

D.E.S reconstructed lensing potential template and application to delensing and cross correlation

A. Manzotti
(Dated: March 27, 2015)

Goal: test if, at least on a small patch of the sky 500 deg² LSS survey like D.E.S or DESI can improve the reconstruction of the lensing potential that lenses the CMB photons. This would be crucial to build a template of the B-mode signal coming from the lensing of the primordial E-mode. This will be at multipoles higher than 200 the main contaminants of the primordial B-mode. Preliminary: CIB performs as an equivalent ρ_{eff} (correlation coefficient constant over ℓ) of 0.8. Both D.E.S and DESI are significantly worse, $\rho_{\text{eff}} < 0.6$. DESI is slightly better than D.E.S. To delens we need the bulk of the redshift distribution to follow the CMB kernel, having a few outliers at redshift $z > 1.5$ is not enough. We also have to keep in mind the results of Smith et al. [1], even a perfect LSS survey can not help too much the delensing technique, with the possible exception of futuristic 21 cm.

I. THEORY

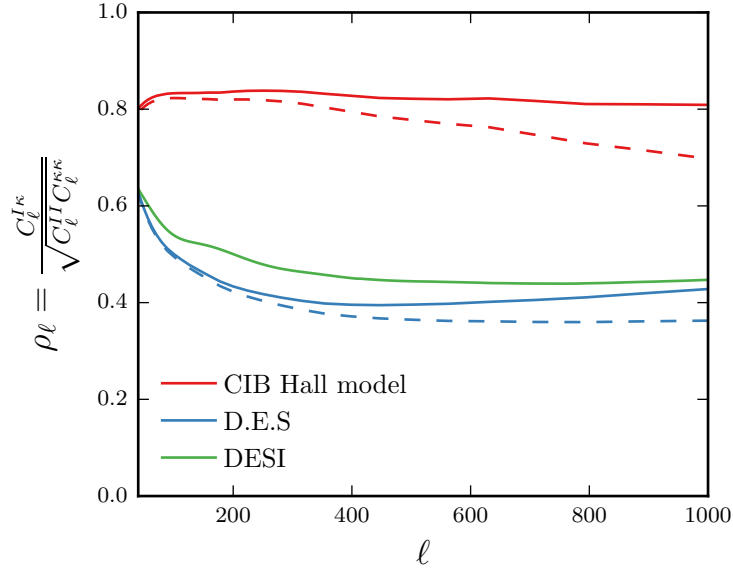


FIG. 1: Correlation factor between galaxies survey and CMB lensing potential.

As for the temperature, the intensity map of photons on the sky, also the Q and U mode decomposition of their polarization is modified by lensing as:

$$Q(\hat{\mathbf{n}}) = Q_{\text{unlensed}}(\hat{\mathbf{n}} + \mathbf{d}); \quad U(\hat{\mathbf{n}}) = U_{\text{unlensed}}(\hat{\mathbf{n}} + \mathbf{d}) \quad (1)$$

where \mathbf{d} is the deflection angle directly related to the lensing potential ϕ .

As a first approximation, the B mode resulting from the lensing of primordial E mode by a convergence field κ is:

$$B^{\text{lens}}(\mathbf{l}) = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W(\mathbf{l}, \mathbf{l}') E(\mathbf{l}') \kappa(\mathbf{l} - \mathbf{l}') \quad (2)$$

where

$$W(\mathbf{l}, \mathbf{l}') = \frac{2\mathbf{l}' \cdot (\mathbf{l} - \mathbf{l}')}{|\mathbf{l} - \mathbf{l}'|^2} \sin(2\varphi_{\mathbf{l}, \mathbf{l}'}), \quad (3)$$

