Study of A1367 Cluster by Curve Fitting Variations

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Abstract. We investigate the possible gain spectrum of the A1367 cluster or more commonly known as the Leo cluster using different polynomial fitting techniques in DRAWSPEC. For one of the aspects of the research on the possible mass of dark matter in the Leo cluster, the mass of neutral hydrogen (M_{HI}) is to be determined using gain analysis in the DRAWSPEC programme, prior to using the virialized mass of the Leo cluster to determine the mass of dark matter in the cluster. This investigation is significant because by using different polynomial fittings, one set of data could yield different gain, thus providing different M_{HI}, ultimately affecting the calculation of mass of dark matter in a cluster. In this paper, we present a comparison between different gain spectrum and M_{HI} using different polynomial fittings and we conclude that the result yields different M_{HI} by using different curve fitting techniques.

Keywords: galaxy cluster-curve fitting-neutral hydrogen mass-gain spectrum-DRAWSPEC

I. INTRODUCTION

When determining the mass of all the observable matter in a galaxy cluster, interstellar matter plays a role in contributing to the mass [1]. Among the interstellar matters taken into consideration, neutral hydrogen (HI) is chosen due to the fact that starlight is not required to give off 21cm line emission and is generally abundant in clusters [2].

There are multiple ways to observe the emission from HI in the universe, but the single dish radio telescope has not been a popular choice due to its low sensitivity [3]. Despite this constraint, the project that this investigation is part of aims to prove that by using longer integration times we could observe HI in galaxy clusters. A medium sized radio telescope also offers a much larger viewing angle, enabling the whole cluster to be observed.

This investigation is set to investigate the various outcomes of the HI mass calculation as the polynomial fitting or curve fitting techniques performed on the observational data are varied. This is significant due to the fact that different HI mass indicates the difference in the potential mass of dark matter [4].

The cluster chosen as the subject of this paper is Abell 1367 (A1367), otherwise known as the Leo cluster. The central region of the cluster is dominated by NGC 3842, an elliptical galaxy that is the Brightest Cluster Galaxy (BCG) of the cluster. Table 1 lists the parameters of the cluster.

TABLE 1. The properties of the Abell 1367 galaxy cluster.

Right Ascension	11h44m36.5s
Declination	19d45m32s
Size (Diameter)	266 arcmin
Redshift (z)	0.022

In Donelly et al. (1998)[5], the authors of the paper studied the temperature structure of A1367 and concluded the occurrence of a localised shock in the intracluster medium (ICM). This was interpreted as proof that A1367 is actually two sub-clusters currently merging into one.

Scott et al. (2010) [6] used the Very Large Array (VLA) to obtain a HI imaging of the North-west field of A1367. Their main objective was to investigate the effect the cluster environment has on the interstellar medium of the spiral galaxies. Their research has shown that the spirals were predominantly found in the northern half of the cluster, particularly the gas rich ones. They also did not find the expected trend for the H_I deficiency to increase closer to the cluster core.

In another research published in 2012, Scott et al. [7] discovered two very long HI tails in the outskirts of A1367. Their paper looked at two galaxies, FGC 1287 and RSCG 42.Observations were again done using the VLA. In the case of FGC 1287, it was not clear how the HI tail came to be so long. A possible candidate for the interaction that caused this was identified, but there is no solid proof. Note that using interferometers generally limits the coverage to a few galaxies at most and often excludes the space between galaxies.

Kiew et al. (2017) [8] has indicated that A1367 and A2199 provided the best constraint in the properties of neutralinos. This paper was done with the assumption that neutralinos are what makes up dark matter. The constraints were derived from the radio halo of the clusters.

II. METHODOLOGY

In this investigation, we have chosen the cluster A1367 cluster to perform the observations due to its large cluster size and its extensive archival data. The observation was done using the Jodrell Bank Observatory's 7-m radio telescope in Manchester, United Kingdom. This telescope is fitted with a 21cm spectral line receiver which detects emission of HI from galaxy clusters.

Using the data obtained, we then performed data reduction and background noise cancellation using the single dish data reduction software named DRAWSPEC developed back in 1994 by H. S. Liszt to obtain useful information of the galaxy cluster observed.

During the data reduction, different polynomial fitting technique is applied to the data set to determine if it will affect the outcome of the HI mass calculation.

