Tutorial: Introduction to Interferometry and Aperture Synthesis

RADIOASTRONOMIA

maggio 2026

1 Introduction

In this tutorial we are going to explore some of the basic properties of interferometry. In particular, we are going to look at the response of an interferometer array, and the images that result from different arrays (so-called aperture synthesis).

For this exploration, we will make sure of a very nice python application, called APSYNSIM. This application allows you to select a model for your source, an set of telescope locations, an observing wavelengths, and some other parameters, and then shows what the spatial response of the interferometer is and what image you will get.

2 Exploring the Interface

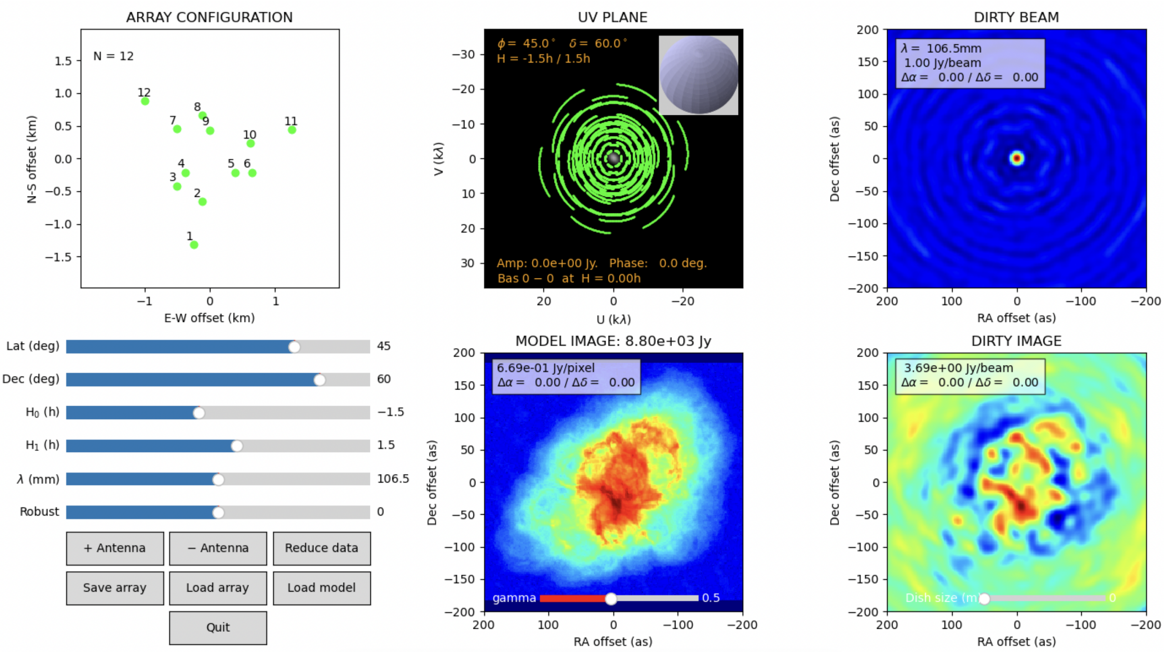

Figure 1: Starting screen of APSYNSIM

Let's explore what we are seeing. Clockwise, from top-left (Fig. 1):

- **ARRAY CONFIGURATION:** Locations of the antennas. You can click on an antenna and move it.

- **UV PLANE:** Every point (u, v) corresponds to a baseline between two antennas. Units are kilo-wavelengths rather than meters, because this is immediately translatable to resolution (remember that resolution goes as λ/B, with λ the wavelength and B the baseline length). Earth rotation causes individual baselines to trace out curved paths.
- **DIRTY BEAM:** The spatial response of the interferometer. For now, think of it as the response of the interferometer to a point source located at the center of the field of view. This is directly comparable to the point spread function that you may know from single dish astronomical imaging.
- **DIRTY IMAGE:** The image as will be produced by the interferometer of the astronomical source. Think of it as the real image of the source convolved with the point spread function (or dirty beam). Units of the plotted intensity are 'Jansky-per-beam' which is equivalent (but not identical) to $\mathrm{W\,m^{-2}Hz^{-1}sr^{-1}}$.
- **MODEL IMAGE:** The adopted image of an astronomical source, or any other model we can come up with. Units of the image are 'Jansky-per-pixel'.
- **Controls (lower right):** Here you can change parameters such as latitude of the observatory, declination of the source, start (H0) and end (H1) hour angles of the observations, wavelength, and the 'robust' parameter. There are also buttons to add or remove antennas, reduce the data, save/load arrays, and load new source models.

