A CLEAR VIEW OF THE PRIMORDIAL UNIVERSE

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1. INTRODUCTION

Cosmic microwave background radiation (CMB) is the afterglow of the big bang which forms the bedrock of precision cosmology shedding light on the origin,contents and evolution of the universe.
A major challenge faced in the study of the CMB is that this radiation is contaminated by microwave light from processes such as free-free collisions, synchrotron and spinning dust emissions from our Milky Way. This project seeks to implement and compare two techniques of removing foreground contaminations to maps which both depend on an internal linear combination algorithm (ILC).

2. METHODS

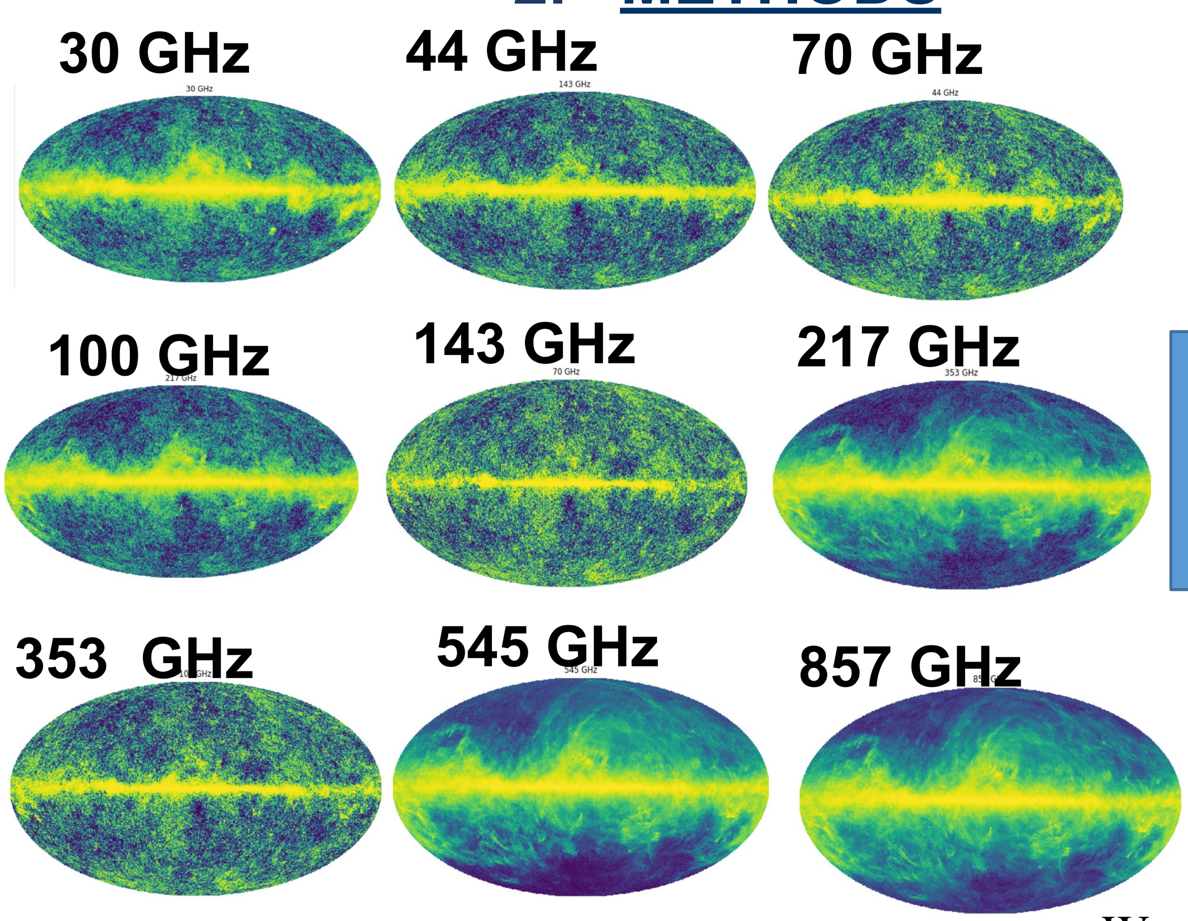
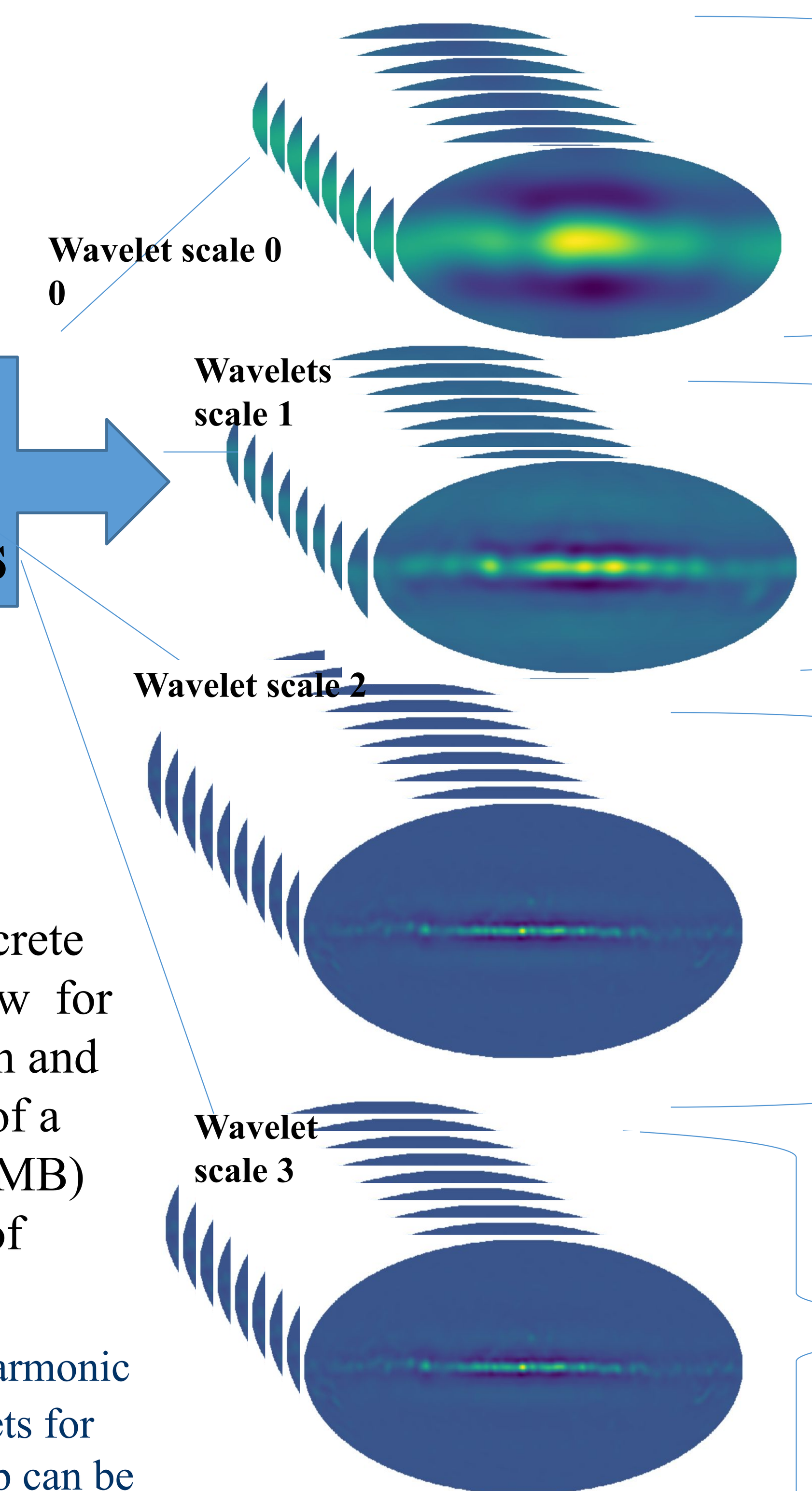


Fig 1. Input Planck Maps at various frequencies.

