BIASES TO CMB LENSING AND DELENSING

***Antón Baleato Lizancos**, IoA and KICC, University of Cambridge*
Member of the Simons Observatory delensing group (see poster by T. Namikawa)

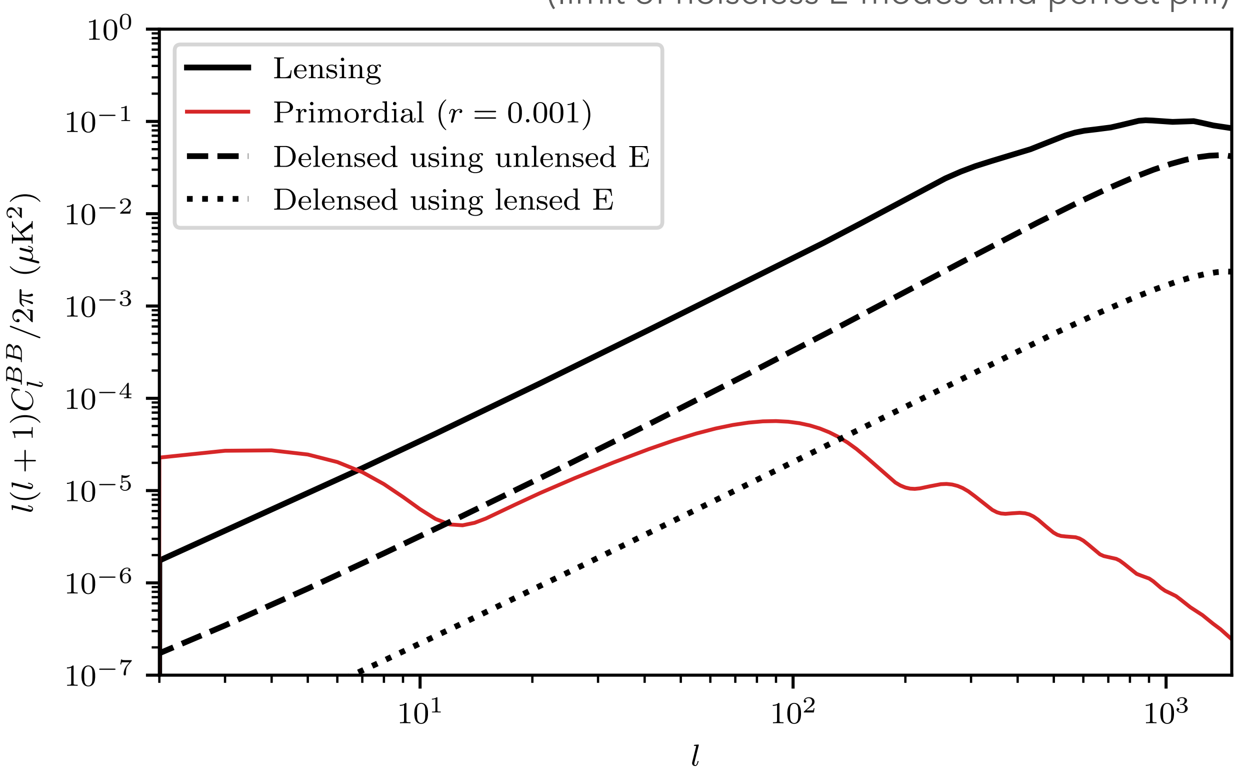
CMB B-mode polarisation

If, as observations suggest, the Universe underwent a period of cosmic inflation early on, primordial gravitational waves must have been generated (Starobinsky 79, Guth 81). Their presence 380,000 years later, when the cosmic microwave background (CMB) was emitted, ought to have left a unique signature on the CMB polarisation: a divergence-free, **primordial B-mode** (Polnarev 85, Kamionkowski et al. 97, Seljak & Zaldarriaga 97). However, this signal is subdominant to the contribution from gravitational lensing of CMB photons by matter, which "rotates" primordial E-modes into **lensing B-modes** (Zaldarriaga & Seljak 98). Detecting primordial B-modes, which would constitute direct evidence for inflation, is made impossible by the large variance associated with lensing.

Delensing

The lensing variance can be mitigated by estimating the lensing B-modes and subtracting them off of observations. A common approach to this is to form a leading-order **B-mode template** by convolving E-mode observations with a proxy of the lensing potential. The latter can be obtained either **internally** from the CMB itself, or **externally** from tracers (galaxies, CIB…) known to correlate with lensing.

