1	46.5	16.4	16.4	16.5	16.6
$f_{sky} = 0.75$	34.1	35.7	37.2	38.3	15.1	15.2	15.3	15.3

Table III: 1-σ constraints on M_ν, in units of meV, from CMB and from CMB+BAO. "CMB" includes lensing.

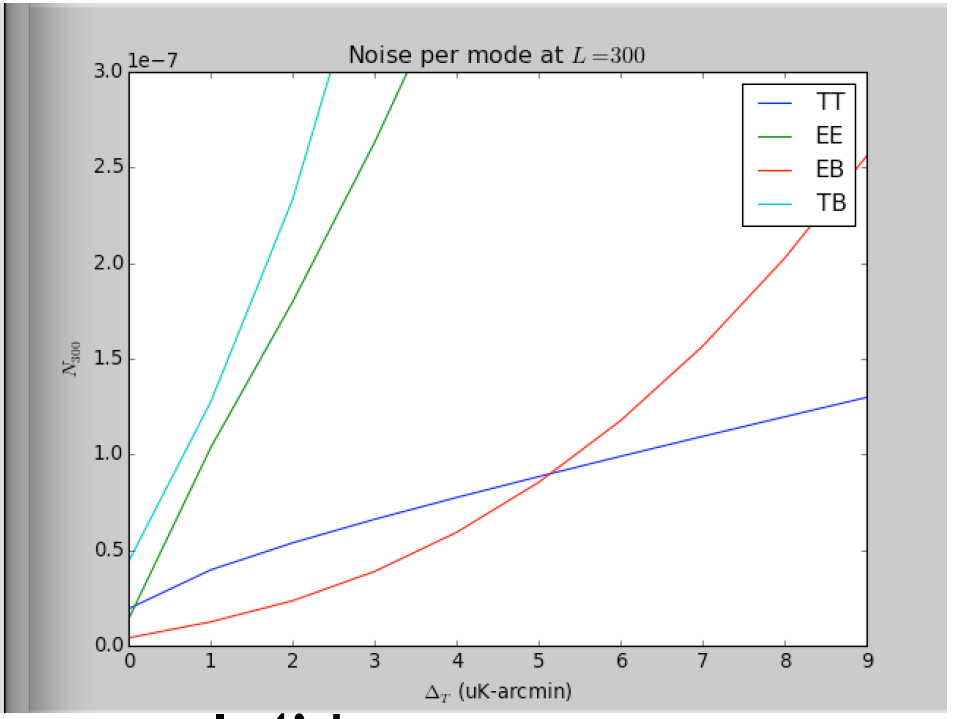


Wu+ 2014

- To date, all results have been obtained with Hu and Okamoto quadratic estimator
- To date, lensing temperature has dominated S/N in results
  (exception: Polarbear 2015, 4σ pol. lensing)
- At low noise these both change - we are in a new regime



4’ beam



1.4’ beam

Note: no iterative delensing here; factor of a few at low noise

Noise levels & Delensing

- Lensed B-modes give a noise floor of 5 uK-arcmin
- Hu & Okamoto quadratic estimator becomes non-optimal
  - Hirata & Seljak maximum likelihood method (or something like it) necessary
  - Reconstruction and Delensing strongly linked

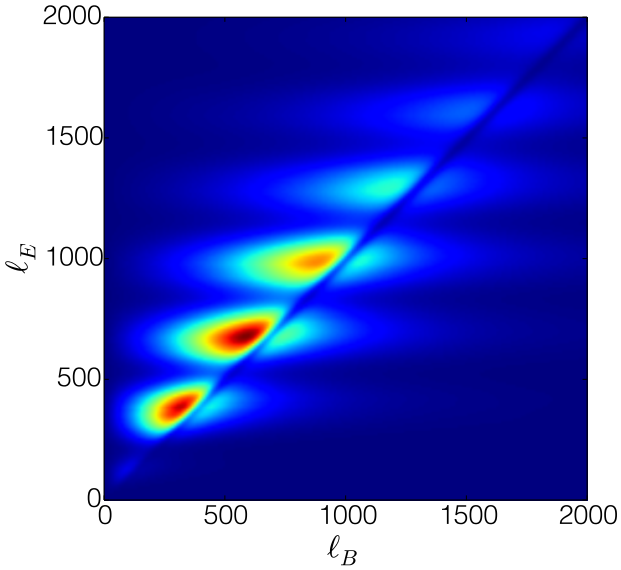
- Forecasted lensing noise based on iterative delensing idea