Planck satellite mission was launched in 2009 by the European Space Agency. This satellite observed the CMB and the cosmic infrared background radiation (CIB). CMB is a source of information on the primordial universe while CIB can reveal information on the oldest large-scale structures of the universe (galaxies and clusters of galaxies).

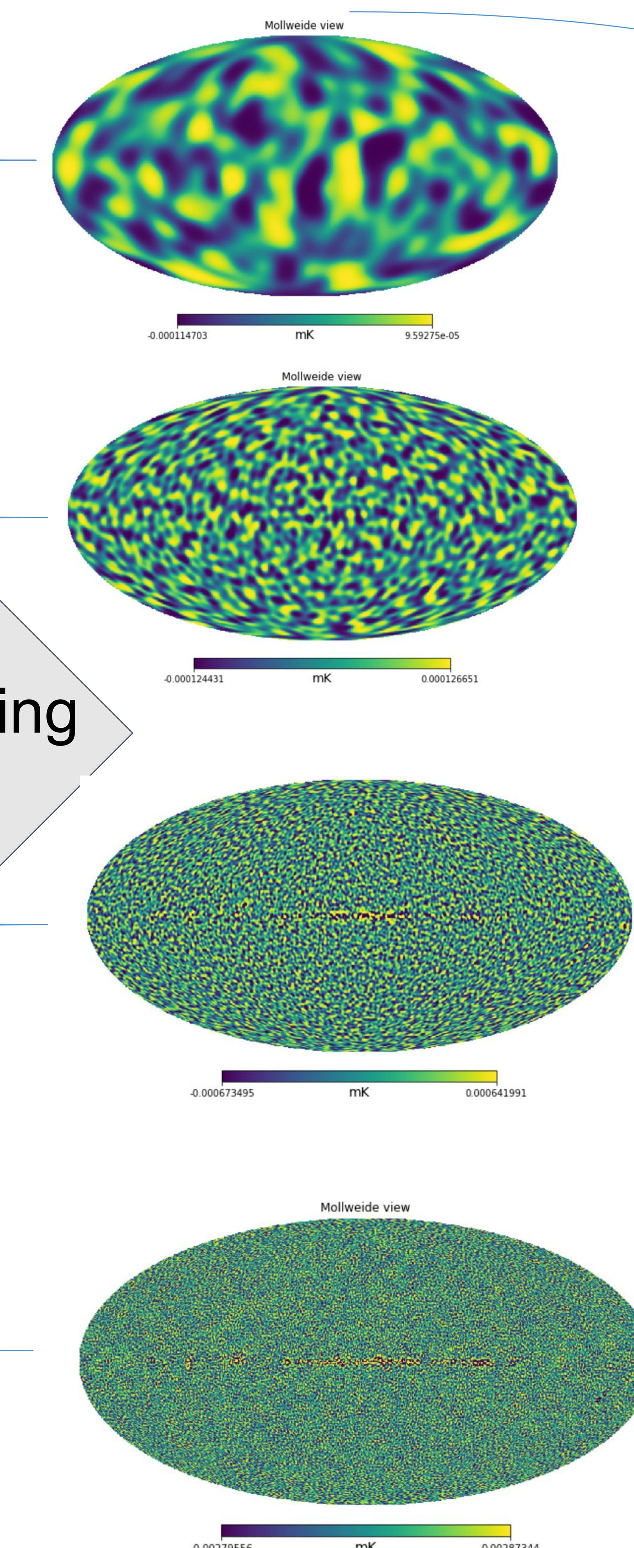
** Wavelet Analysis



Wavelets are discrete functions that allow for the decomposition and reconstruction of a signal(like the CMB) without loss of information.

**Using spherical harmonic coefficients, wavelets for each input Planck map can be analysed. These wavelets help in local correction of foregrounds as the ILC will subsequently be applied to wavelet maps

Applying ILC



Outputs from the ILC for each wavelet scale combined to synthesize a new map

Wavelet Synthesis

Using wavelet analysis, the signal can be studied on various scales thereby allowing for foreground removal at local features of the wavelet synthesised map whereas there are more local contaminations at the local level on the simple ILC output map.