(limit of noiseless E-modes and perfect phi)



By explicitly calculating all contributions, to fourth order in lensing, to the power spectrum of B-modes delensed with a template, we are able to show that 1) corrections to the leading-order calculation of the lensing B-mode power spectrum only enter at the O(1)% level because of extensive cancelations between large terms at next-to-highest order, 2) that these **cancellations disappear when the template is built from unlensed or delensed E-modes, so the residual lensing floor is of O(10)%** of the original power and 3) that **new cancellations arise when lensed E-modes are used in the template, allowing for the lensing floor to be as low as O(1)%** of the original power in practical applications of this method. Once reconstructions allow for more extensive delensing, techniques going beyond leading order ought to be considered.

__ABL__ & A. Challinor 20 (to be submitted very soon)

IMPACT OF INTERNAL-DELENSING BIASES ON PRIMORDIAL B-MODE SEARCHES

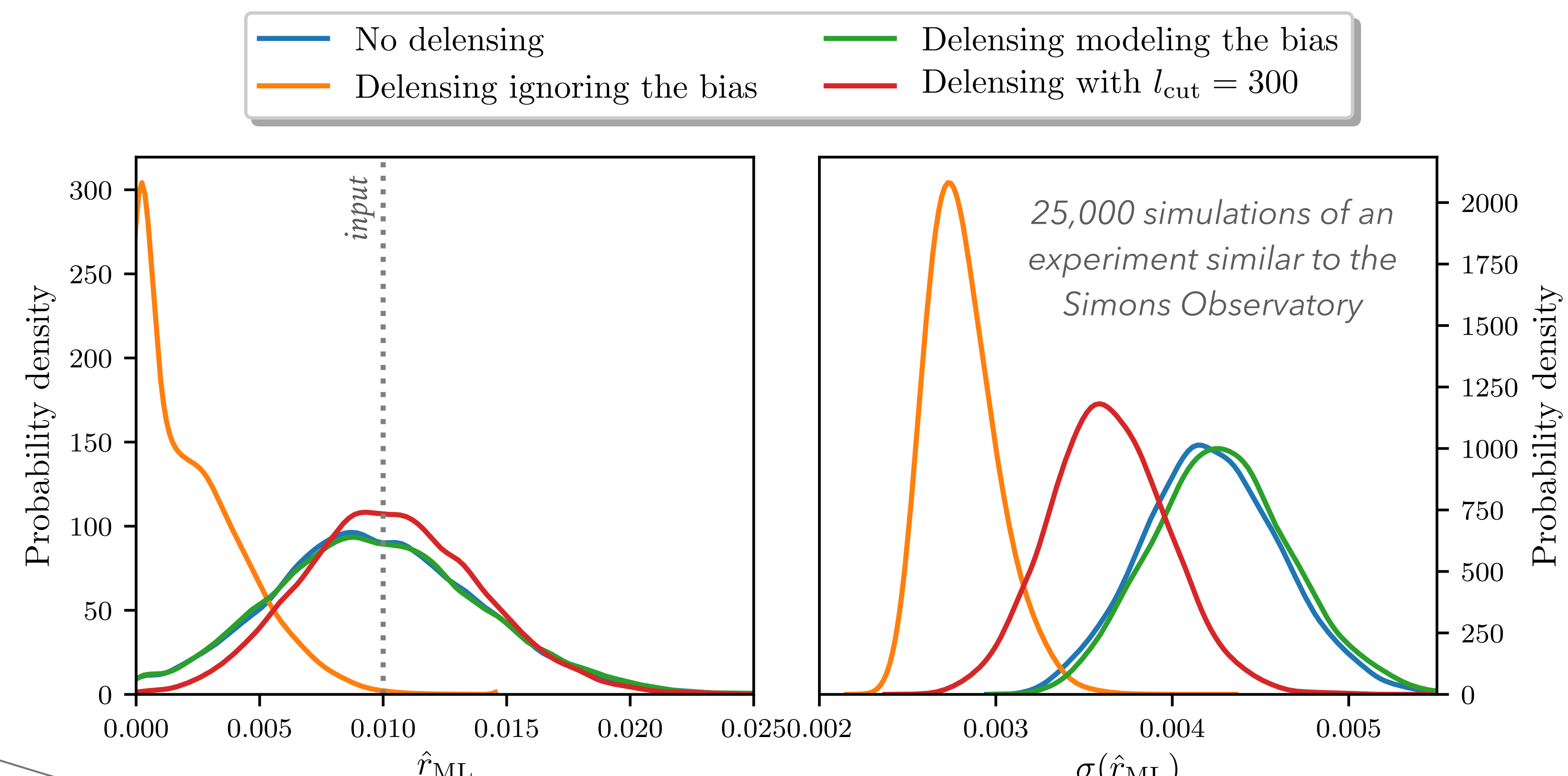
Lensing reconstruction

