Observational Techniques 2 - Assignment 1

Carys Gilbert (GLBCAR006) and Aidan Martin (MRTAID003)

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Introduction

The MeerKAT Galaxy Clusters Legacy Survey (MGCLS) was a programme that involved radio observations of 115 galaxy clusters. Observations were in the range of 900-1670 MHz, the L-band, and took place between June 2018 and June 2019. One of the galaxy clusters that were observed was J1645.4-7334, located at RA/DEC of (16:45:26.2 -73:34:54).

This assignment made use of one of the freely available legacy data products from Data Release 1 of the MGLCS, specifically a frequency cube for J1645.4-7334, consisting of 12 frequency planes of increasing centre frequencies, from approximately 908 to 1656 MHz. These frequency planes show 1.2° x 1.2° of the field.

We aim to extract the spectral indices of 5 chosen point sources visible in the frequency cube, as well as find out any further information on these sources, if any are available in other databases.

Flux Extraction Method and Results

To start extracting data from the frequency cube, the 12 frequency planes were first separated and saved as individual FITS files, with the headers appended to include the frequency of each slice. The first slice was loaded into the visualisation software DS9, and circular regions were drawn around five point sources. The five chosen regions can be seen in Figure 1 below, A larger region was drawn in an area with no sources to capture the background. These five source regions, alongside the background region, were used in the radioflux [1] function *flux_for_files* to find the flux densities of each of the five point sources for every frequency plane.

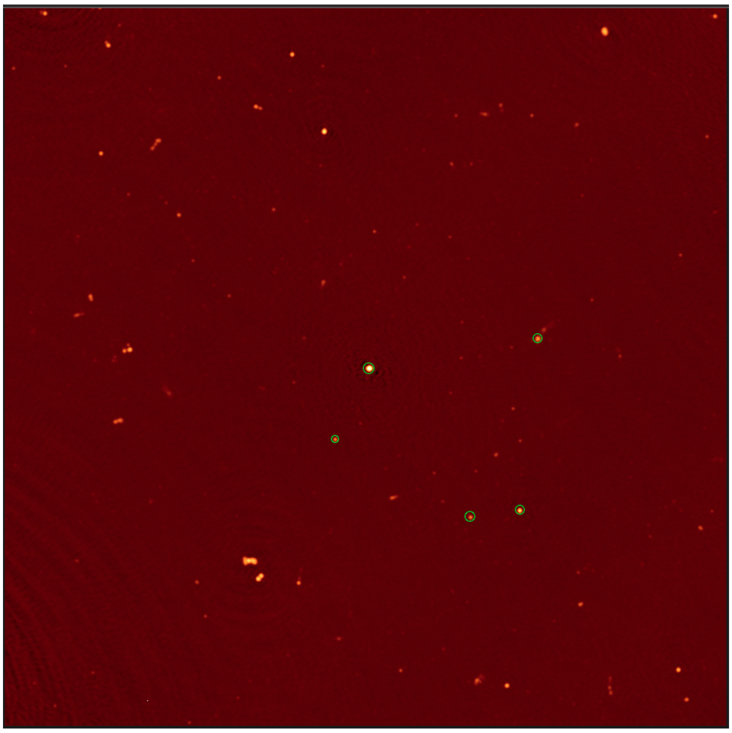

Figure 1: The first frequency slice of the data cube, with the regions drawn around the five chosen point sources shown in green.

Flux density has a power law dependence on frequency given by the spectral index parameter. To find this spectral index, a line of best fit was calculated for each of the five sources by fitting the data with a power law, in the form of:

$$S_\nu \propto \nu^\alpha \Rightarrow S_\nu = n\nu^\alpha \tag{1}$$

where S_ν is the amount of flux, n is some scaling constant, ν is the frequency, and α is a constant, the spectral index. The best fit parameters and their associated uncertainty values are found in Table 1. From these results, we can see that all five sources have negative spectral indices.