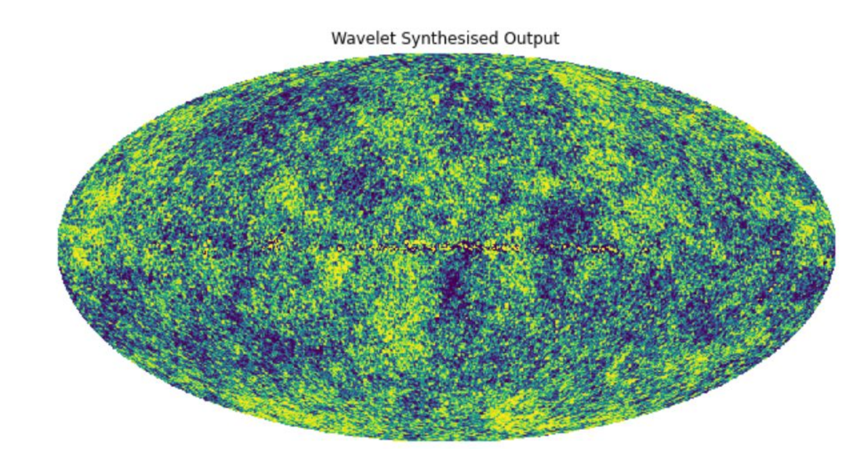


Fig 2. Output Map from Map Cleaning of Planck Maps using Wavelet Processing

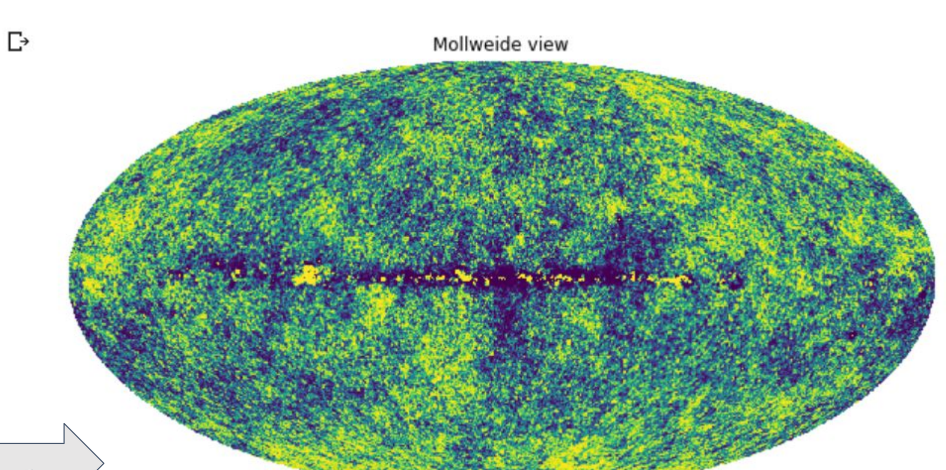


Fig 3. Simple ILC Output (without Wavelet Analysis). A simpler output gotten when the ILC is applied directly to all 9 Planck Input maps without using wavelet analysis

Applying ILC

$$a^{\mathrm{Cleaned}}_{\ell m} = \sum_{i=1}^{n} w^i_\ell \frac{B^0_\ell P_\ell}{B^i_\ell P_\ell} a^i_{\ell m}$$

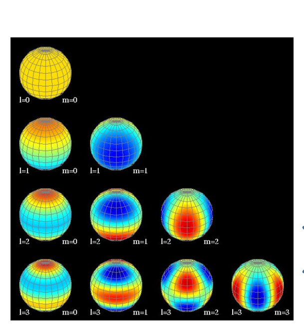
In the ILC equation above, Bl^0 denotes the beam window function of the highest resolution frequency map . The pixel window function, ‘P_l`, cancels in the above equation since all the input maps have same pixel resolution. Lastly, w_l denotes the ILC weight.

