SIR Explorer
User Guide

Version 0.0.0-beta

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Contents

1 SIR Explorer

SIR Explorer, or SIRE, is a Python 3.9 graphical user interface (GUI) application that aims to make the analysis and exploration of inversion inputs and outputs associated with the Stokes Inversion based on Response functions (SIR) code[1] a little faster and a little easier. SIRE is designed to pick up where the highly recommended parallelized Python wrapper to SIR, written by Ricardo Gafeira[2], leaves off. This user guide is written under the assumption that the reader has a basic understanding of SIR. Please visit the excellent online course by Carlos Quintero Noda[3] for training in how to use SIR.

Check out section 2 for instructions on how to run SIRE.

Check out the Usage section 3 for an explanation of SIRE's user interface.

Note: This tool is under active development. To report bugs or make suggestions, please contact ryan.campbell@qub.ac.uk.

1.1 Acknowledging SIRE and terms of use

SIRE is available on GitHub but is not currently licensed, which means all rights are reserved.

Permission is granted to the reader to use SIRE for purely academic (i.e. non-commercial) purposes. If the reader uses SIRE they should cite Campbell et al. (AA 647, A182, 2021). [4]

If the reader wishes to adapt or use the source code for their own projects in any way they should contact ryan.campbell@qub.ac.uk for explicit permission.

2 Installation

2.1 Supported operating systems

SIRE was developed on Mac OS Monterey. SIRE cannot be guaranteed to function on other operating systems.

[1] https://github.com/cdiazbas/SIRcode
[2] https://www.aanda.org/articles/aa/pdf/2021/07/aa36910-19.pdf
[3] https://youtube.com/playlist?list=PLrC8vHMj4MIvfDPwhJo5guNGZONoPN6rN
[4] https://www.aanda.org/articles/aa/pdf/2021/03/aa40028-20.pdf

2.2 Obtaining SIRE

Download the beta version of SIRE here.[5] It is recommended that you move the source files (i.e. the SIRExplorer directory) out of your Downloads folder to a location that is easily accessible.

2.3 Running SIRE in a terminal

To run SIRE, it is highly recommended to obtain a Python 3.9 installation by installing Anaconda[6]. You will then need to install a number of dependencies:

- pyqt
- matplotlib
- astropy
- scipy
- numpy

It is also highly advisable that you make sure you have the most up to date versions of these packages. To install a package, simply open a terminal and type, for instance, 'conda install numpy'. When all dependencies are installed, run SIRE by typing 'python SIRExplorer.py' in a terminal inside your SIRExplorer directory.

2.4 Running SIRE without using a terminal

When Anaconda is successfully installed, an alternative way to run the program is to download and install the community version of Pycharm[7]. The default Python interpreter should be the latest release version (Python 3.9 as of March 2022). When launching PyCharm, choose the directory in which you have stored the SIRE source files as the project directory. If you have launched Pycharm for the first time, some background processes will need to run and these should start automatically. You can track the progress of these processes in the bottom-right of the Pycharm window. Wait until these processes are complete before proceeding.

The required dependencies should be installed by PyCharm by default. If something is missing, to install the dependencies, right-click on 'Python 3.9' in the bottom-right corner of the Pycharm window and left-click 'interpreter settings'. This will open the 'Preferences' window, where you can add packages by left-clicking the '+' icon. Left-clicking the '+' icon opens a third window, where you can search for and install Python packages. Once the packages are installed, run SIRE by right clicking on the SIRExplorer.py file and left clicking 'run SIRExplorer'.

