

Simulate your own interferometer(s)

Getting started

- Read carefully the slides **The Techniques of Radio Interferometry I: The Basics**. This practicum will be based on them. References to these slides will be in red.
- We will make use of Python. Make sure you know how to import modules, define variables and loops, use arrays and matrices in numpy, plot images with matplotlib. If you really want to use a different language, that's fine, but we can't (guarantee to) provide debugging support.
- The practicum is divided into sections of increasing difficulty. Please follow the order.

Evaluation

- At the end of the practicum, you need to produce a short report containing the plots and answering the questions below.
- Read carefully what it is being asked and, in case of doubt, ask.

Goals

- Study different telescope array configurations (Slide 8) and evaluate pros and cons.
- Understand the uv-plane (Slide 33-35) and derive it for the different telescope designs.
- Obtain a synthesised beam (Slide 57, 60) for each telescope and use it to characterise the instrument.

Practicum overview

- Each section will explain what to do and what to put in the final report. Answers and plots to include in the report will be highlighted in blue.
- For each section, we will define a different telescope array and a matrix of its coordinates (Slide 63, 64) where 0s represent empty space and 1s represent antennas.
- You will be asked to simulate the telescope configuration on the ground for different configurations, to calculate the relative uv-plane (Slide 63, 64) and the resulting synthesised beam on the sky.

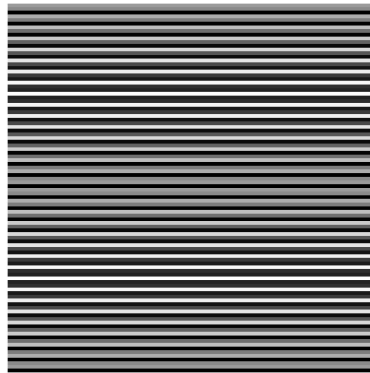
We use some assumptions and approximations. Some of them listed on [Slide 24](#) and [72](#). A not complete list also includes:

- Constant and uniform source located at DEC = 90° (where not explicitly indicated otherwise).
- All the antennas are at the same distance from the centre of the Earth (same geographic altitude).

You received a file called "pract1.py". It is a python script containing some functions useful for the practicum. You can read a quick help for these function inside the file itself. Always use this script when indicated, this will help to have coherent results from all the students.

Part 1 - Setting up the telescope

1. Create a "Practicum1" folder containing your work
2. Copy the received file "pract1.py" into this folder
3. Create a python script for the present section (e.g. part1.py)
4. Import "pract1" inside this script
5. Use the function `get_field` to simulate a telescope containing only two antennas. They will be placed along a vertical line in the middle of the field, at $\frac{1}{3}$ and $\frac{2}{3}$ of the field height. Use the function `plot_matrix` to plot the field. [Insert the plot in the report](#)
6. Write a function similar to `get_field`. It will take as input the same two arrays passed to `get_field`, and will return as output a matrix containing the uv-plane for the telescope ([Slides 51+, 63+](#)). Assume a unitary wavelength. Use the function `plot_matrix` to plot it. [Insert the plot in the report, indicating what are the units along the axes](#)
7. The function `fourier2D` computes the 2D Fourier transform of a matrix. Use it to calculate the synthesised beam and plot it. Check that it looks similar to the plot below and [insert the plot in the report, indicating what are the units on the axes](#)



8. Write in the report a short paragraph addressing the following points (also see [Slide 30](#))
 - a. What would you see observing a bright, point source?
 - b. What would you see observing a bright, extended source?
 - c. Describe one or two possible solutions to improve the observations
9. Try to simulate another simple array configuration. [Inserting in the report the plots of the field, uv-plane and synthesised beam and a brief comparison on the performance of the two telescopes](#)

Part 2 - The Westerbork Telescope

We are going to reproduce the Westerbork telescope, in the Netherlands, one of the destinations of our field trip.

1. Create a new python script for the present section (e.g. part2.py)
2. Read the telescope webpage www.astron.nl/radio-observatory/public/public-0 How many antennas form the telescope? What is their configuration?
3. Have a look at the technical description of the array configuration www.astron.nl/radio-observatory/astronomers/wsrt-guide-observations/3-telescope-parameters-and-array-configuration
4. Simulate the Maxi-Short configuration of the telescope. Insert the usual three plots in the report. How does the observation change over the telescope simulated in Part 1? What is the purpose of the four moving dishes labelled A, B, C and D?
5. How does the instantaneous uv-plane change for a source at DEC=30° between HA=0h and HA=6h? Show it in the report with a plot or a description. Explain why the uv-plane changes.
6. Simulate the uv-coverage in a 12-h observation and plot the associated synthesised beam. You can use the function rotate_matrix to rotate the telescope and track the rotation. Insert the plots of the rotated uv-plane and the resulting beam in the report. How does the telescope response change with respect the instantaneous observation? How does this affect observations?
7. What are the weak features appearing in the image around the central beam? How do they affect an observation?
8. Modify the for loop inside the function rotate_matrix in order to simulate uv-plane for sources not at DEC=90°. Use the equations on Slide 64, considering that the telescope lies on a plane (Slide 51) and it has a E-W configuration. Recreate the plots on Slide 60 and report them

Part 3 - The Very Large Array (VLA) Telescope

Our next telescope to simulate is the Very Large Array (VLA), which is located in the USA.

1. Create a new python script for the present section (e.g. part3.py)
2. Read the main characteristics of the telescope on the relative Wikipedia page. [Why do you think this particular design has been chosen?](#)
3. Simulate the D configuration. Use the description given by Thompson et al., 1980 (The Very Large Array) reported in Table 3 and Fig. 4. [Insert the three plots in the report.](#) Does your uv-plane look similar to the one represented on [Slide 57](#)?
4. The real VLA is more complicated because the antennas are not equally spaced, but they are denser in the centre of the array. [Explain briefly why](#)
5. VLA antennas are on rails and can be moved closer or more distant from the centre of the telescope along tracks. [Why do you think money and efforts have been spent to enable this feature? Give a justification possibly supported by numerical evidence](#)

Part 4 - LOFAR

Our last telescope to simulate is LOFAR, in the Netherlands, one of the destinations of our field trip.

1. Create a new python script for the present section (e.g. part4.py)
2. Read the main characteristics of the telescope on the two following web pages <http://astron.nl/radio-observatory/astronomers/users/technical-information/lofar-array-configuration/lofar-array-conf> <http://astron.nl/radio-observatory/astronomers/users/technical-information/lofar-stations/lofar-stations-description->
3. Simulate the synthesised beam from the instantaneous uv-coverage for LBA antennas in one international station. You can assume that antennas are randomly placed (numpy.random.randint can help with this). [Report the usual plots.](#)
4. [What is the performance with respect previous array configurations? Why? Why do you think other array configurations were preferred in the past while now pseudo-random configurations are widely used \(e.g. see MeerKAT, SKA\)?](#)
5. LOFAR has different observing modes. It is possible to observe by correlating the antennas within one station, a mode called standalone (which you simulated in the previous question). It is also possible to correlate different stations as if each one were a different dish of a traditional array. Use this information to replicate the two plots at the top of each of the images shown at the bottom of <http://astron.nl/radio-observatory/astronomers/users/technical-information/lofar-array-configuration/lofar-array-conf> and [insert the four plots in the report.](#) You can use approximate and pseudo-random locations for the 24 stations.