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Galaxy and Mass Assembly (GAMA): A WISE Study of the Activity of Emission-line Systems in G23

H. F. M. Yao¹, T. H. Jarrett², M. E. Cluver^{1,3}, L. Marchetti^{1,2}, Edward N. Taylor³, M. G. Santos¹, Matt S. Owers^{4,5}, Angel R. Lopez-Sanchez^{4,5,6,7}, Y. A. Gordon⁸, M. J. I. Brown⁹, S. Brough¹⁰, S. Phillipps¹¹, B. W. Holwerda¹², A. M. Hopkins⁶, and L. Wang^{13,14}

¹ Department of Physics and Astronomy, University of the Western Cape, Robert Sobukwe Road, Bellville, 7535, Republic of South Africa; yao.fortune@gmail.com

² Department of Astronomy, University of Cape Town, Private Bag X3, Rondebosch, 7701, South Africa

³ Centre for Astrophysics and Supercomputing, Swinburne University of Technology, John Street, Hawthorn, 3122, Australia

⁴ Department of Physics and Astronomy, Macquarie University, NSW 2109, Australia

⁵ Astronomy, Astrophysics and Astrophotonics Research Centre, Macquarie University, Sydney, NSW, 2109, Australia

⁶ Australian Astronomical Optics, Macquarie University, 105 Delhi Road, North Ryde, NSW 2113, Australia

⁷ ARC Center of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO-3D), Australia

⁸ Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB R3T 2N2, Canada

⁹ School of physics and Astronomy, Monash University, Clayton, Victoria 3800, Australia

¹⁰ School of Physics, University of New South Wales, NSW 2052, Australia

¹¹ Astrophysics Group, School of Physics, University of Bristol, Tyndall Avenue, Bristol BS8 1TL, UK

¹² Department of Physics and Astronomy, 102 Natural Science Building, University of Louisville, Louisville KY 40292, USA

¹³ SRON Netherlands Institute for Space Research, Landleven 12, 9747 AD, Groningen, The Netherlands

¹⁴ Kapteyn Astronomical Institute, University of Groningen, Postbus 800, 9700 AV Groningen, The Netherlands

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Abstract

We present a detailed study of emission-line systems in the Galaxy And Mass Assembly (GAMA) G23 region, making use of Wide-field Infrared Survey Explorer (WISE) photometry that includes carefully measured resolved sources. After applying several cuts to the initial catalog of $\sim 41,000$ galaxies, we extract a sample of 9809 galaxies. We then compare the spectral diagnostic Baldwin, Phillips & Terlevich (BPT) classification of 1154 emission-line galaxies (38% resolved in W1) to their location in the WISE color–color diagram, leading to the creation of a new zone for mid-infrared “warm” galaxies located 2σ above the star-forming sequence, below the standard WISE active galactic nucleus (AGN) region. We find that the BPT and WISE diagrams agree on the classification for 85% and 8% of the galaxies as non-AGN (star-forming = SF) and AGN, respectively, and disagree on $\sim 7\%$ of the entire classified sample. Thirty-nine percent of the AGNs (all types) are broad-line systems for which the [N II] and [H α] fluxes can barely be disentangled, giving in most cases spurious [N II]/[H α] flux ratios. However, several optical AGNs appear to be completely consistent with SF in WISE. We argue that these could be low-power AGNs, or systems whose hosts dominate the IR emission. Alternatively, given the sometimes high [O III] luminosity in these galaxies, the emission lines may be generated by shocks coming from super-winds associated with SF rather than AGN activity. Based on our findings, we have created a new diagnostic: [W1 – W2] versus [N II]/[H α], which has the virtue of separating SF from AGNs and high-excitation sources. It classifies 3 to ~ 5 times more galaxies than the classic BPT.

Unified Astronomy Thesaurus concepts: Galaxy evolution (594); AGN host galaxies (2017); Infrared galaxies (790)

1. Introduction

Mapping galaxies at different redshifts provides important insights into how galaxies develop and transform throughout cosmic history. One of the major discoveries in astronomy is the existence of black holes at the centers of massive galaxies, which, when associated with an active accretion disk, are called active galactic nuclei (AGNs). Powerful AGNs such as quasi-stellar objects (QSOs) have a much larger luminosity than normal star-forming galaxies, which appears to be due to the accretion of cold materials onto the supermassive black hole (SMBH) at the center of the host galaxy (Kormendy & Richstone 1995; Magorrian et al. 1998; Ferrarese & Merritt 2000; Graham 2016). But generally, AGNs have a large variety of luminosities that can sometimes be dominated by the starlight from the host galaxy (e.g., Graham & Soria 2019). Therein lies the problem, for a galaxy’s global properties such as star formation rate (SFR) or stellar mass are indispensable for understanding galaxy evolution (see review by Kennicutt 1998).

The SFR is derived based on the assumption that the radiation measured originates from hot young stars, subsequently dust reprocessing and then adopting an IMF to estimate the SFR across the aggregate mass spectrum (Driver et al. 2008). Significantly, any AGN activity within the host galaxy could not only contaminate the flux measurement, but also have a direct impact on the star formation process itself via AGN feedback (Kauffmann & Haehnelt 2000; Croton et al. 2006; Graham & Scott 2013; Sahu et al. 2019). Therefore, a reliable AGN selection method is of great importance for both accurate measurement of the host’s properties and a better understanding of the AGN activity. Several methods have been devised to this end based on the characteristics of AGNs in different wave bands spanning radio to γ -rays.

The most common excitation mechanisms in galaxies are photoionization by O and B stars, photoionization by a power-law continuum source, and shock-wave heating. There is also excitation by planetary nebulae, which are photoionized by stars that are usually much hotter than normal galactic OB stars.

So, any classification scheme based on the mechanisms described above could delineate classes of galaxies according to the process taking place. For emission-line diagnostics, from observational studies and simulations the following emission features, [Ne V] $\lambda 3426$, [O II] $\lambda 3727$, [He II] $\lambda 4686$, H β $\lambda 4861$, [O III] $\lambda 5007$, [O I] $\lambda 6300$, H α $\lambda 6563$, and [N II] $\lambda 6584$, were proposed as potentially useful lines for discriminating between different excitation mechanisms. One of the earliest was Baldwin et al. (1981). Their method was based on the optical line ratios ([O III]/H β versus [N II]/H α , [O III]/H β versus [S II]/H α , [O III]/H β versus [O I]/H α) combined to form different planes referred to as BPT diagrams. These line ratios are sensitive to the hardness of the ionizing extreme ultraviolet radiation (EUV), so that they can provide important constraints on the shape of the EUV spectrum and may also be used to estimate the mean ionization parameter and metallicity of the galaxies. AGNs have a much harder ionizing spectrum than hot stars; they can thus be differentiated from star-forming (SF) and starburst galaxies.

As galaxy surveys became much larger with better data, the techniques to understand the BPT diagrams have also improved, and updated cuts for distinguishing SF versus AGN ionization have been published (see Veilleux & Osterbrock 1987; Kewley et al. 2001; Kauffmann et al. 2003; Kewley et al. 2006). For this study, we follow the recipes provided by Kewley et al. (2006), which are the most commonly used. Following Kauffmann et al. (2003), we can classify galaxies into three categories: pure SF, pure AGN, and intermediate objects that lie between the other two categories.

The Wide-field Infrared Survey Explorer (WISE) is ideal to study the interplay between hot dust and AGN activity. The AGN activity is most closely related to cold gas falling onto the central SMBH within the host galaxy. This flow starts from galactic scales beyond 100 pc to the subparsec environment. On the opposite side, the radiative pressure unbinds a large amount of the gas that is expelled via a radiative-pressure-driven wind (Hönig et al. 2019; Leftley et al. 2019). Subsequently, this wind creates the conditions for dust formation (Sarangi et al. 2019). The radiation from the torus of dust around the SMBH and from evolved stars distributed throughout the disk and the bulge populations can be detected in the mid-infrared.

Launched in 2009 December, WISE surveyed the entire sky in four mid-infrared bands: 3.4 μm , 4.6 μm , 12 μm , and 22 μm , respectively, are W1, W2, W3, and W4 (Wright et al. 2010). While W1 and W2 are both sensitive to the continuum emission from evolved stars, the W2 band is in addition sensitive to hot dust; hence, this makes the 3.4–4.6 μm color a good diagnostic to identify galaxies dominated globally by AGN emission (see e.g., Jarrett et al. 2011; Stern et al. 2012). The technique consists of projecting galaxies in the W1 – W2 versus W2 – W3 plane (e.g., Wright et al. 2010). Stars and early-type galaxies have colors near zero, while brown dwarfs are very red in W1 – W2 and blue in W2 – W3, and ultraluminous infrared galaxies (ULIRGs) tend to be red in both colors. Different color cuts have been proposed to separate AGNs from SF galaxies, the most conservative being W1 – W2 = 0.8 mag (Stern et al. 2012; Assef et al. 2013).

The different techniques show some disagreements from one wave band to the other. For example, a substantial number of galaxies classified as X-ray AGNs appear to be SF in the optical (Agostino & Salim 2019), and similar trends are also

seen in the radio (Leahy et al. 2019), the mid-infrared (Ching et al. 2017; Lam et al. 2018), and others.

Given the relative scarcity of X-ray and optical spectroscopic data, WISE (an all-sky survey) is, therefore, a perfect tool for studying mid-infrared AGNs in the local volume of space. For example, in the study of Leahy et al. (2019), WISE data in the G23 region is used in combination with radio continuum fluxes and optical emission-line diagnostics to investigate AGN activity.

However, the WISE survey only provided photometry optimized for point sources, with large and resolved systems often treated as agglomerations of point sources or missing significant flux. Therefore, any work based on nearby and extended galaxies requires reprocessing of all available WISE imaging and the careful extraction of the resolved galaxies (see Jarrett et al. 2013; Cluver et al. 2014; Jarrett et al. 2017, 2019 for details).

Our team earlier targeted the equatorial fields of the Galaxy And Mass Assembly survey (GAMA; Driver et al. 2009, 2011) for which catalogs have already been generated and used for multiwavelength studies (see Cluver et al. 2014; Jarrett et al. 2017). The current study represents the first WISE nearby galaxy catalog in the southern sky (the GAMA G23 field), used in combination with the spectroscopic data available in GAMA to investigate the similarities and differences between the optical and mid-infrared activity.

The structure of this paper is as follows: in Section 2, we describe the data sets and the generation of the WISE galaxy catalog. In Section 3, we describe the properties of the cross-matched sample and the methods we use to divide between SF galaxies and AGNs. We also present some detailed case studies. The discussion of our results is presented in Section 4. Finally, Section 5 summarizes our conclusions.

The cosmology adopted throughout this paper is $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$. The conversions between the luminosity distance and the redshift use the analytic formalism of Wickramasinghe & Ukwatta (2010) for a flat, dark-energy-dominated universe, assuming standard cosmological values noted above. All magnitudes are in the Vega system (WISE photometric calibration described in Jarrett et al. 2011) unless indicated explicitly by an AB subscript. Photometric colors are indicated using band names; e.g., W1 – W2 is the [3.4 μm] – [4.6 μm] color. Finally, for all four bands, the Vega magnitude to flux conversion factors are 309.68, 170.66, 29.05, and 7.871 Jy, respectively, for W1, W2, W3, and W4. Here we have adopted the new W4 calibration from Brown et al. (2014a), in which the central wavelength is 22.8 μm and the magnitude-to-flux conversion factor is 7.871 Jy. It follows that the conversions from the Vega System to the monochromatic AB System are 2.67, 3.32, 5.24, and 6.66 mag.

2. Data and Method

The primary data for this study come from the Galaxy and Mass Assembly (GAMA) Survey (see Driver et al. 2011). GAMA is a spectroscopic survey complete down to 19.8 mag in the r band (for the three equatorial fields), covering a total area of $\sim 286 \text{ deg}^2$. Its multiwavelength coverage spans the optical (VST KiDS; Kilo-Degree Survey), near-infrared (VIKING; VISTA Kilo-degree Infrared Galaxy Survey), and far-infrared (Herschel).

2.1. The GAMA G23 Region

Located between R.A. from 339° to 351° and decl. from -35° to -30° , G23 is the largest of the two GAMA southern fields (G23, G02). The main surface area after accounting for lost areas due to bright stars is about 50 deg^2 . The optical spectra were obtained primarily with the 2dF instrument mounted on the 3.9 m Anglo-Australian Telescope at Siding Spring Observatory (Australia), which feeds the AAOmega spectrograph. Additional 2dF data were extracted from the 2dFGRS (Colless et al. 2001) and also from the 6dF Galaxy Survey (6dFGS; Jones et al. 2010), which used the 1.2 m UK Schmidt Telescope, also at Siding Spring Observatory. More details about the GAMA survey strategy and spectroscopic data products can be found in Baldry et al. (2010, 2018), Robotham et al. (2010), Hopkins et al. (2013), Gunawardhana et al. (2013), and Liske et al. (2015). The spectroscopic redshifts used in this study are obtained from G23TilingCatv11. Redshifts are associated with a quality number from 0 to 4. Zero (0) represents a failure of the data reduction, 1 means no redshift is found, and 4 is the highest certainty with an associated probability ≥ 0.95 (Driver et al. 2011).

The raw data from the GAMA survey are processed using the software developed at AAO called 2DFDR (Sharp & Birchall 2010). The spectral output obtained from the 2DFDR is spectroscopically calibrated following the idlspec2d pipeline used for SDSS DR6 (Adelman-McCarthy et al. 2008). Checking the calibrated data for the galaxies observed by both GAMA and SDSS shows good agreement as presented in Hopkins et al. (2013).

2.1.1. Spectral Line Measurements

The optical line fluxes of the galaxies are extracted from the G23 GAMA II catalog (“GaussFitSimplev05” from within the SpecLineSFR DMU; Gordon et al. 2017) with redshifts > 0.002 and a magnitude limit of $i < 19.2 \text{ mag}$.

The spectra are fitted with the IDL code “mpfitfun” (Markwardt 2009), which uses a Levenberg–Marquardt non-linear least-squares minimization to identify the best-fitting parameters for the model given the data and its associated uncertainties.

Among the lines available in the catalog, we use $\text{H}\beta$ $\lambda 4861$, $[\text{O III}]$ $\lambda 4959$, $[\text{O III}]$ $\lambda 5007$, $[\text{N II}]$ $\lambda 6548$, $\text{H}\alpha$ $\lambda 6563$, $[\text{N II}]$ $\lambda 6583$, $[\text{S II}]$ $\lambda 6716$, and $[\text{S II}]$ $\lambda 6731$.

For lines that are always expected to be narrow such as $[\text{S II}]$, the fitting can either be a straight line (in the case of nondetection) or a Gaussian. Fitting $\text{H}\beta$ and $\text{H}\alpha$ in combination with their associated lines $[\text{O III}]$ $\lambda 4959/\lambda 5007$ and $[\text{N II}]$ $\lambda 6548/\lambda 6583$, respectively, can have more levels of complexity above the continuum. For example, fitting $\text{H}\alpha$ + $[\text{N II}]$ $\lambda 6548/\lambda 6583$ can increase in complexity as follows:

1. no emission or absorption, just continuum,
2. $\text{H}\alpha$ in absorption and no $[\text{N II}]$ $\lambda 6548/\lambda 6583$ emission,
3. $[\text{N II}]$ $\lambda 6548$ + $\text{H}\alpha$ + $[\text{N II}]$ $\lambda 6583$ all with narrow emission,
4. $[\text{N II}]$ $\lambda 6548$ + $[\text{N II}]$ $\lambda 6583$ in emission + $\text{H}\alpha$ in absorption,
5. $[\text{N II}]$ $\lambda 6548$ + $[\text{N II}]$ $\lambda 6583$ in emission + $\text{H}\alpha$ in emission and absorption,
6. $[\text{N II}]$ $\lambda 6548$ + $[\text{N II}]$ $\lambda 6583$ in emission + $\text{H}\alpha$ in narrow plus broad emission.

For each of the above fits, three different model selection methods are used to give a single global score based on whether a more complicated model should be chosen versus a simpler one and vice versa. For models with the same number of fitted parameters, the model with the lowest χ^2 value is chosen.

The following limits are applied to the fitting model: the line position is maintained within 200 km s^{-1} of the expected position. The width of the Gaussian (σ) for the narrow emission lines is constrained by $0.75\sigma_{\text{inst}} < \sigma < \sqrt{500^2 + \sigma_{\text{inst}}^2}$, where σ_{inst} is the resolution of the spectrum in km s^{-1} . The precedent constraints are made larger for broad emission lines, $\sqrt{500^2 + \sigma_{\text{inst}}^2} < \sigma < \sqrt{5000^2 + \sigma_{\text{inst}}^2}$, and the position of the line is maintained within 400 km s^{-1} .

Only the AAOmega spectra are flux calibrated and can be used as individual line fluxes unlike in the line ratio used for both calibrated and uncalibrated spectra. For doublets such as $[\text{O III}]$ $\lambda 4959/\lambda 5007$, $[\text{N II}]$ $\lambda 6548/\lambda 6583$, and $[\text{S II}]$ $\lambda 6716/\lambda 6731$, the line with the longest wavelength is generally the strongest (e.g., $[\text{O III}]$ $\lambda 5007$ can be up to three times stronger than $[\text{O III}]$ $\lambda 4959$) and is used to estimate the $\text{H}\alpha/[\text{O III}]$ line ratio. $\text{H}\alpha$ and $\text{H}\beta$ must be corrected for stellar absorption as it was not accounted for in the fitting.