Source	n	u(n)	α	u(α)
1	154.088932	16.056377	-0.772594	0.014698
2	1.492442	0.216776	-0.602387	0.020454
3	8.430980	1.529763	-0.723232	0.025581
4	35.850342	7.664356	-0.866218	0.030182
5	0.328984	0.063768	-0.367788	0.027234

Table 1: Best Fit Parameters for Sources 1-5.

The data and fitted lines are plotted in Figure 2, on the left. Visually, the best fit lines seem to closely approximate the data points, however, the data's frequency range is limited to a region spanning 770 MHz, as a result of the observations being L-band exclusive, from 900 to 1670 MHz. Therefore, while these best fit lines might accurately approximate our current data, it is not necessarily accurate to a broader wavelength range.

Source Information

Using the SIMBAD Astronomical Database [2], additional information in other wavelengths was only found for the source at the centre of the pointing, which we chose to be our first source. This source is the Seyfert 2 galaxy LEDA 254972, located at $z = 0.06922$. and originally identified in the radio in 1975 with the Parkes radio telescope (see [3]). Aside from this source, however, none of the other sources were found on SIMBAD. This is likely due to them being too feint to detect or study precisely in other wavelengths.

Extra Radio Data and Results

To further calibrate the spectral indices of our 5 point sources, additional radio observation data was used in conjunction with the original data. Using the Aladin Sky Atlas software [4], additional flux density measurements that were taken as part of the SUMSS survey [5] were found for each of the sources. These measurements were taken at a frequency of 843 MHZ, which is outside of the range of the L-band and thus broadens our wavelength range. Including these other measurements, and recalculating the line of best fit produces parameters detailed in Table 2.

Source	n	u(n)	α	u(α)
1	154.102917	15.316618	-0.772606	0.014019
2	1.541052	0.248796	-0.606842	0.022739
3	8.449736	1.461432	-0.723541	0.024385
4	35.930592	7.320756	-0.866529	0.028766
5	0.324715	0.059693	-0.365975	0.025837

Table 2: Revised Best Fit Parameters for Sources 1-5 using Additional Radio Observation Data from the SUMSS survey.

The updated data and fits are plotted in Figure 2, on the right. It is clear to see that the SUMSS data is much less precise than the MeerKAT data, resulting in the much larger uncertainties seen. Despite this, as we performed a weighted fit, the addition of the extra point did not significantly alter the fit parameters. This difference in data quality is to be expected, as MeerKAT data is some of the best radio data available at the moment.

This assignment highlighted the differences between MeerKAT and other radio telescopes, as well as the importance of using all wavelengths in astronomy. These point sources which appear so bright in the MeerKAT data were only previously catalogued in the SUMSS survey, and four of the five sources are yet to be explored in any other wavelengths. Hopefully as our instrumentation improves across all wavelengths, sources such as these will be studied as much as possible.

