

# Power spectrum of the Cosmic Microwave Background radiation

## Presentation 3.

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# Structure of codes

- The code consists of three parts
  - CMB temperature anisotropy generation with HEALPix
  - Naive CMB temperature anisotropy generation
  - Processing of Planck's (and WMAP's) CMB maps with HEALPix

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<sup>1</sup><https://sites.google.com/umich.edu/mcmahoncosmology/cmb-school>

# Structure of codes

- The code consists of three parts
  - CMB temperature anisotropy generation with HEALPix
  - Naive CMB temperature anisotropy generation
  - Processing of Planck's (and WMAP's) CMB maps with HEALPix
- Difference between naive and HEALPix generation
  - HEALPix is much easier
  - Naive method follows the method presented by Jeff McMahon at CMB summer school of the The McMahon Cosmology Lab<sup>1</sup>

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# HEALPix generation

- Angular spectrum input, HEALPix array output.

# HEALPix generation

- Angular spectrum input, HEALPix array output.
- Two main functions
  - `load_spectrum()` : Loads power spectrum from file.

```
def load_spectrum(fname, lmax=None):
    """
    Loads an arbitrary angular power spectrum from a file.

    Datasets generated with the LAMBDA tool contains only the :math:`D_{\ell}`
    values, alongside the array of the :math:`\ell` multipoles and the
    corresponding errors.
    """
```

- `gen_maps()` : Generates randomized HEALPix array using synfast.

```
def gen_maps(cls, N SIDE=2048, lmax=None,
            pol=False, pixwin=False, fwhm=5.8e-3, sigma=8.7e-6):
    """
    Generate randomized HEALPix arrays from an input angular power spectrum, using
    the `synfast` subroutine from the `Fortran90` standard implemented in the HEALPix
    library.
    """
```

# HEALPix procession

- Optionally imports HEALPix array from FITS file.
- Main functions for HEALPix array procession:
  - `load_HPX()` : Loads HEALPix array from FITS file.

```
def load_HPX(file, field=1):
    """
    Loads a HEALPix array from a given field of an input FITS file.
```

- `get_projection()` : Maps HEALPix array to given projection.

```
def gen_maps(cls, N SIDE=2048, lmax=None,
            pol=False, pixwin=False, fwhm=5.8e-3, sigma=8.7e-6):
    """
    Generate randomized HEALPix arrays from an input angular power spectrum, using
    the 'synfast' subroutine from the 'Fortran90' standard implemented in the HEALPix
    library.
```

- `plot_cmb()` : Plots the output of `get_projection()`.

```
def plot_cmb(proj, cmap=None, c_min=None, c_max=None,
             save=False, save_filename='default_name_map'):
    """
    Plots an input image generated by a 'healpy.projector' routine and scales the values if needed.
    The routine uses the classic Planck CMB colormap by default to shade pixels on the image.
```

# Usage in the CMB analysis

- Main functions for angular power spectrum procession:
  - `cmb_spectrum()` : Calculates the power spectrum of an input HEALPix array using `anafast`.

```
def cmb_spectrum(hpx, lmax=2500, alm=True):
    """
    Calculates the :math:`a_{lm}` and :math:`C_l` parameters using the
    'anafast' subroutine from the Fortran90 standard, up to a given
    :math:`l_{\mathrm{max}}` bandlimit.
    """
```