If experimental sensitivity and resolution are good enough (as is already the case), the projected matter distribution can be reconstructed statistically from correlations between angular scales seen in CMB fields which wouldn't be there in the absence of lensing. The most common tool, the **quadratic estimator** (QE), examines these correlations in pairs of CMB fields (Hu & Okamoto 02).

Internal-delensing biases

In the near future, the **EB quadratic estimator** will dominate reconstructions. Any overlap in modes between the B-field to be delensed and the B-field from which the reconstruction is derived leads to **a suppression of delensed power beyond that associated with a mitigation of lensing** (Teng et al. 11). Crucially, the variance of the delensed field is also suppressed. Could this help better constrain primordial B-modes?

We model the bias and show that its presence **necessarily degrades the signal-to-noise on a primordial component**. The bias can be mitigated by removing the largest angular scales from the B-field to be fed to the QE. We show that it is in general advantageous to do this rather than modelling or renormalising the bias.



Tensor-to-scalar ratio (parametrises primordial B-mode amplitude)

***ABL**, A. Challinor & J. Carron 20*

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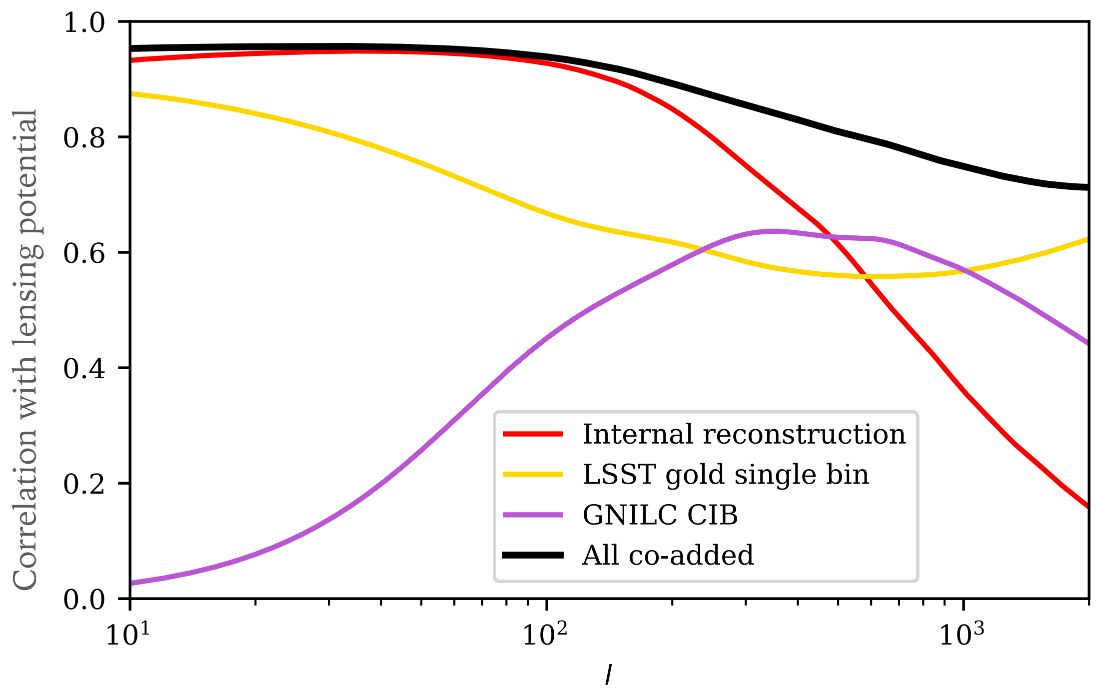
DELENSING B-MODES WITH THE CIB: THE IMPACT OF FOREGROUNDS