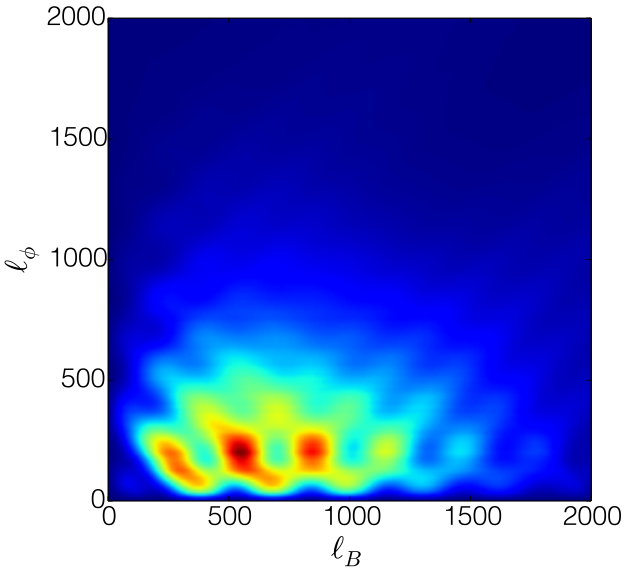
$$N_\ell^{\phi\phi} = \left[\frac{1}{2\ell+1}\sum_{\ell_1\ell_2}|f^{EB}_{\ell_1\ell_2\ell}|^2\left(\frac{1}{C_{\ell_1}^{B_{\rm res}}+N_{\ell_1}^{BB}}\right)\left(\frac{(C_{\ell_2}^{EE})^2}{C_{\ell_2}^{EE}+N_{\ell_2}^{EE}}\right)\right]^{-1}$$

$$C_{\ell_1}^{B_{\rm res}} = \frac{1}{2\ell_1+1}\sum_{\ell_2\ell}|f^{EB}_{\ell_1\ell_2\ell}|^2\left[C_{\ell_2}^{EE}C_\ell^{\phi\phi}-\left(\frac{(C_{\ell_2}^{EE})^2}{C_{\ell_2}^{EE}+N_{\ell_2}^{EE}}\right)\left(\frac{(C_\ell^{\phi\phi})^2}{C_\ell^{\phi\phi}+N_\ell^{\phi\phi}}\right)\right]$$

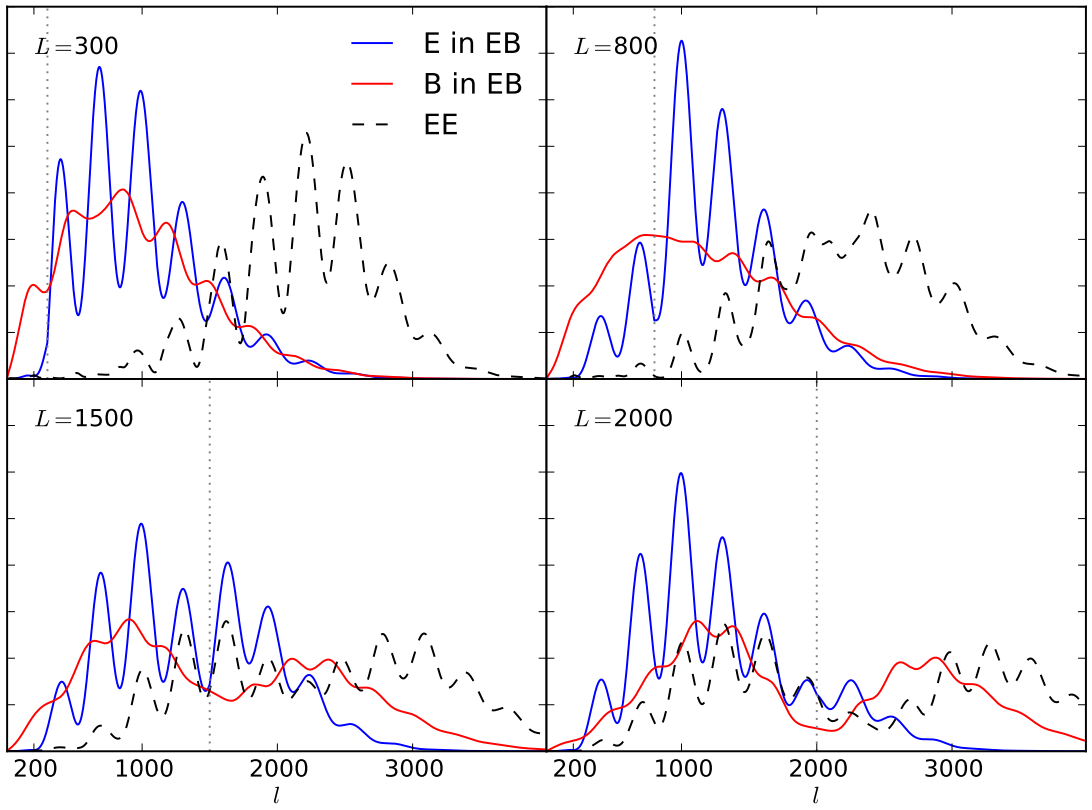
starting by taking $C_\ell^{B_{\rm res}} = C_\ell^{B_{\rm len}}$ in the first iteration.

