

Introduction

Here you will inspect a Very Large Array image, and analyze the radio spectrum of a source whose nature is still greatly debated. The source is co-located with the repeating fast radio burst FRB121102, which is in a galaxy at a distance of $D \sim 700$ Mpc. FRB121102 is the only FRB that has been found to have other associated emission: the compact, non-bursting (“persistent”) radio source, PRS, that you will be analyzing.

Get the data and figure out how to access CASA and/or DS9 here:

<https://sarahspolaor.faculty.wvu.edu/classes/astr700/project-2>

The image is in FITS format, which is the most common file format for astronomical data. You will use either CASA (one of the world’s most popular radio interferometry analysis softwares; works only on MacOS and Linux), or DS9 (a highly popular image analysis software; works on any operating system).

Be sure to check this week that you can run either software; do not wait until just before the project is due.

Here is a paper that gives some science background on FRB 121102 and its PRS:

<http://adsabs.harvard.edu/abs/2017Natur.541...58C>

In this project, you will analyze the continuum spectrum of the target, and discuss what physical emission process(es) might or might not be powering FRB 121102’s mysterious PRS.

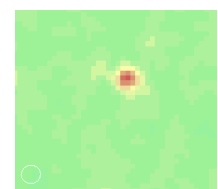
Get familiar with a radio image

First, you will plot an image. Open your image in DS9 or using CASA’s *viewer* task. The image was made from data spanning a 4 GHz bandwidth centered on 10 GHz. It has already been deconvolved from the dirty beam of the VLA, and therefore represents noise plus source structure, within the limitations of the experiment resolution. That is, compact (unresolved) sources should look like a 2D Gaussian with a FWHM the same size as the synthesized beam.

Get familiar with the image properties by playing with the color scaling, and zooming in to various regions.¹ Note that the telescope was pointed directly at the PRS, therefore it is at the center of the image. For your own education, try to witness the following image features:

- The PRS is faint, and at the center of the image. **Zoom in and make an image of it to include in your report.** Be sure to include axes and ensure the source itself is clearly visible. If possible, scale it so you can also see the background noise level (see my reference image below). Use whatever colormap you like; greyscale and false color are probably most popular for radio images.
- The image itself appears to have round corners. This rounded cut-off marks approximately the primary beam FWHM, so we are seeing the full field-of-view of the VLA.
- Note how the background noise gets larger as you move away from the image center. This is because the sensitivity gets worse as you move outwards in the primary beam pattern.
- There is a bright, off-center source in the field. It still has some striping from imperfect deconvolution. Sometimes this happens with bright sources as a result of limitations in calibration.
- Note the measurement units in the image. Ask yourself: is this a flux density or a brightness?

CASA conveniently puts the FWHM synthesized beam shape onto the image (DS9 does not); see the example to the right. The synthesized beam is in white, bottom left. Visually inspect the source as compared to the synthesized beam shape (in your image or mine). Although there is some noise at low levels, this source appears to not be extended beyond the synthesized beam. Thus it is compact! The synthesized beam in this image has a FWHM of approximately 0.6 arcseconds.



¹ Chapter 7 in the CASA users guide gives detailed instruction on the usage of the *viewer* gui, and the online resource linked for DS9 gives instructions on how to work with images for that software.

Analyze the spectrum

Plot and inspect the continuum spectrum. Be sure to include error bars. The file fluxes.txt has a first line that serves as column headers. Now that you have plotted the spectral energy distribution, perform and report the results of three fits to this data:

- A power-law fit to all the data.
- A power-law fit using only lower-frequency data.
- A power-law fit using only high-frequency data.

Discuss the results of this. Specifically, of the emission mechanisms we've discussed in class, which can/cannot be supported by this spectrum? Your discussion here is open-ended, but at the very least should discuss the spectrum in reference to the three mechanisms we've discussed so far. In case you feel lost, the basic calculation/topic you could discuss is whether a single power-law spectrum a good fit to this data or is there evidence of a turn-over or break in the spectrum, and could any mechanism cause this change? This discussion can be as simple as a demonstration of "x mechanism is ruled out, but z cannot be ruled out."

You are welcome to go beyond and try to infer as much physics or detailed analysis as you want or have time for! I will award up to 5 extra points to any correct analysis beyond the above point.

Equipartition analysis

Finally, assuming a single power-law fit to this data, assume that the equipartition condition holds for this object and determine the minimum energy and minimum magnetic field in this object, again assuming the source fills the beam. What is the object's lifetime if its energy source has been turned off?

Final product: your "published" project write-up

As with project 1, write up your results in the form of a short lab report. The report should have an abstract, introduction, methods, data, results, discussion and conclusion sections and include figures/tables where appropriate. For this project, I expect the discussion will be the longest component; you should justify any claim you make with calculations/evidence. As with before, in any paper, you should provide enough description (i.e. how you got to your conclusion via evidence and being explicit about your assumptions) and detail to enable this. Similarly, all plots need axes labels, units, and a brief caption! Remember to include error bars where appropriate.

This table of values will assist with your equipartition analysis.

The functions:†

$$c_{12} = c_2^{-1} c_1^{1/2} \frac{2\alpha - 2}{2\alpha - 1} \cdot \frac{\nu_1^{(1-2\alpha)/2} - \nu_2^{(1-2\alpha)/2}}{\nu_1^{1-\alpha} - \nu_2^{1-\alpha}}$$

$$c_{13} = 0.921 \cdot c_{12}^{4/7}$$

for $\nu_1 = 10^7$ Hz and $\nu_2 = 10^{10}$ and 10^{11} Hz.

In these equations, $S_\nu \propto \nu^{-\alpha}$

α	$\nu_2 = 10^{10}$ Hz		$\nu_2 = 10^{11}$ Hz	
	c_{12}	c_{13}	c_{12}	c_{13}
0.2	2.5 E 07	1.6 E 04	8.3 E 06	8.3 E 03
0.3	2.8 E 07	1.7 E 04	9.8 E 06	9.1 E 03
0.4	3.2 E 07	1.8 E 04	1.2 E 07	1.0 E 04
0.5	3.7 E 07	2.0 E 04	1.6 E 07	1.2 E 04
0.6	4.5 E 07	2.2 E 04	2.0 E 07	1.4 E 04
0.7	5.4 E 07	2.5 E 04	2.8 E 07	1.7 E 04
0.8	6.5 E 07	2.7 E 04	3.9 E 07	2.0 E 04
0.9	7.8 E 07	3.0 E 04	5.4 E 07	2.4 E 04
1.0	9.3 E 07	3.3 E 04	7.1 E 07	2.8 E 04
1.1	1.1 E 08	3.6 E 04	9.3 E 07	3.3 E 04
1.2	1.3 E 08	4.0 E 04	1.1 E 08	3.7 E 04

† For $\alpha = 1/2$ and 1 the functions c_{12} and c_{13} have values following from the appropriate formulae resulting from the integration of equations (7.4) and (7.5).

Table 8 from Pacholczyk's Radio Astrophysics. Here $\nu_1 = \nu_{\min}$ and $\nu_2 = \nu_{\max}$.