2.2. WISE Image Reconstruction

The WISE image mosaics for G23 are reconstructed using the “drizzle” resampling technique (Jarrett et al. 2012; Masci 2013). The final images have a native resolution of $5''.9$, $6''.5$, $7''.0$, and $12''.4$ in W1, W2, W3, and W4, respectively, as opposed to $8''.1$, $8''.8$, $11''.0$, and $17''.5$ given by the WISE all-sky “Atlas” imaging. For more information about the archival data, see Cutri et al. (2012). The source measurement, characterization, and extraction processes are amply described in Cluver et al. (2014) and Jarrett et al. (2013, 2017).

Figure 1 is the four-band combination of all the mosaics in the G23 field ($\sim 50 \text{ deg}^2$). Stars have not yet been removed and are mostly bluer than the extragalactic sources. Some red extended galaxies can be easily identified by eye in the zoomed area.

2.3. Catalog of WISE Galaxies in G23

A positional cross-match between WISE sources from the ALLWISE catalog and galaxies with known redshifts in the GAMA G23 region was performed using a $3''$ cone radius as suggested by Cluver et al. (2014). This cross-match radius is motivated by the fact that the PSF fitting of the ALLWISE pipeline can affect the resulting accuracy of the source’s position particularly for resolved sources. This produces a catalog of 40,843 WISE-GAMA galaxies.

We next briefly describe the extraction and cleaning method used to create our final catalog of WISE galaxies (W1 resolved and point-like sources) in the GAMA G23 region, and the sample used for the current study. This is the fourth catalog of its kind (after the GAMA G12, G09, and G15 fields), and the full procedure is described in Cluver et al. (2014) and Jarrett et al. (2017).

2.3.1. Extraction and Cleaning Method

The whole process of extracting the WISE-resolved sources arises from the fact that the survey was optimized for the

Figure 1. The WISE 50 deg² view of the G23 field. In the zoomed area (14 × 11 arcmin), the reddish extended galaxies are easily distinguishable from foreground stars (blue in general). The image was created by combining the four WISE colors: 3.4 μm (blue), 4.6 μm (green), 12 μm (orange), and 22 μm (red). The 50 deg² area contains about 700,000 WISE sources (galaxies + stars).

detection of point-source galaxies. Potentially resolved galaxies based on the W1 (3.4 μm) band are selected from the ALLWISE catalog using the PSF goodness-of-fit metric, *wlchi2*. We search for values of *wlchi2* > 2, remeasure them with our special resolved source pipeline that characterizes the global and surface brightness emission, revealing sources that are extended beyond the PSF. These candidates are then characterized using the resolved-galaxy pipeline.

Using the reprocessed WISE imaging described above, the photometry can be remeasured as appropriate for a resolved source. The different steps are done via a custom software which adapted tools developed for 2MASS extended sources (Jarrett et al. 2000) and the WISE pipeline (Jarrett et al. 2011, 2013; Cutri et al. 2012). The process is semiautomated such that each level can be visually inspected and corrected if necessary. The details are as follows:

- (i) The point sources are removed by a combination of PSF subtraction and pixel masking. The bright stars in the vicinity are also masked out for a better estimation of the background. The shape of the galaxy is determined based on the 3σ isophote (of the background rms), which is considered to be constant at all isophotes. The first set of photometry is derived at the 1σ isophote, which already encloses more than 90% of the light (Jarrett et al. 2019). A double-Sérsic fit (Graham & Driver 2005) is used to estimate the light beyond the 1σ isophote as well as computing the curve of growth asymptotic fluxes extending down to convergence. Extracted sources are then removed from the images using their smoothed light distribution.
- (ii) The process is repeated until all sources are extracted.
- (iii) The *Rfuzzy* parameter (see Cluver et al. 2014) is the second-order intensity-weighted moment that allows a separation between faint, resolved, and unresolved systems. Each type of object has a characteristic *Rfuzzy* value that is systematically smaller than that of the resolved galaxies. This step is important in order to get our final sample of resolved galaxies.

The final step is visual inspection to validate and identify blends and other complex scenarios. The whole area of study is

divided into smaller areas centered on galaxies identified as resolved and processed by the pipeline. Each one of the galaxies is visualized (by the first author) to make sure that it is definitely not a star or unresolved galaxy, that the deblending is well performed (mostly for close proximity blend cases), and the apertures and position angles follow well the 2D light profile. The pipeline does well when the background is smooth and the signal-to-noise ratio (S/N) high (10 or higher). It needs human assistance in dense and low-S/N environments, and with closely blended pairs. The parameters and source contamination can be interactively adjusted (see Jarrett et al. 2017).

2.3.2. Rest-frame Correction

To account for the redshifted emission across the optical and infrared bands, we applied a “k-correction” to the magnitudes based on spectral energy distribution (SED) fitting before the derivation of any physical value. The SEDs are built by combining flux densities spanning the optical, the near-IR, and WISE mid-IR; for the optical and near-infrared data, we have used preliminary photometry available in G23 (generated by ProFound; Robotham et al. 2018). They are fitted to empirical templates of well-studied galaxies from Brown et al. (2014a, 2019) and Spitzer-SWIRE/GRASIL (Silva et al. 1998; Polletta et al. 2006, 2007). From the rest-frame-corrected catalog, key parameters such as stellar mass were derived using the W1 in-band luminosity and the mass-to-light ratio (*M/L*; Cluver et al. 2014; Querejeta et al. 2015; Kettlety et al. 2018; Meidt et al. 2012). The SFR (SFR_{12μm}) and the specific star formation rate (sSFR) are estimated using *νLν* luminosities and the mid-IR to total-IR calibration from Cluver et al. (2017). The SEDs allow, to some extent, the differentiation of the AGNs from normal SF galaxies. Examples of SEDs are presented in the case studies in the Appendix.

2.4. KiDS

The Kilo-degree Survey (KiDS) is an optical survey of ≈1500 deg² (de Jong et al. 2013; Bilicki et al. 2018) using OmegaCAM inside the field imager on the VLT survey telescope. With its 268 Megapixel wide-field camera that

Figure 2. The number distribution as a function of the redshift. All WISE-GAMA G23 galaxies ($\sim 41,000$ galaxies with GAMA redshifts) represented by the solid pink line of which more than 75% have redshifts < 0.3 . The final sample (dashed orange line) has about 9800 galaxies after applying redshift and magnitude cuts of $z < 0.3$ and $W1 < 15.5$ mag, respectively.

provides a $1^\circ \times 1^\circ$ field of view (with a pixel scale of $0.214''$ pixel $^{-1}$), the exposure time is selected such that it can reach a median redshift of $z = 0.7$, which is well beyond the redshift limit used for the present study ($z < 0.3$). The median seeing is about $0''.7$, and the observations are done in four bands (u, g, r, i), with the r band being the deepest reaching a depth of 25.4 mag (AB system). The resolution of the images is subarcsecond; it is, therefore, a valuable data set to visualize fine details within the galaxies, usually not visible using WISE images. KiDS has several data releases starting from KiDS-ESO-DR1 and the release used in this study is KiDS-ESO-DR4 (see Kuijken et al. 2019 for more details).

3. Results

3.1. Property of GAMA-WISE Galaxies

Figure 2 presents the full WISE-GAMA galaxy catalog in G23 with redshifts (40,843 galaxies). The WISE-resolved galaxies (total of 2695 in G23) have been added to the point-source photometry from ALLWISE to create a quality-controlled catalog, which is well suited for detailed study at low redshifts. The galaxy distribution peaks around $z = 0.2$ with more than 75% located at $z < 0.3$, and most of the resolved galaxies at redshifts less than 0.15.

The differential source counts in W1 for the different WISE and/or GAMA sources are shown in Figure 3. The galaxy source counts for the Galactic North Pole and GAMA G12 from Jarrett et al. (2017) have been added for comparison. The large majority of galaxies at the bright end are resolved up to a W1 magnitude of 13.5 mag (1.2 mJy), where the distribution turns over. The galaxy counts in G23 and G12 are similar all the way to the faint end (~ 17.5 mag), which may be expected because both are focused near the Galactic poles. The WISE-GAMA galaxy counts rise close to the WISE galaxy counts up to 15.5 mag, where it turns over, due to the G23 survey redshift limit. The proximity of the two curves shows that a very high fraction of WISE sources have redshifts in GAMA up to 15.5

Figure 3. Differential W1 ($3.4 \mu\text{m}$) source counts in the G23 region with magnitudes in the Vega system. The ALLWISE sources are shown in solid gray. The WISE star and galaxy counts are the dark blue and black lines, respectively. The WISE cross-matched GAMA galaxies and resolved galaxies are in solid green and light blue lines, respectively. The total number of WISE sources is $\sim 600,000$ (galaxies + stars) and $\sim 41,000$ of the galaxies have GAMA redshifts. The orange dashed-dotted histogram represents our sample which has a magnitude limit in W1 < 15.5 mag (in Vega system) and redshifts < 0.3 . The WISE cross-matched GAMA (G12; Jarrett et al. 2017) galaxies in magenta have been added for comparison. The vertical lines represent Poisson error bars.

Table 1
Number of Galaxies for Different Constraints Applied

Total WISE-GAMA G23 catalog (A)	41,000
A with $W1 < 15.5$ mag, $z < 0.3$ (B)	9800
B with $S/N(W1) > 5$, $S/N(W2) > 5$, $S/N(W3) > 2$ (C)	6493
C with $H\alpha$, $H\beta$, $[O III]$, $[N II]$ all > 0 , all $S/N > 3$ (D)	1173
C with $H\alpha$, $H\beta$, $[O III]$, $[S II]$ all > 0 , all $S/N > 3$ (E)	1037

Note. The letters in brackets represent a given sample (e.g., A).

mag. The ALLWISE counts (galaxies + stars) shows the domination of Galactic stars at the bright end, although we only expect minimal contamination due to our filtering and classification. The faint end, which is not relevant to the study presented here, is expected to have unresolved galaxies with a higher probability of blending as the confusion limit of WISE is reached (Jarrett et al. 2017).

3.1.1. The Study Sample

For the comparative study of WISE colors and optical BPT diagrams, we have applied a magnitude and redshift cut of $W1 < 15.5$ mag (in Vega) and $z < 0.3$, respectively, to the WISE catalog of galaxies in G23 having redshifts, hereafter referred to as “the sample” representing (B) in Table 1. For the resolved galaxies, this corresponds to an average $S/N \approx 30$ in W1, and corresponding lower values for the W2 and W3 bands. An S/N limit of 3 is imposed on all the optical spectral lines used in the BPT. Table 1 shows how the number of galaxies decreases from the initial WISE-GAMA G23 catalog to the final number of galaxies used for the optical and infrared diagnostics. (A), (B), (C), and (D) represent each step. As an

Figure 4. The WISE k-corrected color-color plane $W1 - W2$ vs. $W2 - W3$ (magnitudes are in the Vega system). The upper limits are represented by the magenta arrows, and the dashed blue line is the SF sequence (Jarrett et al. 2019) seen at low $W1 - W2$ (< 0.5 mag). The AGN box is from Jarrett et al. (2011). We also plot the mean $W1 - W2$ and $W2 - W3$ uncertainties with the error bars in the upper-left corner.

example, “A” with $W1 < 15.5$ mag, $z < 0.3$ means that in the second row, a magnitude limit of $W1 < 15.5$ mag and redshift $z < 0.3$ are applied to the total WISE-GAMA G23 catalog.

In Figure 2, the sample (dashed gray) is presented along with the WISE-GAMA galaxy catalog, with more than 70% of galaxies found at redshifts less than 0.2. The magnitude cut in $W1$ (the most sensitive band) ensures detections with high S/N, but also selects well-deblended sources (based on WISE images), hence, good photometry quality in general.

The magnitude limit (in $W1$) of 15.5 mag eliminates most of the low-mass galaxies, $\log(M_{\text{stellar}}/M_{\odot}) < 9$, which are often misclassified using only the WISE color-color diagram (Hainline et al. 2016). Using a sample 18,000 nearby dwarf galaxies ($M_{*} < 3 \times 10^9 M_{\odot}$), selected from the Sloan Digital Sky Survey, they found that while the WISE color-color diagram is reliable in classifying moderate- to high-mass galaxies, the $W1 - W2$ color alone should not be used for dwarf galaxies.

As can be seen in Figure 3, a cut of 15.5 mag offers the best of our carefully measured WISE-resolved galaxies (2383, $\sim 90\%$ of the WISE-resolved sample) and also the brightest unresolved sources (7426 point-like or compact galaxies). A brighter magnitude cut will lead to fewer resolved galaxies, and a fainter cut will include more faint point-source galaxies with lower S/N. In this way, 15.5 mag is the best balance between completeness and mid-infrared ($W1$, $W2$, and $W3$ bands) photometric quality, giving a final sample of 9809 galaxies.

The $W1 - W2$ versus $W2 - W3$ colors (color-color diagram) of the sample, with an S/N cut of 5, 5, and 2 in $W1$, $W2$, and $W3$, respectively, are presented in Figure 4. The lower S/N for $W3$ is to account for the lower sensitivity in this band relative to the $W1$ and $W2$ bands, as well as taking advantage of the large dynamic range (five orders of magnitude) seen in the $W2 - W3$ color. The $W1 - W2$ color is the more critical of the two, as its lower dynamic range requires higher accuracy. The AGN box (Jarrett et al. 2011) is the expected location of luminous AGNs, while the $W1 - W2 = 0.8$ mag is a conservative limit

Figure 5. The distribution of stellar masses for the galaxies in the study sample. The sample contains very few low-mass galaxies with $< 2\%$ having $\log(M_{\text{stellar}}/M_{\odot}) < 9$.

for AGNs; galaxies above are classified as WISE (mid-infrared) AGNs and are frequently in the QSO class. The dashed blue line is the fit to the sequence (Equation (1)) seen in the color-color diagram for all catalogs of WISE-resolved sources (Cluver et al. 2017; Jarrett et al. 2019). The relation is described by Jarrett et al. (2019) as

$$(W1 - W2) = [0.015 \times e^{\frac{(W2 - W3)}{1.38}}] - 0.08. \quad (1)$$

In Figure 5, fewer than $< 2\%$ of the galaxies in our sample have a stellar mass $\log(M_{\text{stellar}}/M_{\odot}) \leq 9$. We therefore do not expect the result in this study to be significantly affected by misclassifications related to dwarf galaxies.

3.2. AGN Classification

3.2.1. Optical Emission-line Diagnostics: BPT Diagrams

In this section, we investigate the optical emission-line properties of the sample derived from our WISE-GAMA catalog. Special care has been taken to derive the photometry of the resolved sources, which makes our sample a high-quality data set for a comparative study between the optical and mid-infrared diagnostics of the activity. The constraints put on the magnitude and the redshift allow us to take advantage of the best photometry from WISE and avoid the required optical lines being shifted out of the wavelength range of the AAOmega spectrograph used in GAMA. All of the optical spectra have been visually inspected to detect any systematic fitting anomalies. To this end, GAMA has a flag for the quality of each fit corresponding to each of the optical lines of interest, but sometimes human supervision is needed for the final decision, notably with broad-line systems. The selection criteria are that we detect the emission lines of $H\alpha$, $H\beta$, and $[O III]$ as well as $[N II]$ or $[S II]$ depending on the diagnostic diagram used. $H\alpha$ and $H\beta$ are corrected for both reddening and stellar absorption using Equation (2), and all the lines have $S/N > 3$ (note that this strict criterion eliminates a large fraction of sources from our sample). The Balmer line absorption

Figure 6. The BPT diagram ($[\text{O III}]5007/\text{H}\beta$ vs. $[\text{S II}]6716, 6731/\text{H}\alpha$) with all of the required lines in emission. The extreme starburst classification line (green solid) and the Seyfert-LINER separation line (black solid) by Kewley et al. (2006). Above the green line lie the AGNs (Seyferts or LINERs) and below it the galaxies that are not AGNs. There are very few LINERs in comparison to the Seyferts. We also plot the mean $[\text{S II}]/\text{H}\alpha$ and $[\text{O III}]/\text{H}\beta$ uncertainties with the error bars (middle right).

correction is applied as follows:

$$F_{\text{corr}} = \left[\frac{\text{EW} + 2.5}{\text{EW}} \right] \times F_{\text{obs}}, \quad (2)$$

where EW is the equivalent width of the line of interest, F_{obs} is the observed flux, and 2.5 is the approximate correction required for GAMA spectra (see Gunawardhana et al. 2011; Hopkins et al. 2013).

The BPT classification on the plane $[\text{O III}]5007/\text{H}\beta$ versus $[\text{S II}]6716, 6731/\text{H}\alpha$ is shown in Figure 6. A count of 1037 out of the 9809 initial sample satisfy the conditions mentioned above. Seventy-five galaxies are classified as Seyferts and five as LINERs.

The redshift (z) cut of 0.3 is only for GAMA-derived spectra. But the catalog also contains 6dF and 2dF spectra, where $z = 0.13$ and $z = 0.2$, respectively, should be used as upper limits when using the $[\text{S II}]$ line flux.

The second BPT diagnostic diagram, $[\text{O III}]5007/\text{H}\beta$ versus $[\text{N II}]6583/\text{H}\alpha$, is shown in Figure 7. Similar constraints have been applied. In total, 1173 galaxies are selected, 122 are classified as AGNs, 170 as composites, and 881 as SF.