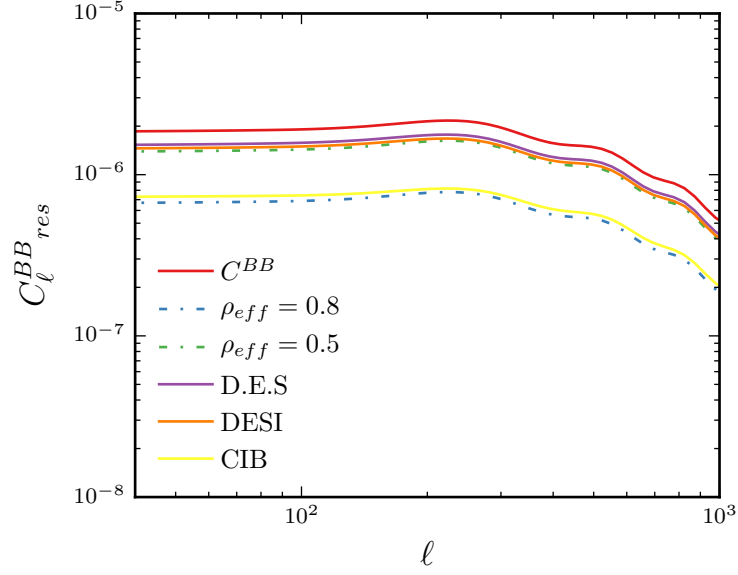


FIG. 2: Residual lensing B modes power spectrum using different large scale structure.

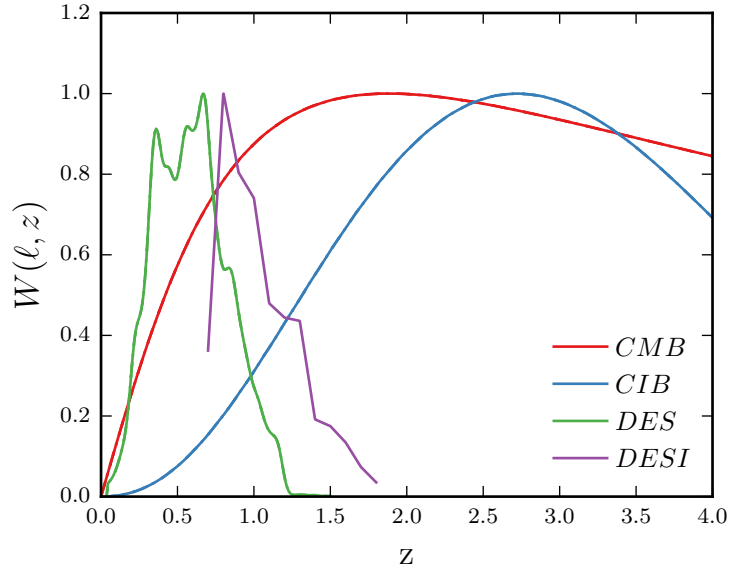


FIG. 3: Comparison of the different kernels used in this analysis. This allow to understand Redshift distribution of D.E.S galaxies (I suspect this is the benchmark, anyway taken from Giannantonio et al.).

As usual we define the power spectrum as:

$$\langle B^{\text{lens}}(\mathbf{l}) B^{\text{lens}*}(\tilde{\mathbf{l}}) \rangle \equiv (2\pi)^2 \delta^D(\mathbf{l} - \tilde{\mathbf{l}}) C_l^{BB, \text{lens}} \quad (4)$$

From this we get that the power spectrum:

$$C_l^{BB, \text{lens}} = \int \frac{d^2 \mathbf{l}'}{(2\pi)^2} W^2(\mathbf{l}, \mathbf{l}') C_{l'}^{EE} C_{|\mathbf{l} - \mathbf{l}'|}^{\kappa\kappa}. \quad (5)$$

Now the full B-mode power spectrum measured on the sky is

$$C_l^{BB,\text{full}} = C_l^{BB,r} + C_l^{BB,\text{lens}} + N_l^{BB}. \quad (6)$$

Now, if we have an LSS measurements \mathbf{I} that traces the lensing potential responsible for the lensing of the CMB we can build a template of the true lensing B mode on the sky with a weighted convolution:

$$\hat{B}^{\text{lens}}(\mathbf{l}) = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W(\mathbf{l}, \mathbf{l}') f(\mathbf{l}, \mathbf{l}') E^N(\mathbf{l}') I(\mathbf{l} - \mathbf{l}') \quad (7)$$

where $f(\mathbf{l}, \mathbf{l}')$ is a weight that must be determined.

The residual lensing b mode will be

$$B^{\text{res}}(\mathbf{l}) = B^{\text{lens}}(\mathbf{l}) - \hat{B}^{\text{lens}}(\mathbf{l}) = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W(\mathbf{l}, \mathbf{l}') \times \\ (E(\mathbf{l}') \kappa(\mathbf{l} - \mathbf{l}') - f(\mathbf{l}, \mathbf{l}') E^N(\mathbf{l}') I(\mathbf{l} - \mathbf{l}')) \quad (8)$$

and its power spectrum

$$C_l^{BB,\text{res}} = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W^2(\mathbf{l}, \mathbf{l}') [C_{l'}^{EE} C_{|\mathbf{l}-\mathbf{l}'|}^{\kappa\kappa} \\ - (f(\mathbf{l}, \mathbf{l}') + f^*(\mathbf{l}, \mathbf{l}')) C_{l'}^{EE} C_{|\mathbf{l}-\mathbf{l}'|}^{\kappa I} \\ + f^*(\mathbf{l}, \mathbf{l}') f(\mathbf{l}, \mathbf{l}') (C_{l'}^{EE} + N_{l'}^{EE}) C_{|\mathbf{l}-\mathbf{l}'|}^{II}] \quad (9)$$

