Demystifying Radio Astronomy: Fundamentals And Data Exploration
Krittika Summer Projects
Week 1

Introduction

Radio astronomy is a quite recently developed field of astronomy, especially when compared to its centuries old optical counterpart. Although a lot of things are common in the two, radio astronomy has its own unique set of problems and subsequent ways to solve them. Over the course of this project, we will be looking to build upon our knowledge of physics and astronomy to explore the radio universe with radio telescopes.

But before we go into the details, a quick brushing up of basics is necessary. Our approach to this project will be two-fold. We shall be going through theory and computational work, simultaneously. This will help you get a stronger grasp on the subject, and understand how to analyse data in radio astronomy, commanding a stronger hold on the subject.

This week shall serve as a time to revisit some important concepts and get a glimpse of why radio astronomy can be instrumental in our pursuit of studying the universe. Our reference text will be **FUNDAMENTALS OF RADIO ASTRONOMY: Observational Methods by Marr, Snell and Kurtz** (henceforth referred to as **the textbook**). We will focus on certain chapters only, however you are encouraged to read other chapters too if you are interested and have the time to do so.

This week, our focus will be Chapter 1 of the textbook. It is highly recommended that you at least glance at the problems throughout the chapter and see if you can solve them (this is only meant for your understanding and does not have to be submitted). You should also write down briefly the important takeaways from the reading material as a general practice that will eventually help with writing your report.

The Tasks section below is meant to be complementary to the reading and you should spend as much time necessary to assimilate all the concepts covered.

Tasks

1 Multi-Wavelength Astronomy

Multiwavelength has been one of the buzzwords in recent astronomy research. Why aren't "normaloptical" telescopes enough, why do we need other wavelengths? We are fortunately equipped with direct evidence to answer this question - so let's have a look. In this activity, we will try to choose interesting portions of the sky and compare the images from different telescopes to see how astrophysical objects differ in their emission at different wavelengths. To obtain the images, we will use the CIRADA image cutout web service as described below. `http://cutouts.cirada.ca/get_cutout/`

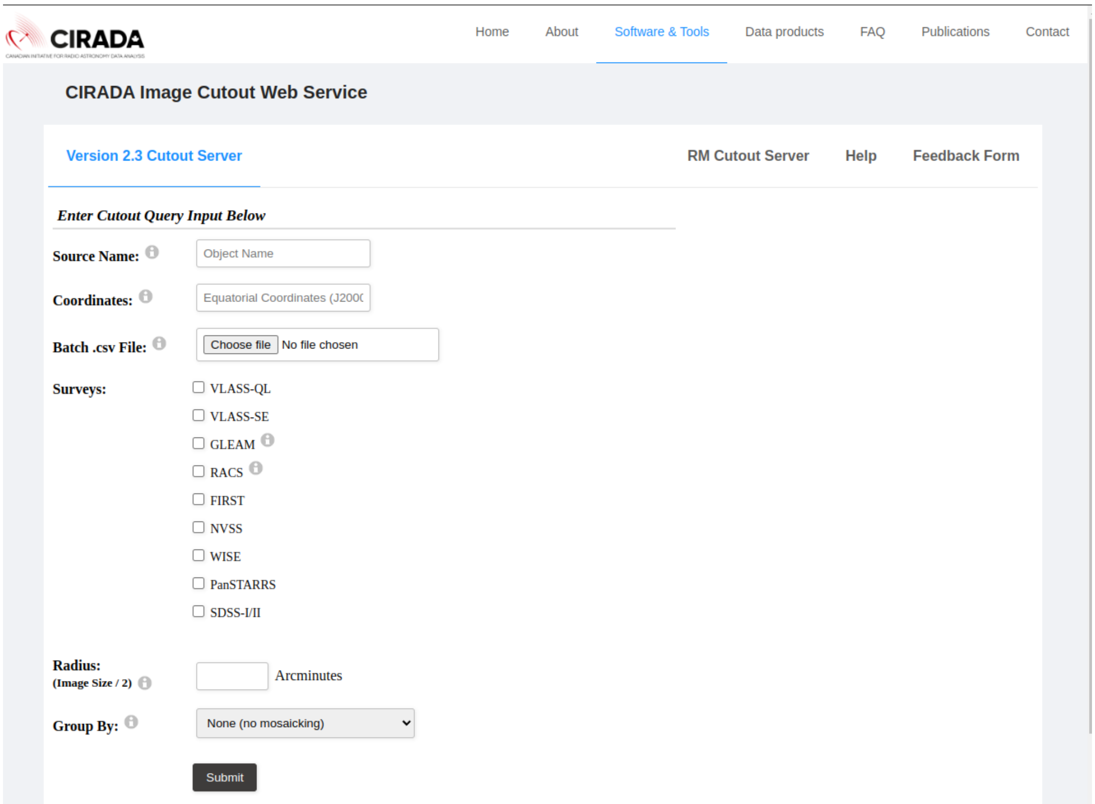

Figure 1: What you should see on the website

1. Enter the coordinates or name of the object you would like to see - a list of interesting objects can be found at `https://ragolu.science.ru.nl/hcat.html`. (Hint: select objects from the Jets and Lobes section for best results.)