The $[\text{N II}]6583/\text{H}\alpha$ line varies as a function of metallicity, which has a correlation with stellar mass (Wu et al. 2016). Therefore, the low-metallicity AGNs could be found below the extreme starburst line presented in Kewley et al. (2019). The study by Kauffmann et al. (2003) shifted the Kewley et al. (2006) line to create a new limit for pure star-forming galaxies. The mixed region in between the two lines supposedly made up by galaxies exhibiting both AGN and star-formation activities is referred to as composites (Kewley et al. 2019). The current optical separation lines derived based on local galaxies are subject to variations with redshift and can be reliably used only at redshift $z < 1$ (Kewley et al. 2013).

The redshift limit used in our study is 0.3 (local universe), where low-metallicity AGNs are extremely rare (Groves et al. 2006).

This is further confirmed by comparing both optical methods in Figure 8. The AGNs seen as outliers in the figure have

Figure 7. The BPT diagram ($[\text{O III}]5007/\text{H}\beta$ vs. $[\text{N II}]6583/\text{H}\alpha$) with all of the required lines in emission. The green line represents the limit between AGN and not-AGN galaxies (Kewley et al. 2006) and the Kauffmann et al. (2003) pure star formation line (red dashed). Above the green line lie the AGNs (violet), between the two lines are the composite galaxies (green), and below the red dashed line lie the star-forming galaxies (blue). Note a clear separation of the AGN group into two distinct subgroups. The second subgroup (right side) tends to be broad-line systems. We also plot the mean $[\text{N II}]/\text{H}\alpha$ and $[\text{O III}]/\text{H}\beta$ uncertainties with the error bars (middle right).

Figure 8. Comparison between both optical classifications. About 85% (998/1173) of the galaxies represented in Figure 7 respect the conditions applied in Figure 6. In this figure, one can see that the two BPT diagrams agree generally on the separation of AGN and SF galaxies. In most cases, the AGNs seen as outliers are very broad-line systems for which the measurement presents challenges that will be addressed in the next sections. We also plot the mean $[\text{S II}]/\text{H}\alpha$ and $[\text{O III}]/\text{H}\beta$ uncertainties with the error bars (middle right).

extremely broad $\text{H}\alpha$ lines that are difficult to be accurately measured as they are deeply entangled with the blended $[\text{N II}]$ lines. The broad-line (BL) AGNs are specially addressed in the current work. One more noticeable feature is the quasi-presence of the composites in the SF region, Figure 8, which appears to confirm indeed the rarity of low-metallicity AGNs in our sample, susceptible of being found in the composite region. Except for particular cases of BLAGNs mentioned above, the two diagrams largely agree on classifying AGN and SF galaxies. So, we do not expect our result to be significantly affected by the misclassification of AGNs as SF caused by the variation in metallicity.

(a) WISE colour-colour for optical SF and composites

(b) WISE colour-colour for optical AGN

Figure 9. The BPT $[\text{O III}]/\text{H}\beta$ vs. $[\text{N II}]/\text{H}\alpha$ classified galaxies from Figure 7 plotted in the WISE color-color diagram. Those also classified as Seyferts and LINERs from Figure 6 are overplotted in magenta and gold circles, respectively. The dashed blue and green lines are the fit to the sequence of galaxies (Equation (1)) seen at low $W1 - W2$ color and the 2σ rms curve of the fit. The AGN box is from Jarrett et al. (2011). The diagram is separated into three zones: Zones 1, 2, and 3 are the respective locations of the WISE powerful AGNs, the low-power AGNs, and finally the non-AGN zone mostly populated by star-forming galaxies. The majority of the galaxies classified as LINERs using $[\text{S II}]$ are classified as composites or SF based on the $[\text{N II}]$ line while the Seyferts are generally classified as AGNs using $[\text{N II}]$. The composites (green) occupy the star-forming zone. The majority of the optical non-AGNs in the WISE AGN zone are broad lines for which using the line ratio is problematic. The optical star-forming galaxies and composites are presented in (a) and optical AGNs in (b); they are separated for clarity.

3.2.2. Classifications Derived from the Combination of Mid-IR and Optical Line Properties

The $[\text{N II}]$ emission lines are stronger than the $[\text{S II}]$ lines, and using the $[\text{N II}]$ rather than the $[\text{S II}]$ line has the added benefit of including composite galaxies in the analysis. Based on these facts, we will be using $[\text{O III}]/\text{H}\beta$ versus $[\text{N II}]/\text{H}\alpha$ as the primary optical AGN diagnostic plane which will be compared to the $W1 - W2$ versus $W2 - W3$ color plane throughout this work, except where explicitly stated otherwise.

For the comparison between WISE and the BPT, the detection S/N in $W1$, $W2$, and $W3$ is also required to be greater than 5, 5, and 2, respectively, giving a total of 1154 galaxies. We use the results from Figure 9, which plots the optical classification from Figure 7 displayed in the WISE color-color diagram, keeping the same color-coding scheme. The violet dots represent the optically selected AGNs (designated as oAGN hereafter), the blue points are the optical star-forming galaxies (oSF), and the green points are the composites (referred to as “composite”), which are in between the two. The crosses represent galaxies identified as broad-line AGNs (BLAGNs). The BLAGN selection is based on the method described in Gordon et al. (2017). However, we only keep the galaxies clearly seen as BLAGNs without ambiguity after visual checking. We overplot in magenta and gold circles the galaxies classified as Seyferts and LINERs (where available in the current diagram) from Figure 6.

We establish a 2σ offset from the SF color-color sequence (Equation (1)) delineated by the green dashed curve in Figure 9. The color-color diagram is divided into three zones represented by the circled numbers: 1, 2, and 3. Zone 1 (pink shade) is where the WISE obscured AGNs, QSOs, LINERs, and ULIRGs are located. Zone 2 (gray shade), just below, is

Figure 10. Summary of the classification combining both the optical BPT and the WISE mid-IR color-color diagrams. The ellipses, rectangles, and colors are chosen to follow the legend as presented in Figure 11. Blue and red represent the optical and infrared classifications that agree, while yellow and orange are in counter-agreement.

where the low-power Seyferts and LINERs reside—we call it the “mWarm” zone signifying warmer $W1 - W2$ color due to greater nuclear activity and corresponding accretion disk emission. Zone 3 (light blue shade) contains the sequence of WISE star-forming galaxies, mostly a mixture of intermediates and star-forming disk galaxies having low (blue) $W1 - W2$ colors.

The diagram in Figure 10 summarizes the galaxy classification considering both their optical emission-line properties and their infrared WISE colors. The galaxies displayed in Figure 9 are divided into different groups, taking into account both their optical line properties and their mid-IR colors in WISE. Galaxies classified as AGNs in Figure 7 (BPT), which are in

Figure 11. Combined optical-infrared BPT diagram, showing the different classes of galaxies. (a) The galaxies classified in Figure 9 are displayed with different colors according to their categories. As can be seen, only six WISE AGNs are classified as star-forming in the BPT while six are composites. Both the oAGN (mAGN) and oAGN (mSF) are clearly divided into two parts. The AGNs in the lower-right corner are almost exclusively broad-line AGNs whose $[\text{N II}]/\text{H}\alpha$ were overestimated giving, therefore, larger $[\text{N II}]/\text{H}\alpha$. The mean $[\text{N II}]/\text{H}\alpha$ and $[\text{O III}]/\text{H}\beta$ uncertainties with the error bars are plotted (middle right). Panel (b) shows the AGN strength represented by the $[\text{O III}]$ line luminosity (not reddening-corrected) as a function of stellar mass. In general, there is a clear separation between the AGN and SF galaxies except for the non-oAGN (mAGN) exhibiting low $[\text{O III}]$ luminosities. All data points including the broad-line AGNs are plotted using a simple Gaussian fit. Only the $[\text{O III}]$ luminosity derived from GAMA spectra (calibrated) are used in (b). The dashed line ($\log L[\text{O III}] = 41.2 \text{ erg s}^{-1}$) is the line above which the great majority of optical AGNs are likely to be found. We also plot the mean $\log M_{\text{stellar}} [M_{\odot}]$ and $\log (L[\text{O III}])$ uncertainties with the error bars in the lower-right corner.

color-color Zone 1 (see Figure 9(b)), are labeled as oAGN (mAGN). The optically classified SF or composites in Zone 1 are labeled non-oAGN (mAGN). The same applies to Zone 2 where the two groups are called respectively oAGN (mWarm) and non-oAGN (mWarm). The mWarm are the galaxies warmer than the typical SF galaxies based on the $W1 - W2$ color. Finally, in Zone 3, all of the galaxies classified as AGNs in the optical which reside in Zone 3 are called oAGN (mSF). The optical SF and composites in Zone 3 (see Figure 9(a)) are called “SF” and “Composite,” respectively.

There is a clear presence of oAGNs in the WISE star-forming zone. Some non-oAGN objects are located in both the mid-infrared warm (mWarm) and the obscured-AGN zone of which 25% in the mAGN zone are composites and 50% are broad-line AGNs misclassified by the BPT (Figure 9(a)). Having some optically classified composite galaxies in the mid-infrared warm or AGN zone is expected as they are a mixture of both AGN and star formation. However, the vast majority lie in the mid-infrared star-forming zone, meaning that their host galaxies generally dominate over the AGN activity. The Seyferts are found in the mid-infrared AGN zone as well as in the SF and are generally classified as oAGNs while in most cases the LINERs (classification based on $[\text{S II}]$ line) designate a non-oAGN (classification based on $[\text{N II}]$ line) and are classified as SF galaxies in the WISE color-color diagram. The nature of LINERs is not well understood, and while they may be associated with SF and shocks thereof, they may also harbor low-luminosity AGNs (Flohic et al. 2006). Our data and analysis are not able to properly address this ongoing issue, and we provide no further analysis on LINERs.

Another trend is the presence of oAGNs in the WISE star-forming zone. There are even a few BLAGNs with SF colors, which is intriguing because WISE seems to be generally very sensitive to broad $\text{H}\alpha$ lines. They constitute very good specimens to be followed up in radio and X-rays.

We now reproject back into the BPT plane the new optical and mid-IR classification codes, as shown in Figure 11(a). The figure shows a clear separation of the oAGN (mAGN) into two subsamples. The lower-right corner above the green curve are broad-line AGNs whose line ratios have been overestimated by the line-fitting algorithm in GAMA. Here it is striking to see all the galaxies with $[\text{N II}]/\text{H}\alpha > 1$ being broad lines with generally overestimated $[\text{N II}]$ fluxes. A larger sample would likely have shown a few non-BLAGNs for which $[\text{N II}]/\text{H}\alpha$ flux ratios are truly > 1 , but these cases are rare. It is sometimes extremely challenging, if not impossible, to separate $\text{H}\alpha$ and $[\text{N II}]$ when the $\text{H}\alpha$ line becomes broad. Even a reassessment of the flux, which will probably give a more reasonable ratio, lower than 1, will shift the galaxy (BLAGN) into the SF zone unless the $[\text{O III}]$ line’s flux is highly elevated. Those galaxies with an underestimated flux ratio constitute 50% of our non-oAGN (mAGN) sample. The GAMA pipeline does not handle the broad lines well, notably the blending of $\text{H}\alpha$ and $[\text{N II}]$. Therefore, the BPT is not appropriate using the automated pipeline data from GAMA. We have displayed them in this diagram to show where they might correctly or incorrectly be located in the BPT diagram.

The oAGN (mSF) are generally located on the upper-left side of the AGN zone along with the oAGN (mAGN). Although classified as AGNs both in WISE and optical, some

Table 2
Subgroups and Their Different Constraints Applied to the Sample

Groups	Number No. (%)	Broad-line AGN BLAGN	Redshift mean(med)	Log M_{stellar} ($M_{\odot}$) mean(med)	SFR $_{12\mu\text{m}}$ ($M_{\odot}\text{yr}^{-1}$) mean(med)	Log (sSFR) (yr^{-1}) mean(med)
WISE/G23	Condition A ^a					
Mid-IR SF (mSF)	6133 (94.5%)	N/A	0.14 (0.13)	10.52 ± 0.003 (10.55)	5.44 ± 0.041 (3.57)	-10.0 ± 0.004 (−9.95)
Mid-IR “warm” (mWarm)	181 (2.8%)	N/A	0.19 (0.2)	10.52 ± 0.014 (10.6)	11.35 ± 0.425 (9.23)	-9.63 ± 0.019 (−9.61)
Mid-IR AGN (mAGN)	179 (2.8%)	N/A	0.19 (0.2)	10.6 ± 0.012 (10.71)	23.98 ± 1.126 (13.84)	-9.49 ± 0.017 (−9.52)
Optical/G23	Condition B ^b					
Optical SF (oSF)	881 (75.11%)	1	0.11 (0.09)	N/A	N/A	N/A
Optical (composite)	170 (14.49%)	15	0.15 (0.14)	N/A	N/A	N/A
Optical AGN (oAGN)	122 (10.4%)	56	0.18 (0.19)	N/A	N/A	N/A
WISE/Optical/G23	Condition C ^c					
SF	838 (72.6%)	0	0.10 (0.09)	10.11 ± 0.01 (10.13)	06.23 ± 0.13 (03.48)	-9.58 ± 0.01 (−9.52)
Composites	138 (12.0%)	2	0.14 (0.12)	10.39 ± 0.02 (10.41)	10.43 ± 0.48 (07.28)	-9.56 ± 0.02 (−9.48)
oAGN (mAGN)	49 (4.2%)	30	0.20 (0.21)	10.90 ± 0.02 (10.93)	32.89 ± 2.67 (24.92)	-9.56 ± 0.03 (−9.58)
oAGN (mWarm)	33 (2.9%)	18	0.17 (0.18)	10.61 ± 0.03 (10.62)	14.84 ± 1.25 (10.86)	-9.58 ± 0.04 (−9.55)
oAGN (mSF)	37 (3.2%)	7	0.17 (0.18)	10.61 ± 0.03 (10.60)	09.33 ± 0.76 (08.82)	-9.78 ± 0.04 (−9.66)
Non-oAGN (mAGN)	23 (2.0%)	11	0.21 (0.21)	10.79 ± 0.03 (10.78)	28.14 ± 2.53 (22.92)	-9.43 ± 0.04 (−9.43)
Non-oAGN (mWarm)	36 (3.1%)	3	0.18 (0.19)	10.46 ± 0.03 (10.51)	16.79 ± 1.43 (13.11)	-9.41 ± 0.04 (−9.37)
WISE/Optical/G23	Condition D ^d					
SF	838 (72.6%)	0	0.10 (0.09)	10.11 ± 0.01 (10.13)	06.23 ± 0.13 (03.48)	-9.58 ± 0.01 (−9.52)
Composites	136 (11.8%)	0	0.14 (0.12)	10.39 ± 0.02 (10.41)	10.42 ± 0.49 (07.02)	-9.56 ± 0.02 (−9.49)
oAGN (mAGN)	59 (5.1%)	41	0.20 (0.21)	10.89 ± 0.02 (10.91)	30.75 ± 2.23 (23.72)	-9.57 ± 0.03 (−9.58)
oAGN (mWarm)	36 (3.1%)	21	0.18 (0.18)	10.64 ± 0.03 (10.64)	15.82 ± 1.26 (11.81)	-9.58 ± 0.04 (−9.55)
oAGN (mSF)	39 (3.4%)	9	0.16 (0.18)	10.60 ± 0.03 (10.59)	09.41 ± 0.73 (09.17)	-9.76 ± 0.04 (−9.66)
Non-oAGN (mAGN)	13 (1.1%)	0	0.20 (0.20)	10.74 ± 0.04 (10.77)	34.18 ± 4.23 (24.68)	-9.29 ± 0.06 (−9.23)
Non-oAGN (mWarm)	33 (2.9%)	0	0.17 (0.19)	10.41 ± 0.03 (10.46)	15.90 ± 1.45 (12.64)	-9.39 ± 0.04 (−9.36)

Notes. The mean and median values of some properties have been added. Condition C was applied to Figure 9.

^a Signal-to-noise ratio (S/N): $W1 > 5$, $W2 > 5$, and $W3 > 2$; redshift < 0.3 ; and magnitude ($W1$) < 15.5 mag (in Vega).

^b S/N (optical lines) > 3 , redshift < 0.3 , $H\alpha > 0$, $H\beta > 0$, $[O III]5007 > 0$, $[N II]6583 > 0$, and magnitude ($W1$) < 15.5 mag (in Vega).

^c S/N (optical lines) > 3 , redshift < 0.3 , $H\alpha > 0$, $H\beta > 0$, $[O III]5007 > 0$, $[N II]6583 > 0$. S/N: $W1 > 5$, $W2 > 5$, and $W3 > 2$; and magnitude ($W1$) < 15.5 mag (in Vega).

^d When in “Condition c,” all broad-line (BL) non-oAGNs are considered to be BL oAGNs and BL composites to be BL oAGN(mSF). Recall that the position of the BLAGNs are highly uncertain on the BPT due to errors related to the $[N II]/H\alpha$ flux ratio.

of the latter galaxies are labeled as either peculiars or late-type spirals by their SED template fits. This could be explained by the fact that they are sharing similar properties with some of the oAGN (mSF), which are also classified as non-AGN based on the SED. Among the non-oAGNs classified as mAGNs, only six are oSFs. The trend is that most of the WISE AGNs are also optical AGNs or at least composite galaxies that need further attention using other diagnostic methods based on radio or X-ray data. Zone 2 (mWarm) seems to be a transition zone where we find the optical star-forming galaxies, the composites, and the BLAGNs in similar proportions.