2. 1 Steps Involved in "Applying ILC "

INPUT MAPS

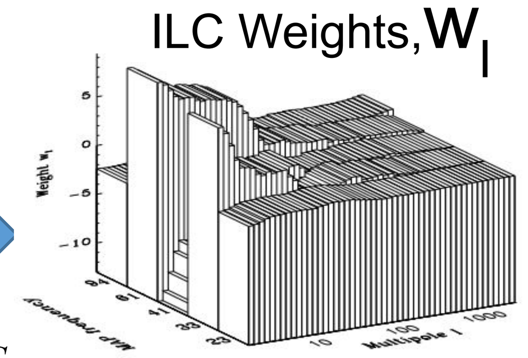
Maps convolved to same angular resolution using spherical harmonic coefficients, a_lm

a_lm



Compute Covariance,C_, and Weights between convolved maps

ILC Weights,W_l



$$\mathbf{w}_\ell = \frac{\mathbf{C}_\ell^{-1}\mathbf{e}}{\mathbf{e}^t\mathbf{C}_\ell^{-1}\mathbf{e}},$$

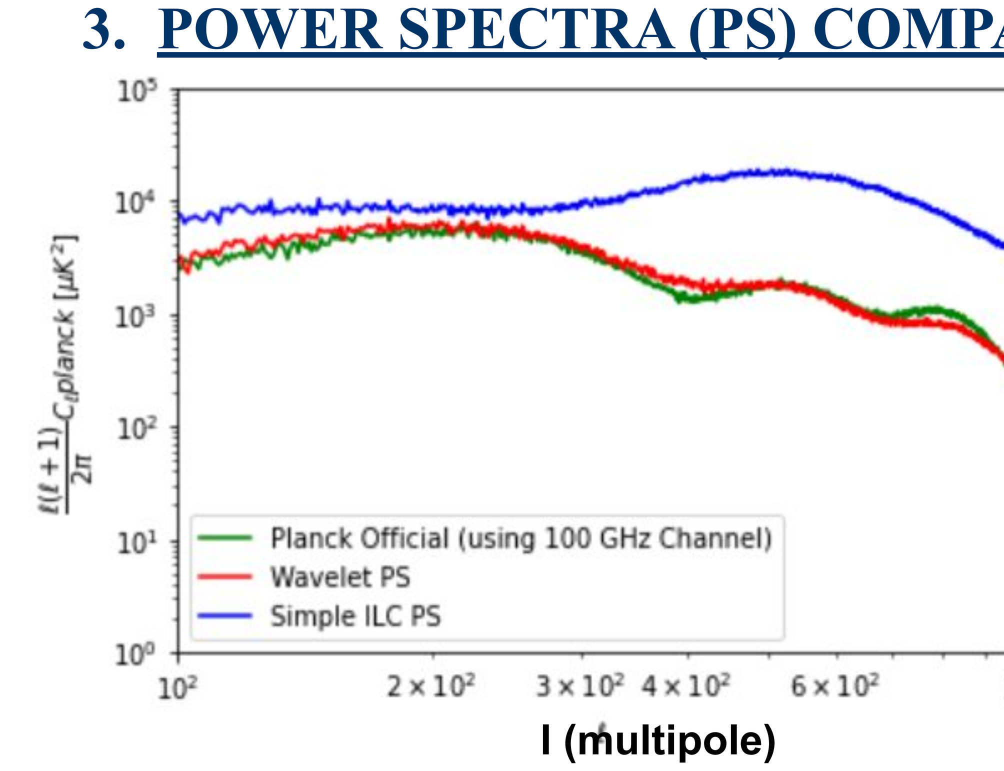
Compute and visualise weighted sum on all maps

CLEANER OUTPUT MAP

4. UNCERTAINTY & LIMITATION

Output maps after ILC cleaning still contain some residual foregrounds. Hence, some regions need to be masked before use for cosmological analyses.
The wavelet analysis used in this project works with an ILC which varies with scale of the input maps. However, an optimal ILC could be obtained by localising weights according to spatial position. Directional wavelets can localise further by morphology of signal.

3. POWER SPECTRA (PS) COMPARISON



From the power spectra, wavelets give a more reliable plot of the primordial power spectrum when compared to that of the Planck Official map. Hence wavelets are efficient for denoising CMB maps.

5. MOVING FORWARD

The ILC can be used to clean other CMB maps that contain polarisation signals. Furthermore the ILC can be applied to other ongoing CMB experiments like the ACT and LiteBIRD.