# User Manual: $B_{LOS}$ Mapping Code

### Terminology

- $B_{LOS}$: Line-of-sight component of magnetic field
- ROI: Region of Interest
- RM: Rotation Measure
- Reference Point: Points representing "off positions"

## 1 Introduction

This software determines the line-of-sight component of magnetic fields ($B_{LOS}$) associated with molecular clouds using the technique described in Tahani et al. (2018). It is automated utilizing user input in configuration files and supplied data files to perform an analysis and output the results as output files for the user's review.

## 2 Installation

### 2.1 Minimum Python Version

The minimum Python version is 3.6.1. Due to library dependencies, it will not work with any python version below 3.6.1.

### 2.2 Quick Setup and Installation

Once Python has been installed, the rest of the installation may be quickly installed via running the *Initialize.py* script, either directly or in the terminal as follows:

```
python Initialize.py
```

The initialization script installs the requisite packages, initializes the configuration files, and then downloads example data. The installation is now complete, and you can now obtain the data.

### 2.3 Obtaining the Data

In order for the analysis to be conducted on a given region, three pieces of data must be obtained.

Rotation Measure Catalog: A rotation measure catalog must be obtained and placed in the Data/RMCatalog directory, with the appropriate format as specified by the example in the file RMCatalogue-Header.csv. The catalog must cover the region or cloud you are interested in, or else there will be nothing to analyze.

Region Fits File: A fits file, either Extinction or Hydrogen Column Density, which has information for the region or cloud you are interested in. Place these files inside the Data directory.

Cloud Parameters: A .ini configuration file, which specifies information about the region of interest, including its distance from Earth, its chemical code parameters, the rotation measure catalog's area of coverage, and image subsections of the fits file. This file ties all the data together. Place these files in Data/CloudParameters. Examples can be seen inside that directory. A template is automatically generated as part of initialization.

The initialization script downloads the Taylor et al. (2009) catalog, as well as the Hydrogen Column Density fits files for a large number of regions. Default clouds with their parameters are provided in the Data directory under the Cloud Parameters directory. Any data other than the provided data must be placed in the appropriate location by the user.

### 2.4 Configuration

Configuration files control the operation of the scripts, and are the primary means by which user input or decision-making is taken into account before the analysis is conducted. They are as follows.

configStartSettings: This file contains a list of parameters involving human judgment or stylistic choices. In particular, parameters related to: Which cloud to analyze, what points to quality or disqualify as potential reference points, and plotting and logging styles are set here. This is the primary configuration file to be adjusted before each analysis.

configDirectoryAndNames: This file contains the names of directories and files utilized and produced by the scripts as part of their analysis. If you dislike the names of the files or directories, or if you wish to leave certain folders elsewhere, it can be adjusted in the config here.

configConstants: This file contains the values of constants utilized in the calculations performed by the scripts. It is recommended that you verify that they are correct before proceeding.

Further details on each configuration option are available within the configuration files themselves, via their naming or the comment that precedes them.

## 3 Conducting the analysis - Quick Overview

### 3.1 Setting Up

Once the files have been installed, we can begin to prepare for conducting the analysis.

1. Check that the constants defined are correct in:
   ‘configConstants.ini’
2. Check that the directory file naming scheme is to your satisfaction in:
   ‘configDirectoryAndNames.ini’
3. Check that the various starting settings and judgment parameters are to your satisfaction in:
   ‘configStartSettings.ini’

The following will need to be done for every given region of interest.

- Check that your region of interest is correctly defined in its ‘Region.ini’ file (located in Data/CloudParameters).
  - If your region of interest is not defined, create a new region.ini data file and fill out the data accordingly. Then place it in the Data/CloudParameters folder.
  - An example template has been placed in the folder for you. It is called ‘0 - template.ini’

### 3.2 Running the analysis

Before conducting the analysis, user input is defined in configStartSettings.ini. Please review these settings before conducting the analysis.

Run-all scripts are provided, which automate the process of running each of the scripts in order. Different quick run scripts are provided for different use cases. Further details on the run-all scripts are as follows:

Run.py: Standard Run-all script which runs each of the seven steps of the analysis in sequence, utilizing the default configuration files. It can be run directly, or through the terminal via:

```
python Run.py
```

RunCloud.py: Meant to be run through the terminal only, and clouds to be analyzed are specified afterwards. Any number of clouds can be specified, so long as the data is available, separated by a space. Ex:

```
python RunCloud.py Oriona Orionb California Taurus
```

RunConfigCloud.py: If the user wishes to run the analysis on an alternatively specified starting configuration file, they can utilize this script. The user specifies the starting configuration file as the first argument in the terminal. It must be of the exact same format as the regular configStartSettings.ini file. Once it finishes, it will rename the output folder with the config file's name, to keep track of what configuration file was used. Ex:

```
python RunParamCloud.py altStartConfig.ini Oriona Orionb Taurus California Perseus
```

If permission issues are encountered, attempt deleting the original FileOutput folder entirely, and closing any other programs which may be utilizing the software's folder.

