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Exploring Low Mass Galaxies at Different Wavelengths

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Abstract – We create a sample of potential AGN hosting dwarf galaxies from the MaNGA survey and AllWISE database for a redshift up to z 0.15. We select our sample with optical data obtained from the MaNGA survey then match these galaxies to sources in the AllWISE database, through a 10 arcsecond diameter search based on the right ascension and declination of our targets, to obtain infrared data. We find 141 likely potential AGN hosting galaxies from optical BPT analysis and 17 potential hosts from IR colour-colour analysis. We have compiled a list of galaxies for further analysis in other AGN indicating wavelengths, like radio and X-ray.

Keywords – Active Galactic Nuclei, AGN, Black Hole, Super Massive Black Hole, MaNGA, WISE, Optical, Infrared, BPT

1. Introduction

Dwarf galaxies, despite being the most common type of galaxy found, as shown by the luminosity function which implies that high luminosity galaxies are exponentially rarer than low luminosity galaxies [16], are an under-studied area of astrophysics, as only recently have wide field low redshift studies been conducted, like the MaNGA survey we will be looking at. This mainly comes from the fact that these dwarf galaxy's low luminosity's makes them harder to detect than the larger galaxies usually focused on. Despite the apparent disinterest historically shown to developing methods to properly study them, new evidence shows that they could play a critical role in furthering our understanding of the universe. We believe this is because they have the potential to reveal some of the physical processes that could have occurred in the early universe and compared to larger more rapidly changing galaxies, there is a higher chance that proof of these early universe conditions will have survived.

Supermassive black holes (SMBHs) play a key role in galaxy evolution by regulating the star formation rates in their host galaxies. They do this when they 'activate', becoming active galactic nuclei (AGN), this means that gas is being accreted onto the surface of the black hole, resulting in the release of large numbers of photons, heating the large molecular clouds and making it impossible for the constituent atoms to collapse into the required density for fusion to occur. The resulting effect is that an AGN will kill off star formation in it's host galaxy making it something known as a dead or quenched galaxy [14]. We will be, for our project, considering a galaxy to be quenched so long as it has no active star formation occurring. Quenched galaxies are theoretically able to re-start the formation of stars, in a process called rejuvenation, but this has to be triggered by a merger with another galaxy that will resupply it with gas, warm dense gas forms rings in the central regions of the merged galaxy [17] with a radius of ~ 6 - 13 kpc. However this type of rejuvenation has not been confirmed observationally, current theories are purely simulation based.

Another process that can limit star formation would be supernova feedback, this occurs after a burst of star formation, which injects heat from supernovae and young stars into the interstellar medium, blowing the gas into the halo and disrupting star formation. When the gas cools and collapses into the center of the galaxy it drives another burst of star formation, with this process taking place over the space of a few 100 Myr as described by simulations in El-Baldry et al. 2016 [3].

Recently discovered evidence suggests that AGN play a much greater role in the evolution of dwarf galaxies than previously thought, brought about by the discovery of many new AGN discovered in nearby dwarf galaxies, shown in papers such as Penny et al. 2018 [22], Reines et al. 2013 [25] and Sartori et al. 2015 [27], with potential signs of AGN activity being, as shown in Penny et al. 2018 [22], an ionised gas component rotating out of alignment with the plane of the host galaxy, this is believed to be because the high energy emissions from the AGN are driving the gas out of its normal path. Potentially, we could find additional AGN by looking for these ionised gasses then observing the host galaxy in multiple wavelengths for reinforcing evidence, expanding upon some of the earliest dwarf galaxy AGN discoveries, like Reines et al. 2013 [25], that were purely observed in optical wavelengths.

We will be searching, in this project, for potential hosts for a specific type of supermassive black hole known as an intermediate mass black hole (IMBH), these black holes are theorised to have a mass ranging from approximately 10^4 $M_\odot$ to 10^6 $M_\odot$ ([19], [24]) and are of great importance to the scientific community, due to the belief that they would, most likely, be similar in mass to the types of black holes formed in the early universe that are theorised to have been the seeds of modern supermassive black holes residing in the larger galaxies we see around us. Finding these IMBHs would allow us to gain a valuable insight into the evolution of supermassive black holes and how they affect their host galaxy's evolution.

We would be especially interested in finding these IMBH as, due to their relatively unchanged nature, we would be able to create more advanced models and simulations of galaxy evolution. As we have previously discussed, AGN play an important role in the evolution of their host galaxies, this means that by having more accurate data to base the starting conditions off of, more accurate simulations can be constructed to better describe the changes that take place over the lifetime of the galaxies in our universe. Additionally, with observational evidence from other instruments, like the James Webb Space Telescope, we could create a mostly complete timeline for the evolution of the multiple types of galaxies we know of. These models would grant us a greater understanding of the universe at large, bringing us closer to understanding the underlying principles behind greater structure formation in the universe, by potentially allowing us to predict why certain galaxies exist in the positions and ratios that they do.

AGN in galaxies can be difficult to spot due to a multitude of reasons, however it is found that the main reasons are due to, either the supermassive black hole being in an inactive state, or possibly because of a low concentration of dust surrounding the black hole, making it hard for any emissions to be detected at optical wavelengths ([2], [28], [29]). By looking at figure 1 we can see why this is a problem, in the structure of the AGN dust is a major contributor to emissions, this is because the dust in the torus, BLR and NLR absorb and re-emit the light detected by our telescopes, so without sufficient dust the strength of the emissions may be too weak to be detected, most likely due to being drowned out by other sources, such as star forming regions, in the host galaxy.

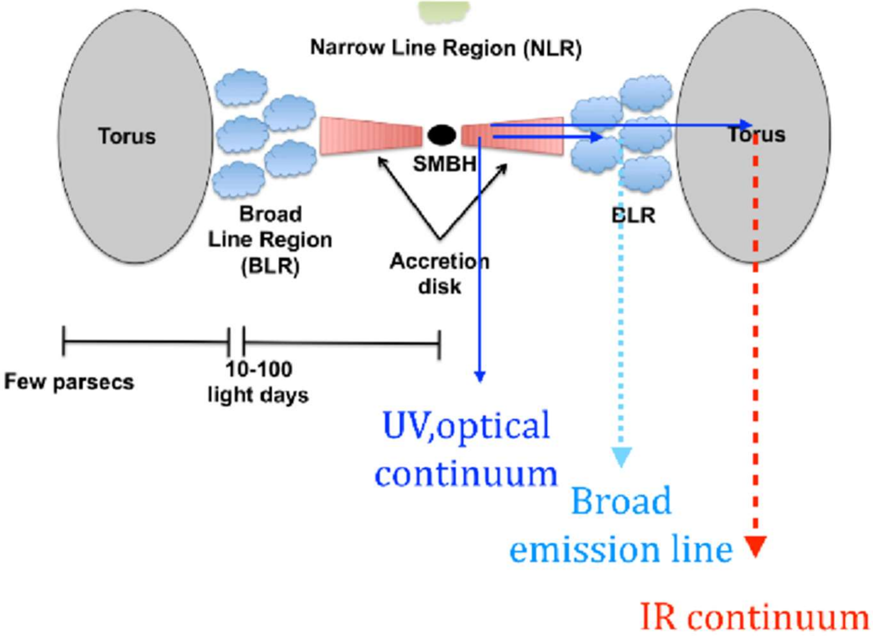

Figure 1. Diagram (not to scale) detailing the rough structure of an AGN and the sources of certain wavelengths [9], [26].