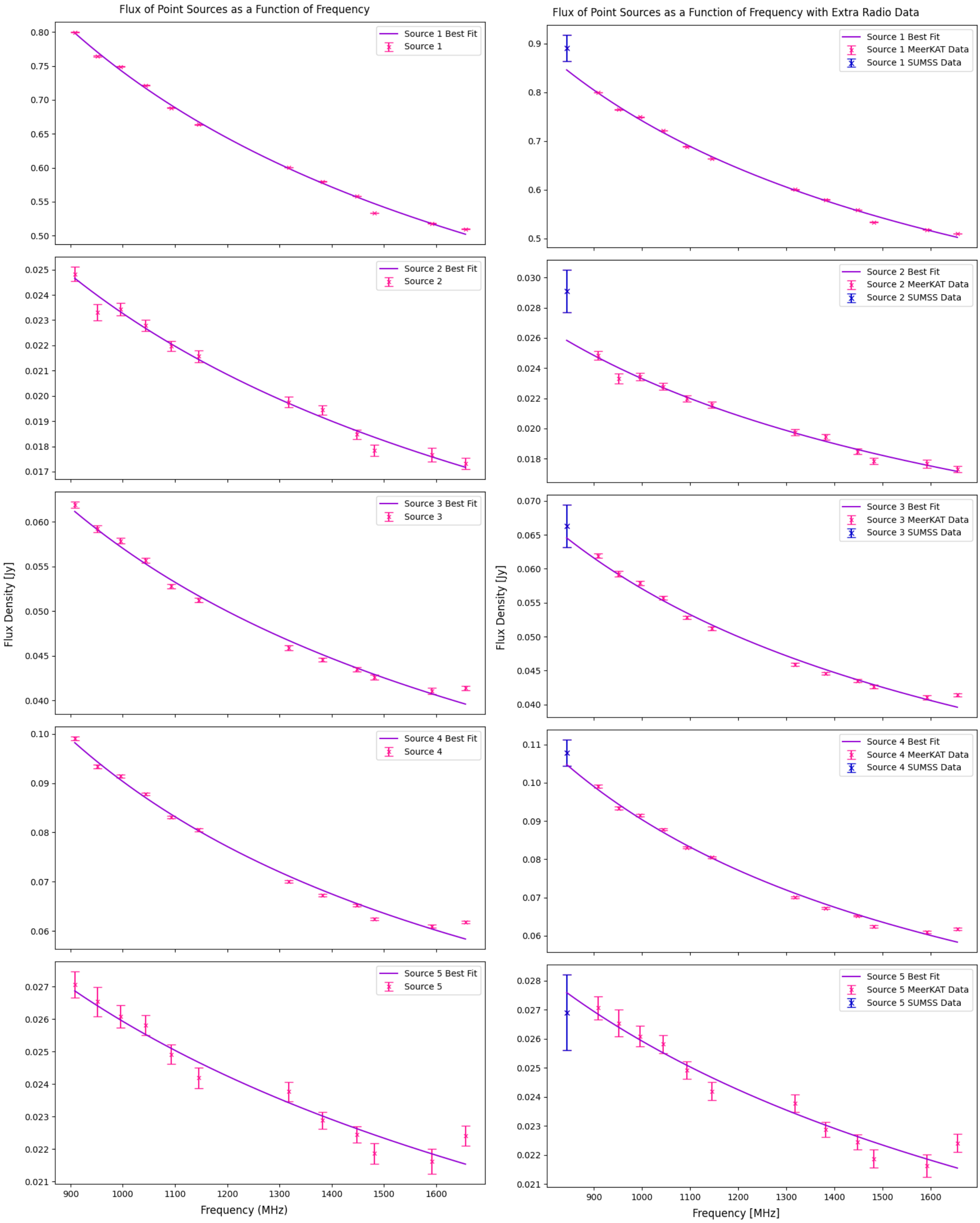

Figure 2: Plots of Flux as a function of frequency for the 5 point sources, along with respective lines of best fit in the form of the power law defined in Equation 1. The left column shows only the extracted flux densities from the MeerKAT cube, while the right column shows the inclusion of the SUMSS data points.

References

[1] M. Hardcastle. *radioflux - Measuring radio flux density with ds9*. Version 1.3. June 13, 2020. URL: `https://github.com/mhardcastle/radioflux`.

[2] M. Wenger et al. "The SIMBAD astronomical database. The CDS reference database for astronomical objects". In: 143 (Apr. 2000), pp. 9–22. DOI: `10.1051/aas:2000332`. arXiv: `astro-ph/0002110 [astro-ph]`.

[3] J. G. Bolton and P. W. Butler. "The Parkes 2700 MHz Survey (Eighth Part): Catalogue for the Declination zone -65^o to -75^o". In: *Australian Journal of Physics Astrophysical Supplement* 34 (Jan. 1975), p. 33.

[4] F. Bonnarel et al. "The ALADIN interactive sky atlas. A reference tool for identification of astronomical sources". In: 143 (Apr. 2000), pp. 33–40. DOI: `10.1051/aas:2000331`.

[5] T. Mauch et al. "SUMSS: a wide-field radio imaging survey of the southern sky - II. The source catalogue". In: 342.4 (July 2003), pp. 1117–1130. DOI: `10.1046/j.1365-8711.2003.06605.x`. arXiv: `astro-ph/0303188 [astro-ph]`.