# 159MHz Spherical Harmonic Diffuse Southern Sky Map

## Created with the Engineering Development Array (EDA2)


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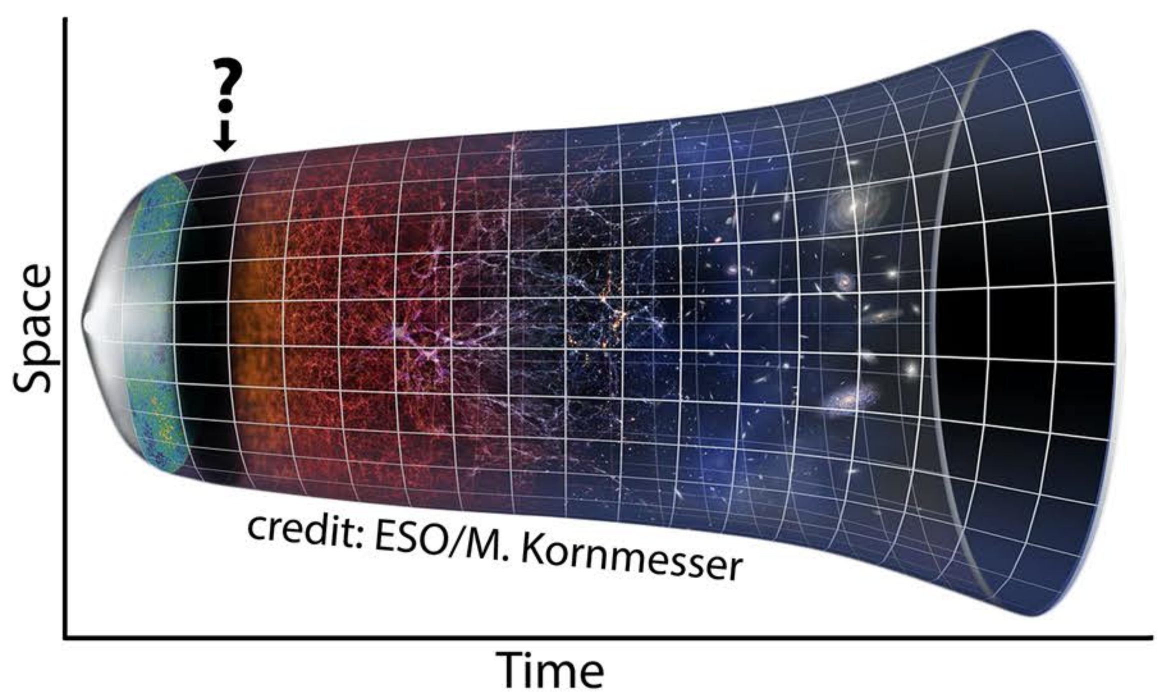


### Background

One major priority in radio astronomy is understanding the early universe formation history. Although the Cosmic Microwave Background (CMB) is well measureable, the epoch that followed, due to neutralisation of ionised gas from the CMB (due to its opague nature), is not. This period is also known as the Dark Ages (DA). However, one can infer DA characteristics by looking at the differential temperature between the CMB and the Cosmic Dawn (CD) where the first stars started to form, sparking the Epoch of Reionisation (EoR) leading to the full reionisation of the Universe. This can, for example, be achieved by probing the 21 cm hyperfine electron spin flip transition line from neutral hydrogen.