Although AGN can be hard to spot in certain wavelengths, they may be easier to detect in others. For example, an AGN may be obscured by the dust torus surrounding it, making it almost impossible to see in visible light, however it would most likely be visible in infrared (IR) or X-ray wavelengths. by using multiple wavelengths, we can easily verify other methods of detecting AGN used, by checking if multiple methods agree on a certain galaxy hosting an AGN we can confidently state whether it is a host for an AGN. Furthermore, this would allow us to figure out why certain wavelengths are giving either false positives or negatives and hopefully allow us to further refine our analysing methods, similar to what was done in Mecua et al. 2020 [20].

2. Methodology

This project uses optical data from the MaNGA survey with additional infrared (IR) WISE data to search for AGN in nearby ($z < 0.15$) dwarf galaxies. We have defined dwarf galaxies as having a mass between $5x10^7M_\odot$ and $5x10^9M_\odot$ and an r band magnitude of $r < -12$ as this gives us a sample of 2946 dwarf galaxies to analyse. We will be searching for these AGN by using observations ranging from near UV to visible from MaNGA, with additional attention being paid to emission lines in $[N_{II}]$ (6585λ) as it correlates to metallicity, $[O_{III}]$ (5008λ) as it correlates to star formation rate (SFR), H_α and H_β, with IR measurements being obtained from WISE.

2.1. MaNGA Survey

In this project we will be using data from the MaNGA survey (Mapping Nearby Galaxies at Apache Point Observatory) from the SDSS-IV (Sloan Digital Sky Survey) [6]. We will be using data release 17 as it is the latest release and contains the most up to date observations [15]. MaNGA provides observations in the visible and near UV ranges of the EM spectrum (from 360nm to 1000nm), which should allow us to detect signs of AGN activity from the accretion disk surrounding the supermassive black hole in the dwarf galaxy we are observing by using certain emission line ratios, using a method described in Baldwin et al. 1981 [4].

The MaNGA survey is a database of over 10,000 nearby galaxies up to a redshift of around $z = 0.2$. This is ideal for our project as we want to observe specifically dwarf galaxies that, due to their size and luminosity, are relatively hard to obtain useful measurements for. These difficulties arise mostly due to the data being collected usually having a low signal to noise ratio, which is only made worse by any nearby luminous foreground or background objects obscuring the galaxy we are attempting to observe.

MaNGA is also useful for the fact that it uses integral field units (IFUs) that, using fibre optic cables, can take measurements from any position inside the IFU allowing us to break down emissions from different parts of each observed galaxy. This is useful to us as it can allow us to search individual areas of a galaxy for AGN readings, e.g. we can compare the core to the outer edges to see if extreme starbursts are drowning out the key features that allow us to determine the likelihood of an AGN existing in our galaxy. By plotting each point inside a galaxy, we can create a BPT for the separate areas we are looking at thereby making the analysis easier.

We accessed the MaNGA database using Python in a Jupyter Notebook on the SciServer website, in this notebook we imported the astropy module and used it to build the query that was then fed to SciServer's built in database reader. We then fed the output back into astropy as it would create a readable table from the data.

2.2. AllWISE Catalogue

We will also be utilising data from the WISE (Wide-field Infrared Survey Explorer) space telescope's AllWISE database. we will be using the W1 (3.4 μm), W2 (4.6 μm), W3 (12 μm) and W4 (22 μm) bands. These should allow us to find signs of AGN activity by searching for the IR emissions given off by the dust torus surrounding the AGN when it absorbs high energy photons given off by the accretion disk as showed in figure 1.

The AllWISE data we are using contains observations for over 747 million sources. We have matched the MaNGA and AllWISE databases by querying the AllWISE catalogue with a 10 arcsecond diameter search based on the right ascension and declination of the observed object and considering the nearest source a match, this is the default option on the Caltech website and we saw no need to change it. By doing this query, we have obtained matches for all 2946 of our sample dwarf galaxies chosen in the MaNGA survey, this allows us to observe where objects fall on the BPT and IR colour-colour diagrams to compare the two methods to see how many dwarf galaxies are agreed on by both diagrams (figure 3). We will cover this in greater detail in the colour-colour analysis section.

2.3. BPT Diagram Analysis

The BPT diagram (Baldwin, Phillips, Terlevich diagram), as defined in Baldwin et al. 1981 [4], is a method of searching for AGN using the intensity ratios of certain emission lines, it is done using 2 emission lines of similar wavelength so as to minimise errors due to reddening corrections. However, it should be mentioned that by using forbidden [O$_{III}$] (5008λ) Å and [N$_{II}$] (6585λ) Å lines, the BPT becomes sensitive to the [N$_{II}$]/[O$_{III}$] abundance ratio. The BPT works as the strength of the [O$_{III}$]/H$_\beta$ line depend on the heavy element abundances.

Signs of AGN activity can be detected by looking at certain emission lines in the spectra of an observed galaxy, by measuring the magnitudes of the emissions and plotting them it allows us to separate the different types of activity in galaxies into extreme star formation, AGN activity and LINERs (low-ionization nuclear emission-line region) as they will each fall into different sections in the BPT diagram. Although there are various forms of BPT diagrams, each uses different emission lines to separate activities, we will be using [NII]/H$_\alpha$ against [O$_{III}$]/H$_\beta$ [4] for this project as the [N$_{II}$] and [O$_{III}$] emission lines are very prominent in the spectra and will therefore be easier to measure accurately.

