A Short Manual for Running VIMAP

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This short documentation[1] is about how to run VIMAP, VLBI IMage Alignment Program, to make spectral index maps of radio-bright Active Galactic Nuclei. Explanations regarding built-in tasks and several remarks are provided. For more general information, see Kim & Trippe (2014).

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[1] This document was made using the `refman` package of LaTeX, which is available on CTAN.

1 Prepare to start the job

Once you have obtained the program and this document, you should check several things.

Add-on packages : First of all, Python add-on packages listed in Kim & Trippe (2014) should be installed to use numerical functions, to display results, to read FITS files, and to enable these works in the GUI interface. They are quite easy to install, just as you may have done for other Python packages.

Python path : If you already have or finished installing the add-on packages, check your Python path. For example, type `which python` in your terminal to see your path to Python. In the author's desktop the path is `/usr/bin/python`. Then, change the first line of `VIMAP_v1.2.py` to your Python path. Be careful NOT to remove the `#!` mark in the beginning. Also, type `chmod +x VIMAP_v1.2.py` to give users permission to execute the program directly.

Run : If you are ready, put the program in your working directory. Then just type `VIMAP_v1.2.py` on your terminal.

2 Main Tasks

You will see a window that looks like Fig. 1. Your work starts from loading the images and ends finally by examining the resultant spectral index distributions.

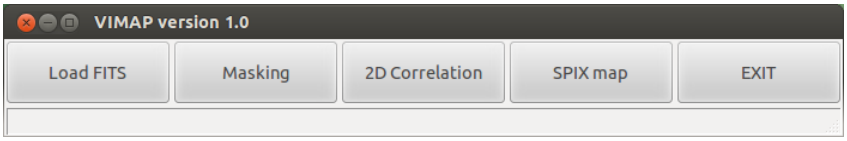

Figure 1: Main window of VIMAP running on Ubuntu 12.04. It may look differently on different working platforms.

`Load FITS` : This button will load two VLBI maps (in FITS format) of the sources taken at different frequencies. You should first load the lower frequency map, followed by importing the higher frequency map.

`Masking` : In this task, you will put two elliptical masks on the source intensity maps, usually on the apparent cores of AGN. See later sections for specific descriptions.

`2D Correlation` : 2D cross-correlation is computed from the two intensity maps. The result will be displayed as a 2D correlation map.

`SPIX map` : You can check resultant spectral index distributions with various parameters with this task. See later sections for more detailed descriptions.

`EXIT` : Terminate the program.

3 Loading Images

Loading your radio-AGN VLBI maps taken at different frequencies can be done with the `Load FITS` button. A familiar I/O dialogue box will show up and you can select your FITS files. In Ubuntu 12.04 the dialogue box looks like Fig. 2

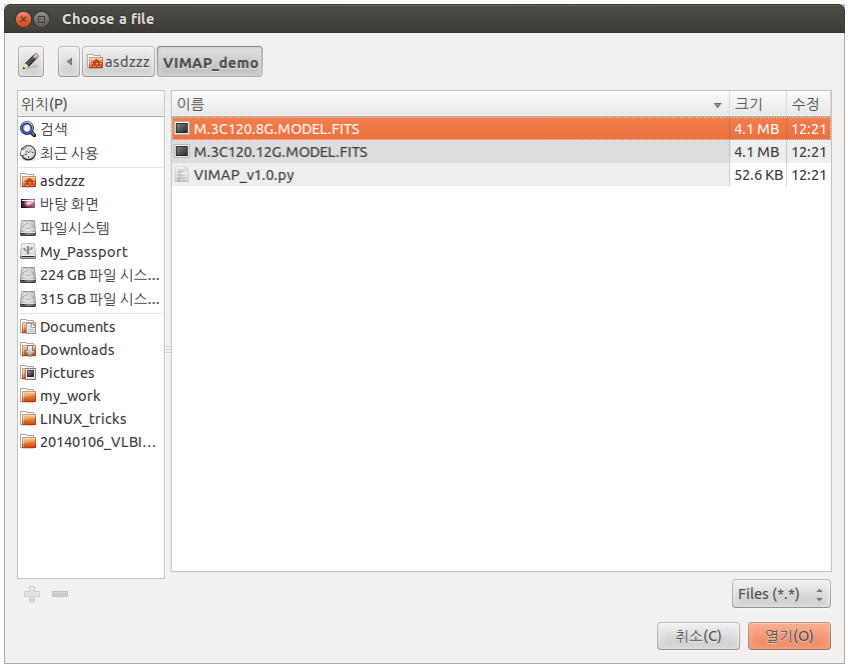

Figure 2: Dialogue box for loading FITS files, as shown in Ubuntu 12.04

4 How to mask Cores

If you have loaded two intensity maps, you can go to the `Masking` task. A window like Fig. 3 will show up when you click the button. Descriptions regarding the parameters are given below.