[5] https://github.com/incidentfrog/SIRExplorer
[6] https://www.anaconda.com
[7] https://www.jetbrains.com/pycharm/download

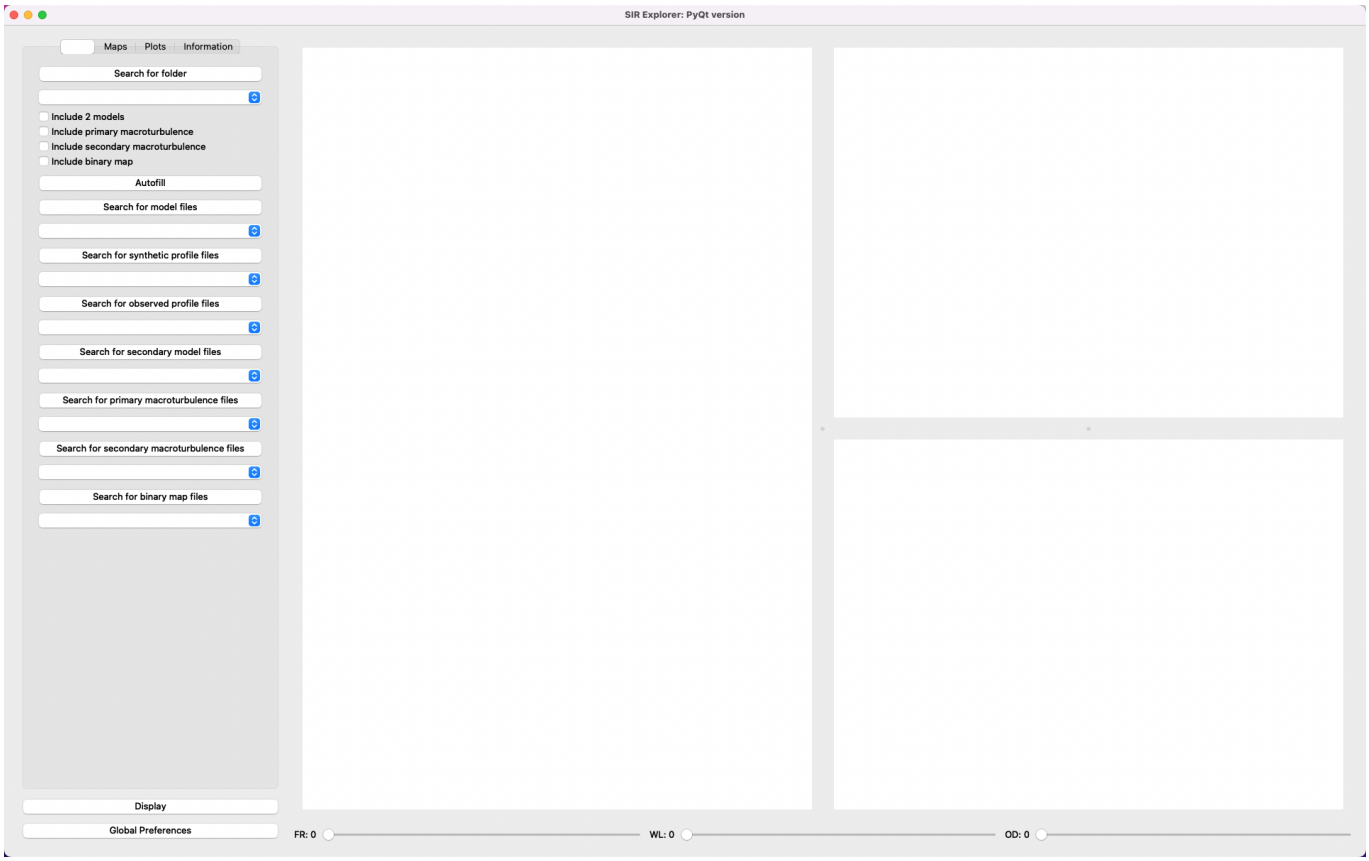

Figure 1: The main window of SIRE as shown on start up.

3 Usage

The purpose of this section is to explain how to use SIRE. On launch of SIRE, you should be greeted with the main window as shown in Figure 1. The UI of SIRE is split into three main regions:

1. The control panel (section 3.1), on the left of the main window, which allows the user to load datasets,
2. The three canvases (section 3.2), upon which datasets are displayed, and
3. The widget bar (section 3.3.2), underneath the canvas, which has three sliders to control the frame (FR), wavelength (WL), and optical depth (OD) indices.