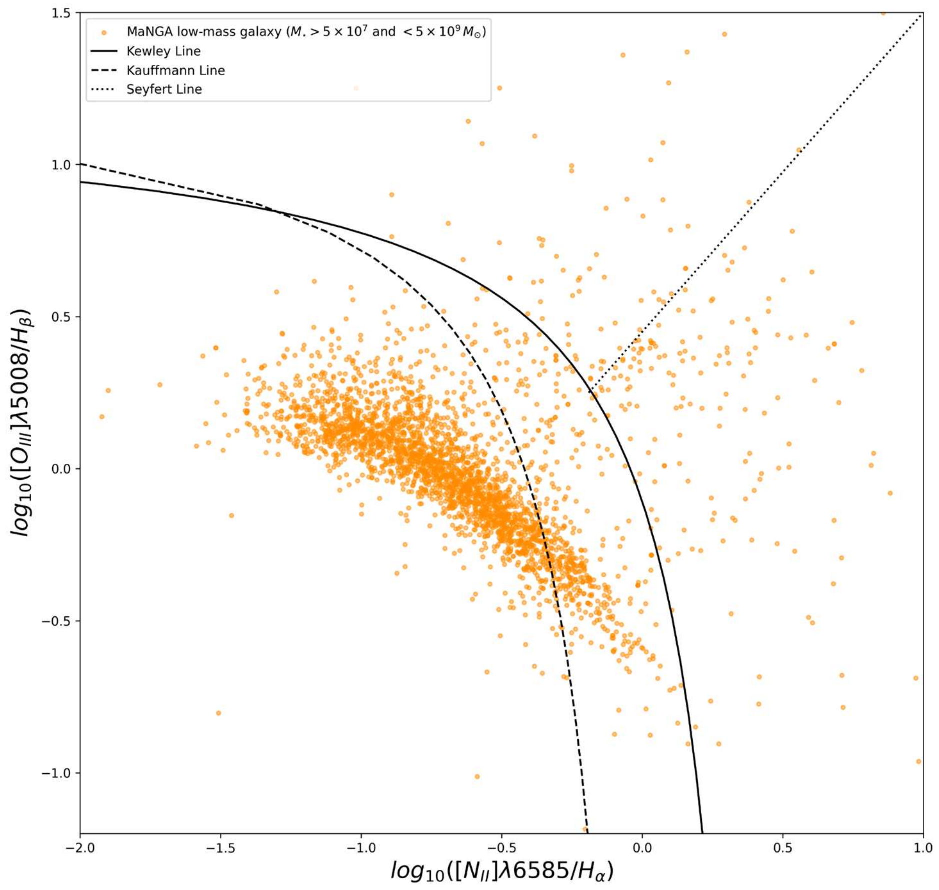

Figure 2. [N$_{II}$]/H$_\alpha$ against [OIII]/H$_\beta$ BPT diagram showing MaNGA dwarf galaxies.

The [NII]/Hα against [OIII]/Hβ BPT diagram can be broken into roughly 4 sections, by looking below the Kauffmann line [12] we can see galaxies where the emissions are likely coming from extreme star formation (figure 9), by looking between the Kewley [13] and Kauffmann lines we can see galaxies in the composite AGN region (figure 8), where the emissions sources are less clear, with them potentially coming from AGN activity, by looking to the right and above the Kewley line we can see the AGN region (figure 6), where galaxies emissions are likely to come from predominantly AGN activity and finally by looking to the right and down from the Kewley line we can see the LINER region (figure 7), where emissions likely come from LINER activity [31].

The [N$_{II}$] lines represent the metallicity of the star population in the host galaxy whilst the [O$_{III}$] lines represent the SFR of the galaxy, hence why we can identify AGN in galaxies with a high metallicity, signifying an older star population, and low SFR signifying quenching due to processes like AGN activity.

By using the [N$_{II}$]/H$_\alpha$ against [O$_{III}$]/H$_\beta$ BPT diagram we can make an estimate for the number of AGN we will find in our sample, by doing this we find 141 galaxies in the AGN region (LINER and Seyfert).

2.4. WISE Colour-Colour Diagram Analysis

Mid IR data from WISE can also be used to detect AGN [1], we will be doing this by plotting, on a W2-W3 against W1-W2 colour-colour graph (as shown in figures 3 & 5), the colours of our dwarf galaxies. By doing this we can break down which processes in a certain galaxy are taking place predominantly, for star formation we will see the galaxy on the lower track whilst AGN activity should fall into the AGN wedge [18].

For this project we are using a modified AGN wedge we have created, meaning we are relaxing our selection criteria. We did this by simply applying an offset to the y axis of -0.25, this was done as the original wedge was designed for more massive and luminous galaxies which would show up as higher in magnitude for IR wavelengths. This was done as, due to findings in Toba et al. 2014 [35], luminosity has been shown to affect where objects are positioned in the W2-W3 against W1-W2 colour-colour diagram (figure 10).

In our WISE colour-colour diagram most galaxies lie on a main track running along the bottom of the graph with AGN fitting into the wedge above it (figure 3). On the far left of this track we see galaxies with low to no star formation occurring and towards the right we see star formation dominate. We have calculated the mean and variance for the galaxies that show up in the BPT AGN, Composite AGN and Extreme Starburst regions (figure 4), this allows us to see where, for each type of process, the average galaxy falls.