Which CMB modes need to be measured?





$\ell_B(\partial C^B_{\ell_B}/\partial C^X_{\ell_X})C^X_{\ell_X}$ where $X \in \{E, \phi\}$



$A_{ij}(L, l_1) \propto \int l_1 d\varphi_{l_1} f_{ij}(\mathbf{l}_1, \mathbf{l}_2) W_{ij}(\mathbf{l}_1, \mathbf{l}_2)$

Simard+ 2015

Which algorithm to use?

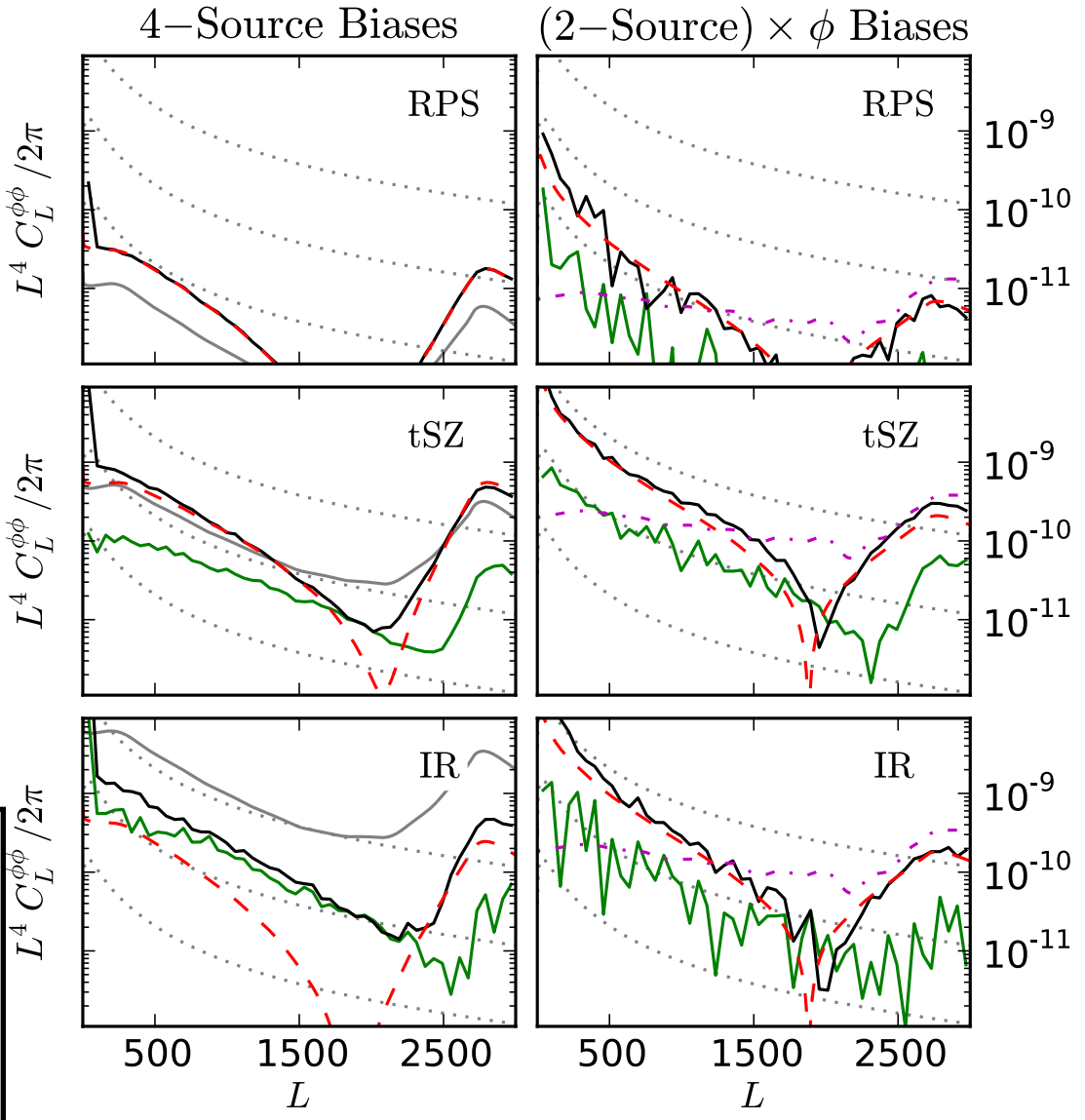
- Hirata & Seljak (2003) global maximum likelihood
- Local maximum likelihood (Anderes+ 2011)
- Iterative template solution (Hanson, Smith, Dvorkin)
- Gibbs sampling (Anderes+ 2015)
- Others?