To calculate the mass of HI, the following equation is used:

$$M_{HI} = 2.36 \times 10^5 D^2 \int S_v d_v \, M_\theta \tag{1}$$

where we define D as the distance of the cluster from Earth in Mpc, S_v as the integrated flux of the cluster, d_v as the velocity width of the cluster, and M_θ is in the unit of solar mass.

The S_v that was obtained from the data would need to be converted from counts to units of Jansky (symbol Jy) by multiplying the value with 1.021 Jy [9].

The end result would be the stacking of all the fitted curves to reveal the general trend of the curves and this would enable the usage of equation (1) in calculating the HI mass. Then a comparison between different fitting techniques will determine the conclusion whether doing so will produce different results.

III. RESULTS AND ANALYSIS

The data set obtained from the observation has a total number of 579 raw plots, one of it is as shown below using the DRAWSPEC programme.

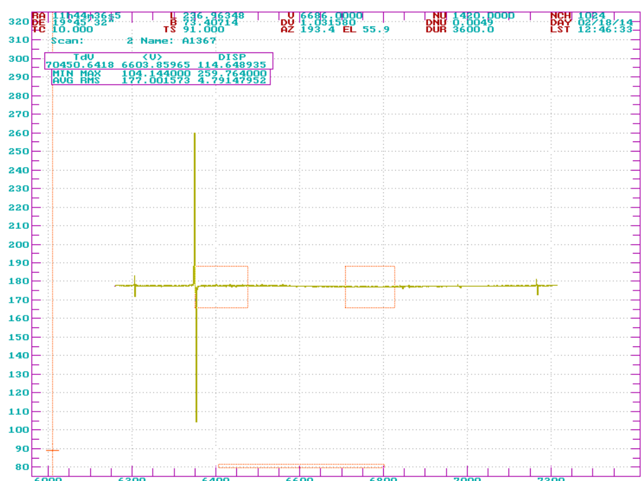

FIGURE 1. Observational data of A1367 cluster collected at 18/2/2014 12:46:33.

All of the raw data are then processed by fitting it into polynomial zero and zapping away background noises to show usable spectrum as indicated in Figures 2, 3, 4, 5, 6, and 7 below.

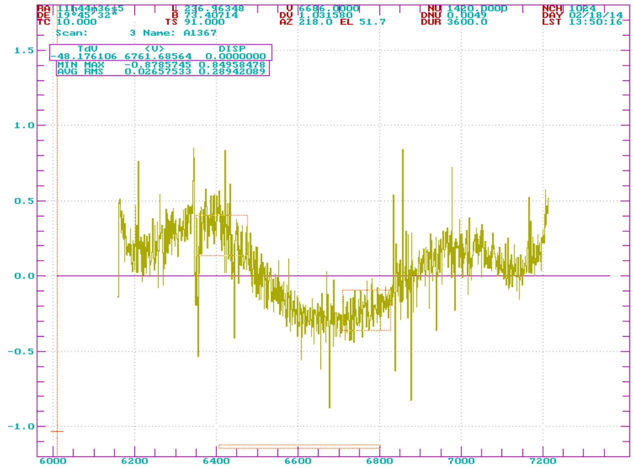

FIGURE 2. Processed data of A1367 cluster collected at 18/2/2014 13:50:16.

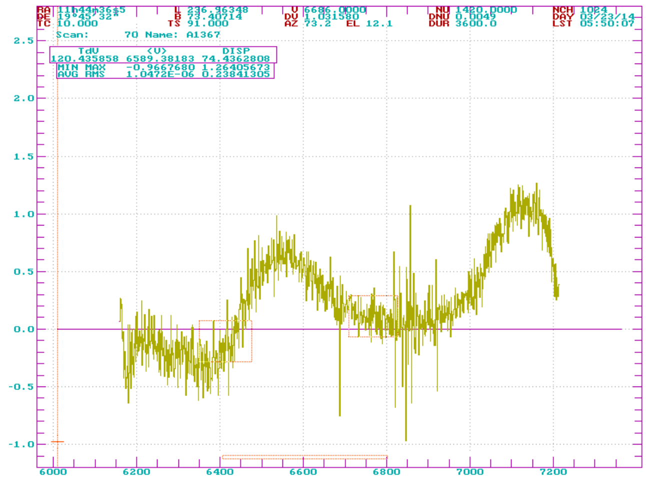

FIGURE 3. Processed data of A1367 cluster collected at 23/3/2014 05:50:07.