Figure 11(b) shows the host stellar mass as a function of $[O III]$ line luminosity. In this figure, which requires the use of individual fluxes unlike the BPT based on line ratios, only the calibrated measurements are used (see Hopkins et al. 2013 for the data description). The number of galaxies, therefore, is reduced. The distribution can be separated into two regions, with optical AGNs generally having luminosity greater than $10^{41} \text{ erg s}^{-1}$ and the SF galaxies with lower values. The BLAGNs appear to have also strong $[O III]$ lines. Most of the oAGN (mSF) present a strong $[O III]$ luminosity confirming the presence of nuclear activity (if we assume that $[O III]$ lines are always related to the AGN or nuclear shocks). As expected, the

non-oAGN (mAGN) usually have weak $[O III]$ luminosity, like the SF and composites, with a few exceptions. WISE classifying them as AGNs probably has to do with other processes beyond that of a central AGN activity. Some interesting cases such as oAGN (mSF) with high $[O III]$ luminosity are discussed in Section 3.3.

Table 3 contains the detailed measurements used in this study, organized by their BPT-IR classification. $W1$, $W2$, and $W3_{\text{PAH}}$ are rest-frame fluxes (using SED fitting; see Jarrett et al. 2017 for more details). The stellar emission has been subtracted in $W3$. $W1 - W2$ and $W2 - W3$ are the rest-frame colors used for the color-color diagram. $[O III]/H\beta$ and $[N II]/H\alpha$ represent the optical line ratios used for the BPT diagnostic. Stellar masses and SFRs ($\text{SFR}_{12\mu\text{m}}$) are derived using the calibration by Cluver et al. (2014) and Cluver et al. (2017), respectively (see Table 4). The specific SFR is the ratio between the SFR and the stellar mass. The galaxies have been classified according to their different AGN groups.

Table 2 gives the number of galaxies and their average parameter values in the subsets for different conditions applied to the sample. The number of BLAGNs included in each subset is also shown. “Condition A” presents only the infrared classification, while in “B” the optical classification is presented. Both

Figure 12. Left panel: (a) distribution of the $SFR_{12\mu m}$ as a function of stellar mass for the galaxies classified as non-AGNs in both optical and mid-IR. Panel (b) shows the $sSFR$ as a function of stellar mass for the same non-AGN sample, with the dashed lines representing lines of constant SFR ($0.1, 1, 10, 100 M_{\odot} \text{ yr}^{-1}$). The right panel is similar to the previous panel but applied to our different groups of AGNs as indicated in the legend. We do expect the stellar mass and the $SFR_{12\mu m}$ to be overestimated due to the AGN activity within the galaxies (in the right panel). Notably for those in which AGNs dominate (i.e., QSOs and BLAGNs). We also plot the mean uncertainties with the error bars for each parameter in the lower-right corner.

diagnostics are combined in “C,” giving a total number of 1154 classified galaxies. “Condition D” is where we reclassify BLAGNs based on the fact that they are clearly optical AGNs that were misclassified by the BPT diagram. Notably, the 2 BLAGNs found in the composite group were reclassified as oAGN (mSF), the BLAGNs (3 galaxies) found in the non-oAGN (mWarm) group become oAGN (mWarm), and finally 11 non-oAGN (mAGN) become oAGN (mAGN). We consider the galaxies in the mWarm region to have AGN activity; therefore, in “D,” both methods agree on the final classification of 84.4% and 8.2% of the galaxies as non-AGNs (SF + composite) and AGNs, respectively, and disagree on the classification of 7.4%. The redshift distribution of the different groups of galaxy is presented in the next section Figure 13.

3.2.3. Galaxy Properties in the Different Activity Classifications

In Figure 12, we plot $SFR_{12\mu m}$ as a function of stellar mass and include the main-sequence relation of the local galaxies from Grootes et al. (2013), Cluver et al. (2020), Parkash et al. (2018), and Jarrett et al. (2017).

The upper limits trace the galaxies with the lowest SFR corresponding to the passively evolving galaxies (also presented

in Figure 4). All the groups share the same mass range from $10^{9.8} M_{\odot} < M_{\text{stellar}} < 10^{11.5} M_{\odot}$. The low-mass end ($M_{\text{stellar}} < 10^{9.8} M_{\odot}$) is exclusively populated by SF galaxies having low star formation along with a few non-oAGN (mWarm). The high-mass end ($M_{\text{stellar}} > 10^{11} M_{\odot}$) is populated by galaxies with broad Balmer lines (panel (b)), which are classified as AGNs, both in the optical and the mid-infrared. The linear fit to the selection of Jarrett et al. (2017), which is similar to our sample (except that here the AGNs have been separated from SFs), follows our sequence, especially the high-mass end, which is generally populated by AGNs. The new sequence fit by Cluver et al. (2020), based on a sample of isolated SF galaxies, also traces our distribution with a slightly flatter slope.

Grootes et al. (2013) UV-selected a sample of nearby ($z < 0.13$) spirals in GAMA that gives a flatter $SFR-M_{*}$ relation. The relation given in Parkash et al. (2018) traces best our low-mass galaxies and also seems to follow the background distribution of galaxies (the gray points), which likely includes absorption-line features. Our sample is limited to only bright galaxies ($W1 < 15.5$ mag); moreover, it requires at least a detection in W3 (dusty), which might preferably select more massive, star-bursting systems, compared to UV or optically

Table 3
Measured Properties of a Representative Sample of Galaxies from Each Activity Group

CATAID	z_{spec}	W1 (mJy)	W2 (mJy)	W3 _{PAH} mJy	W1 – W2 (mag)	W2 – W3 (mag)	[O III]/H β	[N II]/H α
SF (blue circles)								
5241095*	0.0274	0.42 $\pm$ 0.01	0.26 $\pm$ 0.02	0.7 $\pm$ 0.2	0.14 $\pm$ 0.08	3.08 $\pm$ 0.33	3.6 $\pm$ 0.09	0.07 $\pm$ 0.01
5240983*	0.0274	0.72 $\pm$ 0.02	0.49 $\pm$ 0.03	1.97 $\pm$ 0.59	0.24 $\pm$ 0.07	3.49 $\pm$ 0.33	2.37 $\pm$ 0.08	0.1 $\pm$ 0.0
5306682*	0.0053	14.13 $\pm$ 0.16	7.99 $\pm$ 0.15	21.08 $\pm$ 3.24	0.03 $\pm$ 0.04	3.08 $\pm$ 0.17	0.78 $\pm$ 0.03	0.28 $\pm$ 0.01
5135645*	0.1912	0.51 $\pm$ 0.01	0.55 $\pm$ 0.02	9.68 $\pm$ 2.16	0.74 $\pm$ 0.06	5.04 $\pm$ 0.25	0.44 $\pm$ 0.04	0.38 $\pm$ 0.01
5325430	0.0648	0.59 $\pm$ 0.01	0.34 $\pm$ 0.02	1.93 $\pm$ 0.15	0.06 $\pm$ 0.07	3.86 $\pm$ 0.11	0.29 $\pm$ 0.06	0.33 $\pm$ 0.01
5327563	0.0652	0.4 $\pm$ 0.01	0.27 $\pm$ 0.02	1.11 $\pm$ 0.43	0.22 $\pm$ 0.09	3.54 $\pm$ 0.43	1.01 $\pm$ 0.14	0.25 $\pm$ 0.03
5325339	0.1247	0.66 $\pm$ 0.01	0.44 $\pm$ 0.02	1.71 $\pm$ 0.1	0.2 $\pm$ 0.07	3.46 $\pm$ 0.09	0.37 $\pm$ 0.09	0.38 $\pm$ 0.03
5123445	0.0795	0.4 $\pm$ 0.01	0.29 $\pm$ 0.02	1.19 $\pm$ 0.18	0.28 $\pm$ 0.09	3.53 $\pm$ 0.19	0.41 $\pm$ 0.12	0.38 $\pm$ 0.03
5138489	0.0852	0.24 $\pm$ 0.01	0.15 $\pm$ 0.02	0.7 $\pm$ 0.17	0.15 $\pm$ 0.13	3.63 $\pm$ 0.29	0.42 $\pm$ 0.15	0.35 $\pm$ 0.03
5153375	0.0807	0.39 $\pm$ 0.01	0.28 $\pm$ 0.01	1.36 $\pm$ 0.16	0.28 $\pm$ 0.06	3.71 $\pm$ 0.14	0.67 $\pm$ 0.15	0.3 $\pm$ 0.02
5261290	0.0834	1.16 $\pm$ 0.02	0.79 $\pm$ 0.03	5.57 $\pm$ 1.25	0.23 $\pm$ 0.05	4.08 $\pm$ 0.25	0.16 $\pm$ 0.04	0.4 $\pm$ 0.02
5187670	0.1067	0.27 $\pm$ 0.01	0.16 $\pm$ 0.02	0.78 $\pm$ 0.12	0.08 $\pm$ 0.15	3.72 $\pm$ 0.23	0.18 $\pm$ 0.06	0.31 $\pm$ 0.04
5281879	0.0286	2.89 $\pm$ 0.03	1.75 $\pm$ 0.04	6.64 $\pm$ 0.16	0.1 $\pm$ 0.04	3.44 $\pm$ 0.05	0.26 $\pm$ 0.03	0.41 $\pm$ 0.01
5281521	0.0288	0.35 $\pm$ 0.01	0.18 $\pm$ 0.02	0.45 $\pm$ 0.17	−0.06 $\pm$ 0.11	3.03 $\pm$ 0.43	1.6 $\pm$ 0.14	0.14 $\pm$ 0.01
5305483	0.086	0.46 $\pm$ 0.01	0.33 $\pm$ 0.02	1.68 $\pm$ 0.43	0.28 $\pm$ 0.07	3.74 $\pm$ 0.29	0.36 $\pm$ 0.03	0.31 $\pm$ 0.01
5222747	0.2084	0.22 $\pm$ 0.01	0.15 $\pm$ 0.01	0.56 $\pm$ 0.09	0.24 $\pm$ 0.07	3.4 $\pm$ 0.18	0.55 $\pm$ 0.15	0.37 $\pm$ 0.04
5266202	0.0844	0.74 $\pm$ 0.02	0.49 $\pm$ 0.03	3.09 $\pm$ 0.15	0.19 $\pm$ 0.07	3.97 $\pm$ 0.09	0.18 $\pm$ 0.06	0.36 $\pm$ 0.01
5185570	0.0594	0.53 $\pm$ 0.02	0.31 $\pm$ 0.02	0.3 $\pm$ 0.12	0.08 $\pm$ 0.09	2.15 $\pm$ 0.45	0.31 $\pm$ 0.04	0.31 $\pm$ 0.02
5256068	0.223	0.67 $\pm$ 0.01	0.6 $\pm$ 0.01	6.5 $\pm$ 0.11	0.54 $\pm$ 0.04	4.52 $\pm$ 0.04	0.82 $\pm$ 0.1	0.36 $\pm$ 0.01
Composites (green circles)								
5205726*	0.0592	1.68 $\pm$ 0.02	0.99 $\pm$ 0.02	1.94 $\pm$ 0.14	0.08 $\pm$ 0.04	2.78 $\pm$ 0.09	0.38 $\pm$ 0.18	0.6 $\pm$ 0.02
5322507	0.0608	1.38 $\pm$ 0.02	0.81 $\pm$ 0.03	1.05 $\pm$ 0.16	0.07 $\pm$ 0.05	2.41 $\pm$ 0.17	0.55 $\pm$ 0.11	0.76 $\pm$ 0.05
5246049	0.1064	0.87 $\pm$ 0.01	0.64 $\pm$ 0.02	5.13 $\pm$ 1.16	0.32 $\pm$ 0.05	4.2 $\pm$ 0.25	0.29 $\pm$ 0.05	0.53 $\pm$ 0.01
5277048	0.1088	0.21 $\pm$ 0.01	0.16 $\pm$ 0.02	1.31 $\pm$ 0.18	0.34 $\pm$ 0.12	4.25 $\pm$ 0.19	1.62 $\pm$ 0.28	0.36 $\pm$ 0.09
5251443	0.2361	0.21 $\pm$ 0.01	0.11 $\pm$ 0.01	0.37 $\pm$ 0.13	−0.08 $\pm$ 0.09	3.37 $\pm$ 0.39	0.41 $\pm$ 0.13	0.62 $\pm$ 0.04
5279625	0.0842	0.63 $\pm$ 0.01	0.42 $\pm$ 0.02	2.61 $\pm$ 0.61	0.19 $\pm$ 0.06	3.96 $\pm$ 0.26	0.57 $\pm$ 0.1	0.46 $\pm$ 0.01
5285888	0.2012	0.46 $\pm$ 0.01	0.32 $\pm$ 0.02	3.11 $\pm$ 0.77	0.25 $\pm$ 0.07	4.41 $\pm$ 0.28	1.36 $\pm$ 0.27	0.52 $\pm$ 0.06
5159722	0.0656	1.84 $\pm$ 0.02	1.2 $\pm$ 0.04	7.04 $\pm$ 0.21	0.18 $\pm$ 0.05	3.88 $\pm$ 0.06	0.62 $\pm$ 0.11	0.46 $\pm$ 0.02
5154601	0.0789	0.33 $\pm$ 0.01	0.18 $\pm$ 0.01	0.67 $\pm$ 0.13	−0.04 $\pm$ 0.08	3.46 $\pm$ 0.22	0.8 $\pm$ 0.15	0.42 $\pm$ 0.03
5264991	0.1897	0.3 $\pm$ 0.01	0.25 $\pm$ 0.01	2.09 $\pm$ 0.14	0.44 $\pm$ 0.07	4.24 $\pm$ 0.1	1.16 $\pm$ 0.34	0.55 $\pm$ 0.08
5364072	0.0955	0.2 $\pm$ 0.01	0.1 $\pm$ 0.01	0.55 $\pm$ 0.12	−0.13 $\pm$ 0.14	3.84 $\pm$ 0.28	1.09 $\pm$ 0.3	0.38 $\pm$ 0.04
5249313	0.0799	0.9 $\pm$ 0.01	0.54 $\pm$ 0.02	0.86 $\pm$ 0.17	0.08 $\pm$ 0.06	2.61 $\pm$ 0.22	0.25 $\pm$ 0.04	0.61 $\pm$ 0.02
5280475	0.0675	0.45 $\pm$ 0.01	0.27 $\pm$ 0.02	3.5 $\pm$ 0.95	0.1 $\pm$ 0.08	4.72 $\pm$ 0.3	1.35 $\pm$ 0.06	0.37 $\pm$ 0.01
5154381	0.0832	0.4 $\pm$ 0.02	0.25 $\pm$ 0.01	0.87 $\pm$ 0.13	0.15 $\pm$ 0.08	3.34 $\pm$ 0.18	1.16 $\pm$ 0.28	0.4 $\pm$ 0.04
oAGN (mAGN) (red circles)								
5339805* +	0.0894	3.14 $\pm$ 0.04	3.43 $\pm$ 0.07	6.15 $\pm$ 0.14	0.74 $\pm$ 0.04	2.64 $\pm$ 0.05	0.39 $\pm$ 0.03	3.0 $\pm$ 0.09
5151978* +	0.2349	0.36 $\pm$ 0.01	0.57 $\pm$ 0.02	4.41 $\pm$ 1.08	1.15 $\pm$ 0.06	4.16 $\pm$ 0.27	12.17 $\pm$ 0.73	0.92 $\pm$ 0.02
5145801	0.1975	0.7 $\pm$ 0.01	0.8 $\pm$ 0.03	2.9 $\pm$ 0.76	0.79 $\pm$ 0.05	3.37 $\pm$ 0.29	2.96 $\pm$ 0.07	0.99 $\pm$ 0.06
5252110	0.1309	1.86 $\pm$ 0.03	2.53 $\pm$ 0.06	8.6 $\pm$ 1.89	0.98 $\pm$ 0.04	3.29 $\pm$ 0.24	3.89 $\pm$ 0.28	0.62 $\pm$ 0.02
5237160	0.0604	0.59 $\pm$ 0.01	0.93 $\pm$ 0.03	10.49 $\pm$ 2.26	1.15 $\pm$ 0.05	4.56 $\pm$ 0.24	8.9 $\pm$ 0.46	0.56 $\pm$ 0.02
5340595+	0.1882	1.2 $\pm$ 0.02	1.44 $\pm$ 0.04	4.67 $\pm$ 1.05	0.84 $\pm$ 0.04	3.24 $\pm$ 0.25	0.69 $\pm$ 0.02	2.97 $\pm$ 0.14
5286102+	0.2425	1.24 $\pm$ 0.02	1.37 $\pm$ 0.03	3.01 $\pm$ 0.76	0.76 $\pm$ 0.04	2.84 $\pm$ 0.28	0.51 $\pm$ 0.05	2.43 $\pm$ 0.12
5108709	0.1528	0.44 $\pm$ 0.01	0.63 $\pm$ 0.02	3.13 $\pm$ 0.16	1.04 $\pm$ 0.05	3.69 $\pm$ 0.07	3.41 $\pm$ 0.12	0.5 $\pm$ 0.01
5369226	0.1367	1.28 $\pm$ 0.02	1.84 $\pm$ 0.05	12.08 $\pm$ 2.58	1.04 $\pm$ 0.04	3.98 $\pm$ 0.23	5.51 $\pm$ 0.83	0.8 $\pm$ 0.03
5162821+	0.2459	0.34 $\pm$ 0.01	0.42 $\pm$ 0.01	0.76 $\pm$ 0.11	0.86 $\pm$ 0.05	2.66 $\pm$ 0.17	4.71 $\pm$ 0.5	1.27 $\pm$ 0.08
5233898	0.2039	0.82 $\pm$ 0.01	1.05 $\pm$ 0.03	4.38 $\pm$ 1.02	0.91 $\pm$ 0.05	3.51 $\pm$ 0.26	3.81 $\pm$ 0.63	0.63 $\pm$ 0.06
5197408+	0.2086	0.36 $\pm$ 0.01	0.41 $\pm$ 0.01	0.81 $\pm$ 0.13	0.79 $\pm$ 0.05	2.73 $\pm$ 0.17	2.81 $\pm$ 0.12	2.03 $\pm$ 0.08
5312967+	0.1963	0.27 $\pm$ 0.01	0.31 $\pm$ 0.01	0.53 $\pm$ 0.14	0.8 $\pm$ 0.06	2.58 $\pm$ 0.28	6.63 $\pm$ 0.63	0.9 $\pm$ 0.07
5305653+	0.2124	0.69 $\pm$ 0.01	0.71 $\pm$ 0.01	1.29 $\pm$ 0.11	0.67 $\pm$ 0.04	2.66 $\pm$ 0.1	2.74 $\pm$ 0.28	0.87 $\pm$ 0.04
5216684+	0.2096	1.13 $\pm$ 0.02	1.94 $\pm$ 0.05	8.59 $\pm$ 1.86	1.23 $\pm$ 0.04	3.56 $\pm$ 0.24	8.23 $\pm$ 0.36	0.83 $\pm$ 0.01
5342686+	0.1861	2.98 $\pm$ 0.03	4.1 $\pm$ 0.08	9.12 $\pm$ 1.93	0.99 $\pm$ 0.04	2.85 $\pm$ 0.23	4.95 $\pm$ 0.15	0.32 $\pm$ 0.02
5213139+	0.1228	2.43 $\pm$ 0.03	2.86 $\pm$ 0.06	9.16 $\pm$ 2.0	0.83 $\pm$ 0.04	3.23 $\pm$ 0.24	1.72 $\pm$ 0.06	1.37 $\pm$ 0.03
5155308+	0.209	4.63 $\pm$ 0.03	5.99 $\pm$ 0.03	21.22 $\pm$ 4.44	0.93 $\pm$ 0.03	3.33 $\pm$ 0.23	1.71 $\pm$ 0.08	2.33 $\pm$ 0.04
5240292+	0.2238	0.5 $\pm$ 0.01	0.66 $\pm$ 0.03	2.69 $\pm$ 0.7	0.93 $\pm$ 0.06	3.48 $\pm$ 0.29	0.43 $\pm$ 0.02	1.45 $\pm$ 0.03
oAGN (mWarm) (red squares)								
5347780* +	0.089	2.15 $\pm$ 0.03	1.89 $\pm$ 0.05	5.81 $\pm$ 0.14	0.51 $\pm$ 0.04	3.2 $\pm$ 0.05	1.17 $\pm$ 0.05	1.53 $\pm$ 0.07
5294374* +	0.107	5.17 $\pm$ 0.06	4.63 $\pm$ 0.1	14.27 $\pm$ 2.81	0.53 $\pm$ 0.04	3.2 $\pm$ 0.22	1.09 $\pm$ 0.04	1.81 $\pm$ 0.03
5112784+	0.0578	1.74 $\pm$ 0.02	1.49 $\pm$ 0.04	2.31 $\pm$ 0.62	0.48 $\pm$ 0.04	2.52 $\pm$ 0.3	0.96 $\pm$ 0.18	2.52 $\pm$ 0.38

