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Re-examining 183GHz Megamaser Disk Detections: New Insights through Cross-Correlation

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ABSTRACT

We introduce a linear cross correlation technique aimed at detecting 183 GHz water megamasers in accretion disks encircling supermassive black holes in active galaxies. In a recent paper by Pesce et al. (2023), 20 galaxies were observed using the ALMA interferometer to explore 183 GHz maser emission in galaxies already known to exhibit 22 GHz disk masers. Among this group, 13 galaxies were found to exhibit discernible 183 GHz maser emission. Among these, 5 displayed both systemic and high-velocity maser emission indicative of a disk origin, while the remaining 8 showcased solely systemic maser emission. Our cross-correlation technique tentatively reveals the presence of 183 GHz maser disks in 6 of the initially systemic-only detections, while also pinpointing systemic and/or high-velocity maser emission in 3 of the 7 galaxies previously categorized as non-detections. Our cross-correlation analysis demonstrates promising potential in uncovering previously elusive 183 GHz maser phenomena, solidifying the prediction of their coincidence with 22 GHz maser disks.

Keywords: Water Masers (1790) — Megamasers (1023) — Radio astronomy (1338)

1. INTRODUCTION

Water megamasers orbiting closely around a supermassive black hole (SMBH) have been investigated for decades due to their use in precise calculations in our universe, including SMBH mass and the Hubble constant. Water megamasers are water molecules that emit radio waves in a wide range of frequencies, depending on the excitation. The most commonly studied frequencies for circumnuclear water megamasers are $\tilde{2}2.23508$GHz and 183.310087GHz, or the $6_{1,6} - 5_{2,3}$ and $3_{1,3} - 2_{2,0}$ rotational transitions in the ground vibrational state of the ortho and para H_2O molecule, respectively (Pesce et al. 2023). Masers exist in warmer regions, of temperatures near 1000K, which coincides with the temperatures of the environment orbiting closely around a low-luminosity active galactic nucleus (AGN). Because of the lower temperature requirement of the 183GHz megamasers, this population is predicted to be located further out from the supermassive black hole, orbiting the SMBH at a slower velocity. Water megamasers that are found to be orbiting around a SMBH in a disk or ring are extremely useful in the realm of cosmology and astrophysics. The Megamaser Cosmology Project (MCP) is an international collaboration in search of maser disks within Seyfert 2 galaxies to use in order to calculate an extremely accurate Hubble Constant. Using Very Long Baseline Interferometry (VLBI), the emission from these maser disks can be used to generate an accurate representation of the maser disk as well as a Position-Velocity (PV) diagram, that shows either Keplerian or sub-Keplerian rotation of the disk. Using these diagrams, geometry, and simple conversions, the maser disks can be used to calculate their distance to the galaxy and thus be used in a calculation of the Hubble constant (Pesce et al. 2020). When using 22GHz masers, the Hubble constant has been calculated to be 73.9 ± 3.0 km s^{-1} Mpc^{-1} (Pesce et al. 2020).

Masers that orbit around a SMBH located in maser disks have a characteristic triple peaked emission. The presence of three peaks is due to a combination of effects. In order for the radio telescope to pick up the emission, the megamasers must be aimed toward our line of sight. Thus, this leaves only masers on the leftward, rightward, and center of the disk to be seen. The outer masers are named red and blue-shifted "high velocity" masers–depending on the rotational direction of the disk. The central masers are titled "systemic" masers due to the fact that they appear on a flux-velocity spectrum at the recession–or systemic–velocity of the galaxy. See Figure 1 for a direct comparison of the visualization of a maser disk and how to correlates to the triple-peaked spectra of maser emission. We present a python pipeline that uses a variable triple-peaked square template that searches for hidden high velocity and/or systemic maser emission through linear cross-correlation. The methodologies as to why a square template was used and how detections were verified will be investigated in this paper. This pipeline intakes .txt and/or .fits files of radio spectra for both 22GHz and 183GHz, and outputs best-matched templates (BMTs) with the corresponding predicted rotational velocity as well as the cross-correlation pattern associated with this template and specific spectrum. The program also outputs a boxcar smoothed spectrum with an overlay of the BMT for visualization for the user. The discovery of 183GHz maser disks within galaxies will exponentially increase the amount of scientific evidence we can gather to further verify the updated value of the Hubble constant the collaborators of the MCP are finding. The pipeline that is presented in this paper was created to find new maser disk galaxies that previously were determined to contain 22GHz maser disks. The applications of this code can be applied to any frequency of disk maser emission.

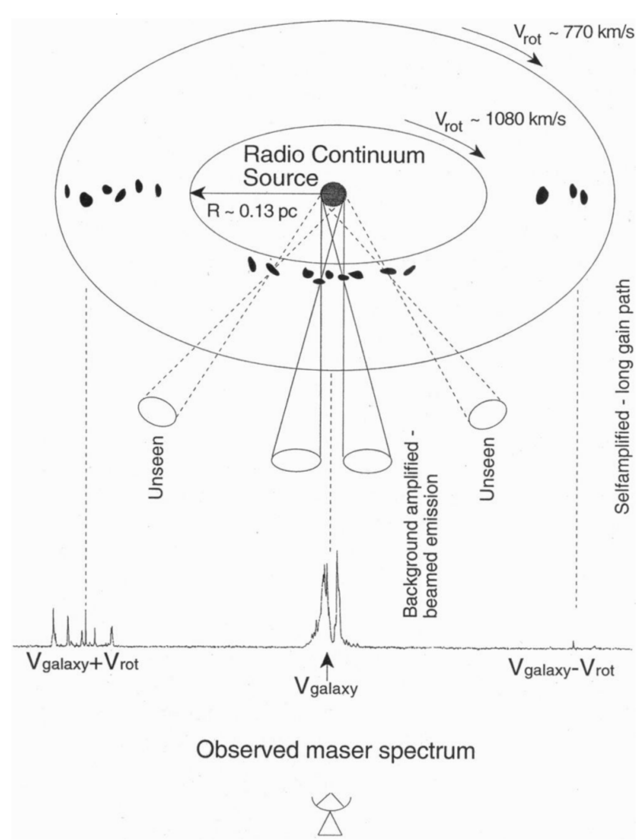

Figure 1. A direct visualization of the three types of maser disk emission to the triple peaked maser spectra. Note that the high-velocity blue-shifted masers (moving toward the observer) and red-shifted masers (moving away from the observer) have different rotational velocities as compared to the systemic masers. The systemic masers sit at the recession velocity of the galaxy itself, and thus the rotational velocity of the galaxy itself is measured through the high-velocity masers. Note that this spectra runs from high velocity to lowest, which is the reverse of the spectra studied in this paper. Source: Moran et al. (1995)

2. DATA

All 20 of the galaxies that were investigated both in this paper and in Pesce et al. (2023) were observed using the Atacama Millimeter/submillimeter Array (ALMA). The dataset is from ALMA projects 2017.1.00909.S and 2018.1.00321.S that were investigated in Pesce et al. (2023). All 20 of the galaxies observed in this dataset were known to contain 22GHz maser disks, observed by the Green Bank Telescope (GBT). All ALMA observations were taken in Band 5 and were in a range of redshifts to z≈0.05 (Pesce et al. 2023). Within the 20 galaxies observed, 13 of them were said to have some sort of emission (P23). Out of the 13 with detections, 5 contained both systemic and high-velocity emission and 8 with systemic-only emission. Pesce et al. (2023) boxcar smoothed each spectra by a factor of 10 for their conclusions, therefore the same was done to the raw data for this re-evaluation. The boxcar smoothing was done with `convolve` and `Box1DKernel` from `astropy.convolution`.