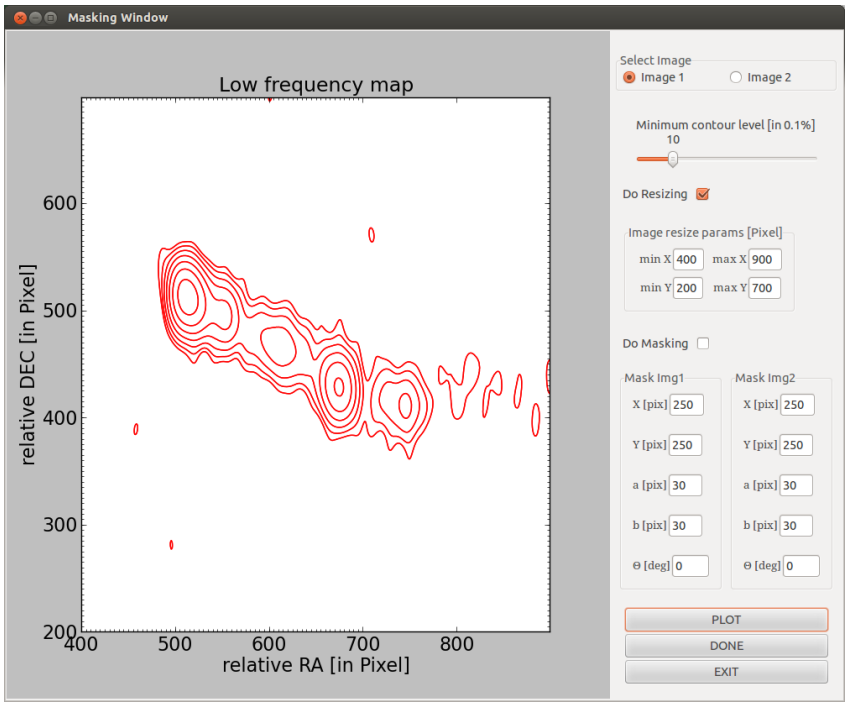

Figure 3: Masking panel of VIMAP. The source is 3C 120 at 8 GHz observed by VLBA, which was also used in Kim & Trippe (2014) for demonstration.

`Select Image` : You can determine which map will be displayed and be modified by clicking one of two buttons. `Image 1` is the map loaded first, i.e., the lower frequency intensity map, and `Image 2` refers to the higher frequency map.

`Minimum contour level` : As usual in displaying VLBI maps, you can determine minimum level of intensity contours by moving this slider. The contours increase by a factor of $\sqrt{2}$. Please note that the unit of the tick value is *0.1% of peak intensity*.

`Do Resizing` : Activate this button if you want to resize your selected intensity maps. It is recommended to do so because the source probably fills about 1/4 of your maps. In order to exclude source-free regions and to improve computing performance, users can trim the images to custom sizes. Please be careful not to clip large fraction of extended structures because VIMAP calculates the cross-correlation by using only the resized maps. It means resizing a map to a fairly small size will produce incorrect results.

`Image resize params` : Minimum/maximum of RA/DEC ranges for trimming can be determined here. Both images have to be equal in size and pixel scale. Note that VIMAP adopts pixel as the unit for RA and DEC. This is mostly the same for other tasks.

`Do Masking` : Activate this button if you want to put masks on the source maps.

`Mask img1/2` : Parameters describing elliptical masks that are supposed to cover apparent radio-AGN cores. An ellipse is mathematically defined in VIMAP as

$$\frac{(x-\mathtt{X})^2}{\mathtt{a}^2}+\frac{(y-\mathtt{Y})^2}{\mathtt{b}^2}=1 \tag{1}$$

where `X` and `Y` are the coordinates of center of an ellipse in RA/DEC direction (in units of pixel) and `a` and `b` are semi-major/minor axes (also in pixel), respectively. This ellipse is rotated by θ degree in counter-clockwise direction and sets intensity values included in the boundary to zero.

`PLOT` button : Plot the selected source map by using the settings described above.

`DONE` button : Click this when you think two input images are trimmed and masked properly so that you now want to compute the 2D cross-correlation. The two masked maps will be saved temporarily inside VIMAP. See the following section for more descriptions about the correlation task.

`EXIT` button : Close this window. Be aware that VIMAP will NOT keep the updated source maps for 2D cross-correlation unless you click `DONE` button.

5 Performing the 2D correlation

Basically, users can just click the `2D Correlation` button to perform the correlation and to get the results.