3.1 Control panel

The control panel provides the user with the tools necessary to select file paths for datasets. Before discussing the control panel, it is necessary to outline the possible input files that can be provided to SIRE.

3.1.1 Input file structure

There are three **mandatory files** that are required under all circumstances. These include:

1. Primary model files (model 1): the one-dimensional atmospheric files that result from SIR inversions. These files are *output* files from SIR.
2. Observed profiles: the input Stokes vectors provided to SIR. The word "observed" does not imply that these profiles need to be real observations. If inverting synthetic profiles e.g. produced from MHD simulation snapshots, these profiles may of course be synthetic in origin. These profiles are the *input* profiles for SIR.
3. Synthetic profiles: the final output Stokes vectors produced by SIR when solving radiative transfer. These profiles are the *output* profiles from SIR.

There are a number of **optional files** that can be provided. These include:

1. Secondary model files (model 2): if SIR is employed with 2 models, this is the second model as *output* from SIR.
2. Primary macroturbulence files (model 1): this file, despite its name, contains more than the macroturbulence of model 1. It also includes the filling factor of the model and the stray light fraction in that order.
3. Secondary macroturbulence files (model 2): as above, but for model 2. If a secondary model is provided, but a secondary macroturbulence file is not, SIRE will determine the filling factor of model 2 from the filling factor of model 1.
4. Binary map: a user-defined array which may be provided to remove selected pixels from the map. This array should have values of 1 and 0 or 1 and NaN-values. The binary map is only applied to magnetic parameters (B, αB, γ and ϕ). This file is not an output or input of SIR.

3.1.2 Loading data

There are two options for loading datasets:

1. Search for a folder, and autofill selected files, or
2. Search for files individually.

To use the first method, begin by navigating to the 'Files' tab in the Control Panel (see Fig. 2). Click the 'Search for folder' button and select a directory which contains all necessary input files. Next, tick or untick the boxes as necessary to specify if two models are to be loaded and whether any optional files should be included. Remember, if only one model is to be loaded, then there are only three mandatory files. However, if two models are to be loaded then there are five mandatory files

File	Array shape (t = 1)	Array shape ($t > 1$)
Model$^{\star\ \diamond}$	[11, log $\tau_{500\text{nm}}$, y, x]	[t, 11, log $\tau_{500\text{nm}}$, y, x]
Observed profiles$^{\star\ \diamond}$	[4, λ, y, x]	[t, 4, λ, y, x]
Synthetic profiles$^{\star\ \diamond}$	[4, λ, y, x]	[t, 4, λ, y, x]
Secondary model$^{\diamond}$	[11, log $\tau_{500\text{nm}}$, y, x]	[t, 11, log $\tau_{500\text{nm}}$, y, x]
Primary macroturb.$^{\diamond}$	[3, y, x]	[t, 3, y, x]
Secondary macroturb.	[3, y, x]	[t, 3, y, x]
Binary map file	[y, x]	[t, y, x]

Table 1: Input file structure for SIRE. Star symbol (*) indicates the input file is mandatory when loading inversion outputs with one model, while the diamond symbol ($^\diamond$) indicates the input file is mandatory for loading inversion outputs with two models.

(refer to Table 1). When you have verified that your selections are correct, click the 'Autofill' button. The Autofill function will populate the widgets in the 'File search' and 'Optional' tabs (see Fig. **??**). The Autofill function also checks whether the files exist - if they do not, you will receive a pop-up error. Verify that the autofilled details are correct, and if they are, click 'Display'. For this method to work, the files in the selected directory *must* have the following names:

- mod1.fits (primary model)
- obs_prof.fits (observed profiles)
- syn_prof.fits (synthetic profiles)
- mod2.fits (secondary model)
- mac1.fits (primary macroturb.)
- mac2.fits (secondary macroturb.)
- binary.fits (binary)

To use the second method, tick the boxes to indicate to SIRE that the required optional files should be included, and proceed to search and select each file individually. When you have verified that your selections are correct and complete, click 'Display'.

