First Release of Gauss–Legendre Sky Pixelization (GLESP) software package for CMB analysis

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Abstract. We report the release of the Gauss–Legendre Sky Pixelization (GLESP) software package version 1.0. In this report we present the main features and functions for processing and manipulation of sky signals. Features for CMB polarization is underway and to be incorporated in a future release. Interested readers can visit \url{http://www.glesp.nbi.dk/} and register for receiving the package.

Key words. cosmology: cosmic microwave background – cosmology: observations – methods: data analysis

1. Introduction

The CMB temperature fluctuations on a sphere can be written as a sum over spherical harmonics

$$\Delta T(\theta, \phi) = \sum_{l=2}^{\infty} \sum_{m=-l}^{l} |a_{lm}| e^{i\phi_{lm}} Y_{lm}(\theta, \phi),$$

where \( |a_{lm}| \) are the moduli of the spherical harmonic coefficients of the expansion and \( \phi_{lm} \) are the phases defined in \([0, 2\pi] \). The angular power spectrum is defined as

$$C_l = \frac{1}{2l+1} \sum_{m=-l}^{l} |a_{lm}|^2,$$

and

$$D_l = \frac{l(l+1) C_l}{2\pi T_0},$$

where \( T_0 \) is the CMB temperature 2.726 K.

In this article, we report the first release of the Gauss–Legendre Sky Pixelization (GLESP) software package for the CMB analysis. The GLESP scheme (Doroshkevich et al. 2005) is based on the Gauss–Legendre polynomial zeros, allowing one to perform strict orthogonal spherical harmonic expansion of the CMB temperature anisotropies. The GLESP package has been tested on the following operating systems: RedHat Linux, SGI Irix and Solaris. Features for CMB polarization are under preparation.

2. Features in the GLESP package v1.0

2.1. Basic features for CMB analysis

The basic features of the GLESP package includes spherical harmonic analysis of a map, map synthesis from a given set of \( a_{lm} \) coefficients, and simulation of a Gaussian map from a given angular power spectrum \( C_l \), or \( D_l \).

cl2map

cl2map synthesizes CMB temperature maps from spherical harmonic coefficients \( a_{lm} \). Inversely, it can decompose an input CMB temperature map into its spherical harmonic coefficients \( a_{lm} \) and/or power spectrum. If the input is a power spectrum \( C_l \), or \( D_l \), cl2map generates a Gaussian map of CMB anisotropies by assigning the \( a_{lm} \) mutually independent Gaussian-distributed real and imaginary parts, both with a standard deviation \( \sqrt{C_l/2} \) at each \( l \) harmonic.

rsalm

rsalm convolves or deconvolves a map with a symmetric beam via

$$a'_{lm} = B_l a_{lm},$$

where \( B_l \) is the expansion in Legendre polynomials of a symmetric beam. The symmetric beam can be input by reading in an ASCII file containing the profile of \( B_l \) or by providing the FWHM for a symmetric Gaussian beam, where \( B_l = \exp[-\sigma^2(l+1)/2] \) and \( \sigma = \text{FWHM}/\sqrt{8\ln 2} \).
For deconvolution, a simple Tikhonov regularization scheme is applied via
\[
\alpha_{lm} = \frac{a_{lm}}{B_l + \alpha},
\]  
(5)
where \(\alpha\) is the regularization parameter.

\section*{2.2. Advanced features: map and \(a_{lm}\) manipulation}

The package offers several advanced features that allow the users to manipulate pixelized maps or sets of \(a_{lm}\).

\subsection*{difmap}
\textbf{difmap} performs linear combinations of maps, map rotation, conversion of a map from Galactic to equatorial coordinate base. It can display simple map information such as pixel numbers and resolution, histogram, mean and variance, maximum and minimum temperature values and positions in \((\theta, \phi)\).

\subsection*{difalm}
\textbf{difalm} performs arithmetic operations over \(a_{lm}\) such as addition, subtraction, multiplication and division by a factor. It also allows to swap the amplitudes and phases between two sets of \(a_{lm}\). It can multiply/divide \(a_{lm}\) by given vectors \(v(l)\).

\subsection*{mapcut}
\textbf{mapcut} modifies a map in various ways. It can single out an area (either circular or rectangular) and set temperature values to zero in the area or outside the area. Furthermore, it can systematically remove or withhold several circular (or rectangular) areas by reading in a file containing those areas’ positions and radii (or two corners). It can dissect a rectangular area from a map and output to a file in FITS format. \textbf{mapcut} can also display temperature values of a GLESP map at given positions in one of the 3 coordinate systems: spherical polar, Galactic, and equatorial.