Each step of the analysis corresponds to the scripts numbered in the main directory, and are meant to be run one at a time in the order indicated by their name. Each step will produce output either in the form of a figure or a table of data. Output will be saved to a folder with the same name as the region of interest. It is strongly recommended that the output be critically examined after each analysis, and starting configuration parameters adjusted accordingly.

## 3.3 Input and Output Files

At a high level, the program takes in the data about a region and information from the user's judgment, processes it, and then returns output in the form of the analyzed results. All of these are encoded within files. By default, unless changed in the directories configuration file (*configDirectoryAndNames.ini*), their names will be as outlined here.

### 3.3.1 Input Files

The input files consists of the configuration files, and the input data. The configuration files are located in the main directory, alongside the main scripts, and further information on the parameters controlled by the configuration files can be found in this manual in the sections before, or in the configuration files themselves. As for the input data itself, the input data is stored in the *Data* directory, which has the following structure:

- Fits files - Extinction fits files should be stored directly within this directory, rather than any sub-directory.
- CloudParameters - This directory contains the Region of Interest files which a user must create in order to analyze a given region. Examples for multiple regions come with the software. These files contain information on a region and point to the relevant fits file and chemical abundance information for the given region. An example template can be found with *0- cloudTemplate.ini*. These files can be opened and edited with any text editor.
- ChemicalAbundance - This directory contains the results of the chemical evolution code which are utilized in the analysis. Each sub-directory corresponds to a given set of parameters, the files within which correspond to the results of those parameters.
- RMCatalog - This directory contains the rotation measure catalogs.

### 3.3.2 Output Files

By default, the final results and data on the intermediate calculations by the program are output files, which are stored in the *FileOutput* folder within the program directory. Within the folder, the results of the analysis are stored in a folder corresponding to the name of the region analyzed. Within the output files folder for the given region, the files are further sorted into folders:

- Logs - Each file inside corresponds to human-readable logs for one of the scripts corresponding to the steps of the technique. Each log provides information on what the script is doing, why it is doing what it does, important values to be aware of, and where the files are being saved at each stage of the analysis. Reading these scripts is recommended for understanding the program's decisions.

- IntermediateData - Each file inside corresponds to calculated values utilized between stages of the analysis which may not be of interest to the user except to verify the integrity of the analysis. The files are as follows:
  - AnomRej.csv - Potential reference points rejected for having anomalous reference values.
  - FarHighExtRej.csv - Potential reference points rejected for being too far from a point of high extinction.
  - NearHighExtRej.csv - Potential reference points rejected for being too near a point of high extinction.
  - Rejected.csv - Potential reference points rejected for any reason.
  - Remaining.csv - Potential reference points remaining after all the reasons to reject them.
  - FilteredRMExtinction.csv - Potential reference points remaining after the policy on maximum fraction of reference points is applied.
  - QuadrantDivisionData.csv - Data on the equations which split the extinction map of the region into four equally-weighted quadrants.
  - RegionThresholdData.csv - Data on the extinction thresholds utilized to judge the region.
  - TrendDataTable.csv - Data on the magnetic field stability trend's input.

- DensitySensitivity - The results of density variation on magnetic field calculations are stored here. The name of the file corresponds to the variation - B_Av_T0_n[].csv, where [] corresponds to the percentage change. Utilized for uncertainty calculations. Assumes no temperature variation.

- TemperatureSensitivity - The results of temperature variation on magnetic field calculations are stored here. The name of the file corresponds to the variation - B_Av_T[]_n0.csv, where [] corresponds to the percentage change. Utilized for uncertainty calculations. Assumes no density variation.

- Plots - Informative plots meant to be utilized or examined by the end user. These can be divided into two categories - plots meant to provide feedback on the steps of the analysis, and plots which represent the final products of the analysis. Plots meant to provide feedback on The plots are as follows:
  - RMMap.png - A map of all the rotation measures and where they are in the extinction map of the region.
  - AllPotRefPts.png - A map of all the potential reference points, as filtered by the maximum extinction criteria.
  - ExtRefPts.png - A map of the extinction thresholds defined in the config, and how they cut up the region.

- Filter_[].png - The potential reference points rejected for the reason in [], plotted against the extinction map. For example, Filter_AnomRM.png plots the potential reference points rejected for having an anomalous rotation measure.
- AllRefPointSorted.png - All the potential reference points, sorted between those which have been rejected, and those that remain.
- QuadrantDivisionPlot.png - The division of the region into four quadrants for the four-quadrant analysis.
- ChosenRefPoints.png - the reference points chosen as off positions for the region.
- BLOS_vs_NRef_AllPotentialRefPoints.png - Stability trend graph with all potential reference points.
- BLOS_vs_NRef_ChosenRefPoints.png - Stability trend graph with only the chosen reference points.

