Observation Techniques 2 Assignment 1

Spectral index for 5 targets in the Abell 85 cluster from the MGCLS survey

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Abstract

We present the spectral indices of five targets within the Abell 85 galaxy cluster, identified from the MGCLS survey: G4Jy 77, NVSS J004151-092548, MCG-02-02-086, NVSS J004230-092204, and FIRST J004258.8-091347. Of these, G4Jy 77 and MCG-02-02-086 are of particular interest. G4Jy 77, with a measured spectral index of $\alpha = -3.626 \pm 0.084$, is notably classified as a "radio phoenix", exhibiting the characteristic steep spectral index. In contrast, MCG-02-02-086, with a spectral index of $\alpha = -1.126 \pm 0.017$, is catalogued as the brightest source in the Abell 85 field and is included in the central cluster galaxy catalogue.

1 Introduction

The Abell 85 galaxy cluster, residing in the constellation of Cassiopeia is home to over 500 individual galaxies. The central galaxy Holm 15A hosts an ultra-massive black hole (40 billion solar masses), one of the most massive black holes ever discovered [2]. In the radio frequency regime, we observe a diffuse, complex, filamentary radio source classified as a radio phoenix [4]. The goal of this short report is to extract the flux densities and spectral indices from 5 sources in the radio images of the Abell 85 galaxy cluster from the MeerKAT Galaxy Cluster Legacy Survey (MGCLS) [1] across 12 different frequencies. We then compare findings with results from the literature, if available, and address any noteworthy finding among the chosen targets.

2 Methodology

Leveraging the unprecedented sensitivity of the MeerKAT telescope, numerous radio sources were both visible and resolved. The five selected targets represent a mix of point-like sources and more diffuse structures, chosen for their brightness and morphology. These targets are illustrated in Figure 1. We used the Python package astropy.photutils to perform aperture photometry on each target, calculating their flux densities (considering the background noise as sources of error) across various frequency slices (approximately: 0.908, 0.952, 0.997, 1.044, 1.093, 1.145, 1.317, 1.381, 1.448, 1.520, 1.594, 1.656 GHz). A simple power law fitted the resulting flux density versus frequency plots.

$$\rho_{flux} = a\nu^{\alpha} \tag{1}$$

where ρ_{flux} is the flux density, a is a scaling factor, ν is the frequency and α is the spectral index we aim to calculate.

The best-fit plot for the first target is shown in figure 2. The rest of the plots can be found in the appendix having an identical format to that of target 2. The extracted spectral indices along with their corresponding fit uncertainties and goodness of fit test can be found in Table 1. The astroquery.simbad package was used to query the SIMBAD database for object ID's associated with the observed emission.

3 Results

The 5 chosen targets from the MGCLS Abell 85 field are shown below:

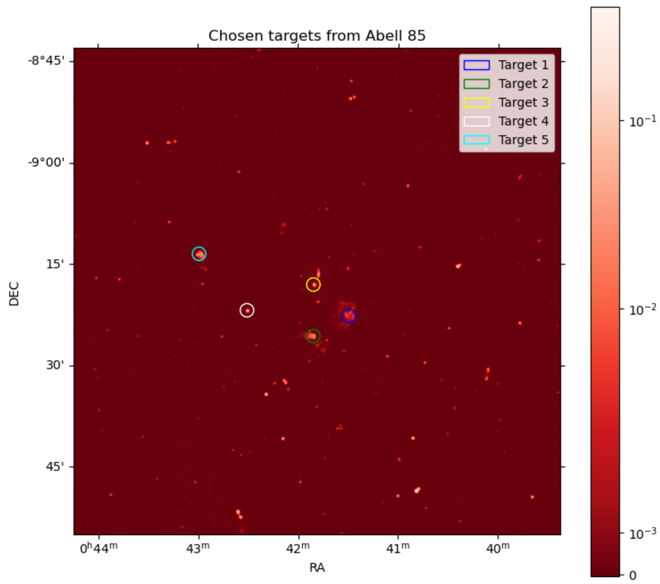


Figure 1: Flux (in Jy) is plotted as a heat map for the Abell 85 MeerKAT field, with five targets for spectral index analysis shown as colored circular apertures. These apertures, identical in size, indicate the area used to calculate flux density. Target 1, which is larger than the aperture, has been studied in detail to determine the spectral index across its position [4]. This analysis focuses only on the core region, excluding filament arms and parallel strands, due to the assignment's limited scope. Despite this, the core remains significant enough to include.

While many other potentially interesting sources exist in this field the scope of this assignment only allows for 5 targets. As described in 2 these choices are arbitrary and represent only what we perceive to be firstly relatively bright and secondly visually interesting.