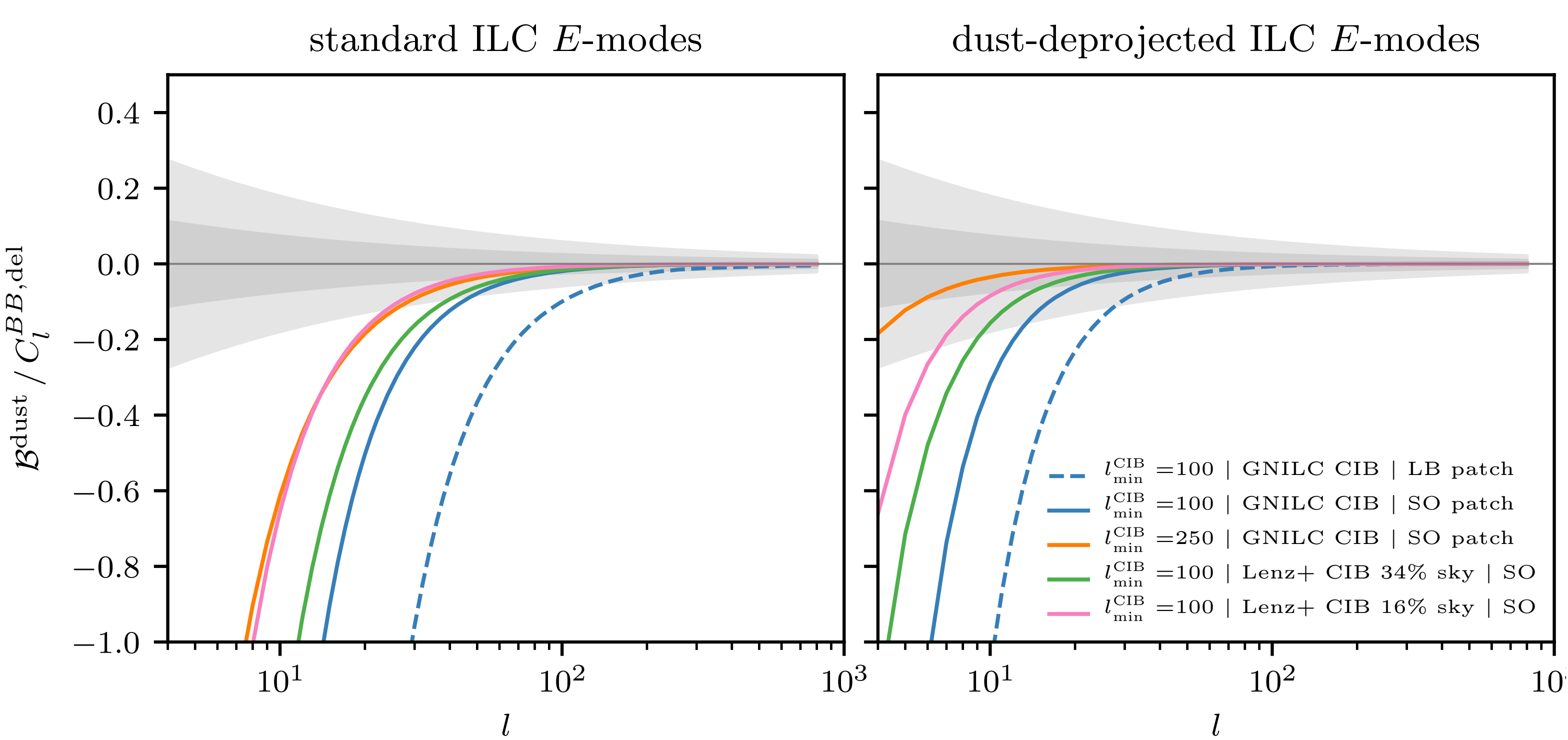


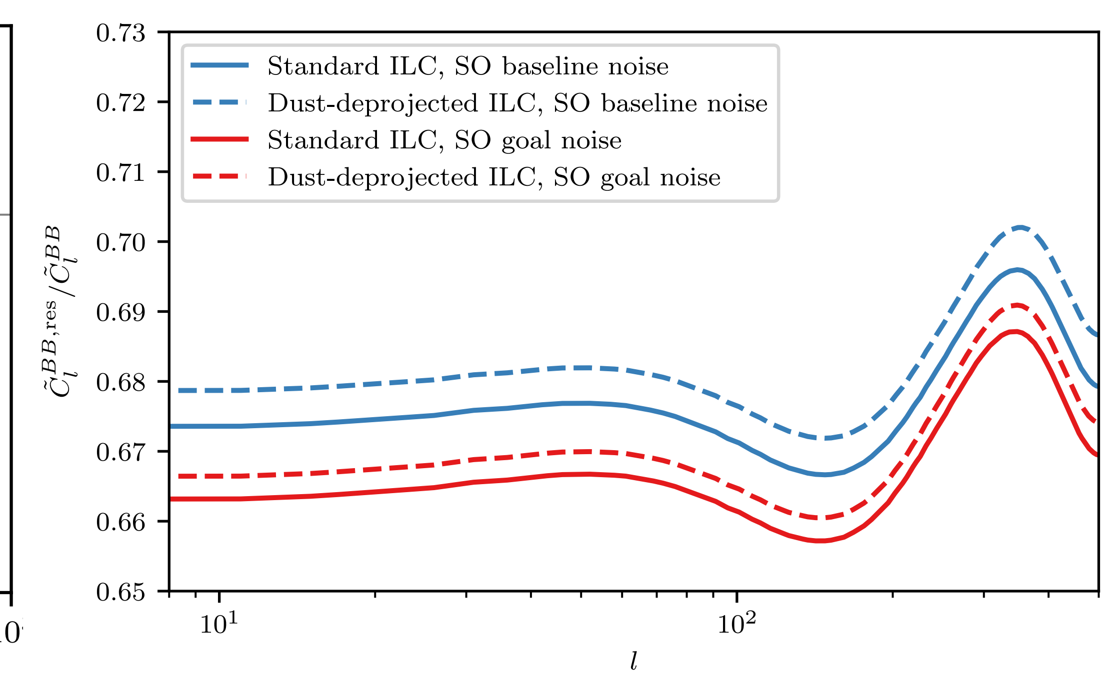
For near-future experiments, the best estimate of the CMB lensing potential will arise from co-adding internal reconstructions with external matter tracers such as the cosmic infrared background (CIB) (Sherwin & Schmittfull 15), which provide access to small-scale lenses at high redshift that internal reconstructions cannot yet probe.

Galactic dust and the CIB have very similar SEDs, so disentangling them is difficult. We worry that dust/CIB residuals left over in CMB maps can couple with residuals in the CIB intensity maps used as matter tracers for delensing and bias the power spectrum of delensed B-modes (and hence r).

Using analytic arguments, we show that, for the expected extent of point-source masking in any foreseeable application of CIB delensing, **bias from higher-point functions of CIB itself is negligible**.

Bias due to <BEI> bispectrum of galactic dust is non-negligible, particularly for space-based experiments going after very large angular scales, where the bias is larger. However, we show that **a simple mitigation technique** (deprojecting dust from E-modes in an ILC) **is very effective while incurring little loss in delensing efficiency**.