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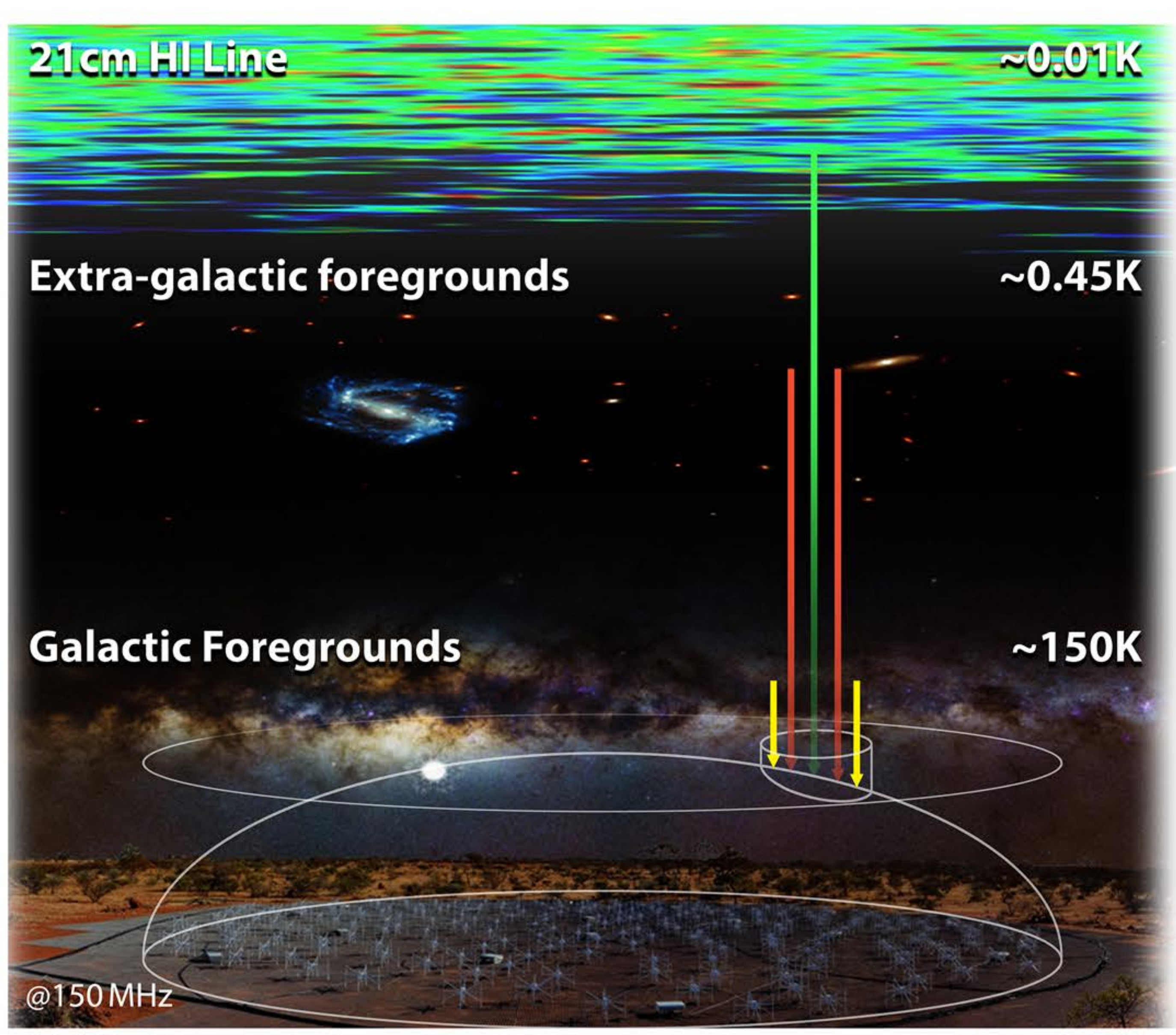