3. PIPELINE

In this section we investigate the methods that the pipeline uses in order to find and conclude whether or not a spectrum has 183GHz emission. We discuss the template options, plot outputs, and verification methods that were used for all of the spectra.

3.1. *Methodology*

In order to accurately search for the signature triple-peaked emission within the noisy spectra, a triple-peaked square template was used. The possibility of a triple-peaked gaussian template was also investigated, but it was found that the emission from masers is typically non-gaussian, and thus a square template would take into account the non-gaussian emission shapes that we would more commonly find, as well as any possible gaussian-like emissions. The height of the template varied in order to directly correlate to the spectra that was being evaluated. The height would exactly match the height of the systemic maser emission, or if no systemic emission was present, would match to the highest emission in the spectrum in order to not inaccurately inflate the resulting plots. This was found to be the best method in order to accurately evaluate the cross-correlation patterns. The central peak of the template was matched to the systemic maser velocity–which is the same or extremely similar to the recession velocity of the galaxy. The high-velocity peaks began directly neighboring the central square, but with each iteration of the code, moved out further to the right and left, respectively.

3.2. *Cross-Correlation*

Linear cross-correlation is a way to measure similarity between a template and signal. For each iteration of the pipeline, the template was "moved" overtop of the spectra. This was done one channel at a time, with the y-values for the template and signal being multiplied together and output into the cross-correlation pattern. This results in a cross-correlation pattern that is the same length as both the template and signal. For this particular project, a quintuple peaked cross-correlation pattern, with the highest peak in the middle, was the desired shape for a detection.

3.3. *Verification Methods*

In order to further verify detections outside of the signature quintuple-peaked cross-correlation pattern, verification methods had to be created. By completion of the project, a total of five further verification methods were used for each possible detection. The methods were the following:

1. Rotational Velocity Comparison
2. Template Overlay with Smoothed Spectrum
3. Cross-Correlation Pattern Image
4. Systemic Maser Emission Replaced by Noise
5. High-Velocity Maser Emission Replaced by Noise

3.3.1. *Rotational Velocity Comparison*

For each galaxy, the 22GHz spectrum was also run through the pipeline in order to calculate the rotational velocity. Because of the nature of the excitation of the 183GHz masers, they are predicted to be located further out on the disk, thus rotating slower than their 22GHz companions. Thus, when a 183GHz spectrum had an equal or slower rotational velocity to the 22GHz spectrum, it was marked as a possible detection.

3.3.2. *Template Overlay with Smoothed Spectrum*

In order to better visualize where the pipeline detected high-velocity emission, the template was laid on top of a spectrum that was boxcar smoothed 100 times. This extreme smoothing is simply to guide the eye as to where the possible detection is located within the spectrum, and is not meant to be used as an actual visual detection method. A conglomeration of all of the verification methods and pipeline results is used to determine detection validity.

3.3.3. *Cross-Correlation Pattern Image*

The cross-correlation patterns that were created for each iteration of the pipeline were combined into a 2D array and plotted using `matplotlib.pyplot.imshow()`. Each row of the image represents the cross-correlation pattern for one iteration of the pipeline. Thus for each row, the high-velocity square peaks in the template were moved out further leftward and rightward by 10 channels. When a strong detection was marked by the pipeline, these images showed a dark central spot, indicating the run in which the best-matched template occurred, see Figure 2.

3.3.4. *Systemic Maser Emission Replaced by Noise*

Another method of verification that was used was actually replacing the central most channels, where the systemic maser emission is located, with perfectly gaussian noise, and running this spectrum through the cross-correlation. For this method, the template was adjusted to only have two peaks–the two high-velocity peaks in order to have a more decisive conclusion in the cross-correlation pattern. If systemic and high-velocity emission was originally present, then the cross-correlation would simply be a triple-peaked pattern. If the spectrum only contained systemic emission, then the cross-correlation pattern is expected to be perfect gaussian noise, assuming that the noise of the spectrum is gaussian noise, on average. Finally, if the spectrum was expected to have only high-velocity emission, then the cross-correlation pattern should be triple-peaked, and match the original cross-correlation that was not altered. The shapes of both the original and removed systemic cross-correlations were compared to determine what emission was present.

3.3.5. *High-Velocity Maser Emission Replaced by Noise*

The final method of verification that was used to separate false detections from real ones was removing all emission in the spectrum except for the systemic emission. This method was used for verifying the detection of high-velocity masers. The process was repeated that was

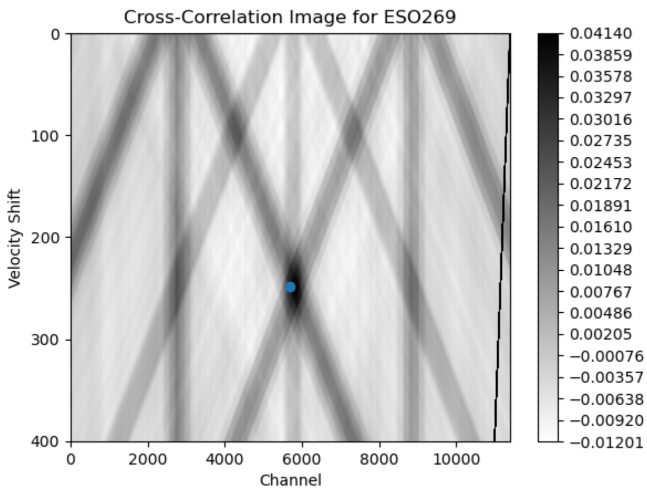

Figure 2. The cross-correlation image of galaxy ESO 269-G012. The central black circle, marked by the blue dot, indicates the run of the best-matched template for the spectrum. These images were created for every galaxy and were used for further verification of detections marked by the pipeline.

used for removing the systemic masers, except the placement is the opposite. Gaussian noise was put into the spectrum except for the central most channels, where the systemic emission is located. In this method, however, the template was not changed and still contained the three square peaks.

4. RESULTS & DISCUSSION

4.1. *CGCG 074-064*

CGCG 074-064 had previously detected systemic and high-velocity lines in the 183GHz data. The systemic emission was detected at 6910 km s^{-1} with a width of 60 km s^{-1} (P23). A blue-shifted high-velocity emission was detected around 6387 km s^{-1} (Pesce et al. 2023). The pipeline detected the systemic and blue-shifted maser emssion, and also detected a possible red-shifted maser emission at 7460 km s^{-1}. See Apendices C and E for cross-correlation patterns and verifications.

4.2. *CGCG 165-035*

Pesce et al. (2023) previously determined CGCG 165-035 to be a non-detection. The pipeline detected a red-shifted high-velocity maser emission at 10152.34 km s^{-1}. See Appendices B and D for the cross-correlation and verifications.