Extracting the flux densities for these targets as a function of frequency as described in 2 and fitting for the spectral index we find:

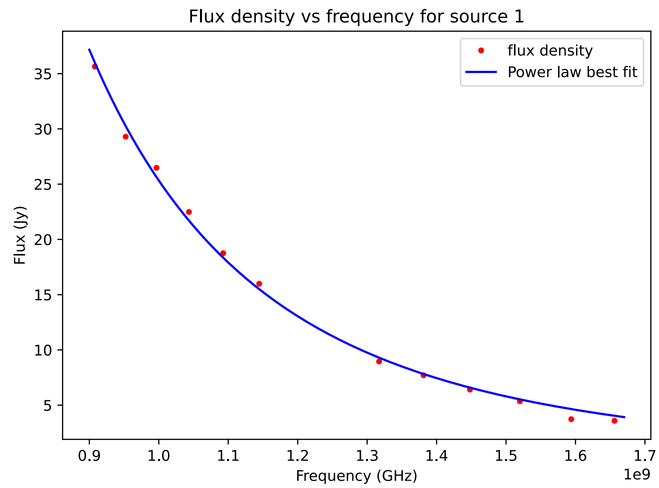


Figure 2: Flux density vs frequency for target 1 with a best fit spectral index $\alpha = 3.626 \pm 0.084$

Plots for the other 4 targets are given in the appendix. Table 1 summarises the fit results for each target:

Target	Spectral index	fit uncertainty	χ^2
1	-3.626	0.084	0.36
2	-1.069	0.016	0.029
3	-1.126	0.017	0.032
4	-0.235	0.014	0.016
5	-0.648	0.015	0.036

Table 1: Best fit spectral indices shown for each target along with the uncertainty of the fit given to 1σ and a χ^2 measure of goodness of fit. All values are quoted to two significant figures.

Table 1 shows that all targets have a negative spectral index with varying steepness. Each fit (1-5) aligns well with the calculated flux densities, confirming the power-law distribution as a good fit. Notably, target 1 has a particularly steep spectral index, distinguishing it from the other sources, which have relatively flat spectra.

Galaxy clusters are well-studied, but the focus varies by wavelength. In the radio regime, studies typically concentrate on individual galaxies within the cluster, especially those with AGN-driven emissions or radio relics. Optical and infrared studies, however, focus on overall cluster dynamics, including matter distribution and velocity dispersion. Many radio-bright galaxies are faint in optical wavelengths and are often overlooked unless of particular interest. Similarly, X-ray studies prioritize the density of the Intra Cluster Medium (IGM) and tend to ignore individual galaxies. We will now examine each target, review past studies, and cross-check our spectral index calculations with other radio data where available.

3.1 Target 1

Target one, G4Jy 77, is thought to be a radio phoenix [4], formed by the compression of dormant plasma from past AGN activity. This compression, likely due to cluster mergers or galaxy interactions, generates low-Mach shock waves that re-ignite synchrotron radiation, resulting in steep spectral indices as observed here and in other studies [3]. The spectral index found in this study aligns with previous findings at corresponding frequencies but is less steep at lower frequencies (323 MHz - 700 MHz) [4].

3.2 Target 2

Target two, also known as NVSS J004151-092548, has an optical counterpart with SDSS-ID: 1666-301-5-0261-0079. No other radio data was found for the source and no published literature mentions this source.

3.3 Target 3

Target three, also known as MCG-02-02-086, is a central cluster galaxy with multiple literature mentions calculating redshift, galackinematics and looking at its gas halo in x-ray.

3.4 Targets 4 and 5

Target four(NVSS J004230-092204) has no optical counterpart and is classified as a radio source. It has only appeared in two surveys previously (FIRST and NVSS). Target five, also known as FIRST J004258.8-091347, is classified simply as a radio source and has no optical counterparts. No literature sources mention this source.

4 Conclusion

In this brief study, we extracted flux densities, plotted flux density versus frequency for twelve frequencies, and determined spectral indices through curve fitting for five radio sources within the Abell 85 galaxy cluster using MGCLS data. We identified G4Jy 77 as a radio phoenix, characterized by a steep spectral index consistent with the literature [4].Target 3 (MCG-02-02-086) was also identified as a central cluster galaxy and the brightest source in the Abell 85 field. While limited in scope, our findings highlight the need for continued investigation into the diverse and complex radio sources in galaxy clusters like Abell 85.