\subsection*{mappat}
\textbf{mappat} performs the conversion between ASCII and FITS binary formats for a GLESP map. The derivative of this is that it allows one to input any patterns such as point source positions in ASCII and produce their whole-sky distribution.

\subsection*{2.3. Conversion between HEALPix and GLESP}

The package also provides map conversion between HEALPix \cite{Gorski99} and GLESP.

\textbf{f2map}
\textbf{f2map} performs repixelization of a GLESP map to HEALPix or to equidistant grid FITS Basic format. In the process of conversion to HEALPix, \textbf{f2map} can perform repixelization either using spline interpolation algorithm or direct mapping.

\textbf{cmap}
\textbf{cmap} performs repixelization of a HEALPix map to GLESP using spline interpolation for re-pixelization. On conversion to GLESP, the resolution is determined by the \(N_{side}\) value in HEALPix, otherwise, the resolution can be set according to user’s input. \textbf{cmap} can also display temperature values of a HEALPix map, or output the HEALPix map in ASCII format in 3 columns: \(\theta, \phi\) and temperature. \textbf{cmap} also reads the 2nd field of Binary Table Extension in HEALPix maps.

\textbf{ntot}
\textbf{ntot} calculates the total pixel number and size for both GLESP and HEALPix schemes. By giving a resolution, \textbf{ntot} calculates the parameters of the nearest allowed resolution for both schemes.

\section*{3. Objectives}

\subsection*{3.1. Operation on a single map}

Decomposing a map for its \(a_{lm}/C_l\) \textbf{cl2map}
Simulating a Gaussian map from given \(C_l\) \textbf{cl2map}
Displaying the map \(T_{max}/T_{min}\), map resolution mean/variance \textbf{difmap}
Map rotation \textbf{difmap}
Arithmetic operations \textbf{difmap}
Producing the histogram \textbf{difmap}
Converting the map coordinate system to equatorial coordinates \textbf{difmap}
Casting a mask on a map \textbf{difmap}
Plotting the map and putting markers on the figure \textbf{f2fig}
Displaying the temperature value at a given coordinate \textbf{mapcut}
Truncating the temperature fluctuation to a given temperature range \textbf{mapcut}
Removing or keeping specified areas from the map \textbf{mapcut}
Map convolution and deconvolution \textbf{rsalm}

\subsection*{3.2. operation on a single set of \(a_{lm}\)}

Calculating the amplitude \(|a_{lm}|\) \textbf{alm2dl}
Calculating the phases \(\phi_{lm}\) \textbf{alm2dl}
Synthesizing \(a_{lm}\) for the map \textbf{c12map}
Arithmetic operations on \(a_{lm}\) \textbf{difalm}
Shifting phases \hspace{1cm} \texttt{difalm}

3.3. \textit{Operations over several maps}

Linear combinations over maps \hspace{1cm} \texttt{difmap}
Cross correlation of 2 maps \hspace{1cm} \texttt{difmap}
Multiplication of 2 maps \hspace{1cm} \texttt{difmap}

3.4. \textit{Operation over several sets of $a_{lm}$}

Linear combinations of $a_{lm}$ \hspace{1cm} \texttt{difalm}
Swapping phases and amplitudes of 2 $a_{lm}$ \hspace{1cm} \texttt{difalm}

3.5. \textit{Conversions}

Converting GLESP FITS to HEALPix FITS \hspace{1cm} \texttt{cmap}
Converting HEALPix FITS to GLESP FITS \hspace{1cm} \texttt{f2map}
Converting FITS binary to ASCII \hspace{1cm} \texttt{mappat}
Converting/creating FITS binary from ASCII \hspace{1cm} \texttt{mappat}
Information on pixel number and size \hspace{1cm} \texttt{ntot}

4. \textbf{Acknowledgment of using GLESP software package}

Those who use the GLESP package for producing results should acknowledge in the publication. The reference should include the paper introducing the GLESP concept: Doroshkevich et al. International Journal of Modern Physics D, Vol 14, No.*, *** (2005).

5. \textbf{Problems and Suggestions}

For any technical issues, bugs, problems or suggestions, please send email to \texttt{glesp@nbi.dk}.

\textbf{References}

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