Extragalactic foregrounds?

- For single-frequency temperature maps, the trispectra of point sources and tSZ give few-%-level biases (van Engelen+2013, Osborne+2013)
    - size of bias depends strongly on both beam size (flux cut) and map noise level
    - clustering of sources and correlation with φ both give contributions

Projecting out the foregrounds
Temperature case: Osborne+ 2013

- Project data-derived $S^2 \times S^2$ and $S^2 \times \Phi$ terms from the lensing estimate -- "bias-hardening"



Here, l_{max} = 3000, no noise

Black: Sehgal 2010 sim

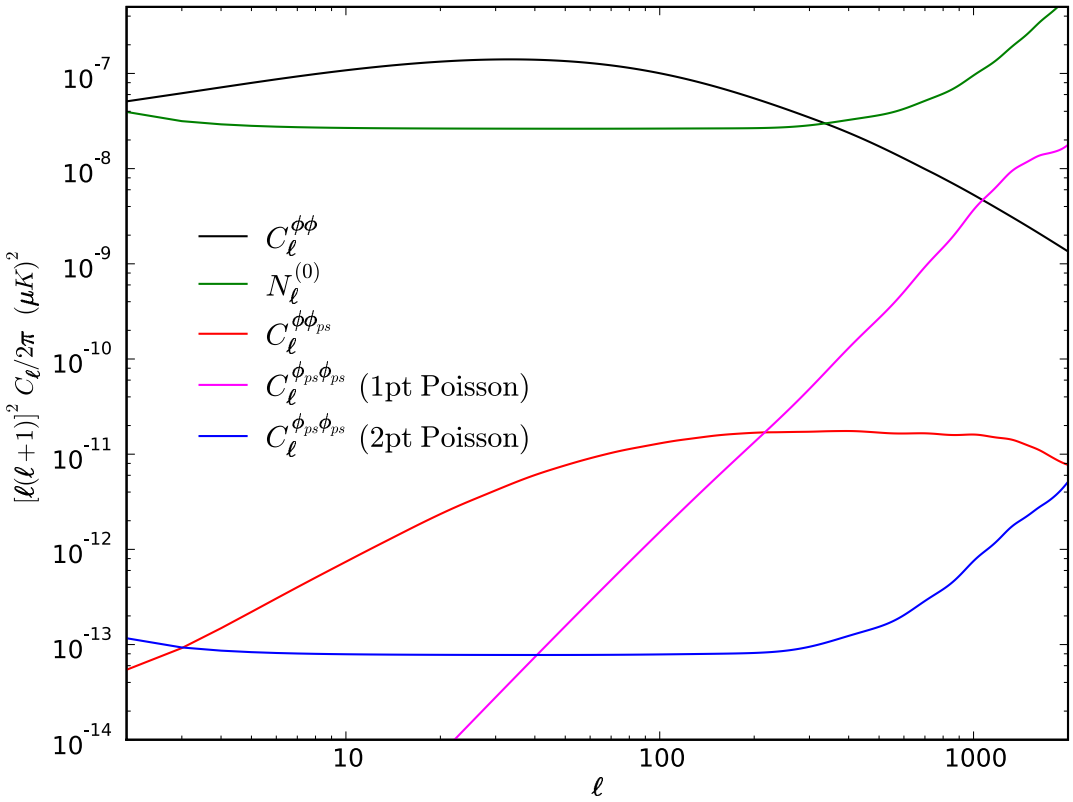
Green: Sehgal 2010, bias-hardened

Red: simple modelling

Grey: disconnected N0 bias

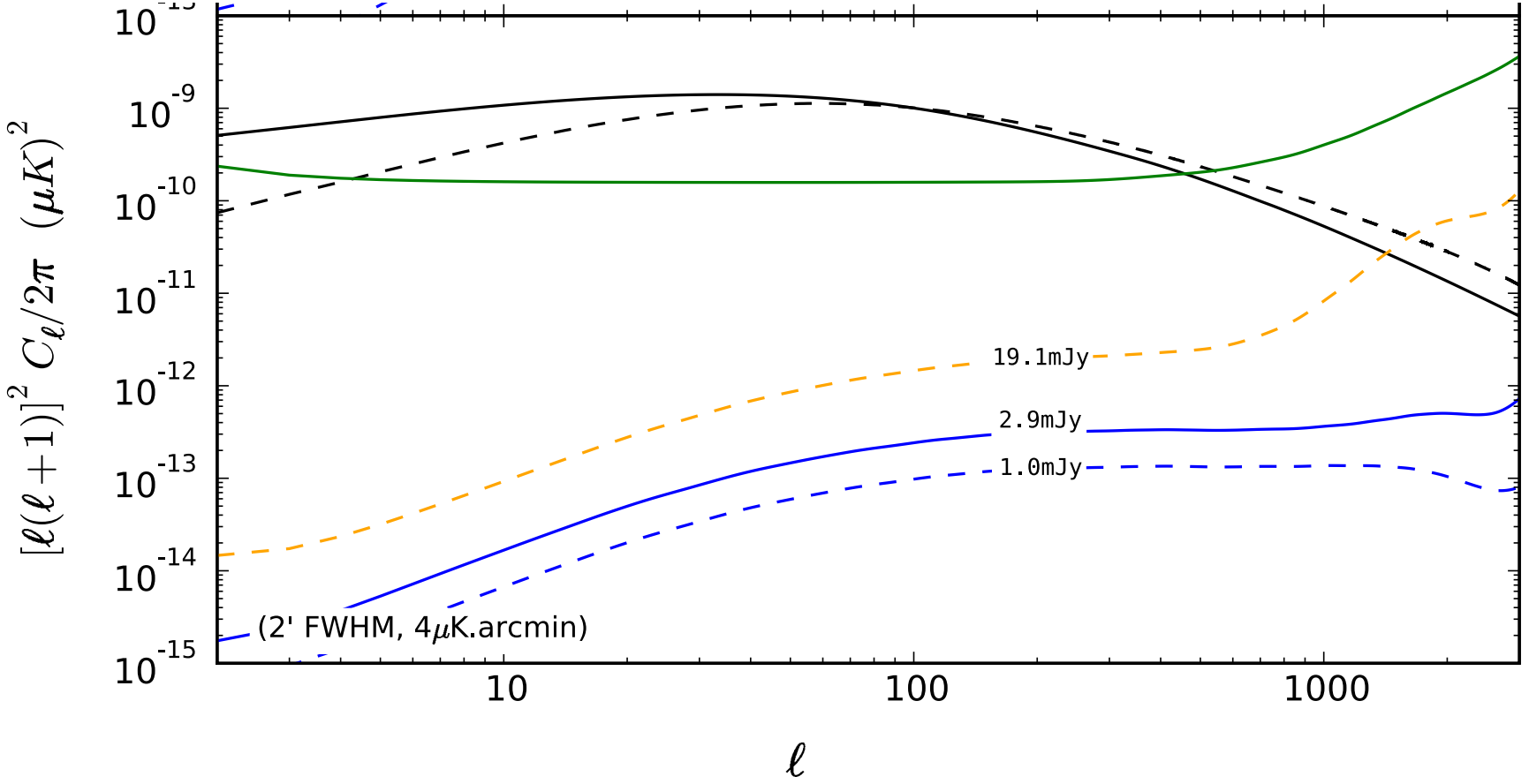
Polarized extragalactic sources

- CMBPol white paper (Smith+ 2008)
  - assume Poisson radio sources (but correlated with φ) at 150GHz
  - 10% pol. fraction
- Biases small



Polarized extragalactic sources

- Strong dependence on flux cut (beam size)



CMBPol white paper (Smith+ 2008)

Galactic Dust?