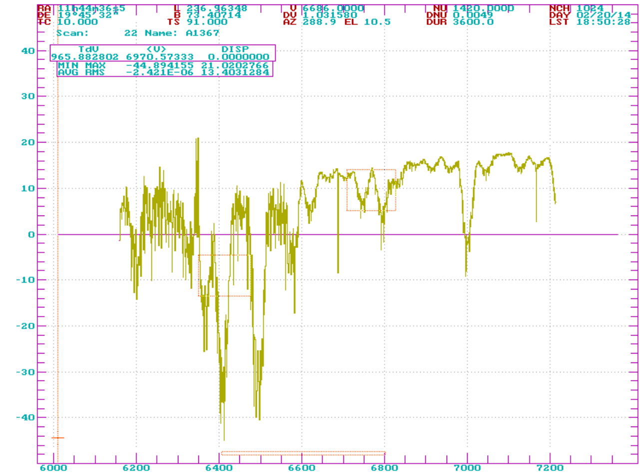

FIGURE 4. Processed data of A1367 cluster collected at 20/2/2014 18:50:18.

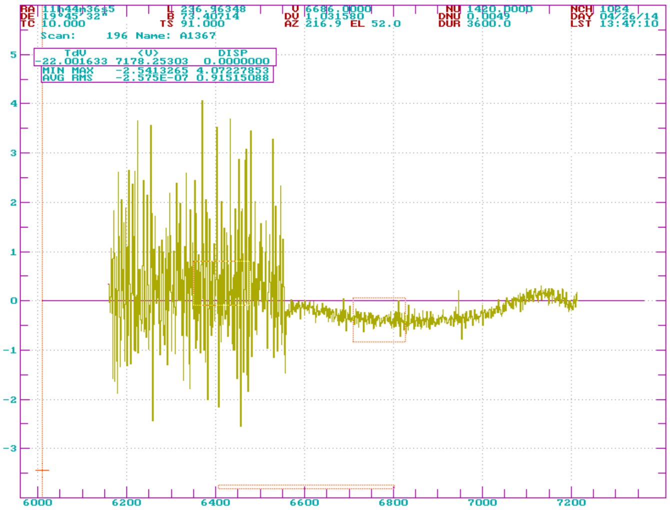

FIGURE 5. Processed data of A1367 cluster collected at 26/4/2014 13:47:10.

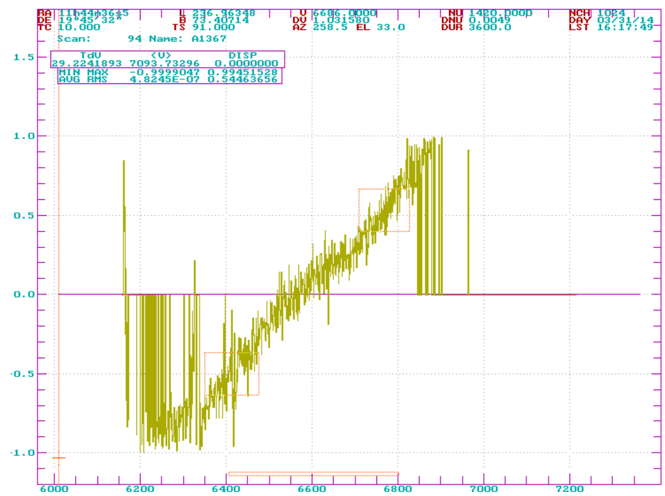

FIGURE 6. Processed data of A1367 cluster collected at 31/3/2014 16:17:49.

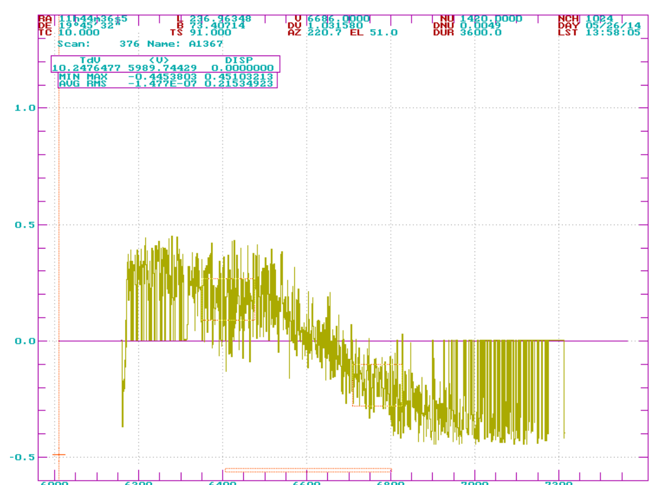

FIGURE 7. Processed data of A1367 cluster collected at 26/5/2014 13:58:05.