4.3. *Circinus*

Circinus was previously determined to have both red and blue-shifted high-velocity masers, but lacked systemic maser emission. The pipeline identified both the red and blue-shifted high-velocity masers, but also detected a slight presence of systemic maser emission. Due to the large width of the high-velocity emission, Circinus was not further studied in great detail using this program.

4.4. *ESO 269-G012*

Detailed investigations have been done into the 183GHz megamaser emission from ESO 269-G012 due to it's strong flux intensity compared to other sources. ESO 269-G012 was mainly used as a comparison for the rest of the dataset because of it's strong detection. It's cross-correlation and verifications are included in Appendices B and D for the reader.

4.5. *ESO 558-G009*

The systemic emission from ESO 558-G009 was detected in Pesce et al. (2023) at 7585 km s^{-1}, with conclusions of possible high-velocity maser emission at 7075, 7150, and 8120 km s^{-1}. The pipeline's conclusions coincide with possible high-velocity detections as well, with possible detections at 8072 km s^{-1} and 7097 km s^{-1}. These detections correlate strongly with the predicted rotational velocity of the 183GHz masers using the 22GHz maser disk and match Pesce et al. (2023). See Appendices C and E for further verification and visualization.

4.6. *IC 485*

IC 485 was determined to have only systemic maser emission, located at approximately 8355 km s^{-1} (P23). The pipeline concluded that there was a possible detection at 8656 km s^{-1}, thus being a red-shifted high-velocity maser. See Appendices C and E for further graphical representation.

4.7. *IC 2560*

Pesce et al. (2023) detected only systemic maser emission of IC 2560 at approximately 2925 km s^{-1} originally. We conclude the same.

4.8. *J0109-0332*

J0109-0332 was listed originally as a non-detection in Pesce et al. (2023), and we conclude the same.

4.9. *J0126-0417*

The galaxy J0126-0417 was originally concluded to be a non-detection by Pesce et al. (2023), with no visible systemic or high-velocity emission. However, when the spectra was run through the pipeline, it detected possible systemic, blue, and red-shifted emission. The systemic emission was located at approximately 5638 km

Table 1. 183GHz Megamaser Detections by Galaxy

Galaxy ID	Pesce Conclusions	Mintz Conclusions
CGCG 074-064	S, B HV	S, B&R HV
CGCG 165-035	None	R HV
Circinus	B&R HV	S, B&R HV
ESO 269-G012	S, B&R HV	S, B&R HV
ESO 558-G009*	S	S, B&R HV
IC 485	S	S, R HV
IC 2560	S	S
J0109-0332	None	None
J0126-0417	None	S, B&R HV
J0847-0022	S	S, B&R HV
Mrk 1419*	S	S, B&R HV
NGC 1068	None	S
NGC 1194	S, R HV	S, B&R HV
NGC 1386	None	None
NGC 3393	None	None
NGC 5495	S	S, B HV
NGC 5643	S	S
NGC 5765b	S, B&R HV	S, B&R HV
NGC 6264	None	None
UGC 6093	S	S, B&R HV

Table 2. A summary of the updated detections using this pipeline. Note that HV stands for high velocity masers, with R standing for red-shifted and B for blue-shifted. Those marked with stars are possible detections.

s^{-1}, with the blue-shifted emission at 5395 km s^{-1} and the red-shifted at 5880 km s^{-1}. See Appendices B and D for verification and cross-correlation patterns.

4.10. *J0847-0022*

The original determination of J0847-0022 was systemic-only emission. However, upon running it through the pipeline, two strong high-velocity emissions were detected at approximately 15924 km s^{-1} and 14665 km s^{-1}, with the systemic emission at 15295 km s^{-1}. This detection is one of the strongest detections found by the pipeline, and the graphical representation can be found in appendices B and D.

4.11. *Mrk 1419*

In Pesce et al. (2023), Markarian 1419 was determined to be a systemic-only emission detection. The pipeline overall concluded that there are possible high-velocity detections, located at 5403 km s^{-1} and 4367 km s^{-1}. This galaxy was marked as a possible detection, and can be seen in Appendices C and E.

4.12. *NGC 1068*

NGC 1068 was previously determined by Pesce et al. (2023) to be a non-detection galaxy. When run through the pipeline, NGC 1068 was determined to contain a systemic maser emission at approximately 1142 km s^{-1}, with a peak of 0.05 mJy and width of 350 km s^{-1}. See Appendices B and D for verifications and cross-correlation patterns for this galaxy.

4.13. *NGC 1194*

The determination of NGC 1194 in Pesce et al. (2023) was that the spectrum contained systemic and red-shifted maser emission, emitting at 4104 km s^{-1} and 4593 km s^{-1}, respectively. The pipeline agreed with both of these detections, but also found a strong blue-shifted emission within the spectrum, located at approximately 3616 km s^{-1}. The rotational velocity detected from the pipeline was 487.62 km s^{-1}, which matches extremely well with Pesce et al. (2023)'s rotational velocity measurement of 487 km s^{-1}. See Appendices B and D for the cross-correlation and verifications.

4.14. *NGC 1386*

In Pesce et al. (2023), NGC 1386 was classified as a non-detection galaxy, and our pipeline agrees with these findings.

4.15. *NGC 3393*

NGC 3393 was determined to lack all possible maser emission. Our pipeline agrees and further classifies this galaxy as a non-detection.

4.16. *NGC 5495*

Pesce et al. (2023) previously found systemic maser emission only in their investigations, with the emission located at 6787 km s^{-1}. The pipeline determined that there was a possibility of blue high-velocity maser emission located at 6323 km s^{-1}. See Appendices C and E for smoothed overlay, verifications, and the cross-correlation patterns.

4.17. *NGC 5643*

NGC 5643 was determined by Pesce et al. (2023) to contain systemic-only emission. Our pipeline concludes the same.

4.18. *NGC 5765b*

NGC 5765b was determined by Pesce et al. (2023) to contain systemic, blue, and red-shifted emission. Our pipeline concludes the same.

4.19. *NGC 6264*

NGC 6264 was determined to be a non-detection galaxy by Pesce et al. (2023). Our pipeline agrees with their findings.

4.20. *UGC 6093*

UGC 6093 was previously determined to contain only systemic maser emission, located at 10848 km s^{-1}. P23 determined that there were possible emissions at both 10100 km s^{-1} and 11600 km s^{-1}, but it could not be concluded that these were actual detections. Our pipeline determined that there are in fact, blue and red-shifted high-velocity lines located at 10137 km s^{-1} and 11559 km s^{-1}, respectively. These are very close matches to the velocities determined by Pesce et al. (2023) to be possible detections, and the rotational velocity agrees. See Appendices B and D for further graphical representation.

5. CONCLUSIONS

The pipeline that was created for the purpose of finding hidden maser emission from circumnuclear water megamaser disks was successful. The linear cross-correlation method in combination with the triple-peaked square template was successful in finding both systemic and high-velocity maser emission in noisy spectra from taken by ALMA.

