CosmoCov Notes

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Configuration Space Covariances for Projected Galaxy 2-Point Statistics, built on CosmoLike. We provide a flat sky covariance module, computed with the 2D-FFTLog algorithm, and a curved sky covariance module. We also provide a response covariance module written by Alex Barreira and Elisabeth Krause.

The non-Gaussian (NG) covariances (including connected NG and super-sample covariance) are by default evaluated using halo model.

→ **Papers to Cite**

1 Quick Guide

Make sure you have the latest `gcc` compiler, `gsl` and `FFTW` libraries installed, and then follow the steps below:

1. Clone this repository to the directory you like;

2. Navigate to the `covs` directory and run command:
   `make covs`

3. Several executables are created: "`cov_flat_fft`" is for the flat sky covariances (using 2D-FFTLog algorithm); "`cov`" is for the curved sky covariances (using Limber approximation for galaxy-galaxy lensing and cosmic shear angular spectra, but non-Limber for galaxy clustering angular spectra);

4. As an exmaple, run command:
   `./cov 1 ini_files/cov_test_g.ini`
   to compute the 1st block of the curved sky 3×2pt Gaussian covariance of the test example, specified by the ini file "`ini_files/cov_test_g.ini`". The result of this block is output to the directory: "`output/out_cov_test/`".

5. There are 66 blocks in total for the example run above. One can compute all of them by running command:
   `for i in {1..66}; do ./cov $i ini_files/cov_test_g.ini; done`

   Warning: non-Gaussian covariances can take hours to compute for each block, so one may consider computing different blocks in parallel.

6. After finishing all the blocks, one can make a plot of the precision matrix by first combining all the blocks and then running the provided plotting script `plot.py`:
   `f="cov_test"; cat output/out_cov_test/t* > $f; python plot.py $f`
   The combined covariance file is specified by variable `f`, and the plot (in `.pdf`) will be saved in the same directory.

1.1 Input

The ini files contain all the settings, including

- `Omega_m, Omega_v, sigma_8, n_spec, w0, wa, omb, h0`: the cosmological parameters,
- `area`: the survey area (in square degrees),
- `c_footprint_file`: (optional) a footprint file containing the mask power spectrum, which is read-in in `C_survey_window` in `cosmolike_core/theory/covariances_3D.c`; the normalization of the power spectrum is automatically adjusted,
- `clustering_REDSHIFT_FILE, shear_REDSHIFT_FILE, lens_tomobins, source_tomobins, lens_n_gal, source_n_gal`: the lens and source galaxy samples (file paths, the numbers of tomographic bins, the number densities in each bin),
- `sigma_e`: the total shape noise of the weak lensing measurement,
- `lens_tomogbias`: the linear galaxy bias parameter of each lens galaxy bin (with `b_mag` described in Section 5.1.3 of Fang et al. (arXiv:1911.11947)),
- `lens_tomo_bmag`: the magnification bias parameter of each lens galaxy bin,
- `IA`: 0 or 1, the switch of running the intrinsic alignment NLA model,
- `A_ia, eta_ia`: the parameters of the NLA model (see Eq. 4.9 of Fang et al. (arXiv:1911.11947), but with `A_ia` represented by $a_{\rm IA}$ in the equation),

- `tmin, tmax, ntheta`: the min and max of the angles in arcmins, and the number of logarithmically spaced bins, specifying the binning of the angular correlation functions,

- `ng`: 0 or 1, the switch of running the non-Gaussian covariances,

- `cng`: 0 or 1, the switch of including the connected non-Gaussian contribution in the non-Gaussian computation,

- `outdir, filename, ss, ls, ll`: the path and filename prefix of the output, the options of computing blocks of the covariance involving the shape-shape (ss), position-shape (ls), position-position (ll) angular correlation functions. Computing 3×2pt covariance means setting all the options as `true`.

1.2 Output

The covariances will be output as separate blocks in `output/out_cov_.../`, with each block representing the covariance matrix of two 2-point functions. The header of each file contains a list of papers to be cited based on the module used.

The ordering of the corresponding data vector is also output in various `order_...` files. The columns are

- column 0: index i;

- column 1: bin-averaged angular scale (in radians);

- column 2: the type of the 2-point function {w, gammat, xi+, xi-};

- column 3, 4: the {s: source, l: lens} galaxy tomographic bin index 1 and 2;

The columns of each covariance block are

- column 0, 1: matrix indices of the element in the full covariance matrix;

- column 2, 3: the corresponding bin-averaged angular separations (in radians) of the element;

- column 4, 5, 6, 7: the tomographic bins involved;

- column 8, 9: the Gaussian part and the non-Gaussian part of the element. The total value is the sum of the two;