After manual calculation of the occurrence of the above patterns, the Figure 2 pattern (hereafter addressed as Pattern 1) has shown up 235 times; Figure 3 pattern 107 times; Figure 4 pattern 4 times; Figure 5 pattern 46 times; Figure 6 pattern 18 times; Figure 7 pattern 24 times. All of these totals up to 434 scans with the remaining 145 as errors. For the case of this investigation, we are only considering Pattern 1 which has the highest occurrence among all.

Below shows the polynomial fitting of the curves from one to six (in red), and only three and five fits the curve, while one, two, four and six did not fit.

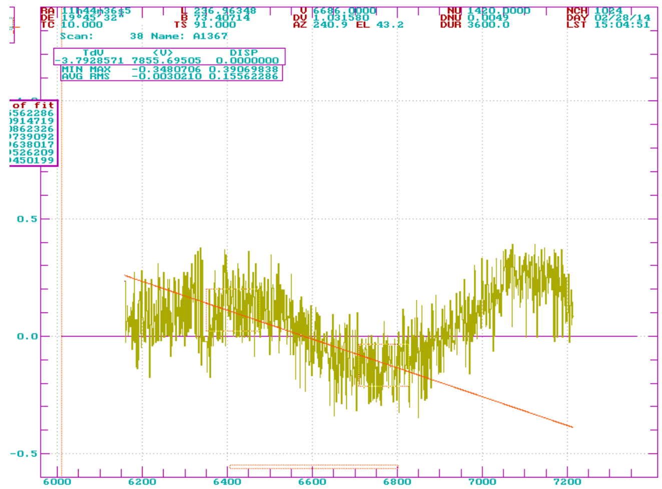

FIGURE 8. Polynomial fitting of one on Pattern 1.

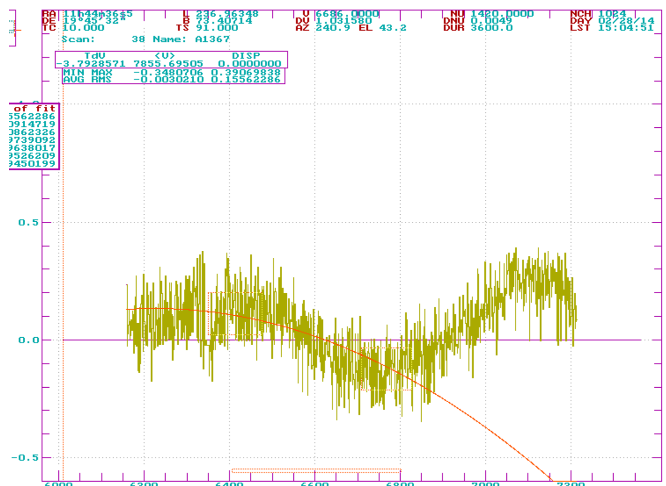

FIGURE 9. Polynomial fitting of two on Pattern 1.

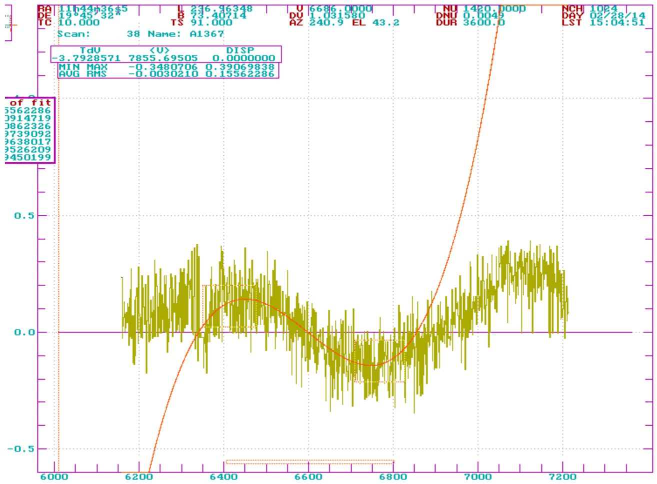

FIGURE 10. Polynomial fitting of three on Pattern 1.