The plots meant to represent the final products of the analysis are as follows:

- BDensitySensitivity.png - A figure of the density sensitivity of the region based off how much it changes relative to changes in density. Part of the error analysis.
- BTemperatureSensitivity.png - A figure of the temperature sensitivity of the region based off how much it changes relative to changes in temperature. Part of the error analysis.
- BLOSPOintMap.png - The map of the magnetic line of sight of the region.

• FinalData - The final results of the analysis, meant to be utilized by the end user. The files are as follows:

- MatchedRMExtinction.csv - All the rotation measure points in the region with their matched extinctions relative to the region.
- AllPotentialRefPoints.csv - All the rotation measure points which have sufficiently low extinction as to be a potential reference point for the off position.
- SelectedRefPoints.csv - The reference points chosen to sample the galactic contribution (non-cloud contribution).
- ReferenceData.csv - The reference values of the galactic contribution as calculated utilizing the chosen points.
- BLOSPoints.csv - The calculated magnetic field values for the given region.
- FinalBLOSResults.csv - The final magnetic field values with uncertainties calculated.

# 4 Installation Information and Troubleshooting

## 4.1 What *Initialize.py* Does

When run, the script runs the three setup 00 scripts in order:

- 00aInstallPackages.py - Installs the python packages required for the program to work.
- 00bMakeConfig.py - Creates or resets the three configuration files.
- 00cDownloadExampleData.py - Downloads the default example data set, consisting of the Taylor et al. (2009) catalog, and hydrogen column density data for many regions.

These scripts can be run on their own, if only specific steps are needed, or their steps manually completed. Further elaboration on those steps are given in the following subsections.

## 4.2 Installing Required Modules

The following packages are installed by *Initialize.py*, which invokes *00aInstallPackages.py*.

- astropy
- matplotlib
- pandas
- requests
- adjustText
- numpy
- scipy
- sklearn

These packages can also be manually installed in case the script fails, by utilizing the terminal with the command:

```
pip install –upgrade [package]
```

Where [package] is to be replaced with the name of the package to be installed.

### 4.3 Initializing Resetting Configuration Files

If the software fails to load due to configuration errors, or a clean slate configuration is desired, the config files can be reset by simply rerunning *00bMakeConfig.py*. This will write over the three configuration files (or recreate them, if missing) with the default configuration and values.

## 5 MC-BLOS - Structure and Explanation

### 5.1 Overview of Steps

The $B_{LOS}$ Mapping method is conducted over 7 steps. each of which may have several associated scripts, as detailed in Tahani et al. (2018).

Step 1: Preparation: (01): The necessary output folders and sub-folders are created.

Step 2: Rotation Measure-Extinction Matching: (02a): The rotation measure points are read from the defined catalog and matched to visual extinction values using a map of the region of interest. (02b): Optionally, the rotation measure points can be plotted over a map of the region of interest in order to get a sense of the rotation measure coverage.

Step 3: The reference points are chosen. These points represent "off positions" on the cloud, as defined in Tahani et al. (2018). (03a): First, candidate reference points are identified, and filtered for disqualifying features. (03b): Next, the remaining points are sorted between off positions and cloud envelope according to a stability heuristic, and to ensure even sampling of the cloud's surroundings. (03c): Optionally, the results of this stage may be plotted for information on the decision making process conducted by the script.

Step 4: (04): The $B_{LOS}$ directions and values are determined and calculated for the rotation measure points in the region of interest using the reference points found in step 3.

Steps 5 & 6: The $B_{LOS}$ uncertainties that result from using different density (05a) and temperature (06a) values as input parameters to the chemical code are determined. (05b and 06b): The results are then plotted.

Step 7: (07): The total uncertainty in $B_{LOS}$ values is calculated (resulted from RM, $RM_{off}$, extinction values, and input parameters to the chemical code).

### 5.2 Notes on Step 3

Step 3 requires the most input from the starting configuration file, as this is the step in which reference points are chosen. Reference points are meant to sample "off positions" around the cloud in order to estimate the Galactic contribution to the observed rotation measure.

The primary criterion for determining reference points is visual extinction. The program will list all points with extinction less than a specified threshold value, numbered in order of increasing extinction, as "potential reference points". Depending on the distance (and location) of the cloud, this threshold value should be modified. The map of these points should be reviewed to ensure that all sides of the cloud are sampled properly by their selected reference points.

The program will then recommend an optimal number of points to take as reference points using a trend stability analysis. Afterwards, it will ensure that sufficient points have been sampled from around the cloud. The reference points chosen after these two steps will go on to form the reference values for the off positions.

The program will also flag and remove points that are too close to the cloud, and points that have odd anomalous rotation measure values. The program can also flag and remove points which are too far from the cloud to be considered to be sampling its background. Points with these properties may require additional consideration from the user as to whether they are suitable reference points. Figures displaying the location of these points, and their relevant data, are produced for user review, in case parameters need to be changed for the next analysis.

## References

Tahani, M., Plume, R., Brown, J. C., & Kainulainen, J. 2018, A&A, 614, A100

Taylor, A. R., Stil, J. M., & Sunstrum, C. 2009, ApJ, 702, 1230