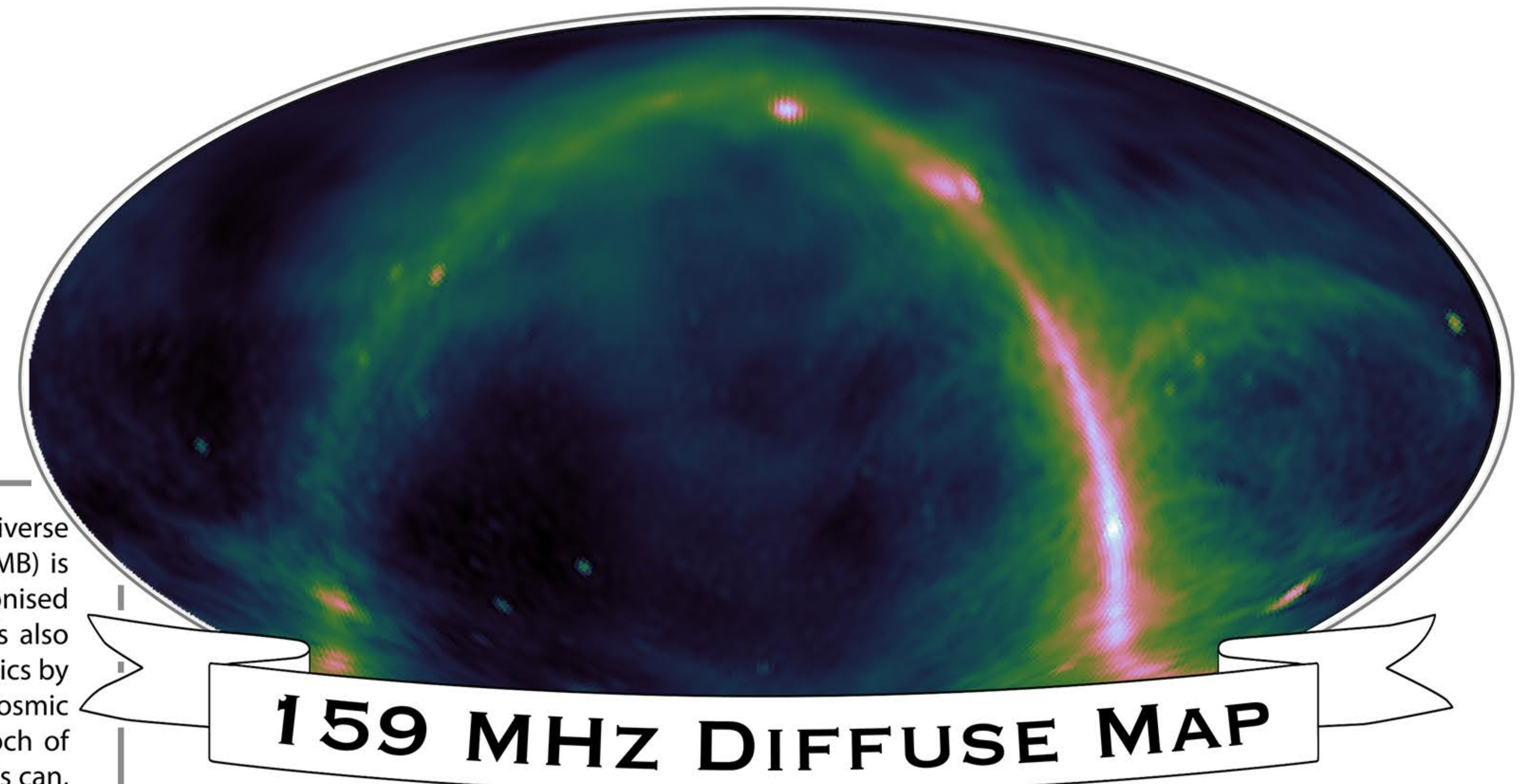


### Problem Statement

However, measuring the 21 cm line is not trivial as it is swamped by extra-galactic and galactic foregrounds that are around 3-5 orders of magnitude brighter.

One way to combat this is through the generation of multiple sky maps spanning a wide ranges of angular scales and frequencies. These can then be used to generate a foreground model to subtract from the 21-cm (background) signal. However, although small scales and point-source foregrounds are well defined, low-frequency diffuse foreground emissions (especially on the Southern hemisphere) are not.

This is mostly due to the complexity of solving the three-dimensional interferometric measurement equation; which is often simplified using a flat-sky approximation. This results in loss of wide-field accuracy as well as the ability to measure the full sphere. Forcing one to use more complex methods to image the full-sky *e.g.* mozaicing.

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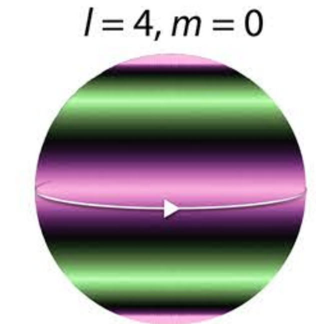
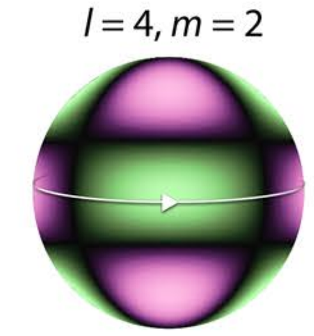
$l=4, m=0$