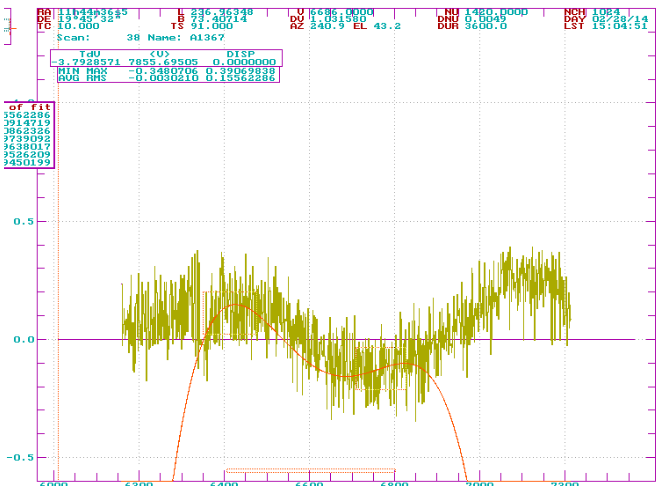

FIGURE 11. Polynomial fitting of four on Pattern 1.

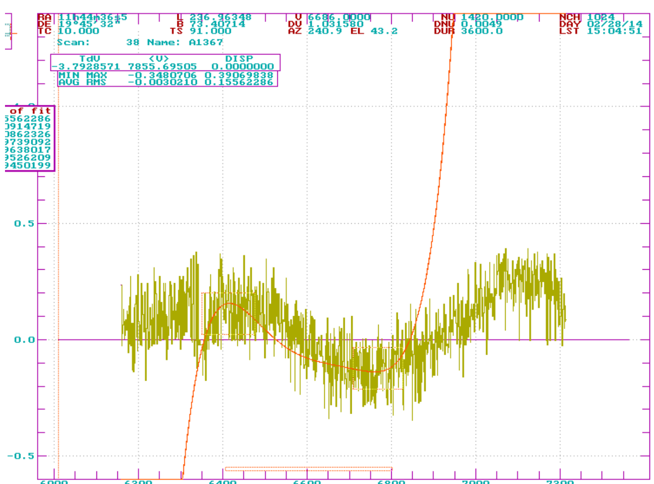

FIGURE 12. Polynomial fitting of five on Pattern 1.

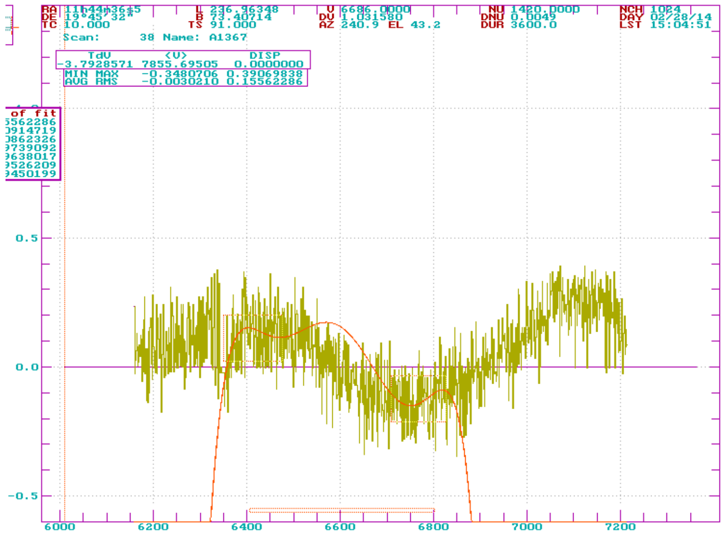

FIGURE 13. Polynomial fitting of six on Pattern 1.

Polynomial Fit to Three

By using polynomial fitting of three on the Pattern 1 data and stacking all of them into one figure to show the general trend, the following pattern is produced.