2 Examples

- **DES Y3-like** Covariance. There are 1035 blocks in total. For the Gaussian curved sky covariances, one can compute all blocks by running the command
  `for i in {1..1035}; do ./cov $i ini_files/cov_desy3_g.ini; done`
  Then test and plot the correlation matrix by running:
  `f="cov_desy3_g"; cat output/out_cov_desy3/d* > $f; python plot_desy3.py $f`
  To run full non-Gaussian covariances, run the command with `ini_files/cov_desy3.ini` instead. However, one should always run these blocks as separate jobs in parallel, as each block can take hours to compute.
  One can switch to using the flat sky FFT transform by executing `./cov_flat_fft $i ini_files/cov_desy3_flat_fft.ini` instead. The output will be in the folder `output/out_cov_desy3_flat_fft`.
  Note that 2D-FFTLog method has no advantage of computing Gaussian-only covariances over the curved sky covariances. Due to our conservative fine sampling in the implementation, the curved sky Gaussian-only covariances can take shorter time than the flat sky FFT covariances.

  About the galaxy samples: DES Y3-like uses `lens_desy1.nz`, the public redshift distribution of the DES Y1 redmagic sample, and `source_desy1.nz`, the public redshift distribution of the DES Y1 meta-calibration sample. Both distributions can be found at `http://desdr-server.ncsa.illinois.edu/despublic/y1a1_files/redshift_bins/y1_redshift_distributions_v1.fits`

- **LSSTY1**. The configuration is given by `ini_files/cov_lssty1.ini`. There are 1830 blocks in total for this configuration.

  About the galaxy samples: `lens_lssty1.nz` and `source_lssty1.nz` use the parametric redshift distributions from LSST-DESC Science Requirements Document, each split into five equally populated tomographic bins as described in Section 5.1.1 of Fang et al. (arXiv:1911.11947).

- **Response Covariance** (Shear-only). This routine uses modules developed by Alex Barreira to compute the matter power spectrum covariance as well as the non-Limber weak lensing super sample covariance using the response approach. The corresponding C and Python scripts for Fourier space covariance model are included in `cosmolike_core/theory/` folder.To compile it, type
  `make response`

The routine requires a `c_footprint_file` (containing the power spectrum of the survey mask) to calculate the super-sample covariance, for example `ini_files/Cl_mask_polarcap_fsky0.36.txt`.

An example Euclid-like configuration is provided in `ini_files/cov_response.ini`, which reproduces *Setup s03* from from Table 1 of (Barreira et al. 2019) for the shear correlation functions $\xi_{\pm}$; this configuration results in 465 covariance blocks. You can run one such block as

```
./cov_response 1 ini_files/cov_response.ini
```

or run all of them in parallel.

About the galaxy sample: `source_Euclid.nz` use a parametric redshift distributions from Amendola et al. 2013 for the Euclid weak lensing sample, split into five equally populated tomographic bins. See Sect. 2.1 of (Barreira et al. 2018) for details.

3 Papers to Cite

Please cite the following papers if you use CosmoLike covariances in your research:

1. E. Krause, T. Eifler; *CosmoLike - Cosmological Likelihood Analyses for Photometric Galaxy Surveys*; arXiv:1601.05779

2. X. Fang, T. Eifler, E. Krause; *2D-FFTLog: Efficient computation of real space covariance matrices for galaxy clustering and weak lensing*; arXiv:2004.04833

In addition, if you use the the non-Limber galaxy clustering power spectra in the Gaussian covariance included in the curved sky covariance module, please also cite:

- X. Fang, E. Krause, T. Eifler, N. MacCrann; *Beyond Limber: Efficient computation of angular power spectra for galaxy clustering and weak lensing*; arXiv:1911.11947.

If you include an approximate shape/shot noise correction for survey geometry, which requires a power spectrum of the survey mask with sufficiently high resolution (see Sect. 1), please also cite:

- M. Troxel, E. Krause, et al. (DES Collaboration); *Survey geometry and the internal consistency of recent cosmic shear measurements*; arXiv:1804.10663;

If you calculate weak lensing covariances using the response model, including the non-Limber super-sample covariance (available for weak lensing only), please also cite:

- C. Wagner, F. Schmidt, C.-T. Ching, E. Komatsu; *The angle-averaged squeezed limit of nonlinear matter N-point functions*; arXiv:1503.03487

- A. Barreira, F. Schmidt; *Responses in Large-Scale Structure*; arXiv:1703.09212;

- A. Barreira, F. Schmidt; *Response Approach to the Matter Power Spectrum Covariance*; arXiv:1705.01092;

- A. Barreira, E. Krause, F. Schmidt; *Complete super-sample lensing covariance in the response approach*; arXiv:1711.07467;

- A.S. Schmidt, S.D.M. White, F. Schmidt, J. Stücker; *Cosmological N-body simulations with a large-scale tidal field*; arXiv:1803.03274

A list of papers to be cited will be autogenerated based on the modules used, and printed in the header of each covariance file.

If you use the given DES Y3 ini files, they will assume public DES Y1 galaxy redshift distributions from `http://desdr-server.ncsa.illinois.edu/despublic/y1a1_files/redshift_bins/y1_redshift_distributions_v1.fits`

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