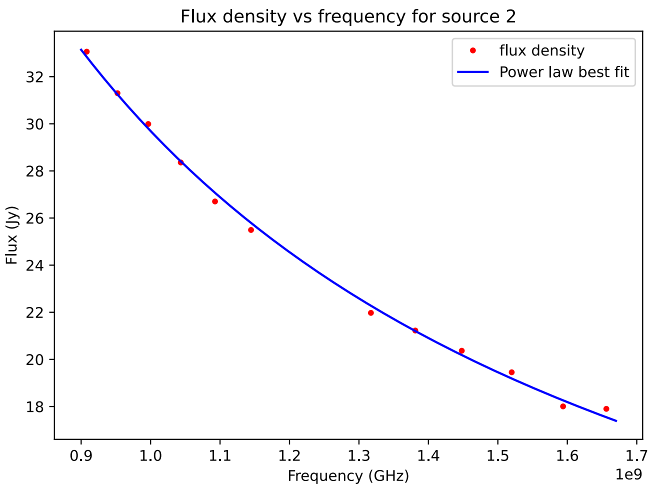
References

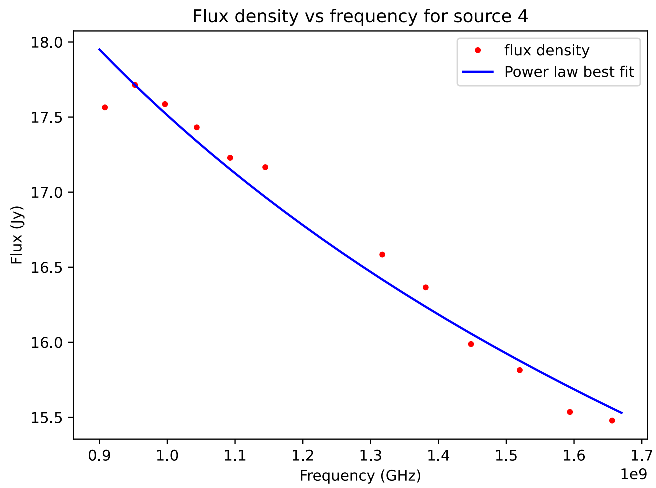
[1] *MeerKAT Galaxy Clusters Legacy Survey – MeerKAT Galaxy Clusters Legacy Survey.* URL: http://mgcls.sarao.ac.za/.

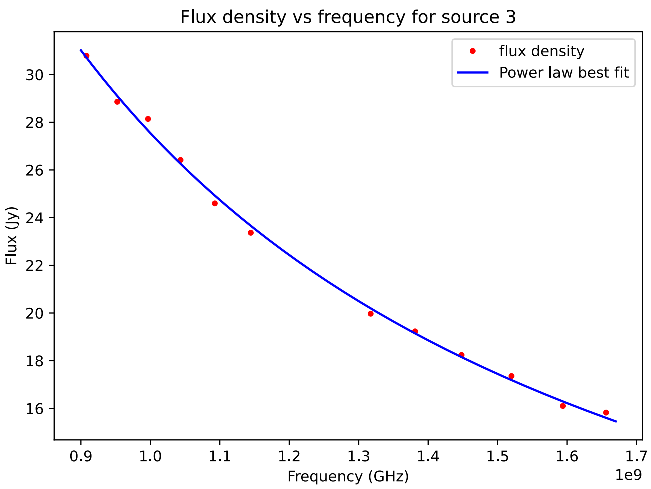
[2] Kianusch Mehrgan et al. "A 40 Billion Solar-mass Black Hole in the Extreme Core of Holm 15A, the Central Galaxy of Abell 85". In: *The Astrophysical Journal* 887.2 (Dec. 2019), p. 195. ISSN: 1538-4357. DOI: 10.3847/1538-4357/ab5856. URL: http://dx.doi.org/10.3847/1538-4357/ab5856.

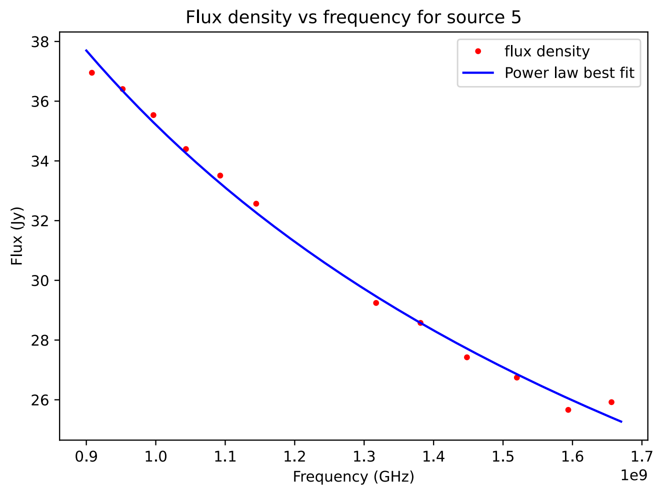
[3] Majidul Rahaman et al. "On the Origin of Diffuse Radio Emission in Abell 85-Insights from new GMRT Observations". In: *MNRAS* 000 (2022), pp. 1–11. URL: https://github.com/bcalden/ClusterPyXT.

[4] Ramij Raja et al. *A Multi-Frequency View of the Radio Phoenix in the Abell 85 Cluster*. 2023. arXiv: 2309.14244 [astro-ph.HE]. URL: https://arxiv.org/abs/2309.14244.


Flux density vs frequency for source 2
flux density
Power law best fit
Flux (Jy)
Frequency (GHz)
1e9


Flux density vs frequency for source 4
flux density
Power law best fit
Flux (Jy)
Frequency (GHz)
1e9


Flux density vs frequency for source 3
flux density
Power law best fit
Flux (Jy)
Frequency (GHz)
1e9


Flux density vs frequency for source 5
flux density
Power law best fit
Flux (Jy)
Frequency (GHz)
1e9