Overall, the detections are the following:

1. Maser disk detections increased by 160%

2. Both Red and Blue High-velocity emission detections increased by 233%

3. Systemic maser emission detections increased by 25%

Overall, this pipeline determined a significant increase in detections of both 183GHz disk masers and systemic masers. The prevalence of 183GHz maser disks in galaxies with 22GHz maser disks is actively being researched further, however, this pipeline hints that the disks do indeed coincide with each other. The galaxies that were determined to be non-detections by the pipeline as well as P23 are ones that contained faint or weak maser emissions at 22GHz. The field of 183GHz masers is one that is growing with the addition of ALMA to the radio telescope cohort searching for maser disks. The coincidence of 183GHz maser disks with 22GHz disks is an active field of research, as well as all other properties of 183GHz maser disks.

6. FUTURE WORK

This pipeline is left to be used by the National Radio Astronomy Observatory to search for any other hidden emissions in spectra. The pipeline is currently being planned to be used to search for 22GHz emission from approximately 4000 spectra observed by Dr. James Braatz using the Green Bank Telescope. Further investigation into either the 183GHz dataset from ALMA or the 22GHz dataset from the GBT may be written into a proposal for each respective telescope upon determination by Mintz and Braatz.

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Facilities: GBT, ALMA

Software: astropy, scipy, numpy, matplotlib

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APPENDIX

A. ALL 183GHZ SPECTRA

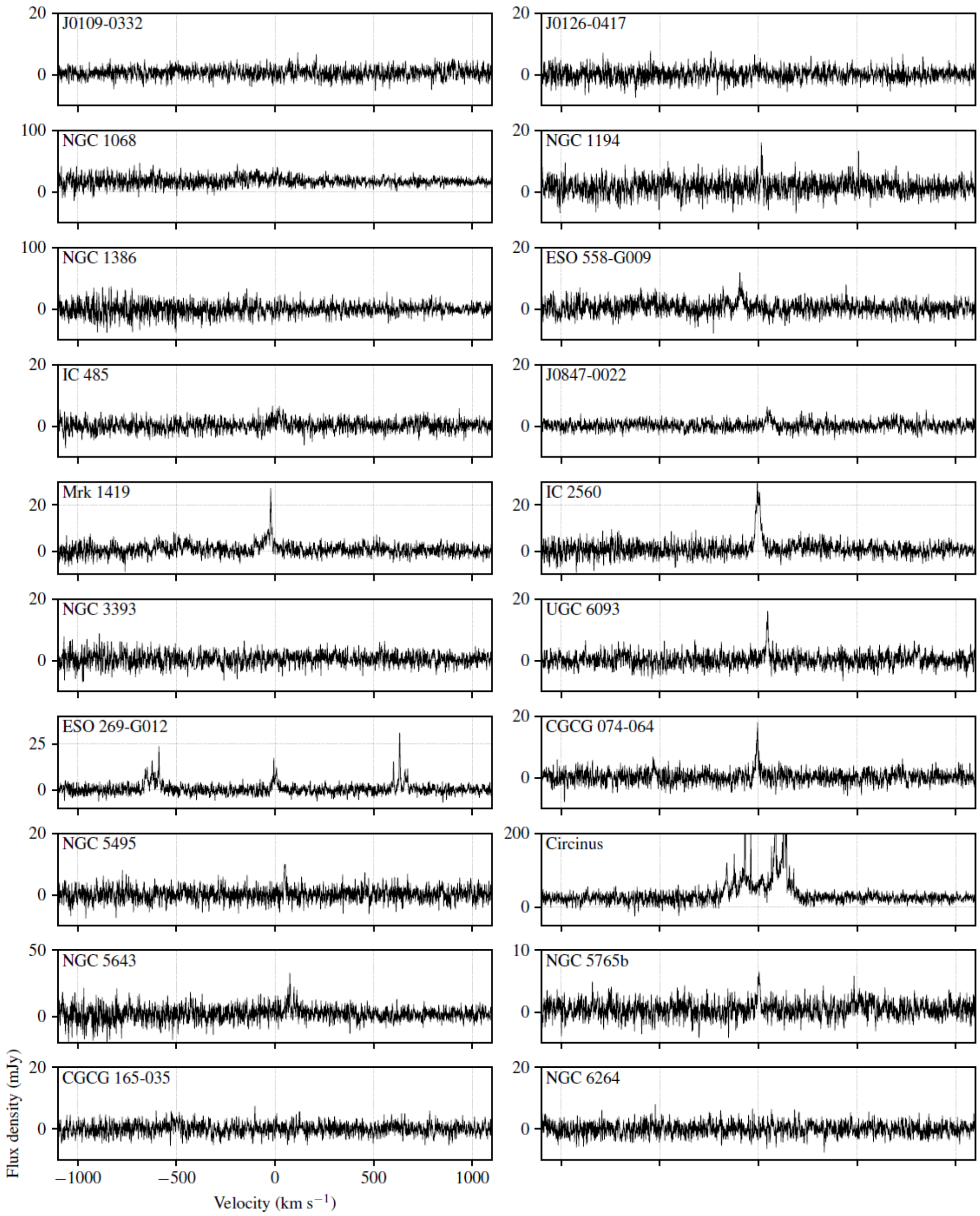

Figure 3. All of the 183GHz spectra investigated in this paper from Pesce et al. (2023). All spectra were boxcar smoothed in frequency by 10. The velocity on the x-axis is with respect to the recession velocity of each galaxy. Note that due to Circinus' extreme flux, it's y-axis has been adjusted.

B. BEST MATCHED CROSS-CORRELATION TEMPLATES OF DEFINITE DETECTIONS

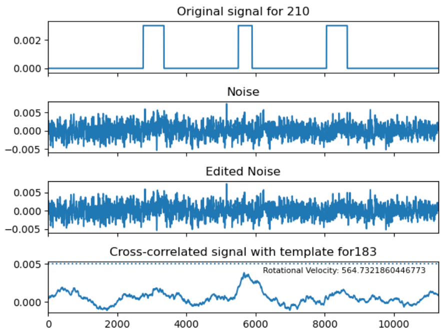

Figure 4. This is the best-matched template for CGCG 165-035. A red-shifted high-velocity maser emission was found at approximately 10152 km s^{-1}.

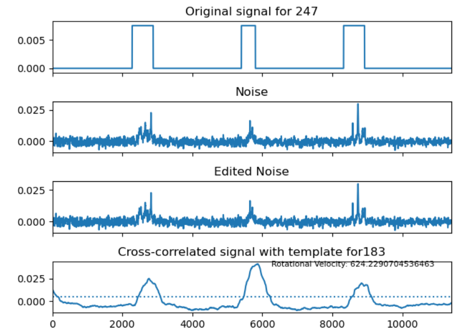

Figure 5. This is the best-matched template for ESO 269-G012. This galaxy was been heavily investigated due to it's strong 183GHz emission.