3.2 Canvases

The canvases are the areas of SIRE's UI in which datasets are displayed. Figure 3 shows an example of a dataset with two models loaded. There are three canvas objects:

1. The maps on the *left* of the canvas of Stokes *I*, Stokes *Q*, Stokes *U*, Stokes *V*, temperature, *T*, inclination of the magnetic vector, γ, the azimuthal angle of the magnetic vector, ϕ, line of sight velocity, v_{LOS}, and the magnetic field strength, *B*.

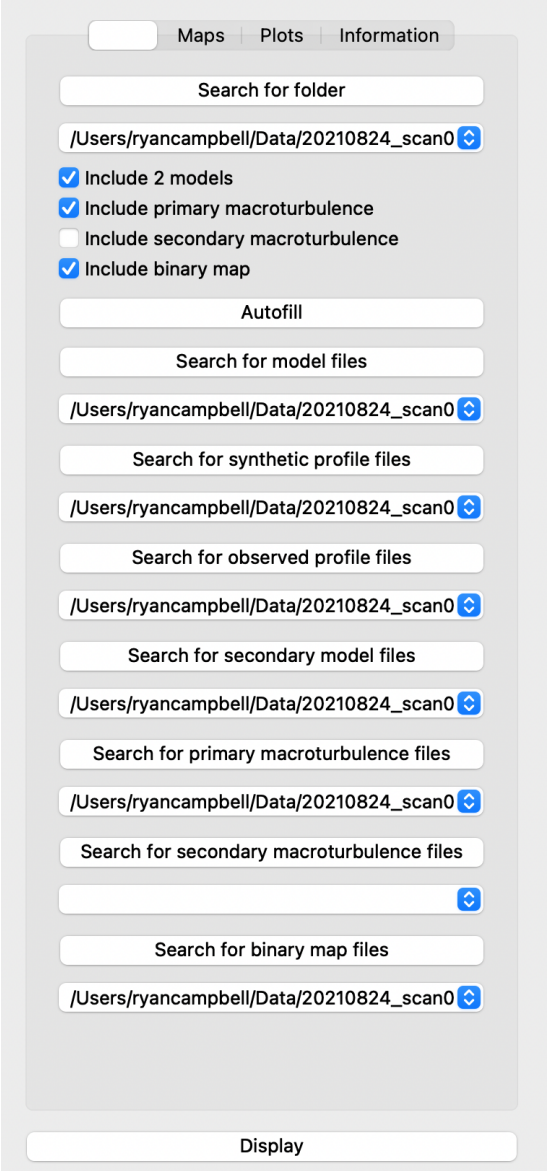

Figure 2: SIRE's Control Panel.

2. The plots on the *top right* of the canvas of the observed and synthetic Stokes vectors for the selected pixel, and

3. The plots on the *bottom right* of the canvas of the model parameters (T, γ, ϕ, v_{LOS} and B) for the selected pixel.

Each of the canvases may be resized in proportion to one another, and each of them may be collapsed entirely. When only one model is supplied, SIRE will load the parameters of that model as one would intuitively expect. However, when two models are loaded, SIRE is designed to assume that model 1 is magnetic and model 2 is non-magnetic. This means the magnetic parameters shown in the maps are the parameters from model 1. Additionally, in this case, instead of showing a map of B, αB (i.e. the magnetic flux density) is shown instead, where α is the filling factor of model 1. At the same time, the v_{LOS} shown is given by the following formula:

$$v_{\mathrm{LOS}} = v_{\mathrm{LOS1}} * \alpha_1 + v_{\mathrm{LOS2}} * \alpha_2. \tag{1}$$

where the subscripts denote that the value belongs to model 1 or 2. If only the primary macroturbulence file is provided (i.e. no secondary macroturbulence file is given) then the filling factor of model 2, α_2, is given by:

$$\alpha_2 = 1 - \alpha_1. \tag{2}$$

Support for two magnetic models will be included in the near future.