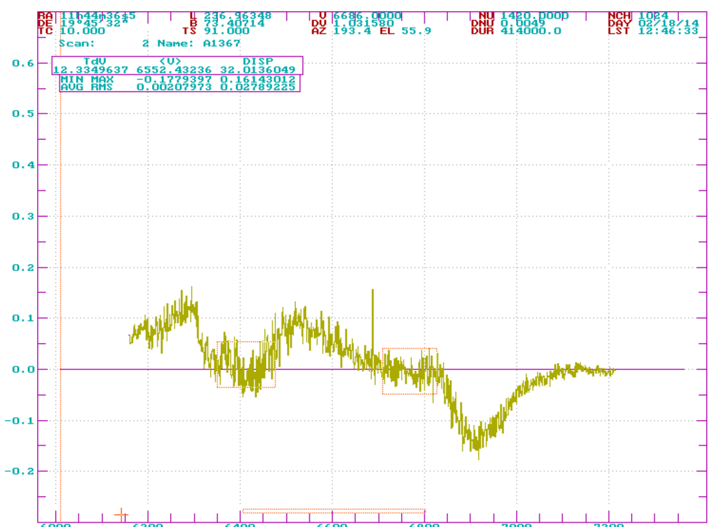

FIGURE 14. Stacked data of Pattern 1 using polynomial fitting of three.

The velocity of A1367 cluster is 6569 km/s, hence the peak that coincides with this velocity from the figure is 0.0966 counts and by using equation (1) above, the mass of HI is obtained as $M_{HI} = 1.189 \times 10^{11} M_{\theta}$.

Polynomial Fit to Five

By using polynomial fitting of five on Pattern 1 data and stacking all of them into one figure to show the general trend, the following pattern is produced.

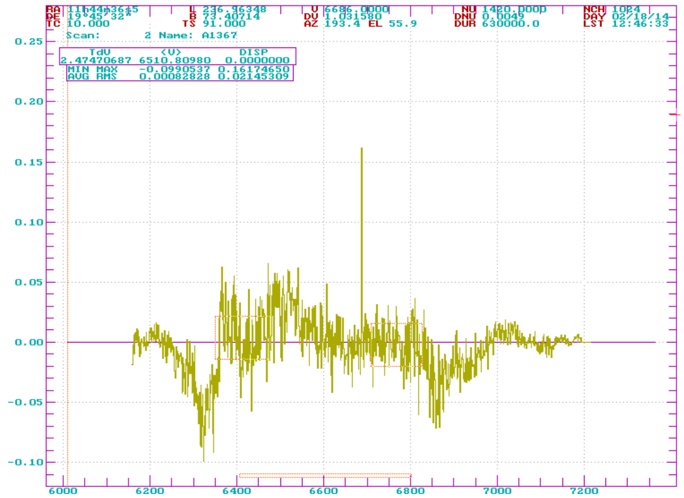

FIGURE 15. Stacked data of Pattern 1 using polynomial fitting of five.

Final Result

The final result is shown in Figures 16 and 17. The HI mass obtained was $4.67 \times 10^{11} M_{\odot}$.

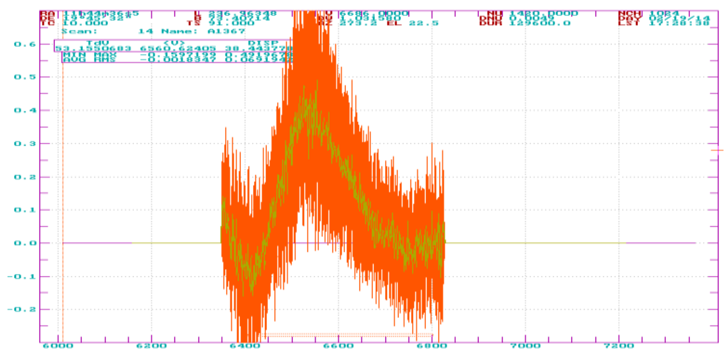

FIGURE 16: The stacked results for A1367

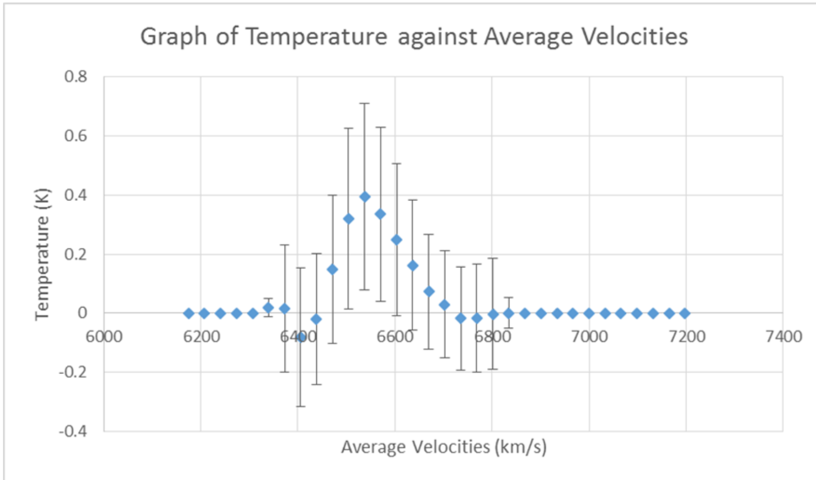

FIGURE 17: The binned spectra for A1367

Comparison to Previous Techniques

Previous Techniques used random baseline shapes and varying polynomial order fitting. The results are shown in Figures 18 and 19.