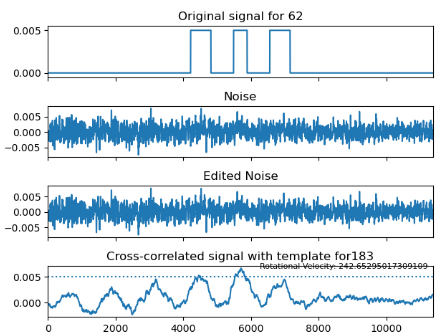

Figure 6. This is the best-matched template for J0126-0332. A systemic maser emission was found by the pipeline at 5638 km s^{-1}, with red and blue-shifted high-velocity emission at 5880 km s^{-1} and 5395 km s^{-1}, respectively.

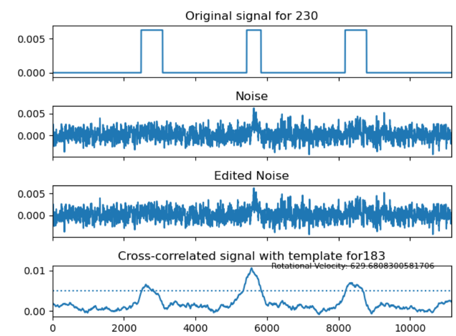

Figure 7. This is the best-matched template for J0847-0022. The pipeline detected red and blue-shifted high-velocity emission at 15924 km s^{-1} and 14665 km s^{-1}, respectively. Systemic maser emission was previously identified by Pesce et al. (2023) at 15296 km s^{-1}, which the pipeline agrees with.

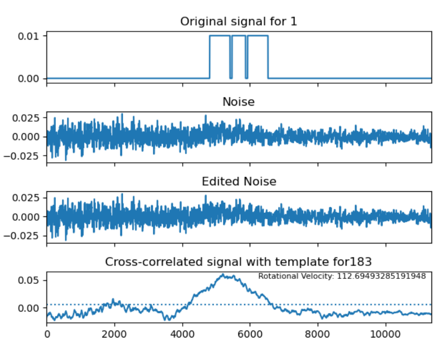

Figure 8. This is the best-matched template for NGC 1068. A systemic maser emission was found by the pipeline at 1142 km s^{-1}, with a width of 350 km s^{-1}. The peculiar cross-correlation is due to the extreme width of the single peak in the spectrum.

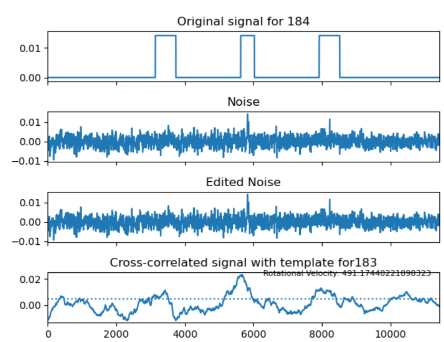

Figure 9. This is the best-matched template for NGC 1194. The pipeline detected blue-shifted high-velocity emission at 3616 km s^{-1}, and agreed with the findings of Pesce et al. (2023) of systemic emission at 4104 km s^{-1} and red-shifted high-velocity maser emission at 4593 km s^{-1}.

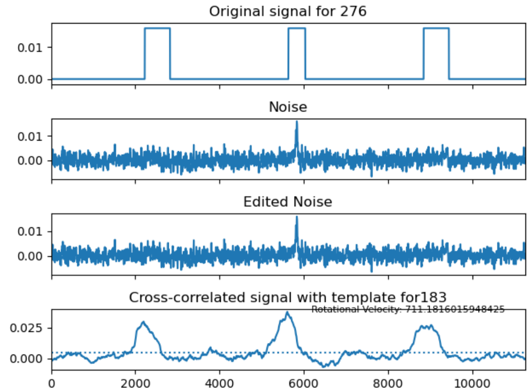

Figure 10. This is the best-matched template for UGC 6093. Originally, Pesce et al. (2023) detected systemic emission at 10848 km s^{-1}, with possible but inconclusive emission at 10100 km s^{-1} and 11600 km s^{-1}. The pipeline definitively concluded red and blue-shifted high-velocity emission at 11559 km s^{-1} and 10137 km s^{-1}, respectively.

C. BEST MATCHED CROSS-CORRELATION TEMPLATES OF POSSIBLE DETECTIONS

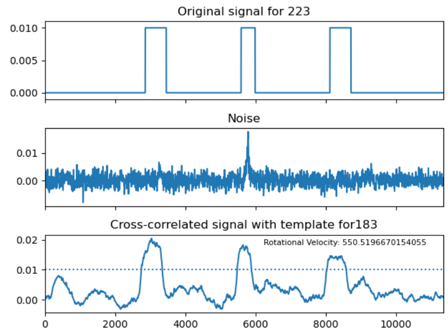

Figure 11. This is the best-matched template for CGCG 074-064. A systemic maser emission was found by Pesce et al. (2023) at 6910 km s^{-1}, with a blue-shifted high-velocity emission at 6387 km s^{-1}. The pipeline detected a possible red-shifted high-velocity emission at 7460 km s^{-1}.

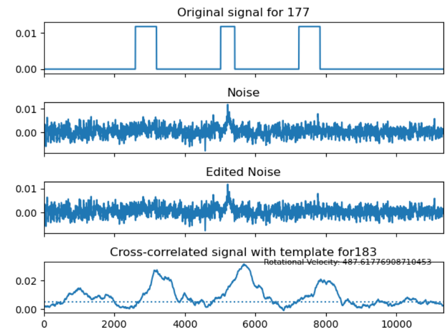

Figure 12. This is the best-matched template for ESO 558-G009. The pipeline concluded possible detections at 8072 km s^{-1} and 7097 km s^{-1}, coinciding with red and blue-shifted high-velocity emission that matches the findings in Pesce et al. (2023).

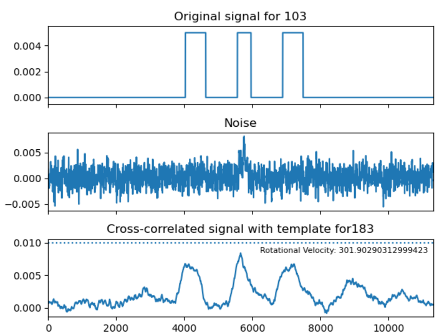

Figure 13. This is the best-matched template for IC 485. The pipeline detected a possible red-shifted high-velocity emission at 8656 km s^{-1}.

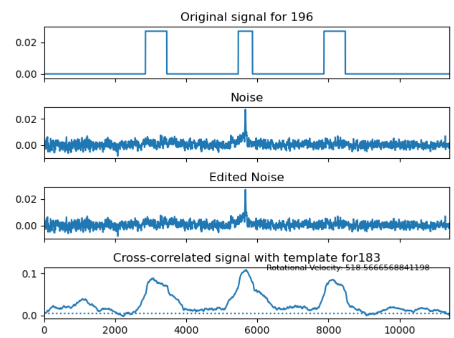

Figure 14. This is the best-matched template for Mrk 1419. The pipeline concluded possible high-velocity detections at 5403 and 4367 km s^{-1}, coinciding with red and blue-shifted high-velocity emission.