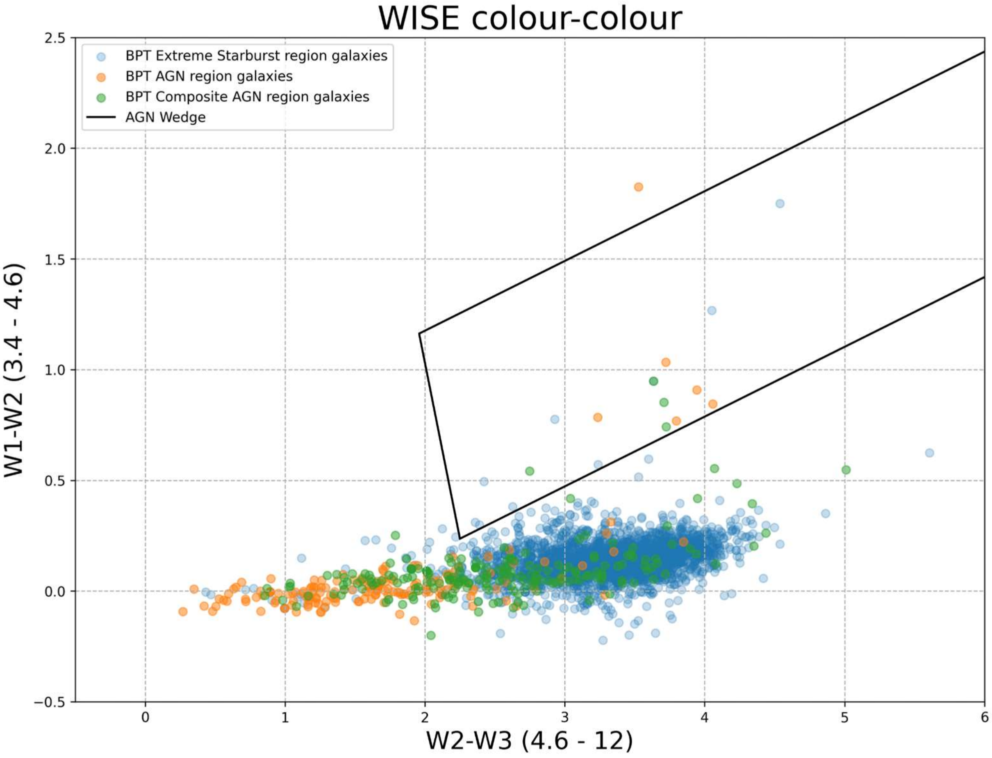

Figure 3. Plot of W2-W3 against W1-W2 for Extreme Starburst region (in blue), AGN region (in orange) and Composite AGN region (in green) for dwarf galaxies observed in MaNGA survey, With custom AGN wedge based on Mateos et al. 2012 [18].

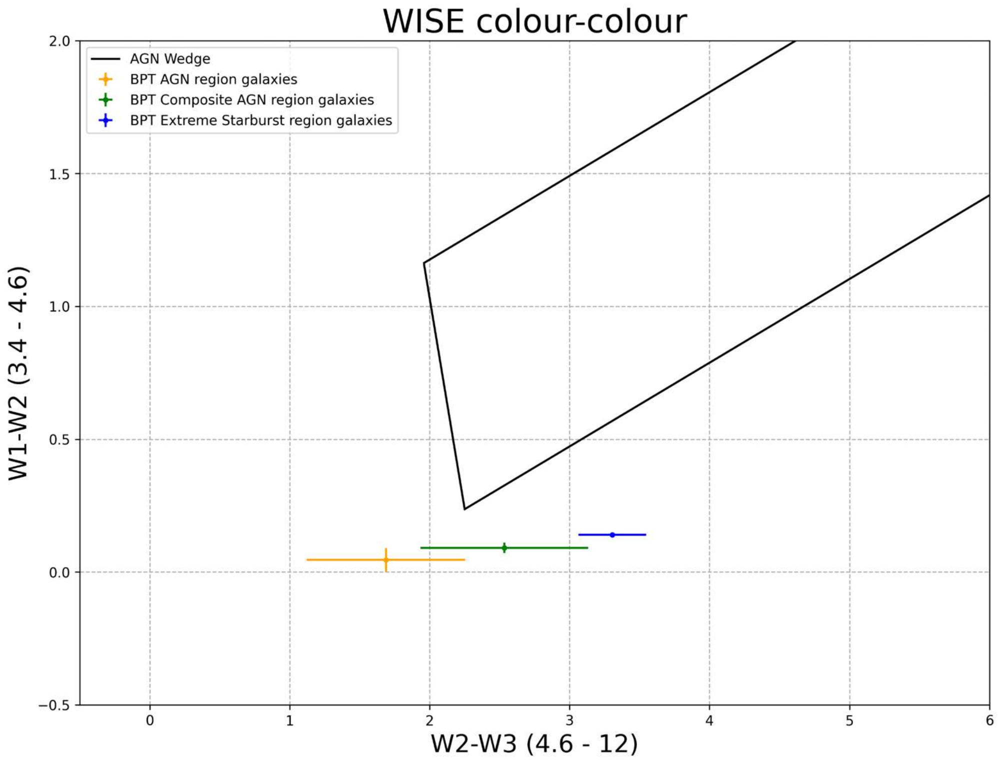

Figure 4. Plot of W2-W3 against W1-W2 for the mean ad variance for our BPT diagram's Extreme Starburst region (in blue), AGN region (in orange) and Composite AGN region (in green), With custom AGN wedge based on Mateos et al. 2012 [18].

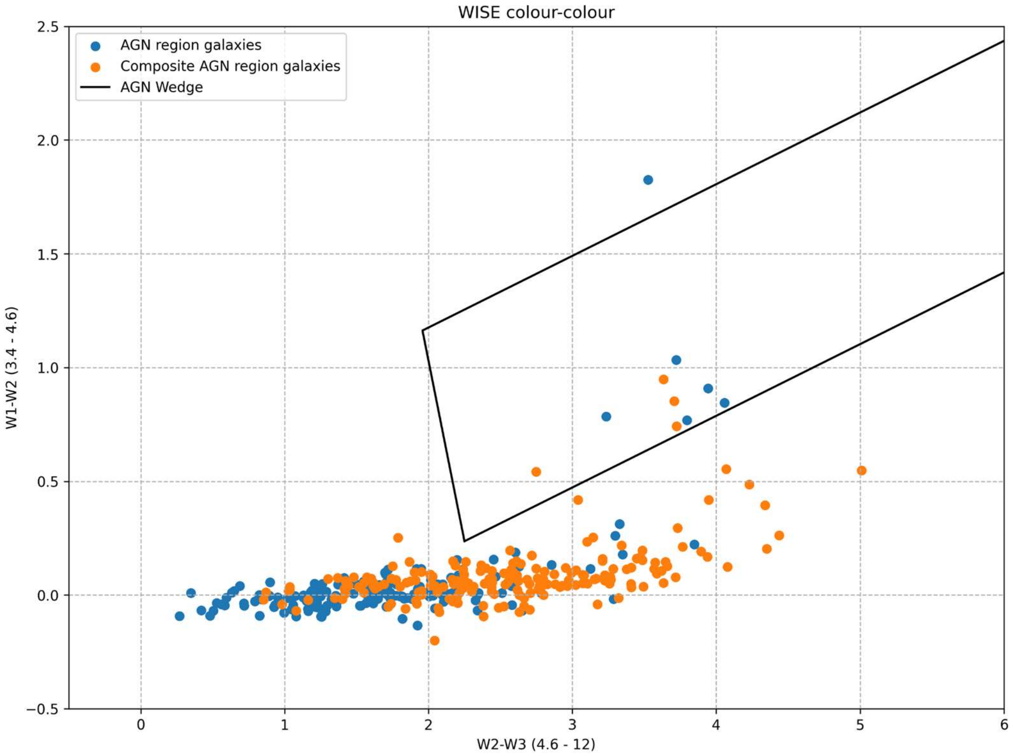

Figure 5. Plot of W2-W3 against W1-W2 for AGN region (in blue) and Composite AGN region (in orange) for dwarf galaxies observed in MaNGA survey, With custom AGN wedge based on Mateos et al. 2012 [18].