3.3 Navigating the dataset

3.3.1 Selecting pixels

When a dataset is first loaded, the pixel with zeroth co-ordinates in each dimension will be plot by default. The user can left click any of the maps and the synthetic Stokes vector, observed Stokes vector, and model parameters for the corresponding pixel co-ordinates will be plotted. In addition, the user may adjust the selected pixel by using the UP, DOWN, LEFT and RIGHT arrow keys on their keyboard. The location of the selected pixel is denoted by vertical and horizontal dotted, red lines on the maps.

3.3.2 Changing the frame, wavelength or optical depth index

The sliders located below the canvas allow the user to adjust the frame (FR), wavelength (WL) and optical depth (OD) indices at which the data is retrieved from the appropriate files. The user can left-click and drag the sliders. The code that updates the maps and plots will not be executed until the slider is released. The user can press the 'Q' and 'E' keys to decrease or increase, respectively, the frame index by 1. Similarly, the user can use 'A' and 'D' for wavelength or 'Z' and 'C' for optical depth.

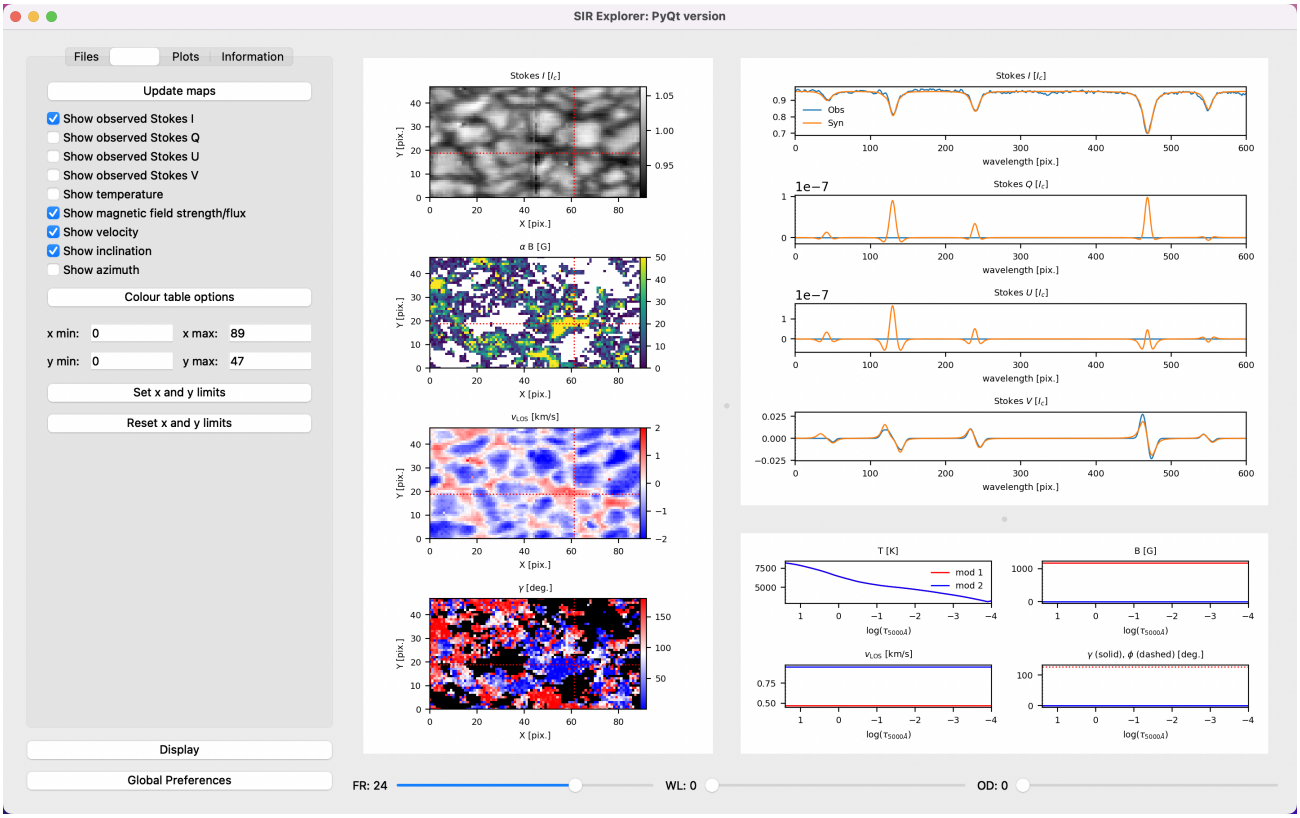

Figure 3: A GREGOR dataset with two models loaded into SIRE.

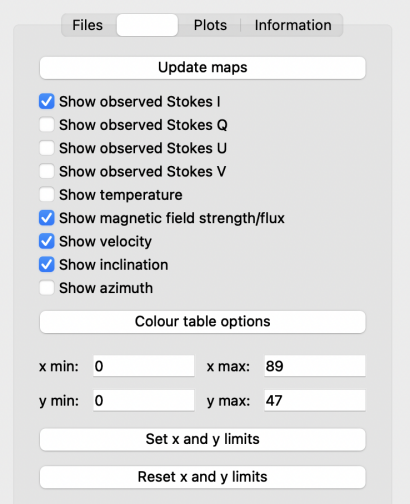

Figure 4: Map options tab.

3.3.3 Maps tab

In the control panel, the Maps tab (see Fig. 4 has a number of options that allows the user to customize how the maps are shown in the left-most canvas.