A short remark : Practically, the correlation is computed by shifting the intensity map obtained at higher frequency. It is good to note that VIMAP does NOT use cross-correlation functions implemented in Numpy or Scipy because the functions (i) do not provide specific options for normalization (yet) and (ii) may be based on Fast Fourier Transform (FFT) method, which improves computing efficiency but could introduce numerical artifacts. For the purpose of obtaining reliable results, therefore, VIMAP simply

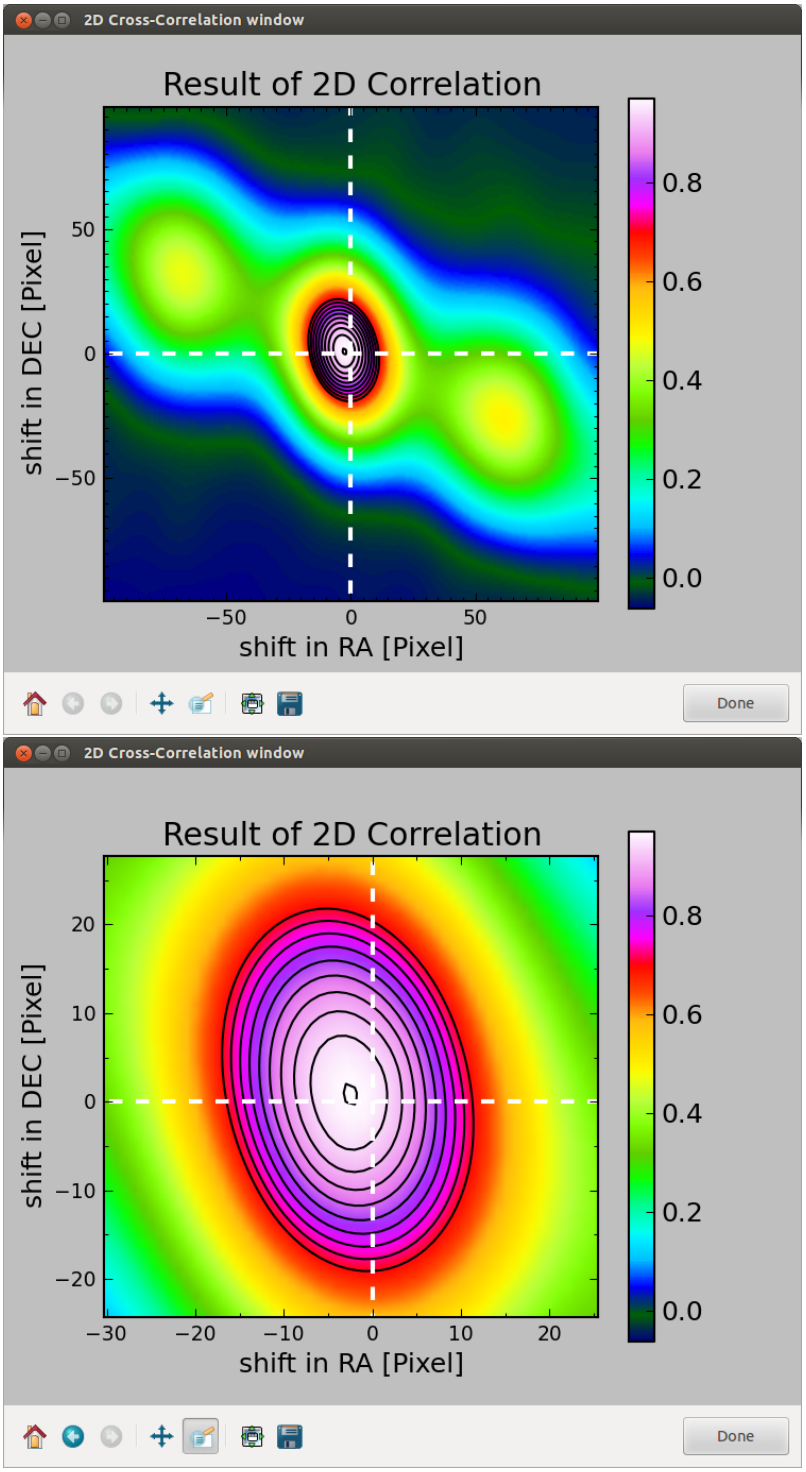

Figure 4: Window showing the 2D correlation array. Colors indicate correlation values and black lines are contours for the correlation values of 0.7, 0.73, 0.76, etc. *Top* : The correlation result. *Bottom* : The same result but is now zoomed onto the center to examine image shift more carefully.

uses loop statements for the calculation. This means `2D Correlation` may take some time to finish the calculation. So please be patient!