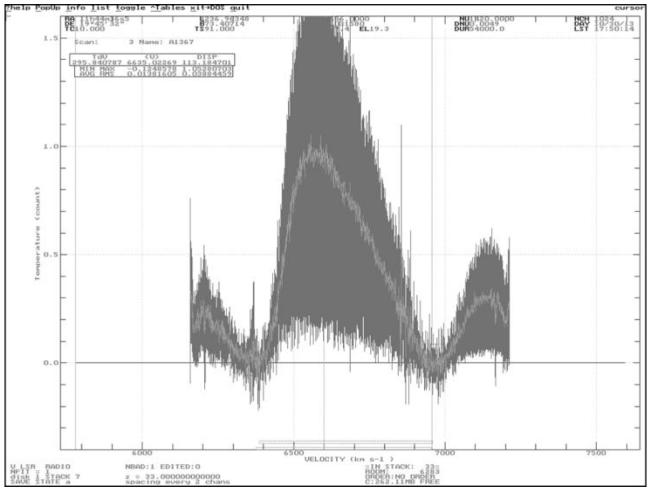

FIGURE 18

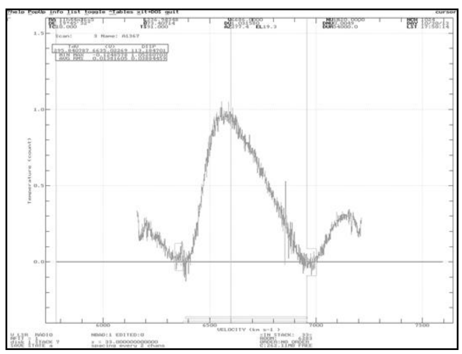

FIGURE 19: Spectra of A1367 obtained previously.

The HI was calculated to be $2.32 \times 10^{12} M_{\odot}$. This shows that the new technique generates better results.

IV. DISCUSSION AND CONCLUSION

In both stacked curves, even though the A1367 cluster gives off relatively strong HI emission [10], the HI peak which is supposedly located at $V = 6569\ km/s$ in both curves showed a slight shift to the left.

This might be caused by the low sensitivity, or resolution provided by the 7-m radio telescope. The radio telescope might not detect fully the HI emission given its short integration time of around 4-10 hours of continuous observation. This issue can be easily overcome by increasing the time to around 24 hours to increase its sensitivity.

Another issue is the obvious peak on Pattern 1 when it is fitted to both polynomials. The peak is an obvious noise which might be caused by radio wave interference around the radio telescope since it is built near a relatively active town. This could also be easily overcome by eliminating the noise using data reduction technique found in DRAWSPEC in the future.

In regards to the HI mass, it is clear that by using different polynomial fitting techniques to the same set of data produces different results, as shown with $M_{HI} = 1.189 \times 10^{11} M_{\theta}$ for polynomial three and $M_{HI} = 3.618 \times 10^{10} M_{\theta}$ for polynomial five, which has a difference of $8.272 \times 10^{10} M_{\theta}$. However, both stacked curves showed similar shape, as shown in Figure 14 and 15. This happens due to the fact that both polynomials share a similar N-shape fitting as shown in Figure 10 and 12. Hence when the curves are fitted into the selected polynomials, they share an almost similar outcome. However, it is evident by the final HI mass calculation that by simply variating the curve fitting techniques, the end result has a difference of one order of magnitude of $8.272 \times 10^{10} M_{\theta}$.

The DRAWSPEC software used in this work has many other uses in the field of radio astronomy. However, as shown in the work of Alapini (2004) [11], this is more suited to larger single dish observations such as the 76m Lovell Telescope which have a much higher resolution.

This finding is significant due to the fact that the HI mass is used all across the astrophysical field to determine various aspects of the universe. This includes research into objects such as Supermassive Black Holes in galaxies like NGC 3482 [12].

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