3. Results and Discussion

By utilising both data from MaNGA and AllWISE, we can see 5 galaxies that show signs of AGN activity in both optical and IR wavelengths (figures 5 & 6), as both methods return a positive for these signs there is a strong possibility that AGN exist in these dwarf galaxies. There are also 4 galaxies from the composite AGN region of the

BPT diagram (figure 8) that appear in the AGN wedge, these are also likely have AGN as they show signs in both optical and IR, however we are less certain of these as optical analyses did not show clear signs of AGN activity. Additionally, we find 8 galaxies from the extreme starburst region of the BPT diagram (figures 3 & 9) that appear in the AGN wedge, these galaxies only show signs of AGN activity in IR wavelengths meaning they are still potential AGN hosts, however we cannot confirm that any of these dwarf galaxies are conclusively hosting AGN in these galaxies without further analysis in other wavelengths.

We find that from a total of 2946 dwarf galaxies, our WISE colour-colour says only 17 are potentially hosting AGN (0.577% of our sample), compared to the MaNGA BPT implying we should see 141 AGN hosts (4.79% of our sample) with a further 221 potential hosts if we include the composite AGN region, for a total of 362 potential AGN hosts (12.3% of our sample). This means, assuming one method is giving the correct amount, that either our BPT is incorrectly identifying dwarf galaxies as AGN hosts or our colour-colour diagram is missing a vast number of AGN host candidates (a difference of 124 dwarf galaxies). As, according to theory, most dwarf galaxies should host a supermassive black hole, we should find many more AGN than both methods are detecting, this shows definitively that we would need at least one more method of detecting AGN to compare to these results. Another possible answer would be that, due to their low luminosity's, dwarf galaxies are occupying a different area than expected on our colour-colour diagram.

By using figure 3 and figure 4 we can see that a majority of the dwarf galaxies that showed as having AGN on the BPT diagram have an almost equal level of light in the W1-W2 colour, with the mean W1-W2 colour being 0.046 and the variance being 0.044 (all values rounded to 2 significant figures), and have a mean W2-W3 = 1.7 and a variance of 0.57. This shows that the majority of the BPT AGN region dwarf galaxies do not show signs in IR wavelengths of AGN activity but are also not exhibiting signs of star formation, however high variance means we will have points scattered across the diagram.

The BPT composite AGN region comes next on the track in our diagram with a W1-W2 mean value of 0.091 and a variance of 0.020, with W2-W3 having a mean value of 2.5 and a variance of 0.60. This shows that the majority of BPT composite AGN region galaxies are also not showing signs of AGN activity in IR wavelengths, but are starting to show signs of star formation. With the small variance on W1-W2 showing the vast majority of these dwarf galaxies lie almost directly on the mean, far below the AGN wedge.

Finally comes the BPT extreme starburst region with a mean value of 0.14 and a variance of 0.0091, with W2-W3 having a mean value of 3.3 and a variance of 0.24. This shows that, as we suspected from the analysis of the BPT diagram, most of the BPT extreme starburst region dwarf galaxies lie definitively outside of the AGN wedge with an extremely low W1-W2 variance showing that despite, on average, being in the correct W2-W3 region for signs of potential AGN activity, only the most extreme outliers will have a W1-W2 colour magnitude value large enough to fall into the AGN wedge. This high W2-W3 but low W1-W2 ratio means that star formation is very likely to be the source of these IR emissions.

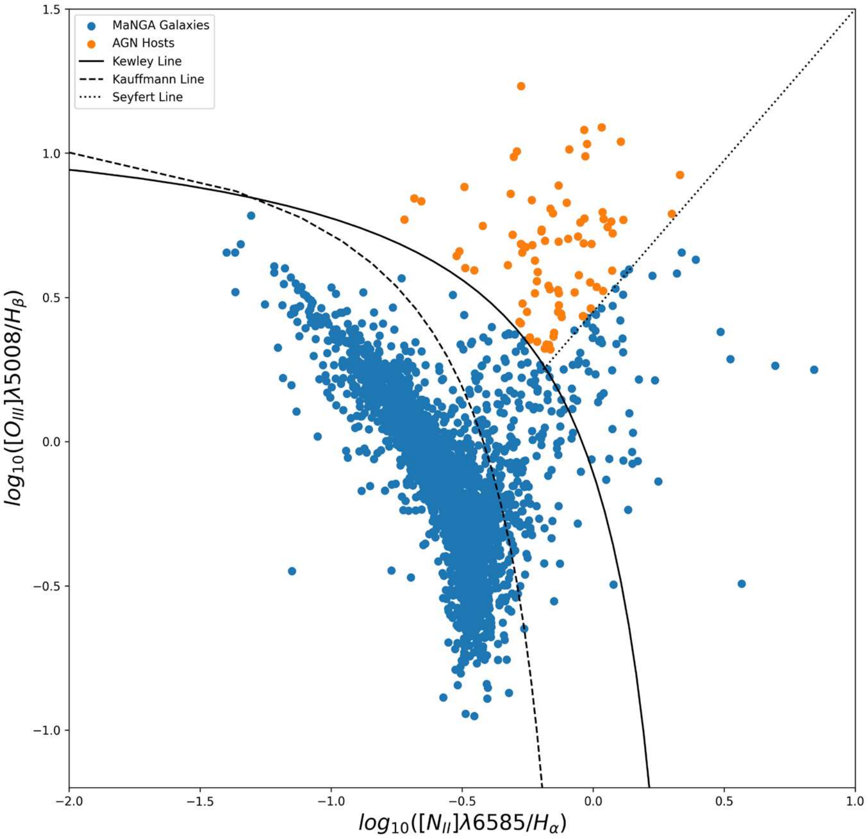

Figure 6. BPT diagram showing AGN region dwarf galaxies in orange.