Table 3
(Continued)

CATAID	z_{spec}	W1 (mJy)	W2 (mJy)	W3 _{PAH} mJy	W1 – W2 (mag)	W2 – W3 (mag)	[O III]/H β	[N II]/H α
5153772	0.189	0.44 $\pm$ 0.01	0.48 $\pm$ 0.02	4.79 $\pm$ 1.15	0.75 $\pm$ 0.06	4.43 $\pm$ 0.27	7.62 $\pm$ 0.4	0.8 $\pm$ 0.06
5351862 ⁺	0.1103	0.75 $\pm$ 0.01	0.7 $\pm$ 0.02	3.62 $\pm$ 0.89	0.56 $\pm$ 0.05	3.74 $\pm$ 0.27	3.43 $\pm$ 0.17	1.19 $\pm$ 0.06
5369229	0.1402	0.53 $\pm$ 0.02	0.48 $\pm$ 0.02	2.97 $\pm$ 0.17	0.55 $\pm$ 0.06	3.92 $\pm$ 0.08	7.45 $\pm$ 0.52	0.71 $\pm$ 0.06
5346487 ⁺	0.1898	0.45 $\pm$ 0.01	0.44 $\pm$ 0.02	3.46 $\pm$ 0.88	0.64 $\pm$ 0.06	4.17 $\pm$ 0.28	0.99 $\pm$ 0.04	1.57 $\pm$ 0.04
5110547 ⁺	0.0889	0.96 $\pm$ 0.01	0.78 $\pm$ 0.02	2.46 $\pm$ 0.65	0.41 $\pm$ 0.04	3.24 $\pm$ 0.29	6.17 $\pm$ 0.32	0.8 $\pm$ 0.02
5180136	0.1056	0.61 $\pm$ 0.01	0.52 $\pm$ 0.02	1.76 $\pm$ 0.18	0.47 $\pm$ 0.05	3.32 $\pm$ 0.12	7.12 $\pm$ 0.67	0.7 $\pm$ 0.02
5137338 ⁺	0.2597	0.45 $\pm$ 0.01	0.43 $\pm$ 0.02	0.65 $\pm$ 0.14	0.6 $\pm$ 0.06	2.48 $\pm$ 0.24	1.77 $\pm$ 0.31	0.67 $\pm$ 0.04
5196019	0.1258	0.69 $\pm$ 0.01	0.72 $\pm$ 0.03	5.65 $\pm$ 1.31	0.69 $\pm$ 0.05	4.18 $\pm$ 0.26	6.96 $\pm$ 0.68	0.78 $\pm$ 0.02
5211450	0.2535	0.36 $\pm$ 0.01	0.34 $\pm$ 0.01	1.32 $\pm$ 0.41	0.6 $\pm$ 0.06	3.43 $\pm$ 0.34	8.64 $\pm$ 1.51	0.51 $\pm$ 0.05
5367800 ⁺	0.2627	0.43 $\pm$ 0.01	0.43 $\pm$ 0.02	0.41 $\pm$ 0.08	0.65 $\pm$ 0.06	2.04 $\pm$ 0.22	1.19 $\pm$ 0.1	1.34 $\pm$ 0.14
oAGN (mSF) (yellow circles)								
5249547 [*]	0.0834	1.36 $\pm$ 0.02	0.8 $\pm$ 0.02	2.13 $\pm$ 0.16	0.07 $\pm$ 0.04	3.09 $\pm$ 0.09	2.17 $\pm$ 0.21	0.79 $\pm$ 0.03
5155115 [*]	0.0869	1.7 $\pm$ 0.02	0.99 $\pm$ 0.03	2.2 $\pm$ 0.18	0.06 $\pm$ 0.05	2.92 $\pm$ 0.1	5.56 $\pm$ 0.57	0.93 $\pm$ 0.05
5163580 ⁺	0.1228	0.51 $\pm$ 0.01	0.36 $\pm$ 0.02	0.39 $\pm$ 0.1	0.25 $\pm$ 0.06	2.22 $\pm$ 0.29	2.54 $\pm$ 0.2	2.71 $\pm$ 0.19
5368644	0.1194	0.43 $\pm$ 0.01	0.34 $\pm$ 0.01	1.18 $\pm$ 0.13	0.37 $\pm$ 0.06	3.35 $\pm$ 0.13	2.55 $\pm$ 0.3	0.6 $\pm$ 0.08
5278828	0.1388	0.22 $\pm$ 0.01	0.18 $\pm$ 0.01	1.15 $\pm$ 0.13	0.42 $\pm$ 0.1	3.97 $\pm$ 0.15	2.7 $\pm$ 0.46	0.59 $\pm$ 0.02
5139540 ⁺	0.2323	0.36 $\pm$ 0.01	0.2 $\pm$ 0.01	0.59 $\pm$ 0.13	0.01 $\pm$ 0.07	3.18 $\pm$ 0.25	0.49 $\pm$ 0.09	1.89 $\pm$ 0.15
5305775	0.133	0.63 $\pm$ 0.01	0.41 $\pm$ 0.02	2.32 $\pm$ 0.59	0.17 $\pm$ 0.06	3.86 $\pm$ 0.28	2.35 $\pm$ 0.34	0.54 $\pm$ 0.03
5355371 ⁺	0.2006	0.25 $\pm$ 0.01	0.2 $\pm$ 0.01	0.92 $\pm$ 0.1	0.42 $\pm$ 0.06	3.62 $\pm$ 0.13	8.12 $\pm$ 0.28	0.58 $\pm$ 0.01
5188449 ⁺	0.1169	0.2 $\pm$ 0.01	0.11 $\pm$ 0.01	0.24 $\pm$ 0.1	−0.01 $\pm$ 0.14	2.95 $\pm$ 0.46	3.32 $\pm$ 0.2	0.68 $\pm$ 0.04
5427366	0.0881	0.45 $\pm$ 0.01	0.32 $\pm$ 0.01	0.87 $\pm$ 0.11	0.27 $\pm$ 0.05	3.11 $\pm$ 0.15	1.84 $\pm$ 0.17	0.68 $\pm$ 0.04
5163246	0.2064	0.37 $\pm$ 0.01	0.25 $\pm$ 0.01	0.3 $\pm$ 0.07	0.2 $\pm$ 0.06	2.34 $\pm$ 0.26	4.53 $\pm$ 0.32	0.63 $\pm$ 0.02
5258350	0.0768	0.89 $\pm$ 0.01	0.6 $\pm$ 0.01	1.94 $\pm$ 0.17	0.21 $\pm$ 0.04	3.28 $\pm$ 0.1	3.07 $\pm$ 0.16	0.59 $\pm$ 0.01
5154519	0.2123	0.21 $\pm$ 0.01	0.17 $\pm$ 0.01	0.95 $\pm$ 0.12	0.43 $\pm$ 0.08	3.83 $\pm$ 0.15	3.61 $\pm$ 0.73	0.79 $\pm$ 0.05
5271798	0.152	0.36 $\pm$ 0.01	0.29 $\pm$ 0.01	3.34 $\pm$ 0.81	0.4 $\pm$ 0.06	4.61 $\pm$ 0.27	4.59 $\pm$ 0.16	0.54 $\pm$ 0.01
non-oAGN (mAGN) (orange circles)								
5200866 [*]	0.1218	0.97 $\pm$ 0.01	1.38 $\pm$ 0.04	17.47 $\pm$ 3.64	1.04 $\pm$ 0.04	4.68 $\pm$ 0.23	0.97 $\pm$ 0.02	0.35 $\pm$ 0.0
5158890 [*]	0.1772	1.43 $\pm$ 0.02	1.63 $\pm$ 0.04	8.14 $\pm$ 0.15	0.79 $\pm$ 0.04	3.7 $\pm$ 0.04	0.95 $\pm$ 0.07	0.51 $\pm$ 0.01
5275222 ⁺	0.2101	0.75 $\pm$ 0.01	0.84 $\pm$ 0.03	2.08 $\pm$ 0.62	0.78 $\pm$ 0.06	2.96 $\pm$ 0.33	0.29 $\pm$ 0.01	0.61 $\pm$ 0.01
5241310 ⁺	0.2283	0.4 $\pm$ 0.01	0.55 $\pm$ 0.04	1.9 $\pm$ 0.54	0.98 $\pm$ 0.09	3.31 $\pm$ 0.32	1.35 $\pm$ 0.1	0.42 $\pm$ 0.02
5362108	0.1669	0.36 $\pm$ 0.01	0.46 $\pm$ 0.02	3.47 $\pm$ 0.84	0.92 $\pm$ 0.06	4.13 $\pm$ 0.27	0.93 $\pm$ 0.23	0.28 $\pm$ 0.05
5154472	0.1107	0.25 $\pm$ 0.01	0.31 $\pm$ 0.01	1.59 $\pm$ 0.12	0.91 $\pm$ 0.07	3.71 $\pm$ 0.1	0.45 $\pm$ 0.15	0.39 $\pm$ 0.03
5129662	0.2045	0.44 $\pm$ 0.01	0.52 $\pm$ 0.02	2.18 $\pm$ 0.56	0.83 $\pm$ 0.06	3.51 $\pm$ 0.28	1.73 $\pm$ 0.1	0.5 $\pm$ 0.01
5246095 ⁺	0.2184	0.7 $\pm$ 0.01	0.84 $\pm$ 0.03	3.08 $\pm$ 0.73	0.83 $\pm$ 0.05	3.38 $\pm$ 0.26	0.78 $\pm$ 0.04	0.71 $\pm$ 0.01
5119859	0.1865	0.2 $\pm$ 0.01	0.25 $\pm$ 0.01	1.41 $\pm$ 0.14	0.92 $\pm$ 0.08	3.81 $\pm$ 0.13	0.2 $\pm$ 0.06	0.34 $\pm$ 0.03
5317117 ⁺	0.2038	0.79 $\pm$ 0.01	0.92 $\pm$ 0.01	2.35 $\pm$ 0.12	0.81 $\pm$ 0.04	3.0 $\pm$ 0.07	0.57 $\pm$ 0.02	0.26 $\pm$ 0.01
5247018 ⁺	0.209	0.22 $\pm$ 0.01	0.49 $\pm$ 0.03	0.78 $\pm$ 0.21	1.52 $\pm$ 0.07	2.48 $\pm$ 0.3	0.3 $\pm$ 0.02	1.01 $\pm$ 0.05
non-oAGN (mWarm) (orange squares)								
5204947 [*]	0.2438	0.68 $\pm$ 0.01	0.73 $\pm$ 0.03	4.38 $\pm$ 1.08	0.72 $\pm$ 0.05	3.9 $\pm$ 0.27	1.86 $\pm$ 0.4	0.39 $\pm$ 0.01
5219936	0.0935	0.63 $\pm$ 0.01	0.66 $\pm$ 0.03	6.72 $\pm$ 1.51	0.7 $\pm$ 0.06	4.47 $\pm$ 0.25	1.02 $\pm$ 0.06	0.3 $\pm$ 0.01
5282867	0.0846	0.25 $\pm$ 0.01	0.21 $\pm$ 0.01	0.85 $\pm$ 0.15	0.46 $\pm$ 0.09	3.49 $\pm$ 0.2	0.71 $\pm$ 0.14	0.26 $\pm$ 0.02
5310140	0.2038	0.26 $\pm$ 0.01	0.23 $\pm$ 0.01	1.41 $\pm$ 0.12	0.54 $\pm$ 0.07	3.9 $\pm$ 0.11	0.84 $\pm$ 0.16	0.34 $\pm$ 0.02
5100400	0.2733	0.52 $\pm$ 0.01	0.41 $\pm$ 0.02	0.65 $\pm$ 0.11	0.37 $\pm$ 0.06	2.57 $\pm$ 0.19	0.11 $\pm$ 0.04	0.42 $\pm$ 0.02
5115102	0.2989	0.22 $\pm$ 0.01	0.2 $\pm$ 0.01	0.85 $\pm$ 0.1	0.55 $\pm$ 0.08	3.55 $\pm$ 0.15	0.61 $\pm$ 0.13	0.48 $\pm$ 0.03
5154420	0.1993	0.28 $\pm$ 0.01	0.25 $\pm$ 0.01	1.56 $\pm$ 0.13	0.52 $\pm$ 0.07	3.96 $\pm$ 0.11	0.3 $\pm$ 0.09	0.4 $\pm$ 0.02
5228724 ⁺	0.2367	0.44 $\pm$ 0.01	0.43 $\pm$ 0.01	1.48 $\pm$ 0.09	0.63 $\pm$ 0.04	3.3 $\pm$ 0.08	1.36 $\pm$ 0.14	0.54 $\pm$ 0.02
5350683	0.2508	0.27 $\pm$ 0.01	0.26 $\pm$ 0.01	1.84 $\pm$ 0.14	0.61 $\pm$ 0.06	4.06 $\pm$ 0.1	0.68 $\pm$ 0.15	0.54 $\pm$ 0.03
5133213	0.2059	0.29 $\pm$ 0.01	0.28 $\pm$ 0.01	1.7 $\pm$ 0.12	0.61 $\pm$ 0.07	3.92 $\pm$ 0.09	0.24 $\pm$ 0.07	0.45 $\pm$ 0.02

Note. The fluxes are k-corrected, and the rest-frame fluxes in W1, W2, and W3 are given in mJy. W1 – W2 and W2 – W3 are rest-frame colors, and the GAMA redshifts are also presented. The selected galaxies for case study in the next section are designated by a star next to their GAMA ID (e.g., 5241095^{*}: for the first selected galaxy in the SF group, etc.) and the BLAGN by a plus sign (e.g., 5340595⁺: a BLAGN in the oAGN (mAGN) group, etc.). The colors used for the different groups as presented in Figure 10 are added for clarity.

selected samples, as discussed in Jarrett et al. (2017). Figure 12(c) shows a flat distribution, with the selected galaxies having generally $\log \text{sSFR} > -11.4 \text{ yr}^{-1}$. The BPT based on emission-

line galaxies might be preferentially selecting galaxies that are still building up their disk and not probing enough intermediate (so-called “green valley”) galaxies. We note that we do expect a mass

Table 4
Derived Properties of a Representative Sample of the Galaxies from Each Activity Group