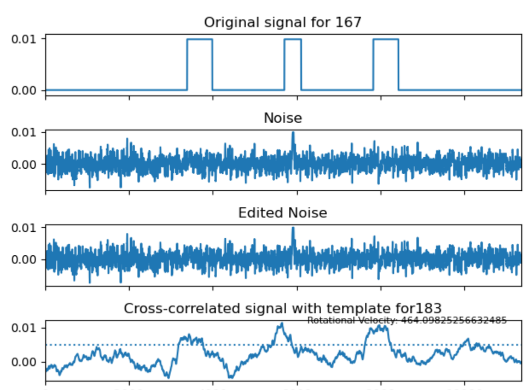

Figure 15. This is the best-matched template for NGC 5495. Originally, Pesce et al. (2023) detected systemic emission at 6787 km s^{-1}. The pipeline concluded a possible blue-shifted high-velocity emission at 6323 km s^{-1}.

D. VERIFICATIONS OF DEFINITE DETECTIONS

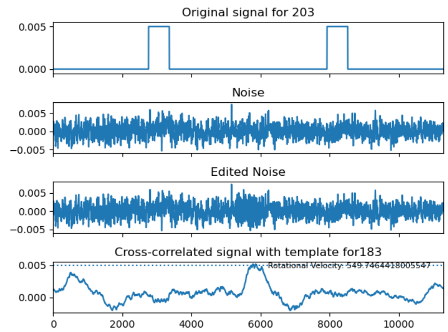

Figure 16. This is the best matched template for CGCG 165-035 with the area of the spectrum with systemic emission replaced with RMS noise.

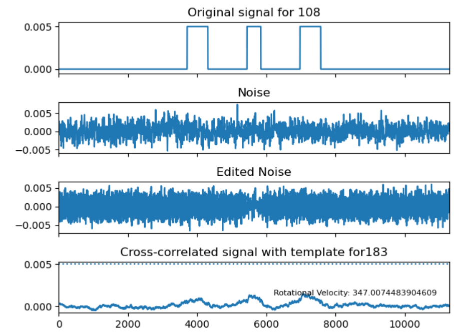

Figure 17. This is the best matched template for CGCG 165-035 with the area of the spectrum with high-velocity emission replaced with RMS noise.

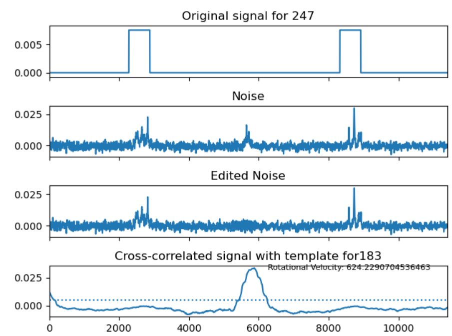

Figure 18. This is the best matched template for ESO 269-G012 with the area of the spectrum with systemic emission replaced with RMS noise.

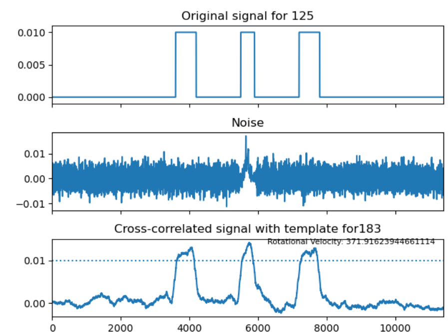

Figure 19. This is the best matched template for ESO 269-G012 with the area of the spectrum with high-velocity emission replaced with RMS noise.

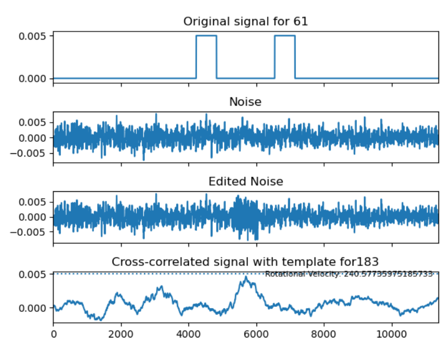

Figure 20. This is the best matched template for J0126-0332 with the area of the spectrum with systemic emission replaced with RMS noise.

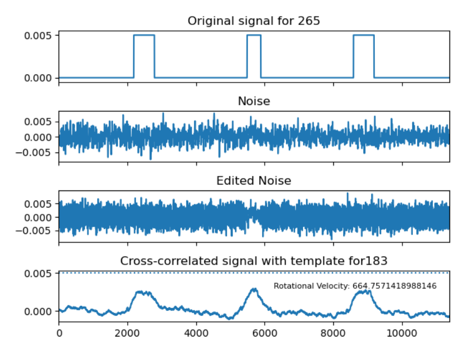

Figure 21. This is the best matched template for J0126-0332 with the area of the spectrum with high-velocity emission replaced with RMS noise.

E. VERIFICATIONS OF POSSIBLE DETECTIONS

F. SMOOTHED OVERLAYS

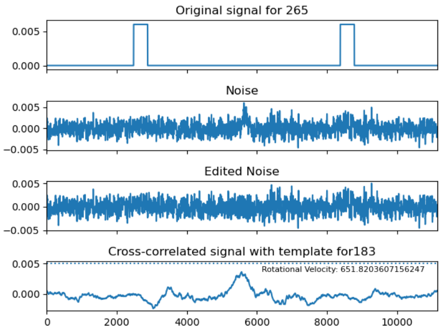

Figure 22. This is the best matched template for J0847-0022 with the area of the spectrum with systemic emission replaced with RMS noise.

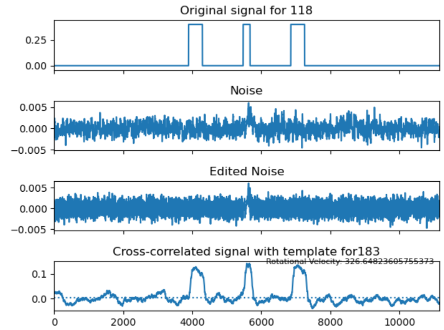

Figure 23. This is the best matched template for J0847-0022 with the area of the spectrum with high-velocity emission replaced with RMS noise.

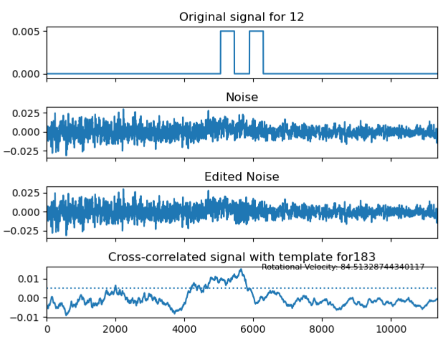

Figure 24. This is the best matched template for NGC 1068 with the area of the spectrum with systemic emission replaced with RMS noise.

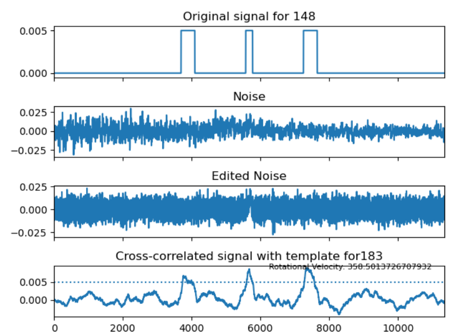

Figure 25. This is the best matched template for NGC 1068 with the area of the spectrum with high-velocity emission replaced with RMS noise.