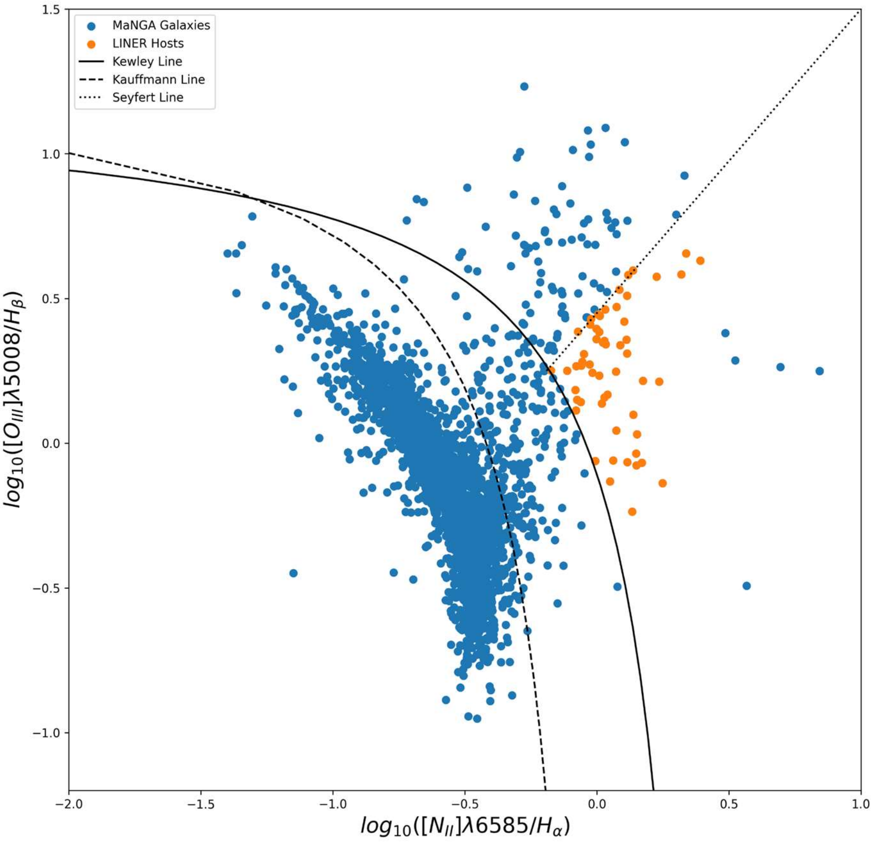

Figure 7. BPT diagram showing LINER region dwarf galaxies in orange.

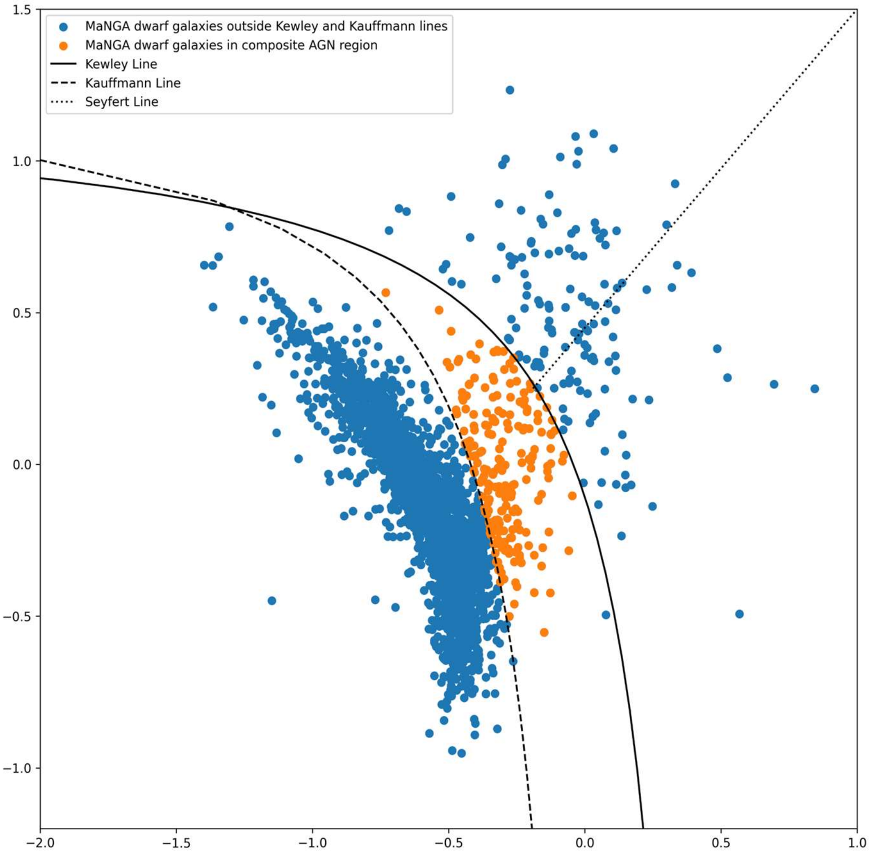

Figure 8. BPT diagram showing Composite AGN region dwarf galaxies in orange.

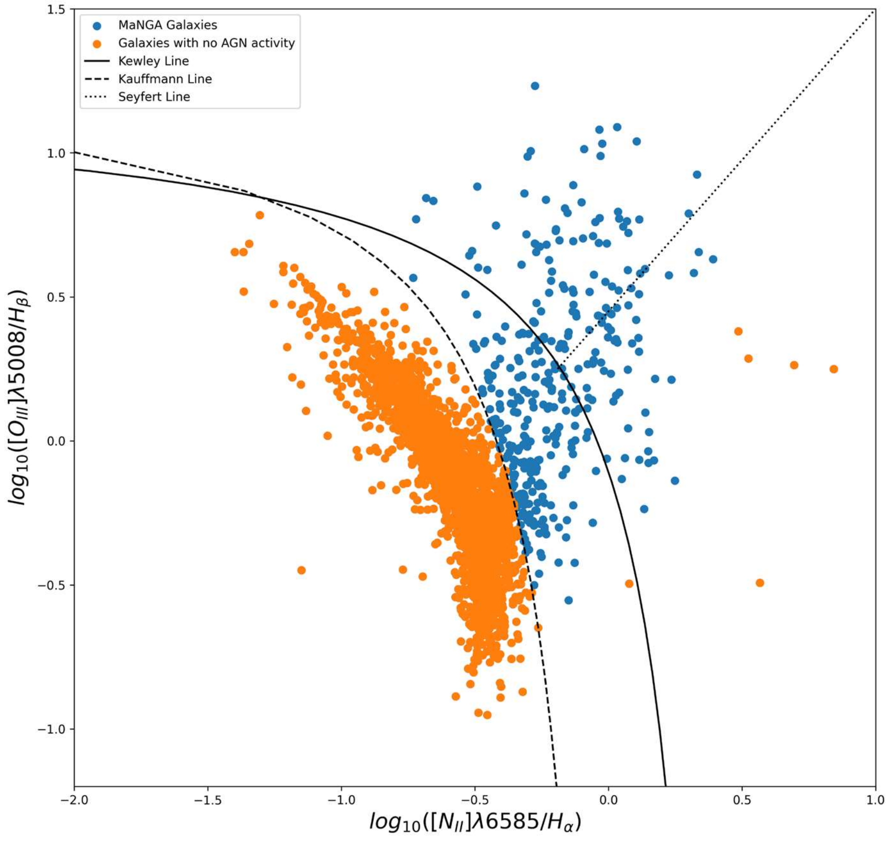

Figure 9. BPT diagram showing dwarf galaxies with extreme starburst activity.