CATAID	$\text{Log } M_{\text{stellar}} (M_{\odot})$	$\text{SFR}_{12\mu\text{m}} (M_{\odot}\text{yr}^{-1})$	$\text{Log } (L[\text{O III}]) (\text{erg s}^{-1})$	$\text{Log } (\text{sSFR}) (\text{yr}^{-1})$
SF (blue circles)				
5241095*	9.05 ± 0.20	0.2 ± 0.09	41.14 ± 0.0	-9.75 ± 0.27
5240983*	9.14 ± 0.19	0.49 ± 0.21	40.94 ± 0.01	-9.45 ± 0.27
5306682*	9.43 ± 0.10	0.21 ± 0.08	39.44 ± 0.01	-10.11 ± 0.19
5135645*	10.78 ± 0.16	73.44 ± 29.20	41.25 ± 0.03	-8.91 ± 0.23
5325430	10.19 ± 0.18	2.3 ± 0.81	40.23 ± 0.08	-9.83 ± 0.24
5327563	9.66 ± 0.24	1.43 ± 0.69	...	-9.51 ± 0.32
5325339	10.48 ± 0.17	7.0 ± 2.45	...	-9.64 ± 0.23
5123445	9.85 ± 0.23	2.2 ± 0.82	...	-9.51 ± 0.28
5138489	9.82 ± 0.33	1.57 ± 0.64	40.23 ± 0.14	-9.62 ± 0.38
5153375	9.85 ± 0.16	2.53 ± 0.91	40.29 ± 0.08	-9.44 ± 0.23
5261290	10.35 ± 0.13	9.29 ± 3.70	40.35 ± 0.11	-9.39 ± 0.22
5187670	10.25 ± 0.38	2.63 ± 0.98	39.94 ± 0.13	-9.83 ± 0.42
5281879	10.04 ± 0.11	1.54 ± 0.54	39.87 ± 0.05	-9.85 ± 0.19
5281521	9.51 ± 0.28	0.15 ± 0.07	40.01 ± 0.02	-10.35 ± 0.35
5305483	9.98 ± 0.19	3.42 ± 1.42	40.54 ± 0.04	-9.45 ± 0.26
5222747	10.50 ± 0.18	7.13 ± 2.65	40.76 ± 0.11	-9.65 ± 0.24
5266202	10.20 ± 0.18	5.67 ± 1.98	40.09 ± 0.14	-9.44 ± 0.24
5185570	10.01 ± 0.23	0.38 ± 0.19	39.86 ± 0.05	-10.43 ± 0.31
5256068	11.05 ± 0.10	70.22 ± 24.32	41.47 ± 0.04	-9.2 ± 0.18
Composites (green circles)				
5205726*	10.51 ± 0.11	1.94 ± 0.68	40.29 ± 0.21	-10.22 ± 0.19
5322507	10.47 ± 0.13	1.19 ± 0.44	...	-10.39 ± 0.2
5246049	10.45 ± 0.14	13.63 ± 5.44	40.57 ± 0.07	-9.32 ± 0.22
5277048	9.85 ± 0.31	4.27 ± 1.56	...	-9.22 ± 0.35
5251443	11.23 ± 0.24	6.3 ± 2.90	40.62 ± 0.13	-10.43 ± 0.31
5279625	10.11 ± 0.15	4.86 ± 1.95	40.32 ± 0.06	-9.43 ± 0.23
5285888	10.78 ± 0.17	29.91 ± 12.21	41.5 ± 0.07	-9.31 ± 0.25
5159722	10.37 ± 0.13	7.32 ± 2.54	40.64 ± 0.07	-9.51 ± 0.20
5154601	10.37 ± 0.21	1.31 ± 0.50	40.18 ± 0.07	-10.25 ± 0.27
5264991	10.55 ± 0.19	18.81 ± 6.60	41.2 ± 0.07	-9.27 ± 0.24
5364072	10.35 ± 0.35	1.55 ± 0.62	40.56 ± 0.08	-10.16 ± 0.39
5249313	10.50 ± 0.14	1.66 ± 0.64	40.01 ± 0.07	-10.28 ± 0.22
5280475	9.99 ± 0.21	4.17 ± 1.75	40.54 ± 0.02	-9.38 ± 0.28
5154381	10.01 ± 0.20	1.8 ± 0.67	40.64 ± 0.1	-9.75 ± 0.26
oAGN (mAGN) (red circles)				
5339805* +	10.85 ± 0.10	11.54 ± 4.00	41.4 ± 0.03	-9.79 ± 0.18
5151978* +	10.83 ± 0.14	55.33 ± 22.54	42.37 ± 0.0	-9.08 ± 0.23
5145801	10.95 ± 0.13	27.1 ± 11.27	...	-9.51 ± 0.22
5252110	10.97 ± 0.11	31.75 ± 12.57	...	-9.48 ± 0.20
5237160	9.76 ± 0.13	8.9 ± 3.51	...	-8.81 ± 0.21
5340595 +	11.13 ± 0.11	37.46 ± 14.92	...	-9.56 ± 0.21
5286102 +	11.40 ± 0.11	42.13 ± 17.32	41.63 ± 0.04	-9.77 ± 0.21
5108709	10.50 ± 0.13	17.61 ± 6.15	42.11 ± 0.01	-9.25 ± 0.20
5369226	10.85 ± 0.11	46.57 ± 18.33	41.73 ± 0.02	-9.19 ± 0.20
5162821 +	10.85 ± 0.12	12.99 ± 4.80	41.89 ± 0.03	-9.74 ± 0.20
5233898	11.05 ± 0.12	41.49 ± 16.68	42.15 ± 0.02	-9.43 ± 0.21
5197408 +	10.71 ± 0.14	9.86 ± 3.67	41.97 ± 0.01	-9.72 ± 0.21
5312967 +	10.53 ± 0.16	6.06 ± 2.50	41.68 ± 0.01	-9.75 ± 0.24
5305653 +	11.01 ± 0.11	15.34 ± 5.42	41.92 ± 0.01	-9.83 ± 0.19
5216684 +	11.21 ± 0.11	79.31 ± 31.31	42.99 ± 0.0	-9.31 ± 0.20
5342686 +	11.52 ± 0.10	66.05 ± 25.95	42.78 ± 0.0	-9.70 ± 0.20
5213139 +	11.03 ± 0.10	29.78 ± 11.78	42.17 ± 0.01	-9.56 ± 0.20
5155308 +	11.82 ± 0.08	174.43 ± 68.32	42.13 ± 0.01	-9.58 ± 0.19
5240292 +	10.93 ± 0.15	32.53 ± 13.51	41.52 ± 0.01	-9.41 ± 0.24
oAGN (mWarm) (red squares)				
5347780* +	10.68 ± 0.11	10.86 ± 3.77	...	-9.64 ± 0.19
5294374* +	11.23 ± 0.10	33.8 ± 13.08	42.0 ± 0.01	-9.7 ± 0.2
5112784 +	10.19 ± 0.11	2.17 ± 0.91	...	-9.86 ± 0.21

Table 4
(Continued)

CATAID	Log $M_{\text{stellar}} (M_{\odot})$	SFR $_{12\mu\text{m}}$ ($M_{\odot}\text{yr}^{-1}$)	Log ($L[\text{O III}]$) (erg s $^{-1}$)	Log (sSFR) (yr $^{-1}$)
5153772	10.70 $\pm$ 0.15	38.63 $\pm$ 15.66	...	−9.12 $\pm$ 0.23
5351862 +	10.42 $\pm$ 0.13	10.73 $\pm$ 4.37	...	−9.39 $\pm$ 0.22
5369229	10.50 $\pm$ 0.16	14.24 $\pm$ 4.98	...	−9.34 $\pm$ 0.22
5346487 +	10.71 $\pm$ 0.15	29.29 $\pm$ 12.05	41.71 $\pm$ 0.01	−9.25 $\pm$ 0.23
5110547 +	10.33 $\pm$ 0.11	5.11 $\pm$ 2.13	41.7 $\pm$ 0.01	−9.62 $\pm$ 0.21
5180136	10.29 $\pm$ 0.12	5.25 $\pm$ 1.88	41.75 $\pm$ 0.01	−9.57 $\pm$ 0.2
5137338 +	11.03 $\pm$ 0.15	12.56 $\pm$ 4.96	41.51 $\pm$ 0.04	−9.93 $\pm$ 0.23
5196019	10.51 $\pm$ 0.13	20.38 $\pm$ 8.18	41.68 $\pm$ 0.01	−9.2 $\pm$ 0.22
5211450	10.90 $\pm$ 0.15	22.25 $\pm$ 9.79	42.56 $\pm$ 0.01	−9.55 $\pm$ 0.24
5367800 +	11.01 $\pm$ 0.14	8.59 $\pm$ 3.32	41.8 $\pm$ 0.03	−10.08 $\pm$ 0.22
oAGN (mSF) (yellow circles)				
5249547*	10.74 $\pm$ 0.11	3.99 $\pm$ 1.40	41.19 $\pm$ 0.02	−10.14 $\pm$ 0.19
5155115*	10.92 $\pm$ 0.12	4.44 $\pm$ 1.57	...	−10.28 $\pm$ 0.19
5163580 +	10.36 $\pm$ 0.16	1.85 $\pm$ 0.77	...	−10.09 $\pm$ 0.24
5368644	10.26 $\pm$ 0.15	4.66 $\pm$ 1.67	...	−9.59 $\pm$ 0.22
5278828	10.11 $\pm$ 0.25	6.08 $\pm$ 2.18	41.0 $\pm$ 0.07	−9.33 $\pm$ 0.29
5139540 +	11.31 $\pm$ 0.18	9.17 $\pm$ 3.65	41.15 $\pm$ 0.07	−10.35 $\pm$ 0.25
5305775	10.60 $\pm$ 0.15	10.37 $\pm$ 4.28	41.35 $\pm$ 0.06	−9.59 $\pm$ 0.23
5355371 +	10.51 $\pm$ 0.16	10.19 $\pm$ 3.67	42.5 $\pm$ 0.0	−9.5 $\pm$ 0.22
5188449 +	10.44 $\pm$ 0.35	1.12 $\pm$ 0.55	40.99 $\pm$ 0.02	−10.39 $\pm$ 0.41
5427366	9.99 $\pm$ 0.13	2.01 $\pm$ 0.73	...	−9.69 $\pm$ 0.21
5163246	10.71 $\pm$ 0.15	4.06 $\pm$ 1.63	42.42 $\pm$ 0.01	−10.11 $\pm$ 0.23
5258350	10.16 $\pm$ 0.10	3.15 $\pm$ 1.12	41.24 $\pm$ 0.01	−9.66 $\pm$ 0.19
5154519	10.49 $\pm$ 0.20	11.78 $\pm$ 4.28	41.87 $\pm$ 0.02	−9.42 $\pm$ 0.26
5271798	10.41 $\pm$ 0.16	18.45 $\pm$ 7.49	42.1 $\pm$ 0.0	−9.14 $\pm$ 0.24
Non-oAGN (mAGN) (orange circles)				
5200866*	10.63 $\pm$ 0.11	51.72 $\pm$ 20.24	41.69 $\pm$ 0.01	−8.91 $\pm$ 0.2
5158890*	11.15 $\pm$ 0.11	54.4 $\pm$ 18.85	41.75 $\pm$ 0.02	−9.42 $\pm$ 0.19
5275222* +	11.04 $\pm$ 0.14	22.92 $\pm$ 9.91	41.78 $\pm$ 0.01	−9.68 $\pm$ 0.24
5241310* +	10.85 $\pm$ 0.22	24.95 $\pm$ 10.65	41.39 $\pm$ 0.02	−9.45 $\pm$ 0.29
5362108	10.49 $\pm$ 0.16	22.85 $\pm$ 9.29	...	−9.14 $\pm$ 0.24
5154472	9.94 $\pm$ 0.17	5.25 $\pm$ 1.85	40.42 $\pm$ 0.13	−9.22 $\pm$ 0.23
5129662	10.78 $\pm$ 0.15	22.59 $\pm$ 9.33	41.87 $\pm$ 0.01	−9.43 $\pm$ 0.24
5246095 +	11.05 $\pm$ 0.13	34.86 $\pm$ 14.10	41.68 $\pm$ 0.02	−9.51 $\pm$ 0.22
5119859	10.34 $\pm$ 0.19	12.84 $\pm$ 4.59	40.56 $\pm$ 0.12	−9.23 $\pm$ 0.25
5317117 +	11.03 $\pm$ 0.09	23.98 $\pm$ 8.37	41.89 $\pm$ 0.01	−9.65 $\pm$ 0.18
5247018 +	10.49 $\pm$ 0.18	9.58 $\pm$ 4.03	41.4 $\pm$ 0.03	−9.51 $\pm$ 0.26
Non-oAGN (mWarm) (orange squares)				
5204947*	11.14 $\pm$ 0.14	59.25 $\pm$ 24.19	42.19 $\pm$ 0.07	−9.37 $\pm$ 0.22
5219936	10.19 $\pm$ 0.14	13.57 $\pm$ 5.41	41.36 $\pm$ 0.02	−9.06 $\pm$ 0.22
5282867	9.70 $\pm$ 0.22	1.84 $\pm$ 0.70	40.28 $\pm$ 0.07	−9.44 $\pm$ 0.27
5310140	10.54 $\pm$ 0.19	15.28 $\pm$ 5.42	41.19 $\pm$ 0.06	−9.36 $\pm$ 0.24
5100400	11.14 $\pm$ 0.15	13.99 $\pm$ 5.27	40.77 $\pm$ 0.14	−9.99 $\pm$ 0.22
5115102	10.84 $\pm$ 0.22	21.03 $\pm$ 7.63	41.0 $\pm$ 0.07	−9.52 $\pm$ 0.27
5154420	10.55 $\pm$ 0.17	16.05 $\pm$ 5.67	40.57 $\pm$ 0.13	−9.35 $\pm$ 0.23
5228724 +	10.92 $\pm$ 0.12	21.46 $\pm$ 7.52	41.47 $\pm$ 0.03	−9.59 $\pm$ 0.19
5350683	10.77 $\pm$ 0.15	29.26 $\pm$ 10.31	41.02 $\pm$ 0.09	−9.3 $\pm$ 0.22
5133213	10.60 $\pm$ 0.16	18.44 $\pm$ 6.48	40.78 $\pm$ 0.11	−9.34 $\pm$ 0.22

Note. The stellar masses are derived based on the M/L from Cluver et al. (2014). The star formation rates (SFR $_{12\mu\text{m}}$) are derived using $\nu L_{\nu}(12\mu\text{m})$ and the calibration from Cluver et al. (2017).

(and SFR $_{12\mu\text{m}}$) overestimation in galaxies having an AGN due to the additional mid-infrared flux coming from the active nucleus, rather than related to the star formation activity itself; this section is therefore intended to be illustrative.

The SF galaxies with the highest SFR $_{12\mu\text{m}}$ (log SFR $_{12\mu\text{m}} > 1.6 M_{\odot} \text{ yr}^{-1}$) are all located at $W2 - W3 > 4.6 \text{ mag}$ and $0.22 \text{ mag} < W1 - W2 < 0.7 \text{ mag}$. The majority of them (7/9,

77%) have $W1 - W2$ well above 0.43 mag, indicating extreme activity. Also, six in a total of nine have a peculiar morphological type (by the SED template and confirmed through visual inspection). This could be a hint that the star formation has been triggered by external processes such as mergers or the tidal influence of the environment. Their masses range from log ($M_{\text{stellar}}/M_{\odot}$) = 10.6 to 11. But on the other

Figure 13. The redshift distribution (fraction of galaxies per redshift bin; the BLAGNs are included in a different AGN category as presented in Table 2 “Condition D”) for the SFs and composites (a) and the different groups of AGNs (b). The colors and shades of the histograms have been kept consistent with Figures 11 and 12. Although the redshift distribution could be only an observation bias due to the higher brightness of AGNs compared to SFs, it is presented here to facilitate the description in this section. There are two main peaks located at redshifts of ~ 0.08 and ~ 0.2 . The SFs and the Composites are concentrated at lower redshift (around $z = 0.08$), while the oAGN (mAGN), non-oAGN (mAGN), and non-oAGN (mWarm) seem to be generally located at redshift $z > 0.2$. The oAGN (mWarm) and oAGN (mSF) group look like a middle class with as many galaxies at low as at high redshifts. An inspection of the galaxy distribution using the entire G23 catalog reveals the depletion around $z = 0.15$ to be related to large-scale structures. The highest peaks at redshift $z \geq 0.2$ are seen among the non-oAGN (mAGN) and non-oAGN (mWarm), which also contain the majority of blended cases not visible in WISE.

hand, the SF galaxies with the highest stellar mass ($\log M_{\text{stellar}} > 11 M_{\odot}$) are SF disk galaxies in the WISE color-color diagram with $2.6 < W2 - W3 < 3.9$ mag. They also have very low $W1 - W2$ color (< 0.13 mag), except one galaxy (CATAID: 5256068; see Table 3), which is warmer ($W1 - W2 \sim 0.54$ mag and $W2 - W3 \sim 4.5$ mag). They are among the lowest sSFR with a mean $\log s\text{SFR}$ of -10.2 yr^{-1} .

We show the specific $\text{SFR}_{12\mu\text{m}}$ ($\text{SFR}/\text{stellar mass}$) as a function of stellar mass in Figures 12(c) and (d). The non-oAGN (mAGN) and non-oAGN (mWarm) have the highest $\log s\text{SFR}$, or building rate, on average, $\sim -9 \text{ yr}^{-1}$. In this case, the environmental influences such as tidal interactions or mergers could have triggered additional star formation. They are therefore warm enough to be classified as warm-AGNs in WISE.