2. Choose the survey you are interested in. For first pass, you can choose the VLASS survey for radio images and the WISE survey for infrared images (you can add PANSTARRS or SDSS for optical). The boxes within these options represent epochs or filters within the survey, you can tick all of them.

3. Choose the cutout size you want ; 1-2 arcminutes is a reasonable starting point.

4. Note: There is a help section in the top right corner that gives you information about the various surveys and the formats to be used while entering the RA-DEC of the desired region.

Task : Select your 3 favourite galaxies that have data in multiple wavelengths. Download their image files with the .fits extension (`https://fits.gsfc.nasa.gov/`) by clicking on the Download icon at the bottom right corner of each cutout. Use astropy and matplotlib to access and plot these images side-by-side for comparison. Note down the differences in a couple of sentences for each.

2 Let's do some theory!

The Giant Metrewave Radio Telescope (GMRT) is our very own world-class facility for research in radio astronomy operated by the National Centre for Radio Astrophysics (`http://www.gmrt.ncra.tifr.res.in/index.html`). In the coming weeks we will learn a lot about how radio telescopes work and how we can deal with the data they collect, but first let's brush up our observing basics. Given a telescope site, there are many things you should be able to deduce that will help you plan observations. Assuming you are an observer located at the GMRT site in Narayangaon, Pune (latitude of about +19 deg N). Let's try answering these questions. If you read the textbook well, these questions should be manageable. We are always here for any sort of doubts that you have.

1. What is the altitude and azimuth of the North Celestial Pole?
2. What is the altitude at transit of an object on the celestial equator (Dec=0 deg)?
3. What is the azimuth of a star on the celestial equator at the moment that it is setting?
4. Assuming GMRT can observe everything above the horizon, which of the following can never be observed with GMRT - M45, M83, Omega Centauri, Cassiopia A, Centaurus A, Large Magellanic Cloud, Andromeda Galaxy, Carina Nebula?
5. GW170817 (named by discovery date - 17 August 2017) was the first ever detection in electromagnetic waves of a compact binary merger event of two neutron stars following its detection in gravitational waves with LIGO (More info : `https://www.ligo.caltech.edu/page/press-release-gw170817`). You are tasked with obtaining radio data of GW170817 (RA 13h 09m 48.08s and Dec -23d 22m 53.3s). What is the expected altitude of GW170817 when it is transiting?
6. **Bonus** : Radio telescopes are capable of observing even during the day as long as the source not close to the Sun in the sky. Check the position of the Sun during GW170817 - can you comment on its visibility during that period? Can you think of some specific time of the year when it would not be possible to observe GW170817?

3 Plotting The Jet Afterglow Lightcurve Of GW170817

GW170817, as mentioned earlier, was a merger of two neutron stars that was accompanied by both gravitational waves and electromagnetic radiation. We will explore this event more in the upcoming weeks. For this activity, we will be using the data for the non-thermal emission from this source that spans across all frequency bands following a single spectral index of $F_\nu \propto \nu^{-0.584}$. The quantity F is the flux density, which measures the amount of energy incident on the detector per unit area of the detector, an indicator of the brightness of the source. A lightcurve is this flux density represented as a function of time. The dataset in the ascii format is present at `http://www.tauceti.caltech.edu/kunal/gw170817/gw170817_afterglow_data_full.txt` which was compiled by Makhathini et al. 2021.

Task: Download this dataset and plot the lightcurve choosing all the VLA `https://public.nrao.edu/telescopes/vla/` 3 GHz data points. Use astropy and matplotlib to plot the lightcurve.

Bonus : Choose another instrument, say Chandra (`https://chandra.harvard.edu/`) an X-ray instrument that has observations of our source at 2.41 x $10^{17} Hz$. Scale the Chandra flux densities to 3 GHz using $F_\nu \propto \nu^{-0.584}$and over plot the Chandra data points over the VLA 3 GHz data points that you just plotted.