Many of the galaxies that show signs of AGN activity in visible wavelengths do not show signs in IR, to confirm the existence of AGN for our sample we would need to add another way of searching for AGN, we would do this by using either X-ray data from the Chandra Data Archive (CDA) data gathered from the Chandra space telescope or XMM-Newton Science Archive (XSA) data gathered by the XMM-Newton space telescope, we would likely do this by using the detection methods described in Birchall et al. 2020 [5]. By looking in X-ray along with optical and IR we would be able to confirm the existence of the AGN in our potential AGN host list.

Processes other than AGN activity can produce X-rays, such as binary neutron star systems [33] or supernovae [11]. These Binary neutron star systems produce X-rays as gas is accreted onto the surface of the neutron star from a normal star, this is similar to the process that takes place allowing AGN to produce X-rays, with the difference being the energy of the photons released and total luminosity. This means that AGN X-ray emissions will show up brighter than binary neutron X-ray emissions. AGN X-ray emissions will be best observable at around 5 - 10 keV and luminosity of L = 10^{41} to 10^{47} ergs^{-1} [10], binary neutron X-rays will be best observable at around 0.25 - 2 keV and luminosity of L = 10^{38} to $10^{40.5}$$\text{ergs}^{-1}$ [30] and Supernova X-ray emissions will be best observable at around 0.3 - 8 keV and luminosity of around L = $10^{51}$$\text{ergs}^{-1}$ [21].

To utilise the data gathered by either Chandra or XMM-Newton we would define an X-ray luminosity threshold for possible AGN activity that we would use to select possible candidates, then on these candidates we would compare the ratio of X-ray to optical or IR intensity. In Yan et al. 2011 [36] it has been shown that the luminosity threshold would be sat at around $L_{bol} = 10^{44}$ ergs^{-1}, however we would need to confirm that the method does not need to be adjusted to work for AGN residing in dwarf galaxies, especially as these would have lower masses than AGN detected in the original paper ($M_* > 10^9\ M_\odot$), especially as a potential AGN hosting dwarf galaxy ($M_* < 3\text{x}10^9 M_\odot$), 1434 X-N, has been discovered with a luminosity of $(1.2\pm0.6)\text{x}10^{40}$ ergs^{-1} [34]. Yan et al. 2011 [36] also potentially uses a more appropriate data set than our plan of using CDA and XSA data, as the All-Wavelength Extended Groth Strip International Survey (AEGIS) survey observes to ~z = 1 using data from the Very Large Array (VLA) as well as the Spitzer, Chandra and Hubble space telescopes (among other data sources). This would cover the bands we are interested in, those being near UV, visible and near IR from Hubble, IR from Spitzer and Chandra and Radio from the VLA.

Unfortunately, after searching the XSA for matches, to our observed MaNGA galaxies, we find that none of the dwarf galaxies that we are interested in have been observed by the XMM-Newton telescope. Whilst this is not unexpected, due to the XMM-Newton mission not being a wide sky survey (although, like Chandra, XMM-Newton still makes observations for objects that cross its line of sight while slewing), it does make confirming our results harder. We also cross referenced our dwarf galaxies to the CDA, with which we had some slightly better success, having 4 results returned when focusing on the AGN and Composite AGN regions. While this is nowhere near enough data to draw any definite conclusions from, we can use this to enhance our understanding of the dwarf galaxies we have got data for, with these dwarf galaxies having MaNGA IDs of 1-298498, 1-153127 and 1-131378 for the AGN region galaxies, and 1-456735 for the composite AGN region galaxy. By utilising MaNGA MARVIN [7] we can check, using our dwarf galaxy's MaNGA ID, other astrophysicist's observations of the same galaxy in various wavelengths. Doing this we find out 3 of our 4 CDA galaxy matches are registered as AGN, these being 1-298498 as an AGN, 1-131378 and 1-456735 as LINER type AGN, found using MARVIN [7].

We could also look at these galaxies in radio wavelengths, these radio-loud AGN would emit powerful radio waves far more luminous than radio emissions from star-formation. It is theorised that between half to a quarter of all AGN will be radio-loud [23], these radio-loud AGN will have radio luminosity ranges from 10^{23} to 10^{27} W Hz^{-1}, with starburst driven radio luminosity ranges from 10^{21} to 10^{23} W Hz^{-1}. A potential radio telescope we could use, in any future work we do, would be the Very Large Array, with a frequency range of 1.2 to 116 GHz [32] it should be able to detect AGN in our sample of galaxies, as has been proven already in other studies like Delvecchio et al. 2017 [8], although it should be noted that these observations were not done on galaxies in the same mass range we have chosen so potentially some adjustments would have to be made to the method to work for our sample. This would also be difficult as telescope time is very competitive.

We have chosen these methods for our project and the potential follow up as, the MaNGA survey is optical and works as a great basis for searching for nearby AGN, it also allowed us to use BPT analysis to search for signs of AGN activity, giving us an idea of how many AGN we can expect to find. IR was chosen as the AllWISE survey has a large crossover in objects mapped by the MaNGA survey and itself, it allowed us to create colour-colour diagrams to search for obscured AGN that would not have been visible in optical. X-ray would be used as it would allow us to search for AGN obscured in both optical and IR whilst also giving us a way of reinforcing our understanding of potential AGN presence in dwarf galaxies identified by our previous analysis. Finally, radio observation would be used because of the high visibility with modern radio telescopes, allowing us to further complete our data and identify more potential AGN hosts.

Further improvements we could make to this project would be to analyse the gas kinematics for our sample of dwarf galaxies, with this we could look for signs of gas that has been blown out of alignment with the plane of rotation. By looking for kinematic offsets, using the SDSS's IFUs ability to record data separately across different fibres, we may potentially find additional hidden signs of AGN in our sample. This was noticed as a side effect of AGN activity in the paper Penny et al. 2018 [22] with the offsets being ≥30° relative to the plane of the galaxy. In addition to this we could also analyse the different dwarf galaxy's spectra across different sections, creating BPT diagrams for separate sections of a dwarf galaxy, to see if AGN activity can be seen in and around the center of the dwarf galaxy. Using these we could look for AGN activity that may be drowned out by other processes in the dwarf galaxy.