$\propto P_l^m(\theta)$

Zonal Harmonics

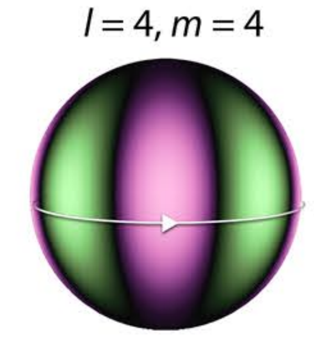
$l=4, m=2$



$\propto P_l^m(\theta)\, e^{im\varphi}$

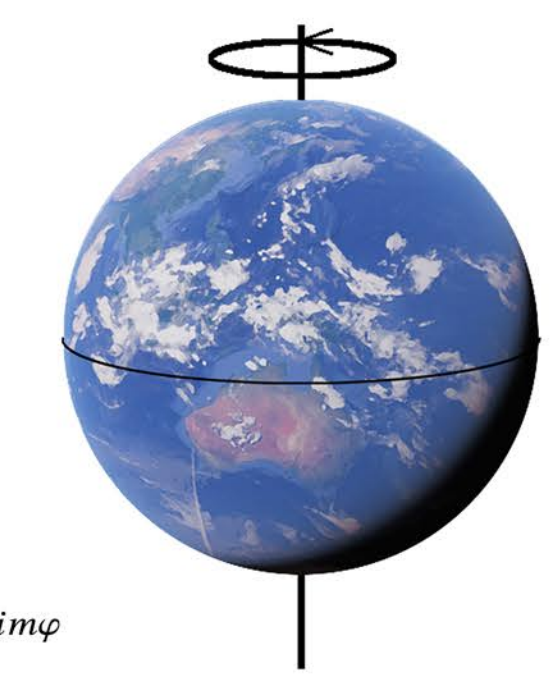
Tesseral Harmonics

$l=4, m=4$



$\propto e^{im\varphi}$

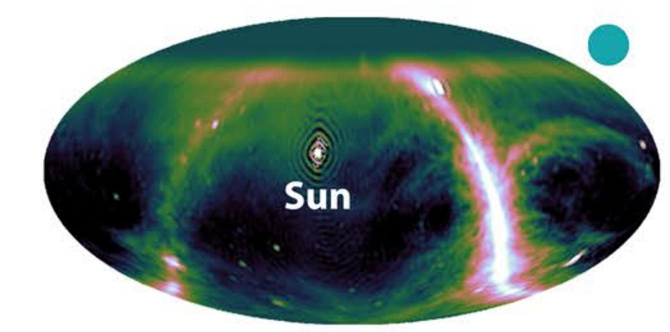
Sectoral Harmonics



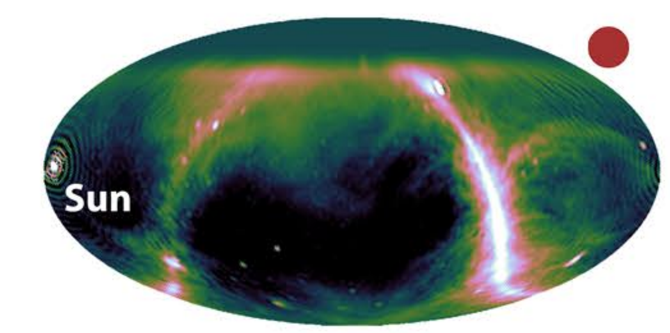
**Spherical Harmonics**

Much similar to how the Fourier basis operates on a circle, spherical harmonics operate on the surface of a sphere.

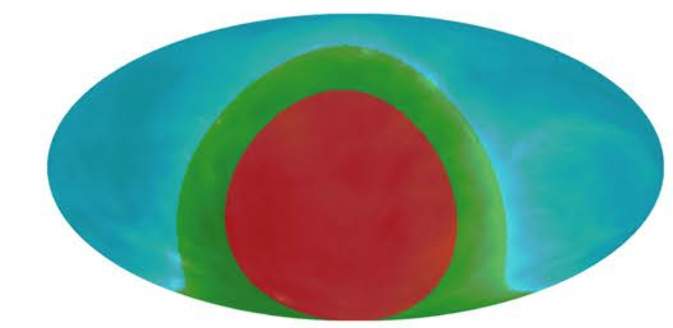
The basis functions can be split up in three types: Zonal, Tesseral, and Sectoral; which depend on the basis function's order ($l$) and rank ($m$).




**159 MHz April Map**




**159 MHz Sept. Map**



**Weighting Map**
red = Sept. data
blue = April data
green = gradient avg.

### EDA2 Sky Map

We present a 159 MHz *m*-mode generated sky map. The map is created using two 24h observations (September & April) to remove the Sun. The map has a 3° angular resolution and is supersampled on a 1° pixel grid. The Northern hemisphere is fit using a rescaled version of the updated desourced Haslam map (Remazeilles+ 2015). This map is the first in a series of diffuse Southern sky maps with goal to help better constrain a diffuse foreground model.

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### *m*-modes

Instead of assuming a flat sky, one could also use spherical harmonics to solve for the measurement equation instead.

During Earth's periodic rotation over a sidereal day sectoral harmonics only vary in the plane of rotation. As they are only rank ($m$) dependent, wide-field zenith-pointed interferometers performing transit interferometry can measure the full sky within a day's timeframe; whilst maintaining exact widefield effects (Shaw+ 2014).

$$V_\nu^{ij} = \int B_\nu^{ij}(\hat{\mathbf{n}})\, T_\nu(\hat{\mathbf{n}})\, d^2\hat{\mathbf{n}} \qquad (1)$$

Fourier transforming the visibilities ($V$) with respect to m, and expanding the beam x fringe ($B$) and sky temperature (T) in spherical harmonic coefficients, reduces (1) to a simple linear equation (2) . Here, solving for the sky (**a**) is just a matter of inverting the Beam coefficients (**B**) (3).

$$\mathbf{v} = \mathbf{B}\mathbf{a} \;\; (2) \longrightarrow \mathbf{a} = \mathbf{B}^{-1}\mathbf{v} \;\; (3)$$

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