

Power spectrum of the Cosmic Microwave Background radiation

Presentation 2.

Balázs Pál

Supervisor : István Csabai, PhD
Eötvös Loránd University

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Planck space observatory

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 - Data gathering between 2009 and 2013
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- Measurements
 - Low and High frequency instruments
 - Measuring intensity and polarization of CMB photons on 9 different frequencies (100 GHz - 900 GHz)
 - Additional foreground effects needs to be filtered, which is done by different processing pipelines (Commander, NILC, SEVEM, etc.)

Data releases

- Data are available on the official page of the IRSA project¹
 - Mostly full-sky maps, with some partially completed surveys
 - Data are sorted by time, type, production pipeline, measuring instrument, etc.
 - Filtered and unfiltered data are also available alongside the intensity and polarisation maps

¹<https://irsa.ipac.caltech.edu/data/Planck/>

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 - Mostly full-sky maps, with some partially completed surveys
 - Data are sorted by time, type, production pipeline, measuring instrument, etc.
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- Data are stored in HEALPix projected .fits format
 - HEALPix is a pretty old standard for the pixelization of the sphere
 - There are some important conventions of HEALPix which needs to be addressed to understand what is the angular power spectrum in case of the CMB and how can we measure it

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Mathematical conventions

- A bandlimited function f on the sphere can be expanded in spherical harmonics Y_{lm} as

$$f(\gamma) = \sum_{\ell=0}^{\ell_{max}} \sum_m a_{\ell m} Y_{\ell m}(\gamma)$$

where γ denotes a unit vector pointing at polar angle $\theta \in [0, \pi]$ and azimuth $\varphi \in [0, 2\pi)$.

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- The angular power spectrum of this function could be then calculated as

$$C_\ell = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} |a_{\ell m}|^2$$

Usage in the CMB analysis

- An example of a „bandlimited function f on the sphere” could be eg. a $\Delta T(\mathbf{n})$ temperature fluctuation map of the sky.

$$\Delta T(\mathbf{n}) = \sum_{\ell=0}^{\ell_{max}} \sum_m a_{\ell m} Y_{\ell m}(\mathbf{n})$$

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- We can calculate then the $\hat{a}_{\ell m}$ coefficients to get the power spectrum as it was defined above. This estimator is fortunately included in the Fortran90 as the anafast function. Since HEALPix was built onto this standard, it is already included that², as well as in the healpy Python build too.

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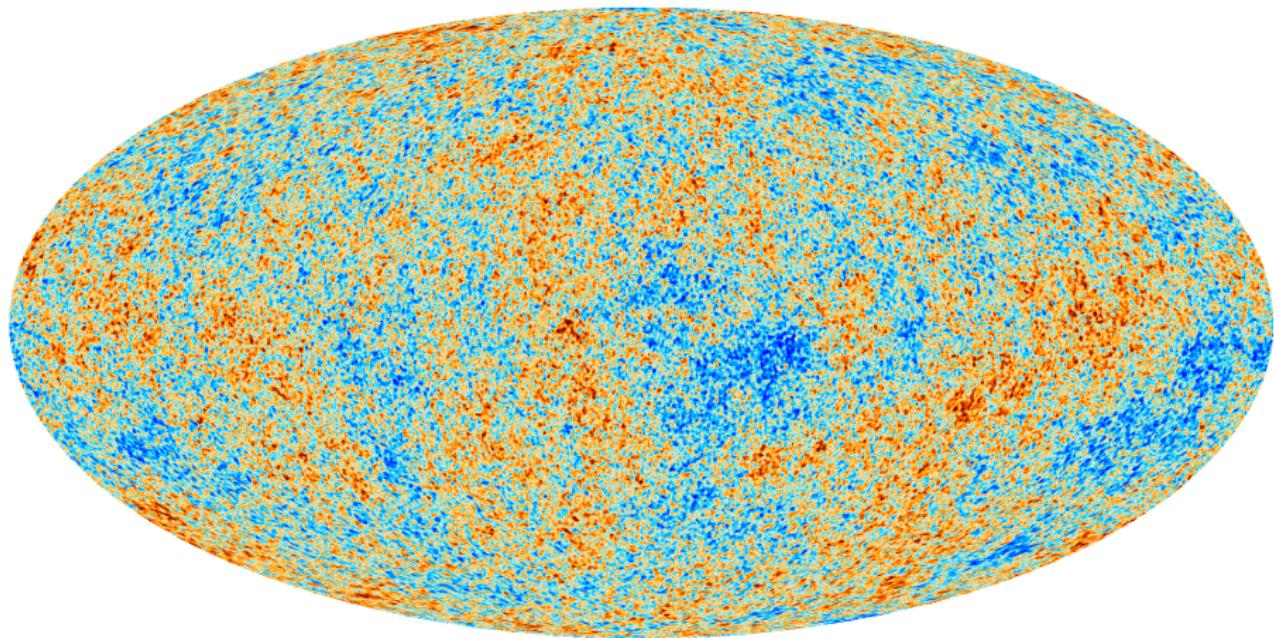
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- It is traditionally (and aesthetically) more appropriate however to show D_ℓ against ℓ in a plot, where

