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Title: Cluster profiles from beyond-the-QE CMB lensing mass maps

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Editor report

This paper considers the application of maximum a posteriori (MAP) CMB lensing reconstruction to galaxy cluster mass estimation. In particular, the paper assesses the performance of MAP CMB lensing reconstruction in delivering cluster lensing profiles and mass estimates, comparing it with that of the standard quadratic estimator (QE) and of the Hu-DeDeo-Vale modified quadratric estimator (HDV QE). The analysis is carried out in the context of a CMB-S4-like experiment. The main finding is that the MAP-based cluster estimator delivers effectively unbiased masses (as does the HDV QE) with a significant signal-to-noise improvement (of about 12-20 %) relative to the HDV QE. This work constitutes an important demonstration that MAP CMB lensing reconstruction performs well in a regime different from the one for which it was originally designed for and is an important step forward towards the optimal exploitation of cluster CMB lensing in upcoming CMB experiments. I would like to recommend for it to be published after the following points have been addressed.

The paper is generally well written and well structured. My only comment about the structure of the paper concerns Section IV (Results), as I don't understand the way the section has been split into two subsections, A and B. In the first subsection (A: Bias in Temperature QE), the bias in the lensing profile for temperature-only and also for polarization-only estimators is discussed. In that regard, I believe the title of the subsection should be modified. Then, in the second subsection (B: Cluster mass constraints), cluster mass constraints are discussed. However, mass constraints have also been discussed, in a slighly different way, in Section A. Therefore, I am also not sure the name of the section is very appropriate either. I would

personally restructure the whole section, perhaps presenting the results on the profile reconstruction first (potentially in a Section A), and then the mass constraints (potentially in a Section B). In addition, I don't understand why different simulated datasets are used for either section, with clusters with different masses and different choices of lmax. It seems to me that all the results could have been obtained with the same simulated dataset. Could the authors please explain why these choices were made?

Here are other minor comments:

I. Introduction:

In paragraph 3 it is stated that "CMB is not free from systematics". Presumably the authors mean "CMB lensing reconstruction". In the next ssentence, it is stated that "at the small scales relevant for CMB lensing, polarized foreground emission is expected to be negligible". I understand the point the authors are trying to make here, but it is not well explained and may be confusing for a non-expert. Could the authors please explain this a bit better, i.e. why polarised foreground emission is relevant here? In paragraph 6, I suggest the authors also cite the recent paper by Levy et al. (2305.06326).

II. CMB lensing by galaxy clusters

First paragarph: Eq. (1) corresponds to a truncated NFW profile, rather than an NFW profile - could the authors please note this in the text? Eq. (2.2): Could the authors please cite where this expression was obtained from? Between Eq. (2.2) and (2.3): "It has the following empirical dependence": Presumably the authors mean that the in the model they assume c200 has that dependence on mass and redshift - could they please make that more clear in the text? Beginning of Section B: I suggest the authors replace the expression "late-time" Universe for something a bit less vague, or drop it altogether. Later in that paragraph: Could the authors please define "unlensed" and "lensed"CMB. They are introduced without a clear definition. Eqs. (2.5), (2.6), (2.7), (2.8), and (2.9): Could the authors please cite the relevant sources for each of these expressions? End of Section B: sigma_kappa0 and sigma_M200 aren't defined, as isn't the SNR. Could the authors please define what these variables are? Alternatively, these could be dropped from here and defined later in the text, when they are used (e.g., in Section III.B).

III. Cluster mass estimators: End of paragraph after Eq. (3.8): It is stated that "This contribution is small and localized at large lensing multipoles, which contributes little to the signal. Hence we neglect the mean field altogether in this paper". Could the authors provide quantitative evidence for this claim? Also, earlier in that paragraph it is stated "In principle there is a noise contribution during...". Could the authors plase make it more clear that the noise contribution is to the mean field? Next paragraph: "random realizations". I assume the authors mean "Gaussian random realizations". Could