We can now easily choose $f(\mathbf{l}, \mathbf{l}')$ so that the residual lensing B mode power is minimized. We find:

$$f(\mathbf{l}, \mathbf{l}') = \left(\frac{C_{l'}^{EE}}{C_{l'}^{EE} + N_{l'}^{EE}} \right) \frac{C_{|\mathbf{l}-\mathbf{l}'|}^{\kappa I}}{C_{|\mathbf{l}-\mathbf{l}'|}^{II}} \quad (10)$$

Notice that the first term consists in the usual inverse variance filter applied to the measured E-mode and the second minimize the difference between the reconstructed ϕ and the CMB lensing potential.

We finally have that the residual power is:

$$C_l^{BB,\text{res}} = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W^2(\mathbf{l}, \mathbf{l}') C_{l'}^{EE} C_{|\mathbf{l}-\mathbf{l}'|}^{\kappa\kappa} \\ \times \left[1 - \left(\frac{C_{l'}^{EE}}{C_{l'}^{EE} + N_{l'}^{EE}} \right) \rho_{|\mathbf{l}-\mathbf{l}'|}^2 \right] \quad (11)$$

with

$$\rho_l = \frac{C_l^{\kappa I}}{\sqrt{C_l^{\kappa\kappa} C_l^{II}}}. \quad (12)$$

The bigger ρ_l is for a LSS field the more it is correlated with the lensing potential acting on the CMB photons. An higher correlation allows for a better reconstruction of the ϕ^{CMB} and, as a consequence, of B^{lens} .

II. DATA

D.E.S, Planck CIB, DESI? [2–13]

