ASTR700, Project 2 **Mystery Source Analysis** **Due 4 April (Weds)**

Introduction

Here you will consider the radio spectrum of a source whose nature is unknown; this is emission that comes from the region around the fast radio burst FRB 121102 ("the repeater"), which is in a galaxy at a distance of D ~ 700 Mpc. The FRB was found to be at the same sky location as a compact, non-bursting ("persistent") radio source, aka the "PRS." You will be extracting and analyzing the radio spectrum of this source using Very Large Array images, with one of the world's most popular radio interferometry analysis softwares, CASA. See this page to get the data and figure out how to get access to/use CASA:
`https://sarahspolaor.faculty.wvu.edu/classes/astr700/project-2`
Be sure to check immediately that you can get CASA to run; 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 spectral shape of the target, and discuss what physical emission process(es) might or might not be powering FRB 121102's mysterious PRS.

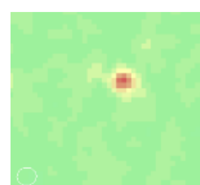
Inspect the images

The "*fits*" format radio images you downloaded have already been deconvolved from the dirty beam of the VLA, and therefore are representative of source structure plus noise. Each image represents a different VLA observation. The *fits* header information can be read in CASA using task `imhead`. Here is an example on how to access a CASA task; each task is designed to interact with the data in some way:

```
> default 'imhead'               [calls up imhead with its default parameters]
> inp                            [displays the parameters available in this task]
> imagename='myimage.fits'       [sets the desired parameter]
> go                             [executes the task]
```

The results of the task show up in the CASA logger window. This listing tells you some information about the observation and image, including the frequency and bandwidth. The telescope was pointed directly at the PRS, therefore the RA/Dec you find here is the PRS's approximate sky position.

Measuring a broad-band continuum spectrum with the VLA usually involves 1) calibrating data; 2) making images; 3) fitting the target source; and 4) fitting the spectral index of the target source across all data. Your colleague Sarah has already performed these steps for the L, S, C, and Ku band data (1, 2, 6, and 15 GHz, respectively). Those results are in file `fluxes.txt` ; for your data files, you will be performing steps 3 and 4. Image fitting can be done graphically using CASA's image-viewing task, `viewer`. Chapter 7 in the CASA users guide gives detailed instruction on the usage of this gui. Get familiar with the viewer gui; play around with the image's color scaling ("transfer function") by selecting the tool. Zoom into an object of interest by using the zoom/unzoom buttons , or box a specific region to zoom in on by using the tool (to zoom, you'll have to draw the box then double click within the region).



Play with the transfer function so you can be sure you can see the PRS. Conveniently, CASA puts the FWHM synthesized beam shape onto the image; 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. Note that the beam has a distribution that is approximately Gaussian, and so although there is some noise at low levels, this source appears to not be extended beyond the synthesized beam. If this is not the case at any of your images, note this for later comparison with the image fit.

Measure the spectrum

Statistical image fitting is a much better way to assess the source's shape and flux density than by-eye analysis. Image fits rely on fitting the source with a 2D Gaussian shape; the fit then reports the modeled source size and peak/integrated flux density properties. Show CASA what object you want to analyze by using  to box a small region around your target of interest, then click the `imfit` tool, . In the dialog box, select "Region" and then click "Fit". The results will appear in the CASA log window. You can optionally save the fit to a text file ("Save Fit Output" and specify details—you want to save "Log" not "Region"). If the program takes more than ~3 seconds after clicking "Fit", your boxed region was probably too big or you forgot to select "Region". If that happens, you can wait or kill CASA and try again.

Once you've run a fit, inspect the image and the output log. The latter reports properties of the synthesized ("clean") beam and results of the fit. The image will now show a trace of the fitted source size. How does the fit compare with the synthesized beam? Inspect the output log and consider the (deconvolved) source size and beam size. Note: imfit's quotation of whether something is a point source or not is often misleading and requires astronomer interpretation. Regardless of whether imfit reports the object to be "a point source", based on the deconvolved size at each frequency, does the object appear to be extended or not? Add your measurements of integrated flux and error to the `fluxes.txt` file and plot/inspect the continuum spectrum.

Analyze the spectrum

Now that you have plotted the spectral energy distribution, run some calculations and have a general discussion about it. In particular, of the emission/absorption mechanisms we've discussed in class, which can/cannot be supported by this spectrum? As a suggestion to guide your analysis: what is the minimum brightness temperature of this emission, assuming the source size fills your beam? Is a single power-law a good fit to this data or is there evidence of a turn-over? What could cause this turn-over? This discussion can be as simple as a demonstration of "x mechanism is ruled out, but z cannot be ruled out." I will grade for that basic level of discussion for emission mechanisms we've discussed. As noted in class, you are welcome to go beyond and try to infer as much physics or detailed analysis as you want or have time for! If you can infer something interesting that I haven't from this data, you will be welcome as a co-author on the paper that will report my own version of this same analysis (aiming to publish this summer). Before or after the project due date, I am happy to discuss any theories or ideas you'd like to bat around.

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. As with before, in any paper, you should provide enough description (i.e. how you got to your conclusion via evidence) and detail (i.e. values of all relevant observed/assumed/telescope set-up parameters) to enable this. Similarly, all plots need axes labels, units, and a brief caption! Remember to include error bars where appropriate.