Simons Observatory Lensing Pipeline

Mathew Madhavacheril

Dec 23, 2020

CONTENTS:

This documentation will walk you through the process of transforming microwave sky maps into a measurement of the CMB lensing power spectrum and cosmological parameters. Broadly, this is achieved by passing a co-added map through a quadratic estimator, calculating its power spectrum, debiasing it with simulations and MCMC sampling for the cosmological parameters.

That sounds simple enough, but with methods that ensure insensitivity to the simulations used and robustness against instrumental and astrophysical systematics, the detailed procedure can be quite complex and computationally intensive. Moreover, a large array of consistency and null tests need to be done to ensure (and iterate on) the quality of the data that is used. This cookbook-style documentaion will guide you through the process.

Note that parts of this documentation strongly overlap with parts of the component separation pipeline, since they share a lot of the pre-processing. The overlapping parts are fully documented here.

CHAPTER

ONE

PIPELINE TASKS

1.1 Preparation

1.1.1 Data access

The ACT and SO map-makers provide sets of maps with mutually exclusive data; each set consists of completely independent TOD samples. This constitutes some splitting of the data. For historical reasons, we refer to each such set as an `array'. This terminology is derived from the fact that the TODs are primarily split by which detector array they originate from, though since 2015, ACTpol and its successors (including Advanced ACT and SO) use multi-chroic arrays, which means each hardware array will provide us multiple (almost always two) `array' map sets even in the same season/year and region. We will now stop using quotes around `array' under the understanding that it applies to some unit of splitting closely related to what is used in ACT.

Within ACT, these arrays typically come from some region or scan (though since 2016 there has primarily been just a wide scan each for day and night) for a particular season and particular frequency band (since the ACTpol PA3 array, one of two within a dichroic hardware array). For SO, under the current simulation design, there will be two array maps for each optics tube because of the dichroic hardware array in the tube.

We will also be combining with Planck, for which we define a Planck array as a particular frequency band, reprojected to the CAR pixelization and subtracted of sources (see planck_reproj).

1.1.2 Planck reprojection

1.2 Simulation

1.3 Co-addition

1.4 Filtering

1.5 Quadratic Estimator

1.6 Normalization

1.7 Multiplicative verification

1.8 Bias subtraction

1.8.1 Mean-field map

1.8.2 Monte Carlo N1

1.8.3 Realization-dependent N0

1.8.4 Diagonal RDN0

1.8.5 MC bias

1.9 Covariance

1.10 Exploration and validation

1.11 Cosmological constraints

1.11.1 Mock external datasets

CHAPTER

TWO

STAGING AND PARALLELIZATION

2.1 Example run

As an example, let's say that we want to perform the following null test on ACT data: check that the debiased lensing power spectrum on a split null for a specific individual array is consistent with zero.

This requires the following:

1. A mask to define the geometry and region of the test
2. Simulations of the

pydpiper config.yaml –stages make_mask pydpiper config.yaml –stages noise_sim_model pydpiper config.yaml –stages generate_noise_sims pydpiper config.yaml –stages coadd_sims,rdn0,mcn1,mcmf pydpiper config.yaml –stages coadd_data,qe,debiased_power

SCRIPTS that save to disk: make_mask noise_sim_model generate_noise_sims kspace_coadd rdn0 mcn1 mcmf qe_maps qe_power cov

CHAPTER

THREE

TESTING

3.1 Verification

Verification tests do not involve any real-world data. The main aim is to make sure that the pipeline is unbiased. These runs involve treating some subset of the simulations as the data, and then averaging the results to residuals with respect to the input. In practice, we expect to find percent level residuals that constiute the MC bias. We provide the following:

- Baseline MC with 1d sims
- Baseline MC with tiled sims
- Baseline MC with time-domain sim
- Extragalactic foreground test
- Galactic foreground test
- Varied cosmology runs

The last run is crucial in re-inforcing our confidence in the percent level MC bias, when percent level precision is called for in the data. We expect the MC bias to primarily be dictated by things like the mask which our simulations accurately capture. The varied cosmology run looks for a cosmology dependence in the MC bias, which should be ideally be negligible.

3.2 Null tests

We run a series of tests which should result in bandpowers we expect to be consistent with zero. These come in two classes, curl tests and data split tests. The latter involves taking two splittings of the data, differencing them and running them through the lensing pipeline. In the absence of systematics, we expect the CMB and foregrounds to cancel. If the debiasing steps are working properly, the resulting bandpowers should be consistent with zero. We provide:

- Curl tests
- 90 GHz - 150 GHz null
- Individual array split differences
- Co-added split difference
- Day vs. night difference
- Difference from Planck nulls

3.3 Bandpower consistency tests

We run the lensing pipeline on various splittings of the data. We then examine the difference of bandpowers, which should be consistent with null. We provide the following:

- Individual array consistency
- Individual array consistency (tiled sims)
- Polarization combination consistency
- Isotropy tests
- Minimum multipole and maximum multipole variations
- Night-only
- Cross-only split-based estimator
- Aggressive dust masks
- 353 GHz subtraction
- Samples from beam error
- Samples from calibration error

CHAPTER

FOUR

INDICES AND TABLES

- genindex
- modindex
- search