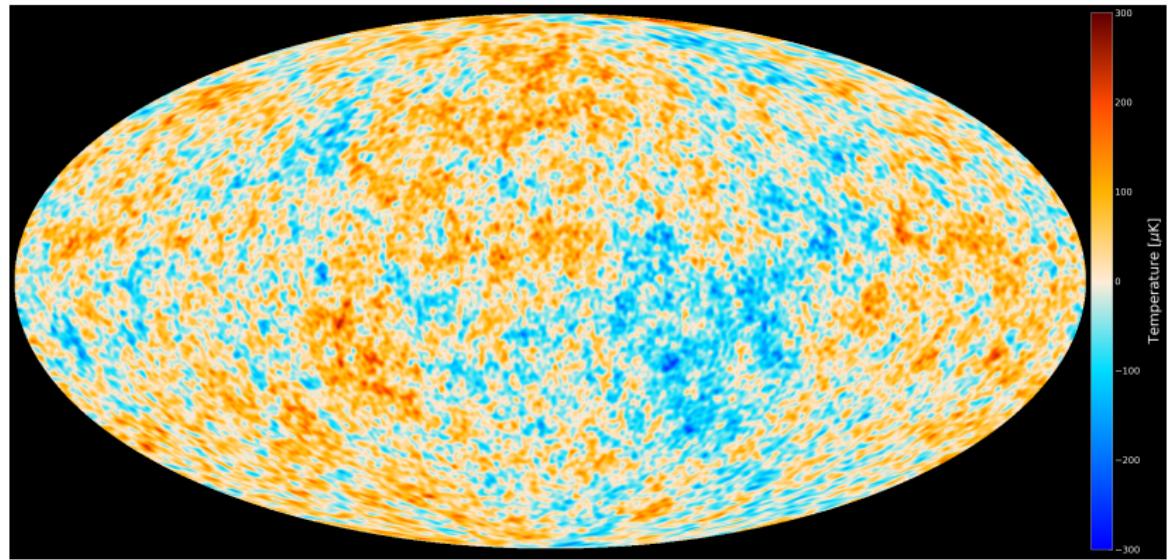
- `plot_spectrum()` : Plots the output of `cmb_spectrum()`.

```
def plot_spectrum(ell, Dl, DLTT,
                  save=False, save_filename='default_name_spectrum'):
    """
    Plots the angular power spectrum of the CMB.
    """
```

## CMB generation – second method

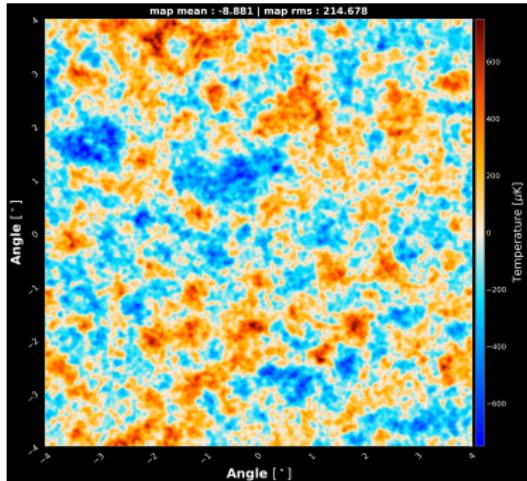
- Consist of several functions and methods
- Capable of the individual generating of the pure CMB radiation, various foreground effects, instrument noise and beam PSF.
- Only effective in the generation of rectangular CMB maps.
- The generation process is completely statistical.

# CMB generation – first method

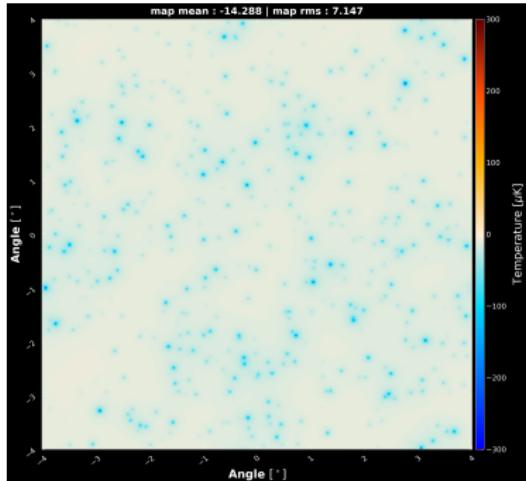


**Figure 1:** Randomly generated full-sky intensity map of the CMB temperature anisotropy using HEALPix routines and conventions.

# CMB generation – second method



**Figure 2:** Randomly generated intensity map of the CMB temperature anisotropy with an  $8^\circ$  by  $8^\circ$  size angle of view.



**Figure 3:** Randomly generated Sunyaev-Zeldovich sources on the sky with an  $8^\circ$  by  $8^\circ$  size angle of view.