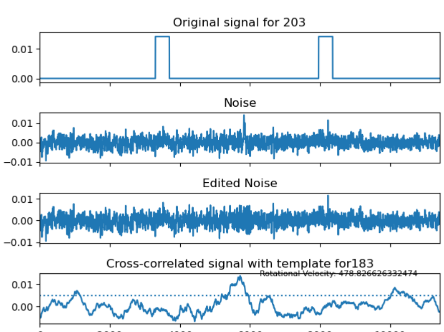

Figure 26. This is the best matched template for NGC 1194 with the area of the spectrum with systemic emission replaced with RMS noise.

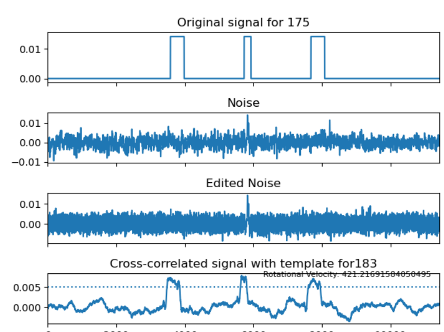

Figure 27. This is the best matched template for NGC 1194 with the area of the spectrum with high-velocity emission replaced with RMS noise.

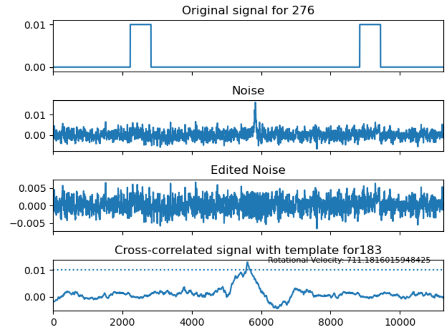

Figure 28. This is the best matched template for UGC 6093 with the area of the spectrum with systemic emission replaced with RMS noise.

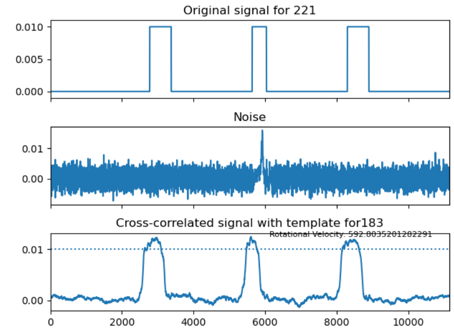

Figure 29. This is the best matched template for UGC 6093 with the area of the spectrum with high-velocity emission replaced with RMS noise.

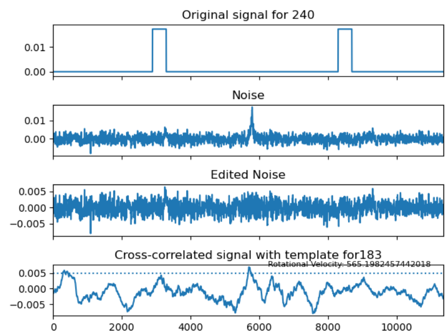

Figure 30. This is the best matched template for CGCG 074-064 with the area of the spectrum with systemic emission replaced with RMS noise.

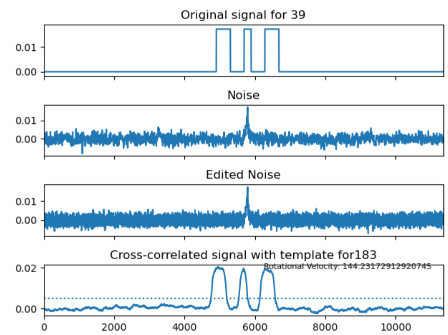

Figure 31. This is the best matched template for CGCG 074-064 with the area of the spectrum with high-velocity emission replaced with RMS noise.

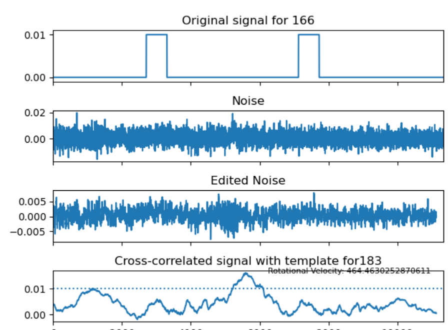

Figure 32. This is the best matched template for ESO 558-G009 with the area of the spectrum with systemic emission replaced with RMS noise.

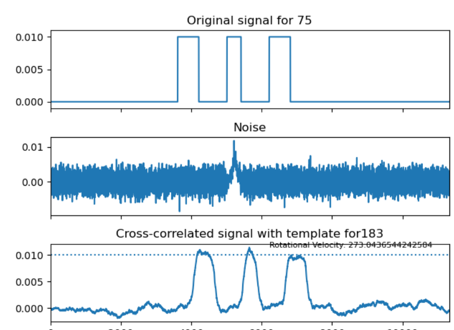

Figure 33. This is the best matched template for ESO 558-G009 with the area of the spectrum with systemic emission replaced with RMS noise.

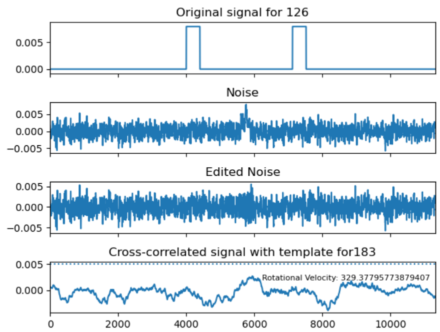

Figure 34. This is the best matched template for IC 485 with the area of the spectrum with systemic emission replaced with RMS noise.

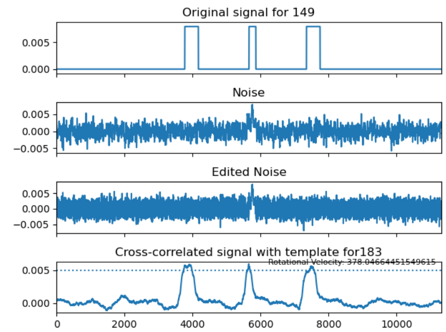

Figure 35. TThis is the best matched template for IC 485 with the area of the spectrum with high-velocity emission replaced with RMS noise.

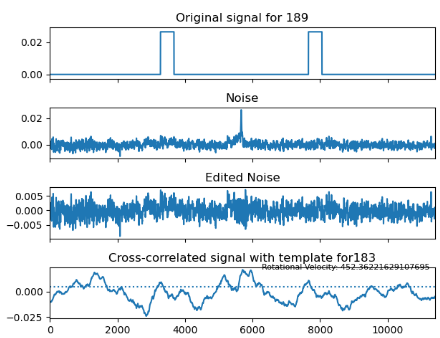

Figure 36. This is the best matched template for Mrk 1419 with the area of the spectrum with systemic emission replaced with RMS noise.

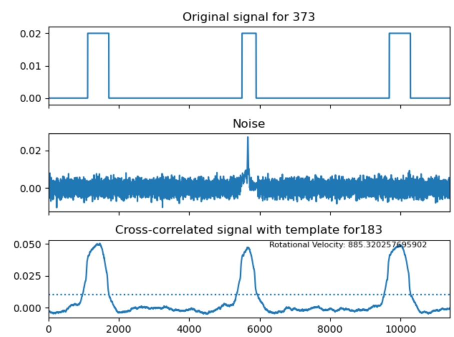

Figure 37. This is the best matched template for Mrk1419 with the area of the spectrum with high-velocity emission replaced with RMS noise.