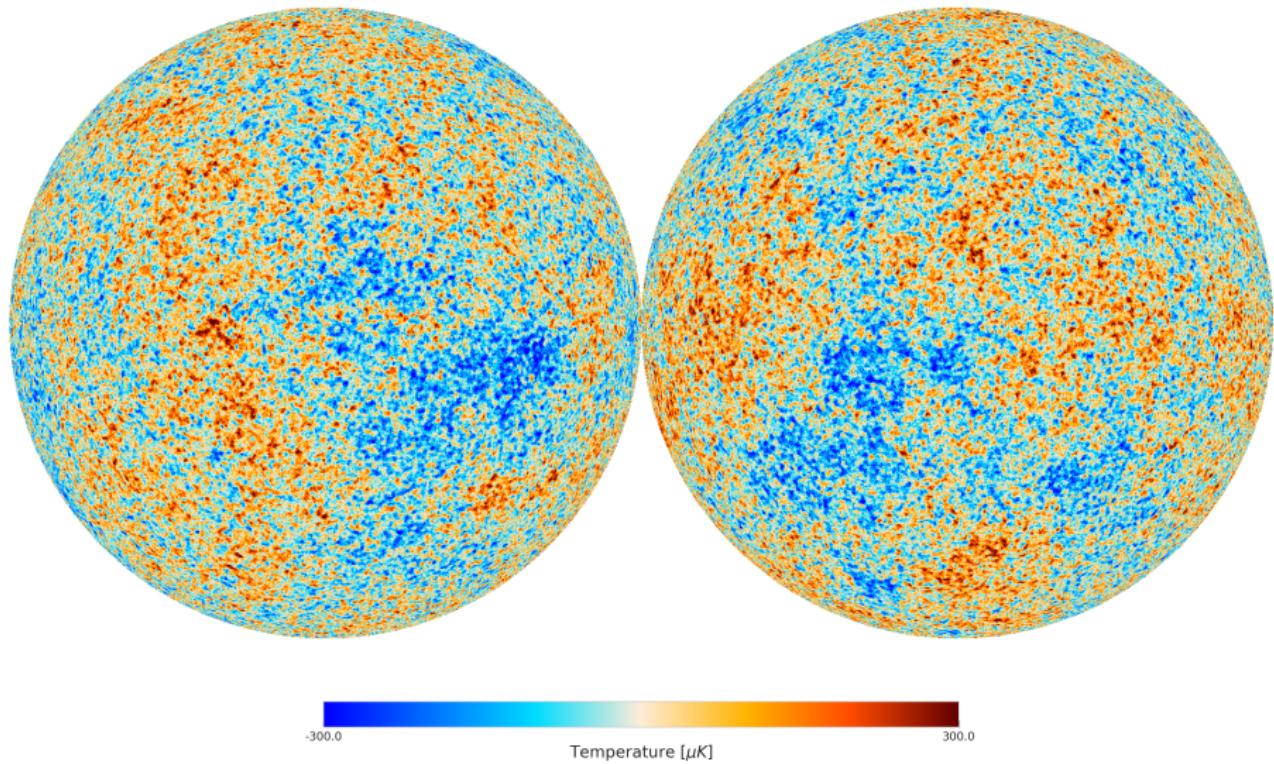
$$D_\ell = \frac{\ell(\ell+1)}{2\pi} C_\ell$$

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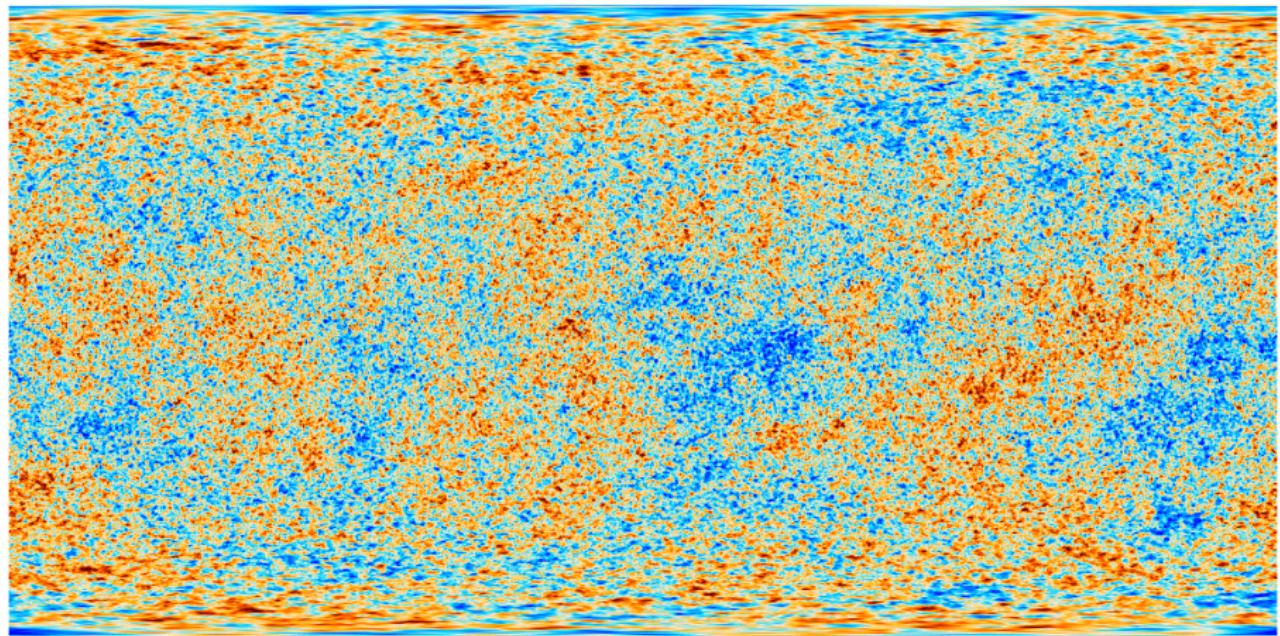
Planck 2018 CMB map (Commander pipeline, full)



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Reconstructed angular power spectrum