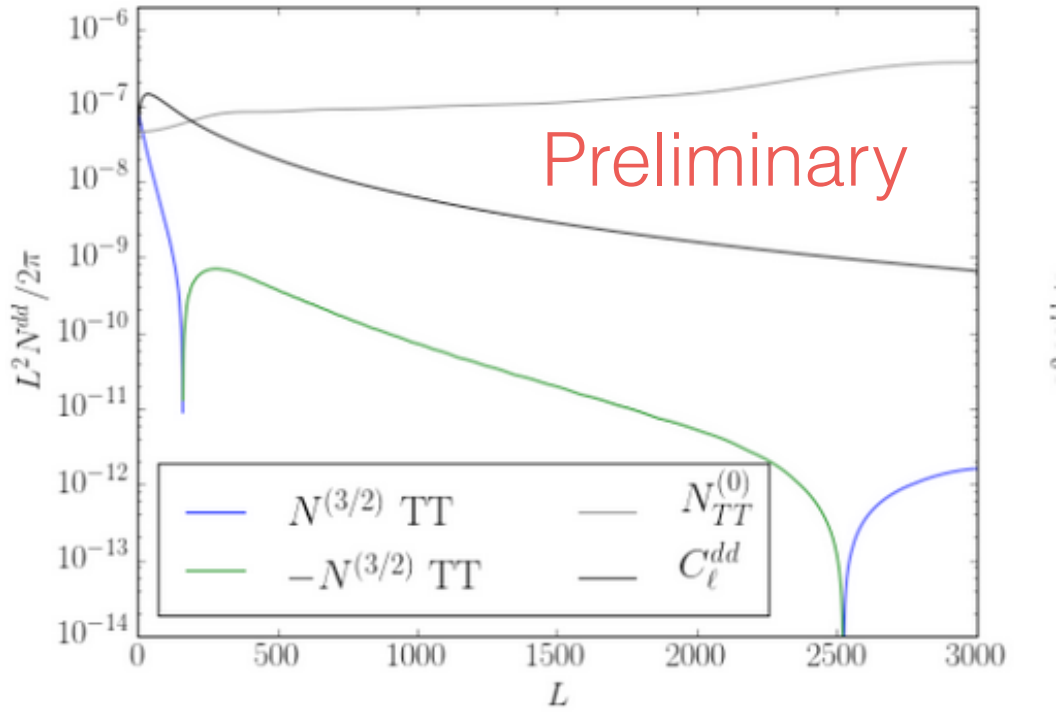
- How large is the four-point function of polarized galactic dust at high ell?

Instrumental Systematics

- What level of control do we need on these?
  - gain variations, monopole leakagge, quadrupole leakage, pointing/beam offsets
- Is the BB power spectrum (or other quadratic estimators) a useful diagnostic after data are taken?

Impact of nonlinear growth?

- Bias from 2nd order perturbations (tree-level bispectrum)
- ~1% for an ACT-like survey



Boehm+ in prep
Sherwin+ in prep