The non-oAGN (mAGN) group with average $\log(s\text{SFR}) = -9.29 \text{ yr}^{-1}$ can be divided into two subsamples. The first is composed of galaxies having a very strong $\text{H}\alpha$ line compared to $[\text{N II}]$ ($\approx 60\%$ of galaxies in this group), where the $[\text{O III}]$ and $\text{H}\beta$ are almost nonexistent. The galaxy 5200866, which is in the starburst zone, has one of the highest sSFR (see Table 4). The second subgroup concerns BLAGNs that have been misclassified by the BPT diagnostic. Indeed, in some cases of BLAGNs, it is impossible to disentangle $\text{H}\alpha$ and $[\text{N II}]$, such that their ratio is either under- or overestimated. The non-oAGN (mWarm) share similar properties to the first group. The third highest mean sSFR group is oAGN (mAGN), and the lowest sSFR are seen among the oAGN (mSF). It looks like the AGNs classified by WISE with almost no/weak $[\text{O III}]$ line exhibit higher sSFR compared to the galaxies classified as AGNs in the optical and SF with very strong $[\text{O III}]$ lines (Table 2 gives a brief summary of the mean values). The fact that the oAGN (mSF) galaxies have the lowest sSFR might be a hint of a quenching activity (AGN feedback) occurring inside the galaxies. Once more, the trend seen could be just related

to the overestimation of the parameters due to the presence of the AGN itself. An alternative way of deriving the parameters (mass, $\text{SFR}_{12\mu\text{m}}$, sSFR), is with the AGN modeled and removed from the host emission (Assef et al. 2010; Hainline et al. 2014), which should provide a more robust separation of AGN and ISM dust emission.

Figure 13 has been added to show the repartition of the different groups of galaxies classified in the current study as a function of redshift. Our sample shows a high concentration of SF galaxies at low redshift that decreases significantly toward higher redshift. This is probably due to an observation bias where fewer galaxies are detected at higher redshift as they get fainter. It is important to recognize that the oAGN (mSF) and the oAGN (mWarm) are equally distributed from low to high redshifts as opposed to the non-oAGN (mAGN) generally found at higher redshift. Recall that the non-oAGN (mAGN) and the oAGN (mSF) groups represent galaxies for which the infrared and optical classification are contradictory.

3.3. Case Studies

In this section, we showcase galaxies selected from the different subgroups created in Figure 9. Each diagram from Figures A1 to A16, presented in the Appendix, illustrates the investigation procedure adopted for the classification of the individual galaxies. Instead of making a comparison based only on the optical and the mid-IR catalogs usually available online, we adopted a more rigorous approach in our study. For a given galaxy, a complete picture showing the BPT and mid-IR classification, the photometric SED with template fit, and the spectrum itself along with the WISE RGB image are presented. Finally, a deeper and more detailed picture is provided by the KiDS r -band imaging. The advantage here is that we see the photometric and physical properties while also pinpointing any

issues related to the data themselves. This combination facilitates a consistency check of the data. A list of the inferred parameter values and their uncertainties can be found in Table 3 (the selected galaxies as study cases are designated by an asterisk). In this section, we will refer to the galaxies by their GAMA catalog ID “CATAID” or “Cat ID” (in blue color on the diagrams). The WISE name, the fluxes in W1, W2, and W3 are also available on the diagrams.

3.3.1. Optical- and Infrared-classified SF Galaxies

Here we present the optical SF galaxies and composites both classified as SF in the mid-infrared (mid-IR). They are by far the most abundant type with a total (SF+composites) of $\sim 84\%$ of the classification (see Table 2). They have the lowest averages of the stellar mass, partly due to the fact that they are young galaxies which are still in the growing process, but on the other hand, unlike the galaxies hosting AGNs whose fluxes are overestimated (as explained above), they have the most unaffected, reliable parameters (mass, $\text{SFR}_{12\mu\text{m}}$, and sSFR).

The galaxies 5241095 and 5240983 (Figures A1 and A2) are an interacting SF pair located at redshift $z = 0.027$. Both galaxies are quite similar in their spectra and location in the BPT and WISE color–color diagram. This galaxy pair is atypical in the sense that each of the galaxies shows the presence of a very high [O III] line, which is stronger than the $\text{H}\alpha$ and a quasi absence of the [N II] line. The best-fit SED template classifies 5241095 as “Irr” and 5240983 as a normal spiral “Sc” galaxy. The KiDS image shows a clear interaction between the two galaxies. It appears as though 5240983 is pulling material from 5241095, which is being ripped apart. Although the parameters here have much smaller values than the averages in their group (SF group, Table 2), the high values of stellar mass, $\text{SFR}_{12\mu\text{m}}$, and sSFR for 5240983 (9.14, 0.49, and -9.45) in comparison to 5241095 (9.05, 0.2, and -9.75) seem to corroborate this scenario. It could also be viewed as follows: galaxies get bigger with time through a series of mergers, which in turn trigger occasional AGN activity (looking at the unusually high [O III] in this pair).

The galaxy 5306682 (Figure A3) is the perfect candidate (typical) to represent the SF group for having a very high $\text{H}\alpha$ line flux followed by [N II], [O III], and $\text{H}\beta$ with significantly smaller relative proportions. It is a good example that illustrates how the deep KiDS image helps to decipher and reveal the host and its environment. Figure A3 shows one of our closest specimens in the total sample (redshift $z = 0.005$). While in the WISE image the magenta circle seems to enclose the entire galaxy, KiDS reveals a far larger galaxy that goes beyond the dusty part presented by WISE (recall that the two images have the same angular size).

The galaxy 5205726 in Figure A4 is presented in the KiDS image as a galaxy with clear spiral arms, a bar, and a nuclear ring. It is a large galaxy ($\log M_{\text{stellar}} = 10.51 M_{\odot}$) with an sSFR ($\text{sSFR} = 10^{-10.22} \text{ yr}^{-1}$). It is classified as a composite in optical with an [O III] luminosity of $10^{40.29} \text{ erg s}^{-1}$.

3.3.2. Optical–Infrared AGNs

In this category, we have galaxies classified as AGNs both in the optical (BPT) and the WISE color–color diagram (5.1% of the entire study sample).

The galaxy with GAMA ID 5339805 (Figure A5) is a typical case in the oAGN (mAGN) group. Its spectrum visually shows a broad $\text{H}\alpha$ line with a greenish color in the WISE three-band image characteristic of mAGNs. The KiDS image reveals a spiral galaxy with a bulge (or pseudo bulge) and a thin disk. It is also confirmed as an AGN by the SED fit.

Although close to $\sim 70\%$ of this sample is made up of BLAGNs, they are mostly located at higher redshifts with a mean value of 0.2 (see Figure 13) as opposed to the current galaxy, which is one of the nearest of its kind (redshift $z = 0.089$). Generally, [N II] gets swallowed up by the broad $\text{H}\alpha$, which leads either to an underestimation/overestimation of [N II]/ $\text{H}\alpha$ line ratios. Indeed, the BPT shows a [N II]/ $\text{H}\alpha$ line ratio of >2 , when in reality the [N II] line is barely visible next to the $\text{H}\alpha$.

In the same group, GAMA ID 5151978 presented in Figure A6 is located at higher redshift with the same typical WISE AGN color. We can see a very strong [O III] line compared to $\text{H}\beta$, which places it well above the AGN dividing line in the BPT. It is located at the edge of the obscured-AGN box. The [O III] line luminosity $>10^{42} \text{ erg s}^{-1}$ makes it a potential obscured quasar according to the criteria by Jarvis et al. (2019). Intriguingly, the SED template suggests a normal late-type galaxy, not an AGN. The KiDS image provides a hint about the issue. Although the nearby source does not seem to interact with our main galaxy, it is close enough for WISE not to be able to disentangle both sources; they are instead treated as a single source due to the large beam of WISE. The main galaxy is surely an AGN as shown by the spectrum and also the WISE color, but the presence of the second might add extra features that somehow affect the SED fitting. Overall, we classify this galaxy as an AGN as demonstrated by the diagnostics presented in the figure.

3.3.3. Optical AGN, Infrared Non-AGNs

This category is made up of galaxies that are classified as AGN based on the optical BPT, but seen as normal SF or as just getting warmer in WISE color. We call galaxies in WISE for which $W1 - W2$ is greater than a certain threshold, but below the AGN zone (recall Figure 9 for the different zones), warm. One has to be careful during the classification for most of the misclassified cases are found in this category. Indeed, taking into account the data quality flag in GAMA and also visually inspecting the spectra reduce the number of galaxies here by 25% not to mention that without a k-correction and a correction for stellar absorption, the number of false positives would have been much greater. The oAGN(mWarm) and oAGN(mSF) groups seem to belong to the same family which evolves with redshift. Both groups have average redshifts of $z = 0.16$ and 0.18 , respectively.

The oAGN(mWarm) group appears to be dominated by broad lines (21/36), which, unlike the general trend, are not able to raise $W1 - W2$ above the threshold required to be classified as infrared AGNs or QSOs. Indeed, WISE is very sensitive to the broad-line systems, and in most cases, such galaxies are classified as AGNs. Maybe a parallel process is at work in the host making it difficult for WISE to have a clear view of the ongoing AGN activity. Galaxy 5347780 in Figure A7 reveals broad $\text{H}\alpha$ and $\text{H}\beta$ lines, associated with a prominent [O III] line, all strong indications of AGN activity. However, $W1 - W2$ is barely close to 0.6 mag, which falls in

the “warm” AGN zone. The explanation of this behavior might lie in the SED characteristic of an SF galaxy (i.e., the host dominates the observed emission).

Galaxy 5294374 in Figure A8 tells a slightly different story. Here, in addition to the spectrum, the SED also presents the galaxy as an AGN, while the WISE color stills fall below the strong AGN threshold. The change, in this case, clearly a late-stage merger, WISE colors could be dominated by an SF galaxy (maybe the larger of the three in the merger) while AGNs could come from any one of these sources.

Galaxies 5249547 and 5155115 in Figures A9 and A10, respectively, are two examples of a clear disagreement between optical and mid-IR classifications. While the optical lines present them as AGNs without ambiguity, the two galaxies sit exactly on the WISE SF main sequence, Equation (1). Furthermore, the SED confirms star formation as the dominant activity. Generally, the galaxies in this category are relatively nearby, with the optical and the mid-IR giving evidence of AGN and SF activity, respectively. We could argue that the galaxies here have a strong-enough AGN to be picked up by the optical, but with continuum (and mid-IR) emission dominated by the star formation of the host. The narrow optical fibers may see only the center, while WISE integrates the flux over the entire galaxy. It could also be that the AGN has recently turned off or shut down. Generally, once the AGN turns off, the BLR, X-rays, and mid-IR shut down within a few decades, while the narrow-line region (NLR) could last thousands of years (Sartori et al. 2018). This might be a plausible justification for some narrow-line optical AGNs being classified as WISE star-forming galaxies. Note that as it can be seen in Figure A9 (5249547, $\log L[\text{O III}] = 41.19 \text{ erg s}^{-1}$), a substantial number of the oAGN (mSF) present high luminosities (see Figure 11(b)) generally indicative of the presence of an AGN. The $[\text{O III}]$ lines in these cases could originate from other processes different from the AGN activity. Possible explanations for this scenario are proposed in the discussion, below.

3.3.4. Optical Non-AGNs, Infrared AGN

We address in this subsection galaxies with no characteristic AGN emission lines in the optical, but classified as either an AGN or warm in the mid-infrared (the orange circles and squares in Figure 11), named non-oAGN(mAGN) and non-oAGN(mWarm), respectively.

In our study, the tension between the optical versus infrared classification is mainly caused by two factors. The first is due to tightly blended galaxies for which the WISE image alone cannot separate them but are clearly distinguishable in the deep KiDS r -band image. By comparing the KiDS versus WISE images in Figures A11, A12, and A15, we can see that multiple sources are mistakenly being considered as single (in WISE) owing to their angular proximity at the given redshift with mean redshift $z = 0.2$ (among the most distant galaxies of the study sample), while the optical (GAMA), which uses the KiDS galaxies location, is only targeting the central galaxy. The outcome of the classification in the mid-infrared will depend on the components of the merging system. A composition of several AGNs will probably lead to a higher $W1 - W2$ color while the opposite could instead lead to a decrease. The system presented in Figure A15 (CATAID: 5204947) is an extreme case where apparently more than three galaxies seem to be merging. As we can see from these three examples (i.e., Figures A11, A12, and A15), 5204947, which

lies below the AGN region, is still the only one presented as an AGN by the SED.

The second cause of misclassification is related to the broad-line measurement. It has been noted several times that for broad $\text{H}\alpha$ lines, it is sometimes challenging to distinguish between $[\text{N II}]$ and $\text{H}\alpha$ to get the correct line ratios. In any case, broad $\text{H}\alpha$ and $\text{H}\beta$ lines are already enough for the galaxy to be classified as an AGN. Using the line ratio here leads to an underestimation of $[\text{N II}]/\text{H}\alpha$, therefore classifying the galaxy as non-oAGN. This picture is seen in Figures A13 and A14 where the broad-line galaxies are correctly classified as AGNs both using the WISE color-color diagram and the SED fitting, though they lie in the composite area of the optical BPT.

The last case study, 5135645 (Figure A16), represents a blended system classified as an optical SF and infrared SF (SF), but located at the extreme limit between the AGN and SF zones. We suspect the second galaxy to be an AGN, justifying the high $W1 - W2$ (0.74 mag, very warm) or related to the fact that the interaction is triggering AGN activity. The extreme $W2 - W3 > 5.04$ mag is not unlike the class of HyperLirgs that WISE has recently uncovered (Tsai et al. 2015). The SED template fit using the famous starburst-AGN hybrid system NGC 3690 gives a glimpse of the probable internal processes taking place. These cases will be part of our next study, which will bring in radio data from SKA pathfinders ASKAP/EMU and MeerKAT already in the reduction phase. In order to better see the central regions, a zoomed KiDS r -band image of each one of the galaxies is presented in Figure A17.

3.4. The New Diagnostic: $[W1 - W2]$ versus $[\text{O III}]/\text{H}\beta$

Based on the optical emission lines and the mid-IR colors, we now attempt to combine them into one diagnostic, where we choose the best parameters for each, namely, the strongest emission lines: $[\text{N II}]/\text{H}\alpha$, and the highest-S/N and most-AGN-sensitive colors: $W1 - W2$. The $[\text{N II}]/\text{H}\alpha$ line ratio is potentially sensitive to metallicity notably for lower stellar mass galaxies, but as noted in Section 3.1.1, our sample will be minimally affected by metallicity.

In Figure 14, we present our new classification scheme combining both the BPT and the WISE color-color diagrams. Figure 14(a) is a modified version of Figure 11, where the ratio $[\text{O III}]/\text{H}\beta$ is replaced by the $W1 - W2$ color, thus avoiding these emission lines that can be difficult to measure. Indeed, the BPT is typically limited by the low S/N of the $\text{H}\beta$ line (and sometimes the oxygen line as well), which represents a strong and significant bias for a WISE-selected sample. The dashed gray line, crossing the $[\text{N II}]/\text{H}\alpha$ line ratio, empirically represents the best separation between AGNs (upper region) and non-AGNs, with the latter divided into the SF and Mixed galaxy regions by the vertical gray line at $[\text{N II}]/\text{H}\alpha = 0.5$. The Mixed division is motivated by the large number of composites, SFs, and oAGNs that inhabit relatively low (blue) $W1 - W2$ colors. The Seyferts found in the star-forming region are the few star-forming galaxies that are found on the AGN side of the BPT as presented in Figure 8. As both optical diagnostics agree generally, these few outliers at the boundary are unavoidable and inherent to any empirical methods. But, the optical AGN found at low WISE colors (in the SF or Mixed zone) are interesting cases that need further investigation either in radio or X-rays. Broad-line and Type-1 AGNs generally lie at $[\text{N II}]/\text{H}\alpha > 1$. The study sample does not include low-mass galaxies with AGNs (a type of low-luminosity AGN), and furthermore, is drawn from the local universe ($z < 0.3$). Therefore,

Figure 14. Optical-IR SF-AGN diagnostic plot. The new method used to classify galaxies based on both the optical BPT and the (WISE) color-color diagrams. In (a), we reproduce the classification of Figure 11, keeping the same galaxy groups with their assigned colors, all the optical lines in emission ([O III], [N II], H β , and H α lines are all positive), and replacing the [O III]/H β by the W1 - W2 color. The Mixed region (delimited by the solid and the dashed gray lines) is a mixture of the composites and the oAGN (mSF). The mean [N II]/H α and W1 - W2 uncertainties with the error bars are plotted in the lower-right corner. (b) is similar to (a), but only the fluxes of [N II] and H α are required to be positive (emission lines). The H β line could be either in emission or absorption. The statistic increases from 893 SFs, 87 Mixed, and 174 AGNs in (a) to 2818 SFs, 853 Mixed, and 364 AGNs in panel (b). The mean [N II]/H α and W2 - W3 uncertainties with the error bars are plotted in the lower-right corner.

our work is relevant to $z < 0.3$, and the limit boundaries here will require adjusting at higher redshift especially when the impact of the metallicity on the BPT ([N II]/H α) lines become more significant.

W1 - W2 < 0.5 mag and the dashed gray line enclose all of the SF and more than half of the composite galaxies. The Mixed region delimited by $0.5 < [\text{N II}]/\text{H}\alpha < 1$ and the dashed gray line described by Equation (3) is a mixture of oAGN (mSF) and composite galaxies and importantly, contains some strong [O III] emitters (see also Figure 11(b)).

$$Y = -0.24 \times \log(X) + 0.35 \quad (3)$$

where $Y = \text{W1} - \text{W2}$ mag, $X = [\text{N II}]/\text{H}\alpha$.