Result panel : After the computation is finished, VIMAP will report quantitative results. It displays the resultant 2D correlation array using black contours and a 2D color map, which may look like Fig. 4. Two white broken lines indicate where (0,0) is in the plot. Users can examine the data with the `Interactive Navigation` provided by `Matplotlib` package shown at the bottom of the window. For example, the map can be zoomed or explored easily with mouse and the resultant map can be saved directly in many graphic formats including png, pdf, and eps. See `http://matplotlib.org/users/navigation_toolbar.html` for more descriptions about its useful utilities.

`Done` button : Quit the panel. If you are not sure about measurements of the relative shift, go back to the masking stage and perform the correlation again. By iterating these steps several times, you may find the desired alignment. If the result seems fine, then proceed further to `SPIX map` panel.

6 Examining Spectral Index Distributions

The `SPIX map` task provides a spectral index map together with an error map. Be careful that VIMAP uses physical MilliArc-Second units for the display. Descriptions of each input parameters are given in the following.

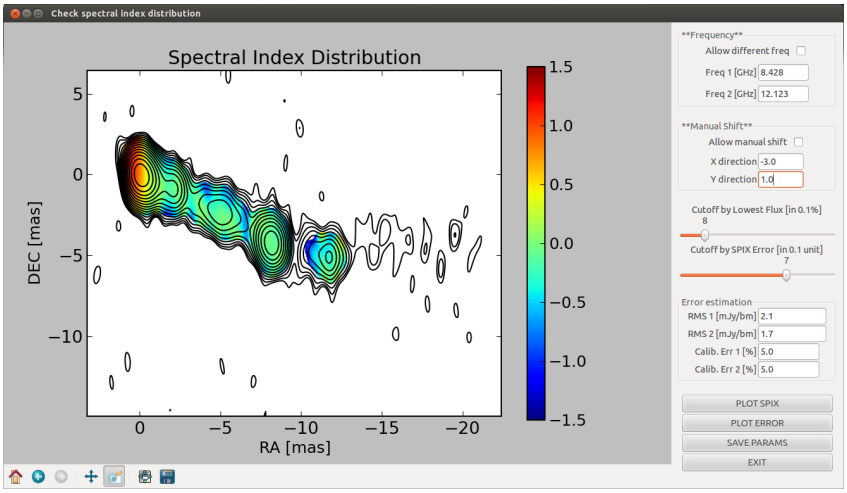

Figure 5: The `SPIX map` result. Colorbar denotes the spectral index value.

`**Frequency**` box : You can set observing frequencies of the two maps manually by using this box even though VIMAP can read frequency information from most FITS files from VLBI observations. `Freq 1/2` are for lower/higher frequency maps, respectively. This option bypasses formatting problems of frequency information in VLBI data.

`**Manual Shift**` box : The shift found by the 2D cross-correlation will be automatically used for the alignment. However, if you want to examine the impact of the alignment for other than the discovered optimal correction, you can check the "Allow" box and then can compute the spectral index again. Note that the input parameters are in units of pixel and it is always the higher frequency map that is shifted relative to the lower frequency map.

`Cutoff by Lowest Flux` slider : We used two cutoff criteria to derive reliable spectral index values. The first one is a marginal intensity boundary, outside of which no spectral information can be extracted. Any spectral index value outside of this

intensity contour will be removed automatically. Note that the unit is *0.1% of intensity peak of your map at lower frequency.*

`Cutoff by SPIX Error` slider : This slider sets a maximum error of the spectral index as additional cutoff. Note that VIMAP scales the indicated value by 0.1 times to set the cutoff.

`Error estimation` box : Spatial distributions of errors can be calculated with several assumptions. To compute errors, RMS levels of each intensity map and systematic amplitude calibration errors are required. `RMS 1/2` are the noise levels in the intensity maps obtained at lower/higher frequency in units of mJy/beam and `Calib.Err1/2` are systematic amplitude calibration errors in units of percent, respectively.

`PLOT SPIX` button : This button will plot the spectral index map by reading the parameters above. The colorbar range is currently fixed from -2 to 2. Please use `Interactive Navigation` of `Matplotlib` to explore the image in more detail.

`PLOT ERROR` button : This button will plot the spectral index error map.

`SAVE PARAMS` button : If you think the spectral index map derived from the image alignment process is good for further analysis, you can record all the input and output parameters as an ASCII file. The file's name would be `VIMAP_output*.dat` with `*` being a number for latest record in the working directory.

References

[1] Kim, J. -Y., & Trippe, S., 2014, VIMAP: an Interactive Program Providing Radio Spectral Index Maps of Active Galactic Nuclei, JKAS, 47, 195