The tick boxes allow the user to change which maps are plotted. For instance, in Fig. 4 only Stokes *I*, magnetic field strength/flux, line of sight velocity and magnetic inclination would be plotted based on the selections. The maps can be updated at any time based on the user's selections by left-clicking the 'Update maps' button.

If the user left-clicks the 'Colour table options' button, a new window will pop up as shown in Fig. 5. The user can change colour maps for each of the parameters that can be shown in the map canvas. The user can also manually control the minimum ('vmin') and maximum ('vmax') extents of the colour scales. If the user clicks 'Enable autoscaling', this enables the default behaviour of the matplotlib.pyplot.imshow function[8], which scales images between their maximum and minimum values. When changing any of the vmin or vmax values, or enabling or disabling autoscaling, it is necessary to click 'Set values and display'. When the user is happy with their selections, they can also left-click 'Save settings'. This will store their preferred settings as the default values so the next time SIRE is opened it will not be necessary to repeat the process of changing the settings again.

The entry widgets allow the user to control the minimum and maximum extents of the maps in the *x* and *y* dimensions. These values must be entered in pixel numbers. After entering numbers, the user must left-click 'Set x and y limits' to update the maps. The user can left-click 'Reset x and y limits' to return to maximal extents as default.

[8] https://matplotlib.org/3.5.1/api/_as_gen/matplotlib.pyplot.imshow.html

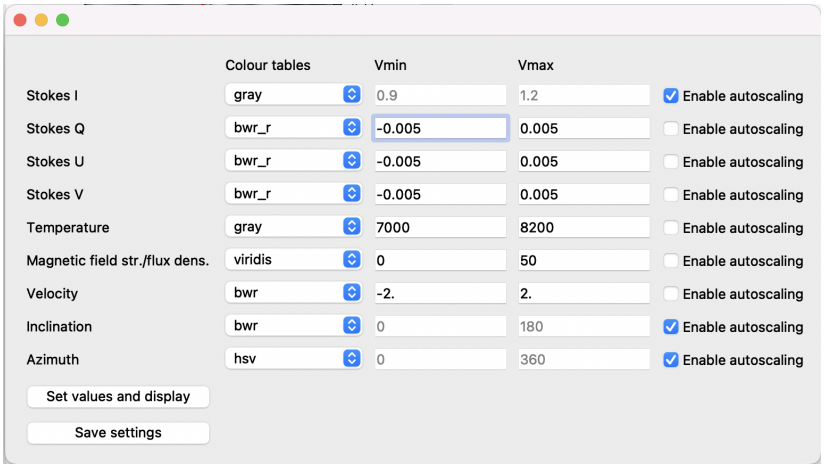

Figure 5: Colour table options.