The remaining classes of galaxies are above the dashed gray line and represent the optical-infrared AGNs (Opt-IR AGN), which makes this new classification scheme an efficient way of disentangling pure SF from galaxies having AGN activity. It allows us to get the best from both methods, and the use of the W1 - W2 color rejects far fewer galaxies than [O III]/H β . In Figure 14(b), the constraints on [O III] (flux > 0) and H β (flux > 0) are removed, leading to more classified galaxies. From the initial number of 1154 classified galaxies in panel (a), 4035 galaxies are now classified in panel (b), where W1 - W2 is used instead of [O III]/H β , hence nearly a 400% increase.

The galaxies from Figure 14(b) are presented in the WISE color-color diagram in Figure 15. It shows the position of the galaxies classified by the new diagram (Figure 14(b)) on the W1 - W2 versus W2 - W3 color diagram with their associated fraction in blue (SF), green (Mixed), and red (AGN). The new rendering of the color-color diagram may be directly compared with the relatively sparse results in Figure 9. More than 99% of the SF and Mixed from the new diagram are found in the star-forming region

of the color-color diagram. About 75% of the AGNs are either mWarm or mAGNs, while 25% are in the mSF zone. The galaxies in the latter case are, in general, close to the mWarm zone (at W1 - W2 = 0.4 mag) and have a high value of W2 - W3 > 3.3 mag (i.e., red, dusty). In rare cases of extreme broad H α or where the [N II] is stronger than the H α line, the AGNs from the new diagram are classified as mSFs. The galaxies with strong [O III] emission are highlighted by the black circles (see Figure 11). They seem to be distributed throughout the diagram but arguably represent a higher proportion of the AGNs (37%) in comparison to the star-forming (2%) and Mixed (5%) galaxies.

4. Discussion

We have conducted a careful analysis of the correspondence between an optically defined host and nuclear activity (using the BPT diagnostic) and mid-infrared colors in this study. There is wide agreement between optical and mid-IR classification, but real differences that highlight the limitations and strengths of each, while also suggesting that a synergy of combinations should provide new information.

Agostino & Salim (2019) found a similar fraction of Seyferts and LINERs in their X-ray AGN sample. We find the opposite trend (BPT using [S II] line) where very few galaxies are classified as LINERs in comparison to the Seyferts. Generally, the LINERs from our sample are classified as mid-infrared SF galaxies. A large majority are also classified as optical SF using the BPT based on the [N II] line. This might be partly due to the very small number of LINERs (five in total) found in our sample. It is possible that the emission in these LINERs is not driven by AGNs (Yan & Blanton 2012; Belfiore et al. 2016), or they could be simply LINERs with low-luminosity AGNs (Filho et al. 2006; Flohic et al. 2006; González-Martín et al. 2009). Additionally, strong shocks

Figure 15. The WISE color-color representation of the galaxies classified in Figure 14(b) using the same key. The AGN are well delimited by the 2σ offset line up to $W2 - W3 \sim 3.8$ mag, where their $W1 - W2$ color tends to be slightly below. The different galaxy groups (derived in Figure 14(b)) are presented with their relative proportions, to the left. The strong [O III] emitters (see Figure 11) are highlighted with black circles. We also plot the mean $W1 - W2$ and $W2 - W3$ uncertainties with the error bars in the lower-right corner.

can significantly contribute to the AGN emission in these objects, creating the LINER-like emission lines (Dopita et al. 1996, 1997; Molina et al. 2018).

Using the KiDS r -band images, we found that a large fraction of the non-oAGN (mAGN) group have more than one galaxy in the aperture, some of which may be interacting or galaxy pairs close enough to be seen as a single galaxy in WISE. As in this case WISE cannot distinguish the two galaxies, then the companion of the targeted galaxy might have some AGN activity. It may also be that an interaction has triggered the AGN activity as suggested by Ellison et al. (2019). Using the Canada France Imaging Survey (CFIS) images, they found that more than 60% of the mid-infrared AGNs are interacting systems and concluded that the interaction might play an important role in the nuclear feeding process.

The non-oAGN (mAGN) galaxies occasionally have their optical flux ratios underestimated due to the presence of broad $H\alpha$ lines, but there are still a few galaxies for which only the obscuration of the torus could explain their classification as non-AGNs in the optical. The Compton-thick clouds such as those associated with galaxy mergers (Ricci et al. 2017; Satyapal et al. 2017) can prevent the optical lines from being detected.

Our study shows about 21% of the optical AGNs to be located in the WISE SF zone. The simplest explanation is that they are low-power AGNs in which the starlight from the host dominates over the AGN. This could be verified through the [O III] line luminosity generally thought to be correlated to the AGN strength (Bassani et al. 1999; Heckman et al. 2005). Unfortunately, not all the optical fluxes in the GAMA catalog are calibrated to be used directly to determine luminosities (see Section 2.1.1). Nevertheless, the available ones range from luminosity $= 10^{41}$ to $10^{42.8}$ erg s $^{-1}$, which appear to be high and AGN-like notably for those with luminosity $> 10^{42}$ erg s $^{-1}$ (see Reyes et al. 2008; Yan et al. 2019).

So, the oAGN (mSF) galaxies with corresponding low [O III] luminosity fall in the category described above where the starlight dominates the AGN. On the other hand, an oAGN (mSF) presenting a high [O III] luminosity could be the consequence of a recent change in the nuclear emission. This implies that the accretion disk has shut down and stopped emitting in the infrared, but not enough time has passed to stop the NLR's emission, which corresponds to thousands of years (Sartori et al. 2016; Keel et al. 2017; D. Stern and R. Assef, private communication). This seems to be the case for galaxy 5249547 (see the case study and Figure A9), which has a strong [O III] luminosity of $10^{41.19}$ erg s $^{-1}$, but whose AGN activity is invisible in WISE ($W1 - W2 \sim 0$ mag).

An alternative explanation could be that the accretion disk is not powerful enough to generate winds that produce broad-line regions (BLRs) or alternatively the [O III] lines are coming from non-nuclear shocks rather than from the central AGN. Berney et al. (2015) found a weak correlation of the hard X-ray fluxes with the fluxes of high-ionization narrow lines such as [O III], [Ne III], [He II], etc. not caused by factors like obscuration or slit size. This begs the question of whether the [O III] lines are always related to the central AGN. Indeed, several studies have shown that while the optical line diagnostics can reasonably well separate AGNs and SFs, they are not able to differentiate between line emission arising from non-nuclear shocked gas and that of the AGN (Monreal-Ibero et al. 2010; Rich et al. 2015; D'Agostino et al. 2019; P. Väisänen, private communication).

These alternative scenarios may be investigated using X-ray data to check the presence of a torus and using long-slit spectroscopy to map the [O III] distribution notably in the circumnuclear SF rings. It will also be useful to understand their radio properties using radio continuum data.

Few BLAGNs are found in the WISE star-forming zone. An investigation revealed them to be part of the rare cases where the $W1 - W2$ color drops (becomes bluer) after the k -correction, examples of where the limited templates (notably for AGNs) are poorly fit to the apparent fluxes.

The comparison between the WISE and the BPT diagrams revealed $W1 - W2$ versus $[\text{N II}]/\text{H}\alpha$ to be a good diagnostic to separate SF galaxies from AGNs. Our study shows the importance of the oAGN (mSF) class, which could provide crucial information about the AGN activity within galaxies. Fortunately, oAGN (mSF) can be reliably found in the Mixed region (Figure 14(a)) that encloses about 90% of their total number. They generally have low $W1 - W2$ color, high $[\text{N II}]/\text{H}\alpha$ ratios, and are separated from the rest of the AGNs by the dashed line (in Figure 14) described by the Equation (3). This new method does not require $\text{H}\beta$ and $[\text{O III}]$, thus allowing classification of galaxies with $[\text{O III}]$ and/or the $\text{H}\beta$ lines either absent (low S/N) or in absorption, which is not otherwise possible using the BPT. Figure 14(b) shows three times more classified galaxies than Figure 14(a). Using this new method, we have separated our larger line-emission sample into over 4000 SF and AGN galaxies (see Figure 15, a 400% improvement over the traditional BPT). As mentioned earlier, the accuracy of the WISE color-color and the BPT (using $[\text{N II}]/\text{H}\alpha$) classifications are potentially affected by the presence of dwarf galaxies and the metallicity, respectively. This study has been conducted on a safe ground where those two caveats have been avoided by using intermediate- to high-mass galaxies, $\log M_{\text{stellar}} > 9 M_{\odot}$, and a sample with a redshift limit of $z < 0.3$. A greater sample combining several GAMA fields could be used in future with radio data to update our new diagnostic method. New and deeper spectroscopic surveys will be useful to extend the study to higher redshift where the $[\text{N II}]/\text{H}\alpha$ line ratio is more susceptible to evolutionary effects.

5. Conclusion

We investigated the optical emission-line properties of galaxies in GAMA G23 using mid-infrared (WISE) photometry. Unlike most preceding studies of the kind, special care was taken in extracting the nearby extended galaxies using our customized extended emission pipeline (see Section 2.3). The photometry was derived accordingly. A magnitude cut was applied to select the cleanest and the highest-S/N galaxies, leading to a high-quality data set of about 9800 galaxies. They were cross-matched to the emission-line catalog and the resulting sample (1154 galaxies) used for comparison between the commonly used BPT and WISE color-color diagrams. Additional visual inspection of all the spectra and the high-resolution KiDS r -band image of each of the classified galaxies was carried out, with examples presented in Figures A1–A16. The derived data set and finding are presented as follows:

1. The first WISE galaxy catalog in the GAMA G23 field has been created including nearby galaxies extracted using the resolved pipeline.
2. Visual checking of the spectra revealed the BPT based on the $[\text{N II}]/\text{H}\alpha$ versus $[\text{O III}]/\text{H}\beta$ to be more reliable than the one using $[\text{S II}]/\text{H}\alpha$ versus $[\text{O III}]/\text{H}\beta$. Most of the strong $[\text{S II}]$ detections are artifacts. This mostly affects galaxies classified as LINERS.
3. Galaxies were classified based on their mid-IR and optical properties in Figures 9 and 11(a). There is good agreement

between the two methods in classifying the non-AGN galaxies. Only 4% of the mid-IR SFs are classified as optical AGNs and 5% of the optical SFs are classified as mid-IR AGNs. However, 29% of the optical AGNs are non-mid-IR AGNs while 33% (if we consider the mWarms as mid-IR mAGNs) of the mid-IR AGNs are not optical AGNs. The optical composites share similar properties to the optical SF galaxies in the WISE color-color diagram, but more than 60% of the non-oAGN(mAGN) are optical composites.

4. Optical AGNs are well selected by high $[\text{O III}]/\text{H}\beta$ while the $[\text{N II}]/\text{H}\alpha$ are generally < 1 . A visual inspection of the spectra revealed the AGN with $[\text{N II}]/\text{H}\alpha$ ratio > 1 in Figure 11(a) to be overestimated due to the broad-line feature of the $\text{H}\alpha$.
5. A detailed study of the different groups of galaxies shows a scenario in which SF galaxies have the lowest redshifts followed by the oAGN (mSF), which have a combination of AGN and SF activity. WISE is often blind to their AGNs, leading sometimes to very low $W1 - W2$ colors. For these galaxies relatively nearby, the spectroscopic fiber might be capturing only the central part while WISE is sampling the flux over the entire galaxy dominated by SF activity. At higher redshifts are the oAGN(mAGN) and the non-oAGN (mAGN). The latter group is made up of galaxies with underestimated $[\text{N II}]/\text{H}\alpha$ (broad $\text{H}\alpha$ line) and by blended systems that are proximal-close and small enough to be seen as a single source by WISE. We were able to identify them using the high-resolution images provided by KiDS.
6. We created a new diagnostic diagram that combines the optical lines and WISE color in the form of $W1 - W2$ versus $[\text{N II}]/\text{H}\alpha$. The $W1 - W2$ color, which is sensitive to AGN emission, can reliably replace the $[\text{O III}]/\text{H}\beta$ ratio (in the BPT diagram), which is limited by the $\text{H}\beta$ and $[\text{O III}]$ detection. It has the distinct advantage of increasing the number of classified galaxies by more than three to four times.

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GAMA is a joint European-Australasian project based around a spectroscopic campaign using the Anglo-Australian Telescope. The GAMA input catalog is based on data taken from the Sloan Digital Sky Survey and the UKIRT Infrared Deep Sky Survey. Complementary imaging of the GAMA regions is being obtained by a number of independent survey programs including GALEX MIS, VST KIDS, VISTA VIKING, WISE, Herschel-ATLAS, GMRT, and ASKAP providing UV to radio coverage. GAMA is funded by the STFC (UK), the ARC (Australia), the AAO, and the participating institutions. The GAMA website is <http://www.gamasurvey.org/>.

Appendix Some Examples for the Cases Study

In Section 3.3, we presented detailed case studies of the different subgroup classifications. The graphics for the case

studies are presented here in the Appendix, and to follow (A1 to A16). The final figure, A17, presents the inner regions as viewed with the KIDS *r*-band imaging. In Figures A1–A4 we have cases of SF or composite galaxies identified as such by both the BPT

Figure A2. Galaxy 5240983. Classified as star-forming (blue).

Figure A3. Galaxy 5306682. Classified as star-forming (blue).

Figure A4. Galaxy 5205726. Classified as a composite (green).

and WISE. Figures A5–A8 are AGNs with broad H α lines in optical which are also seen either as AGN or having Warm W1–W2 colors in WISE. Figures A9 and A10 are cases where galaxies clearly seen as AGNs in optical show no AGN activity in the WISE color-color diagram. Figures A11–A15 present misclassification between the BPT and the WISE color-color diagram. It is mainly caused by tightly blended galaxies observed by the large

WISE aperture or blended H α and [N II] lines in optical leading to a poor quality in the line ratio measurement. An SF galaxy with unusually bright WISE colors is presented in Figure A16. It appears to be a complex interacting system. A zoomed-in version of each KIDS r -band image of the galaxies is presented in Figure A17. Tables 3 and 4 contain the derived and measured properties of some galaxies from our sample.

Figure A5. Galaxy 5339805. A broad-line AGN classified as an oAGN (mAGN).

Figure A6. Galaxy 5151978. A broad-line AGN classified as an oAGN (mAGN).

WISE name: J231708.06-315016.4

Cat ID: 5347780

W1 [mJy]: 2.15

W2 [mJy]: 1.89

W3 [mJy]: 5.81

z: 0.08898

BLAGN

Figure A7. Galaxy 5347780. A broad-line AGN classified as an oAGN (mWarm).

WISE name: J230839.38-333208.4

Cat ID: 5294374

W1 [mJy]: 5.17

W2 [mJy]: 4.63

W3 [mJy]: 14.27

z: 0.10702

BLAGN

Figure A8. Galaxy 5294374. A broad-line AGN classified as an oAGN (mWarm).

WISE name: J225729.80-301707.3

Cat ID: 5249547

W1 [mJy]: 1.36

W2 [mJy]: 0.8

W3 [mJy]: 2.13

z: 0.08345

Figure A9. Galaxy 5249547. Classified as an oAGN (mSF). It is an all-important yellow case.

WISE name: J230318.96-323435.4

Cat ID: 5155115

W1 [mJy]: 1.7

W2 [mJy]: 0.99

W3 [mJy]: 2.2

z: 0.08693

Figure A10. Galaxy 5155115. Classified as an oAGN (mSF) (yellow).

Figure A11. Galaxy 5200866. Classified as a non-oAGN (mAGN) (orange).

Figure A12. Galaxy 5158890. Classified as a non-oAGN (mAGN) (orange).

Figure A13. Galaxy 5275222. A broad-line AGN classified as a non-oAGN (mAGN). Note that the [N II] line cannot be distinguished from H α .

Figure A14. Galaxy 5241310. A broad-line AGN classified as a non-oAGN (mAGN).

WISE name: J224238.55-303058.0

Cat ID: 5204947

W1 [mJy]: 0.68

W2 [mJy]: 0.73

W3 [mJy]: 4.38

z: 0.24378

Figure A15. Galaxy 5204947. Classified as a non-oAGN (mWarm) (orange). Blended system seen as a single in WISE three-band color.

WISE name: J225310.75-332506.7

Cat ID: 5135645

W1 [mJy]: 0.51

W2 [mJy]: 0.55

W3 [mJy]: 9.68

z: 0.19116

Figure A16. Galaxy 5135645. Classified as an SF (blue). Extreme colors in WISE.

Figure A17. Individual KiDS *r*-band images of the galaxies selected from Figures A1 to A16. The GAMA names are on the upper-left corner. All panels are 2' by 2'.

ORCID iDs

H. F. M. Yao <https://orcid.org/0000-0001-8459-4034>
T. H. Jarrett <https://orcid.org/0000-0002-4939-734X>
M. E. Cluver <https://orcid.org/0000-0002-9871-6490>
L. Marchetti <https://orcid.org/0000-0003-3948-7621>
M. G. Santos <https://orcid.org/0000-0003-3892-3073>
Matt S. Owers <https://orcid.org/0000-0002-2879-1663>
Y. A. Gordon <https://orcid.org/0000-0003-1432-253X>
M. J. I. Brown <https://orcid.org/0000-0002-1207-9137>
S. Brough <https://orcid.org/0000-0002-9796-1363>
B. W. Holwerda <https://orcid.org/0000-0002-4884-6756>
A. M. Hopkins <https://orcid.org/0000-0002-6097-2747>

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