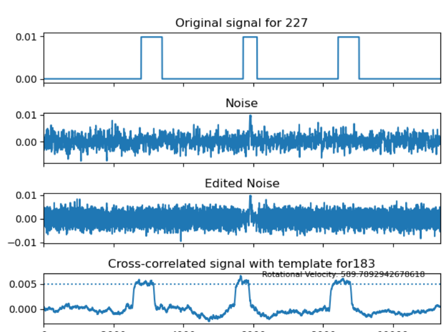

Figure 38. This is the best matched template for NGC 5495 with the area of the spectrum with systemic emission replaced with RMS noise.

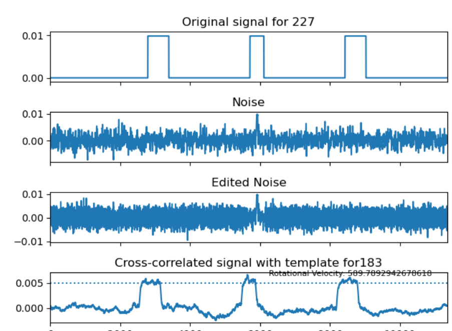

Figure 39. TThis is the best matched template for NGC 5495 with the area of the spectrum with high-velocity emission replaced with RMS noise.

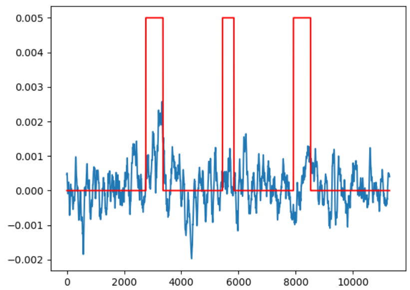

Figure 40. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for CGCG 165-035.

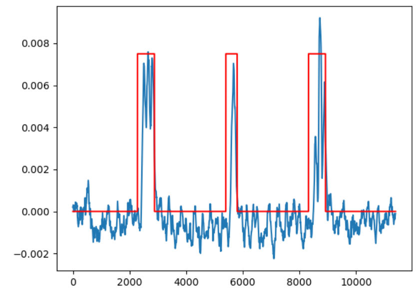

Figure 41. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for ESO 269-G012.

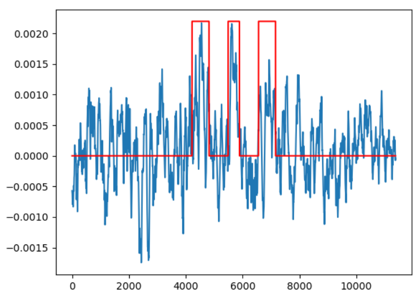

Figure 42. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for J0126-0332.

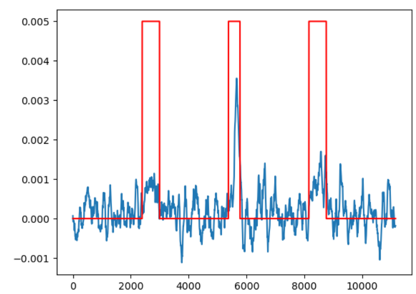

Figure 43. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for J0847-0022.

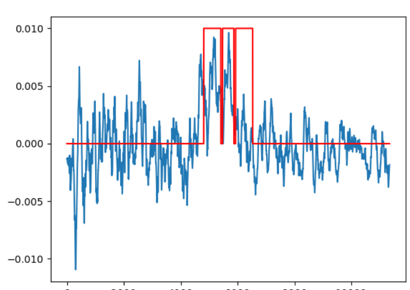

Figure 44. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for NGC 1068.

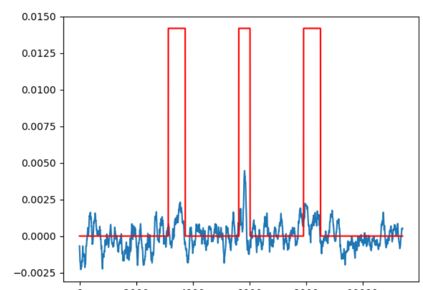

Figure 45. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for NGC 1194.

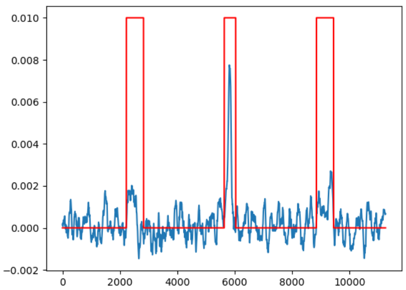

Figure 46. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for UGC 6093.

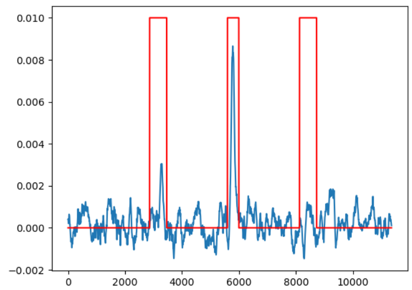

Figure 47. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for CGCG 074-064.

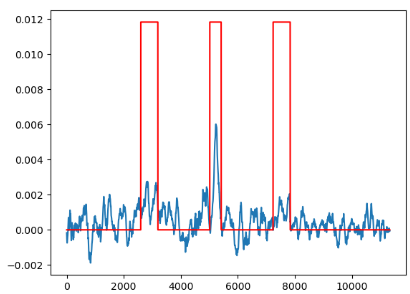

Figure 48. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for ESO 558-G009.

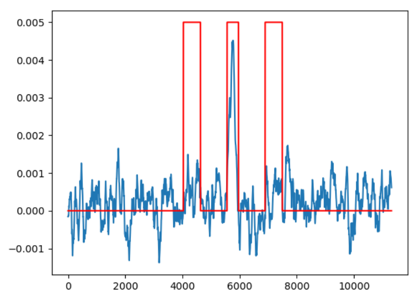

Figure 49. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for IC 485.

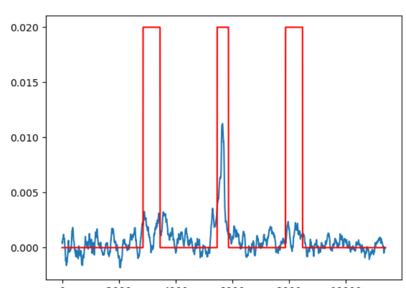

Figure 50. This is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for Mrk 1419.

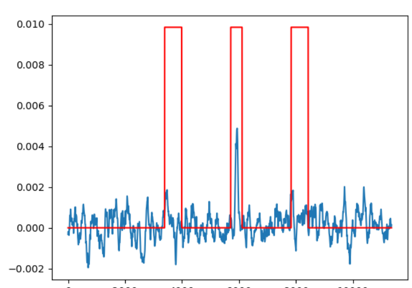

Figure 51. TThis is the best-matched template from the cross-correlation overlaid on top of an overlay smoothed version of the spectrum for NGC 5495.