3.3.4 Plots tab

Much like the tick boxes in the Maps tab, the tick boxes in the Plots tab (see Fig. 6) allows the user to control whether a given parameter is plot in the two right-most canvases or not. When a selection is made, the user must left-click 'Update profiles axes' to update the canvas containing the Stokes vector plots, or 'Update models axes' to update the canvas containing the model parameter plots.

The user can adjust the maximum and minimum wavelength and/or optical depth index range shown in the plots. It is necessary for the user to click 'Set wavelength range' and/or 'Set optical depth range' once values have been entered to update the plots. If the user sets a value which is outside the allowed range, the values will default to maximal and minimal extents.

3.3.5 Information tab

The information tab (see Fig. 7) provides the user with additional information about the selected pixel, including:

- The X and Y co-ordinates of the selected pixel.
- The height (Z) and optical depth (OD) in the model.
- The atmospheric parameters in model 1 at the optical depth selected by the slider.
- The atmospheric parameters in model 2 (if loaded) at the optical depth selected by the slider.

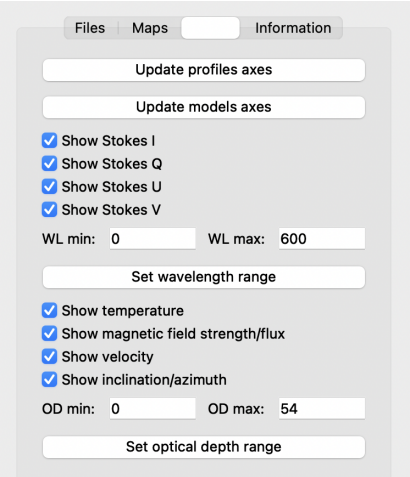

Figure 6: Plot options tab.

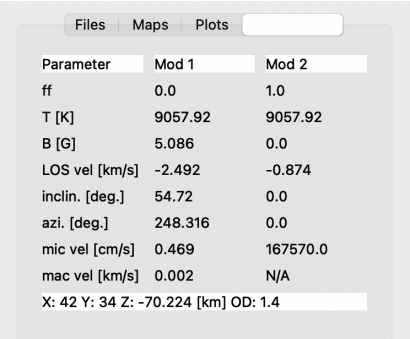

Figure 7: Information tab.

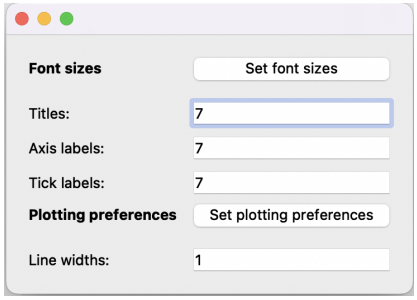

Figure 8: Global preferences window.

3.4 Global preferences

In the bottom-left of the window, the user can left-click the 'Global preferences' button to open a new window. This window allows the user to control a few global properties. Currently, the user can change font sizes by entering numbers and then left-clicking 'Set font sizes'. Additionally, the user can change line widths by entering a number and left-clicking 'Set plotting preferences'. The options available are currently very limited, but will be significant expanded in the future.

4 Glossary

SIR - Stokes Inversion based on Response functions

SIRE - SIR Explorer

UI - User Interface

OS - Operating System

GUI - Graphical User Interface

MHD - Magnetohydrodynamic

OD - Optical Depth

WL - Wavelength

FR - Frame