III. FORECAST

-
- [1] K. M. Smith, D. Hanson, M. LoVerde, C. M. Hirata, and O. Zahn. Delensing CMB polarization with external datasets. *JCAP*, 6:014, June 2012. doi:10.1088/1475-7516/2012/06/014.
 - [2] N. R. Hall, R. Keisler, L. Knox, C. L. Reichardt, P. A. R. Ade, K. A. Aird, B. A. Benson, L. E. Bleem, J. E. Carlstrom, C. L. Chang, H.-M. Cho, T. M. Crawford, A. T. Crites, T. de Haan, M. A. Dobbs, E. M. George, N. W. Halverson, G. P. Holder, W. L. Holzapfel, J. D. Hrubes, M. Joy, A. T. Lee, E. M. Leitch, M. Lueker, J. J. McMahon, J. Mehl, S. S. Meyer, J. J. Mohr, T. E. Montroy, S. Padin, T. Plagge, C. Pryke, J. E. Ruhl, K. K. Schaffer, L. Shaw, E. Shirokoff, H. G. Spieler, B. Stalder, Z. Staniszewski, A. A. Stark, E. R. Switzer, K. Vanderlinde, J. D. Vieira, R. Williamson, and O. Zahn. Angular Power Spectra of the Millimeter-wavelength Background Light from Dusty Star-forming Galaxies with the South Pole Telescope. *Astrophys. J.*, 718:632–646, August 2010. doi:10.1088/0004-637X/718/2/632.
 - [3] B. D. Sherwin and M. Schmittfull. Delensing the CMB with the Cosmic Infrared Background. *ArXiv e-prints*, February 2015.
 - [4] P. A. R. Ade, R. W. Aikin, D. Barkats, S. J. Benton, C. A. Bischoff, J. J. Bock, J. A. Brevik, I. Buder, E. Bullock, C. D. Dowell, L. Duband, J. P. Filippini, S. Fliescher, S. R. Golwala, M. Halpern, M. Hasselfield, S. R. Hildebrandt, G. C. Hilton, V. V. Hristov, K. D. Irwin, K. S. Karkare, J. P. Kaufman, B. G. Keating, S. A. Kernasovskiy, J. M. Kovac, C. L. Kuo, E. M. Leitch, M. Lueker, P. Mason, C. B. Netterfield, H. T. Nguyen, R. O’Brien, R. W. Ogburn, A. Orlando, C. Pryke, C. D. Reintsema, S. Richter, R. Schwarz, C. D. Sheehy, Z. K. Staniszewski, R. V. Sudiwala, G. P. Teply, J. E. Tolan, A. D. Turner, A. G. Vieregge, C. L. Wong, K. W. Yoon, and Bicep2 Collaboration. Detection of B-Mode Polarization at Degree Angular Scales by BICEP2. *Physical Review Letters*, 112(24):241101, June 2014. doi:10.1103/PhysRevLett.112.241101.
 - [5] D. Hanson, S. Hoover, A. Crites, P. A. R. Ade, K. A. Aird, J. E. Austerlmann, J. A. Beall, A. N. Bender, B. A. Benson, L. E. Bleem, J. J. Bock, J. E. Carlstrom, C. L. Chang, H. C. Chiang, H.-M. Cho, A. Conley, T. M. Crawford, T. de Haan, M. A. Dobbs, W. Everett, J. Gallicchio, J. Gao, E. M. George, N. W. Halverson, N. Harrington, J. W. Henning, G. C. Hilton, G. P. Holder, W. L. Holzapfel, J. D. Hrubes, N. Huang, J. Hubmayr, K. D. Irwin, R. Keisler, L. Knox, A. T. Lee, E. Leitch, D. Li, C. Liang, D. Luong-Van, G. Marsden, J. J. McMahon, J. Mehl, S. S. Meyer, L. Mocuano, T. E. Montroy, T. Natoli, J. P. Nibarger, V. Novosad, S. Padin, C. Pryke, C. L. Reichardt, J. E. Ruhl, B. R. Saliwanchik, J. T. Sayre, K. K. Schaffer, B. Schulz, G. Smecher, A. A. Stark, K. T. Story, C. Tucker, K. Vanderlinde, J. D. Vieira, M. P. Viero, G. Wang, V. Yefremenko, O. Zahn, and M. Zemcov. Detection of B-Mode Polarization in the Cosmic Microwave Background with Data from the South Pole Telescope. *Physical Review Letters*, 111(14):141301, October 2013. doi:10.1103/PhysRevLett.111.141301.
 - [6] I. Szapudi, S. Prunet, and S. Colombi. Fast Clustering Analysis of Inhomogeneous Megapixel CMB maps. *ArXiv Astrophysics e-prints*, July 2001.
 - [7] Eric Hivon, Krzysztof M. Górski, C. Barth Netterfield, Brendan P. Crill, Simon Prunet, and Frode Hansen. Master of the cosmic microwave background anisotropy power spectrum: A fast method for statistical analysis of large and complex cosmic microwave background data sets. *The Astrophysical Journal*, 567(1):2, 2002. URL <http://stacks.iop.org/0004-637X/567/i=1/a=2>.
 - [8] Planck Collaboration, P. A. R. Ade, N. Aghanim, C. Armitage-Caplan, M. Arnaud, M. Ashdown, F. Atrio-Barandela, J. Aumont, C. Baccigalupi, A. J. Banday, and et al. Planck 2013 results. XVIII. The gravitational lensing-infrared background correlation. *A&A*, 571:A18, November 2014. doi:10.1051/0004-6361/201321540.
 - [9] Planck Collaboration, P. A. R. Ade, N. Aghanim, C. Armitage-Caplan, M. Arnaud, M. Ashdown, F. Atrio-Barandela, J. Aumont, C. Baccigalupi, A. J. Banday, and et al. Planck 2013 results. XXX. Cosmic infrared background measurements and implications for star formation. *A&A*, 571:A30, November 2014. doi:10.1051/0004-6361/201322093.
 - [10] Planck Collaboration, P. A. R. Ade, N. Aghanim, M. Arnaud, M. Ashdown, J. Aumont, C. Baccigalupi, A. Balbi, A. J. Banday, R. B. Barreiro, and et al. Planck early results. XVIII. The power spectrum of cosmic infrared background anisotropies. *A&A*, 536:A18, December 2011. doi:10.1051/0004-6361/201116461.
 - [11] Planck Collaboration, P. A. R. Ade, N. Aghanim, M. I. R. Alves, G. Aniano, M. Arnaud, M. Ashdown, J. Aumont, C. Baccigalupi, A. J. Banday, R. B. Barreiro, N. Bartolo, E. Battaner, K. Benabed, A. Benoit-Levy, J.-P. Bernard, M. Bersanelli, P. Bielewicz, A. Bonaldi, L. Bonavera, J. R. Bond, J. Borrill, F. R. Bouchet, F. Boulanger, C. Burigana, R. C. Butler, E. Calabrese, J.-F. Cardoso, A. Catalano, A. Chamballu, H. C. Chiang, P. R. Christensen, D. L. Clements, S. Colombi, L. P. L. Colombo, F. Couchot, B. P. Crill, A. Curto, F. Cuttaia, L. Danese, R. D. Davies, R. J. Davis, P. de Bernardis, A. de Rosa, G. de Zotti, J. Delabrouille, C. Dickinson, J. M. Diego, H. Dole, S. Donzelli, O. Dore, M. Douspis, B. T. Draine, A. Ducout, X. Dupac, G. Efstathiou, F. Elsner, T. A. Ensslin, H. K. Eriksen, E. Falgarone, F. Finelli, O. Forni, M. Frailis, A. A. Fraisse, E. Franceschi, A. Frejsel, S. Galeotta, S. Galli, K. Ganga, T. Ghosh, M. Giard, E. Gjerlow,