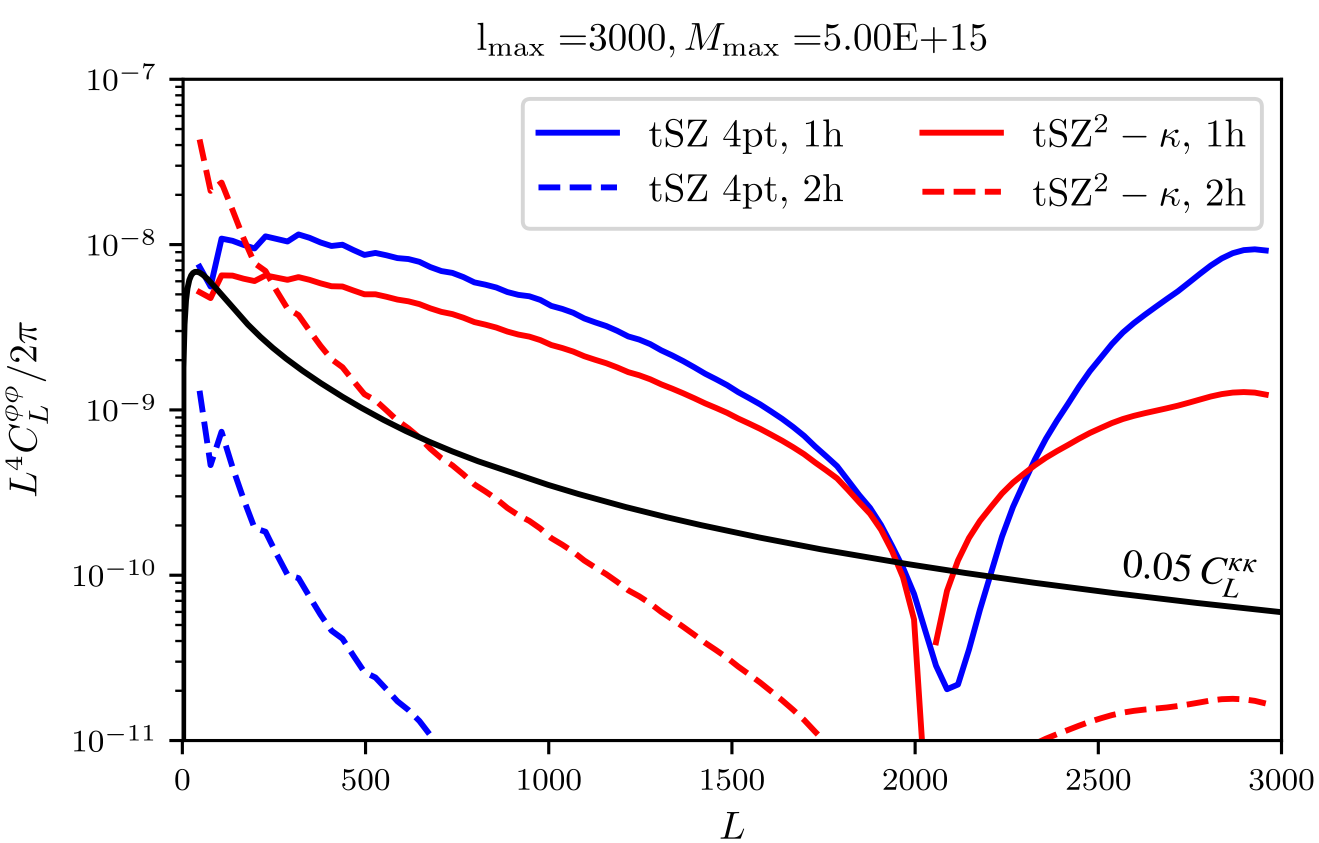
***ABL**, A. Challinor, B. Sherwin & T. Namikawa 20 (to be submitted very soon)*

CMB LENSING BIASES FROM GALAXIES & CLUSTERS

Measurements of the lensing convergence power spectrum can be used to constrain neutrino masses, while cross-correlations with other, lower-redshift tracers of the matter distribution offer information about the growth of structure, primordial non-Gaussianity, curvature and dark energy (see, e.g. Simons Observatory collaboration 19).

However, the **auto- and cross-spectra of a lensing reconstruction derived from a TT QE** (which dominates over other estimators for current and upcoming experiments) is **biased by** the **thermal Sunyaev-Zeldovich (tSZ)** effect from clusters and the **CIB** (Van Engelen et al. 14, Osborne et al. 14). Ongoing experiments have already reached percent-level precision on the power spectrum of CMB lensing reconstruction, so it is imperative to keep these biases in check.

Goal: to **analytically calculate the biases as a function of experimental sensitivity, resolution, point-source masking, etc, using a halo model prescription,** in order to enable marginalisation over them in actual analyses, thus avoiding the variance increase intrinsic to alternative mitigation methods (see, e.g. Simons Observatory collaboration 19), and to improve forecasting and mitigation techniques.



(Example calculation of tSZ biases for an SPT-like experiment)

Preliminary

Two new codes to do the calculation:

- **Very fast, 1D method**. Lensing reconstructions done **using FFTlog** (for fast, discrete Hankel transforms), taking O(10ms) per lensing reconstruction on a single laptop core. Assumes spherical symmetry of pressure/DM profiles and diagonal noise filtering.
- **Slower, 2D method**. Lensing reconstructions done using conventional flat-sky code (QuickLens). **Can incorporate cluster tri-axiality and realistic noise filtering**.

***ABL**, W. Coulton, A. Challinor & B. Sherwin (in prep)*