4. Errors

Potential errors in our project come from the fact that the BPT diagnostic lines are derived from larger, higher mass galaxies than the ones we are looking at, this means the position of the Kewley, Kauffmann and Seyfert lines would have to be modified and re-calibrated for these lower mass and luminosity galaxies. We would have to modify the diagnostic lines by moving them down as the $[O_{III}]$ emission lines can get boosted in low metallicity dwarf galaxies, placing them higher on the BPT than expected.

Another source of errors would be, like Kewley and Kauffmann lines on the BPT, the WISE colour-colour diagram AGN wedge is also not tuned to detect AGN in dwarf galaxies as shown by the luminosity dependence for the position of galaxies in the colour-colour diagram (figure 10), with which our findings agree. This shows that as the luminosity decreases, the position of sources appears to shift downwards out of the AGN wedge. Because of this we have chosen to shift the AGN wedge down by 0.25 on the y axis (W1-W2) which, by eye, creates a better fit. However as we have not studied this with multiple sources we cannot say whether it truly increases accuracy.

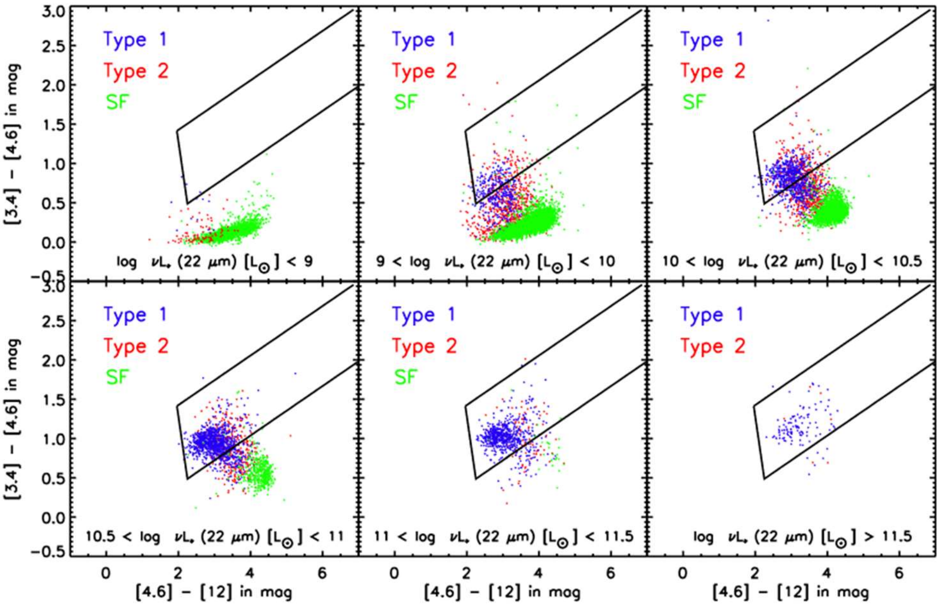

Figure 10. Luminosity relation for galaxies shown in WISE colour-colour diagram, from Toba et al. 2014 [35]}

Additionally, errors can come from the way we have joined these data sets, the way we merged the MaNGA and WISE data is through a 10 arcsecond search on the Caltech AllWISE database website which will return, based on the right ascension and declination of the object, the data for the closest source to the MaNGA galaxy. This can introduce errors as the actual search radius of 10 arcseconds could be large enough for other objects to be mistaken for the target galaxy which would then lead to us misidentifying the processes that seem to be shown from the BPT and the WISE colour-colour. WISE also does not have a very high resolution, with the resolution for each band being W1 = 6.1", W2 = 6.4", W3 = 6.5" and W4 = 12", further reducing likelihood of targets matching correctly.

5. Conclusion

Our aims for this project are to:

- Search for AGN hosting dwarf galaxies found in the MaNGA survey using optical and near UV wavelengths by using a BPT diagram.

- Obtain IR data from the AllWISE catalogue for selected MaNGA dwarf galaxies and analyse whether IR colour-colour diagrams agree with optical analysis on AGN presence.
- Obtain the mass of these observed AGN to determine if any are the intermediate mass black holes we are interested in studying, due to their expected property of being unchanged from when they formed.

This project presents an optical and infrared analysis of dwarf galaxies found out to z = 0.15, found in the SDSS MaNGA survey, that may potentially host AGN. Our sample consists of 2954 dwarf galaxies selected with a mass range $10^7 < M_* < 10^9 M_\odot$, observed in optical and near UV, that have then been cross matched with their AllWISE database IR counterparts. By utilising these data sets, by making a BPT diagram (figures 6, 8 and 11) and an IR colour-colour diagram (figure 3), we have identified 9 likely AGN candidates, with 5 of these showing strongly as AGN hosts and 4 showing as weaker but still likely AGN hosts when analysed by both methods. The colour-colour also identified another 8 potential AGN hosts that were not identified as having an AGN in optical.

We have demonstrated that these detection techniques are effective methods of determining AGN candidates with the BPT identifying 141 strong potential AGN hosts and the IR colour-colour identifying 17 AGN hosts, we end up with a large list of galaxies for follow up analysis and to observations for, in additional wavelengths, by other surveys. These planned follow ups would analyse these dwarf galaxies in X-ray and radio wavelengths using observations from the Very Large Array and Chandra Space Telescope to find signs of AGN activity. By combining data from such a large range of sources we hope to further refine the process of identifying AGN in nearby dwarf galaxies and create a comprehensive list of AGN in the MaNGA survey.

Although we did not manage to achieve all of our stated goals for this project, we have been able to make a sample of low mass galaxies AGN hosting galaxies using a combination of optical and IR data, giving us a clear data set to work with for any follow up analysis we may want to pursue. Below we will describe how we would go about continuing this project. With these AGN identified we would then move onto calculating the mass of the supermassive black hole to look for intermediate mass black holes, we also hope to study how AGN activity has affected the host dwarf galaxy by analysing star formation, gas kinematics and structure formation that has taken place inside it. We expect to see a lack of star formation, due to the energy provided to the large molecular clouds by the AGN, we also expect to see gas that has been blown out of the plane of the dwarf galaxy by AGN emissions, an effect described in Penny et al. 2018 [22].

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Appendix

Attached will be a link to a google drive containing the code used for this project and a list for the MaNGA ID of all dwarf galaxies in our sample. Google Drive: https://drive.google.com/drive/folders/1-wNE3Uc9wRMvLnx3Xu1ZxkHNDH-7Jruv?usp=sharing

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