this be made explicit in the text? Eqs. (3.10) and (3.11): Could the authors please appropriately reference these expressions? Also, the authors have decided to switch from the discrete multipole-space expressions of the previous section (e.g., as in Eq. 3.7) to continuous, integral expressions. Why is this? I suggest that either the integals in Eqs. (3.10) and (3.11) are discretised as sums, or a reason for the switch to integrals is given in the text. Finally, Eq. (3.10) corresponds to a matched filter. Could the authors explicitly state that in the text? A matched filter is alluded to several times later in the text, but is not defined here. Paragraph after Eq. (3.13): "exclusive of the cluster". Presumably the authors mean "not including the cluster". I suggest this sentence is modified with something along those lines, as I don't think it is very clear. Two paragraphs later: Could the authors please explicitly state in the text what is exactly plotted in the y-axis of Figure 1? It can only be found in the y-axis label of Figure 1. Figure 1: The legend doesn't cover all the curves in the plot - please ammend this.

IV. Results

First paragraph: "We simulate the lensing by both the large scale structures and the dark matter halo". Could the authors please explain in more detail how this is done? Figure 2: Could the authors please briefly explain, both in the main text and in the figure caption, why the curves in the upper panel have oscillatory features? This may be a confusing feature for a non-expert, and is something that isn't mentioned in the paper at all. Also, could the authors please explicitly state, both in the caption and in the main text, to what temperature, Q and U combinations do these curves correspond to? The same applies to Figure 3, please specify both in the text and the caption what is the T-Q-U combination being considered. Section A, first paragraph: "lensed-unlensed sky": this is a confusing expression, please choose a better one. Section A, third paragraph: "To reduce the variance during the stacking process, for each reconstructed map we first subtract the convergence estimated from the simulation without the cluster, before stacking them". I don't understand what the authors are doing here. Are they subtracting the convergence without the cluster for the same CMB, LSS, and noise realisations? If this is the case, this is something that presumably cannot be done with real data - could the authors please explain why they are doing this? Next paragraph: "and the harmonic space convergence profile (lower panel)". The lower panel of Figure 2 does not show kappa(L), but a weighted version of it. Please be more precise in the text. Paragraph after Eq. (4.1): "at the cost of a 20 % increase in the standard deviation": Could the authors please specify where this number comes from? Next paragraph: Could the authors please define what the QE bias is? I understand what it is, but it is not clear in the text. Later in the paragaph: Why are the

analytical predictions for the QE bias calculated using curved-sky geometry, instead of flat-sky, as the rest of the analysis is done in within the flat-sky approximation? General point about the results of Section A: There seems to be no statistically significant bias in the mass estimates for the MAP approach, as is also the case for the HDV QE (Figure 3). However, unlike for the HDV QE, the MAP reconstructed cluster profiles are biased (lower panel of Figure 2), low at low L and high at higher L. Is the absence of a bias in the MAP mass estimate due to a cancellation of these biases in the reconstructed profile? If so, could a bias in the mass arise if the input cluster profile were different? Otherwise, what explains that a biased profile leads to an unbiased mass estimate? Section B: As already mentioned in my general comment, why is a different set of simulated observations, with a cluster with a different mass, used here? Also, why is a different lmax chosen? Second paragraph of Section B: please, comment the results in Table I in the text. Table I: Please, add the errors on all the empirical quantities quoted here, namely kappa0 and sigmakappa0 (e.g., estimated with boostrapping). Without the errors it is, e.g., unclear whether the empirical and the theoretical standard deviation are statistically consistent with each other. Figure 5: Please, amake it more clear, in both the caption and the main text, that what is being shown here is the relative error on the stacked/average mass across 1000 clusters, and not that of an individual cluster measurement.

V. Conclusions

Fourth paragraph: "some other analyses": please, specify which analyses are these. Later in that paragraph: The Websky simulation is not an N-body simulation, as it is stated in the text. Please, ammend this. Fifth paragraph: Could the authors briefly mention what would be the complications in the analysis arising from a mask? In particular, they may want to consider the effect of an apodisation mask designed to deal with non-periodic maps (presumably the authors have used periodic CMB realisations) and a point-source mask. Last paragraph: I suggest the authors also mention the rotational SZ effect as a potential problematic foreground.