Questions for Exploration:

- Locate these panels and controls. How many antennas does this array have? Over what distances from each other are they located? At what latitude on Earth is the array located?
- Set the range of H0-H1 to 0 hrs, that is, make the observation really short. What happens to the UV plane? And to the dirty beam? And the dirty image?
- Set the wavelength to the largest possible value. What happens? Set it to the shortest wavelength. What happens now? Explain!
- Move all antennas close to each other. What happens? Now move a few as far away as possible. What happens? Explain!
- Move all antennas to one corner of the EW/NS offset space. What happens? Explain! Note that the absolute position of the antennas doesn't matter. All that matters are the relative distances.

3 A Two-Element Interferometer

Load the *Two-antennas Long* array and the *Point-source* model.

- Explain what you see in the DIRTY BEAM and DIRTY IMAGE panels. Compare what you see to what you have learnt about the two-slit experiment.
- Vary the observing wavelength, and explain what you see.
- Vary the baseline length and direction, and explain what you see.
- Change the length of the observation to run from -5 to +5 hours. Explain what happens. Can you now see where the point source is in your input image?
- Verify that the resolution is approximately λ/B.

- Add a third antenna located on the line through the first antenna. Describe what happens.
- Now move this new antenna to a location north of the line connecting the other two antennas. What happens?

4 An E-W Array and Real Arrays

Load the array *E-W* and (re)load the *Point-source* model.

- Explain what you see. Now add Earth rotation, by extending the observation from -5 to +5 hrs. What happens?
- Move the source to a declination of 0°. Explain what happens. Add a few antennas on a N-S baseline, and return the length of the observation to close to 0 hrs. What happens?
- Now load a real array, the *VLA-A* array. Explain what you see. Repeat this by loading *ALMA-ACA-Cycle1-Conf5*. Why is the DIRTY IMAGE so much clearer?
- With the ALMA array loaded, now load a real source image, *RadioGalaxy*. Vary the wavelength. Explain why for short wavelengths you don't see much in the image, but for long wavelengths, you get a good representation of the source.

5 Creating an Image: The CLEAN Algorithm

An 'imperfect' array (poor (u, v) coverage) will produce many artefacts in the dirty image, corresponding to the sidelobes of the dirty beam. The most widely used technique to remove artefacts is the CLEAN algorithm. This technique assumes that the true image can be described by the sum of many point sources. It creates this model iteratively:

1. Start with the dirty image.
2. Find the brightest pixel, and place a point source with (typically) 10% of that pixel's brightness in the model.
3. Calculate the interferometer's response to this model, including the sidelobes it would produce.
4. Subtract this response from the dirty image, to produce a residual image.
5. Repeat from step 2, finding the next brightest pixel in the residuals.
6. Continue until the only thing left in the residuals is noise.
7. Now produce the 'restore' image by (a) convolving the model with a gaussian that represents the finite resolution of the measurements, and (b) add back in the residuals.

Practical Exercise:

- Select the following setup: *Default Array*, *One Disc* model, $\lambda = 80$ mm, and a very short HA range (~ 0). Click on 'Reduce Data'.
- Without changing any of the settings, press the CLEAN button. What do you see?
- How many CLEAN cycles do you need to get a good image? What do the 'restore' and '+/- residuals' buttons do?
- **Challenge:** Let's throw APSYNSIM a much more difficult setup to clean: *Radio Galaxy*, *ALMA-ACA-Cycle1-Conf5*, $\lambda = 2.7$ mm, and an hour angle range from -1 to +1. You may need a few thousand of iterations to get a good image.