- J. Gonzalez-Nuevo, K. M. Gorski, A. Gregorio, A. Gruppuso, V. Guillet, F. K. Hansen, D. Hanson, D. L. Harrison, S. Henrot-Versille, C. Hernandez-Monteagudo, D. Herranz, S. R. Hildebrandt, E. Hivon, W. A. Holmes, W. Hovest, K. M. Huffenberger, G. Hurier, A. H. Jaffe, T. R. Jaffe, W. C. Jones, E. Keihanen, R. Keskitalo, T. S. Kisner, R. Kneissl, J. Knoche, M. Kunz, H. Kurki-Suonio, G. Lagache, J.-M. Lamarre, A. Lasenby, M. Lattanzi, C. R. Lawrence, R. Leonardi, F. Levrier, M. Liguori, P. B. Lilje, M. Linden-Vornle, M. Lopez-Caniego, P. M. Lubin, J. F. Macias-Perez, B. Maffei, D. Maino, N. Mandolesi, M. Maris, D. J. Marshall, P. G. Martin, E. Martinez-Gonzalez, S. Masi, S. Matarrese, P. Mazzotta, A. Melchiorri, L. Mendes, A. Mennella, M. Migliaccio, M.-A. Miville-Deschenes, A. Moneti, L. Montier, G. Morgante, D. Mortlock, D. Munshi, J. A. Murphy, P. Naselsky, P. Natoli, H. U. Norgaard-Nielsen, D. Novikov, I. Novikov, C. A. Oxborrow, L. Pagano, F. Pajot, R. Paladini, D. Paoletti, F. Pasian, O. Perdereau, L. Perotto, F. Perrotta, V. Pettorino, F. Piacentini, M. Piat, S. Plaszczynski, E. Pointecouteau, G. Polenta, N. Ponthieu, L. Popa, G. W. Pratt, S. Prunet, J.-L. Puget, J. P. Rachen, W. T. Reach, R. Rebolo, M. Reinecke, M. Remazeilles, C. Renault, I. Ristorcelli, G. Rocha, G. Roudier, J. A. Rubio-Martin, B. Rusholme, M. Sandri, D. Santos, D. Scott, L. D. Spencer, V. Stolyarov, R. Sudiwala, R. Sunyaev, D. Sutton, A.-S. Suur-Uski, J.-F. Sygnet, J. A. Tauber, L. Terenzi, L. Toffolatti, M. Tomasi, M. Tristram, M. Tucci, G. Umana, L. Valenziano, J. Valiviita, B. Van Tent, P. Vielva, F. Villa, L. A. Wade, B. D. Wandelt, I. K. Wehus, N. Ysard, D. Yvon, A. Zacchei, and A. Zonca. Planck intermediate results. XXIX. All-sky dust modelling with Planck, IRAS, and WISE observations. *ArXiv e-prints*, September 2014.
- [12] F. Boulanger, A. Abergel, J.-P. Bernard, W. B. Burton, F.-X. Desert, D. Hartmann, G. Lagache, and J.-L. Puget. The dust/gas correlation at high Galactic latitude. *A&A*, 312:256–262, August 1996.
- [13] A. Lewis and A. Challinor. Weak gravitational lensing of the CMB. *Physics Reports*, 429:1–65, June 2006. doi:10.1016/j.physrep.2006.03.002.