

The SAMI Galaxy Survey: Σ_{SFR} drives the presence of complex emission line profiles in star-forming galaxies

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ABSTRACT

Galactic fountains driven by star formation result in a variety of kinematic structures such as ionised winds and thick gas disks, both of which manifest as complex emission line profiles that can be parametrised by multiple Gaussian components. We use integral field spectroscopy (IFS) from the SAMI Galaxy Survey to spectrally resolve these features, traced by broad H α components, and distinguish them from the star-forming thin disk, traced by narrow components, in 3068 galaxies in the local Universe. Using a matched sample analysis technique, we demonstrate that the presence of complex emission line profiles in star-forming galaxies is most strongly correlated with the global star formation rate (SFR) surface density of the host galaxy measured within $1R_e$ (Σ_{SFR, R_e}), even when controlling for both observational biases, including inclination, amplitude-to-noise and angular scale, and sample biases in parameters such as stellar mass and SFR. Leveraging the spatially resolved nature of the dataset, we determine that the presence of complex emission line profiles within individual spaxels is driven not only by the local Σ_{SFR} , but by the Σ_{SFR, R_e} of the host galaxy. We also parametrise the clumpiness of the SFR within individual galaxies, and find that Σ_{SFR, R_e} is a stronger predictor of the presence of complex emission line profiles than clumpiness. We conclude that, with a careful treatment of observational effects, it is possible to identify structures traced by complex emission line profiles, including winds and thick ionised gas disks, at the spatial and spectral resolution of SAMI using the Gaussian decomposition technique.

Key words: galaxies: ISM – ISM: jets and outflows – ISM: kinematics and dynamics

1 INTRODUCTION

The cycling of baryons within and around galaxies plays a critical role in shaping the star formation histories, chemical enrichment, and gas dynamics of present-day galaxies (e.g., [Veilleux, Cecil & Bland-Hawthorn 2005](#); [Tumlinson, Peebles & Werk 2017](#)). In its most basic form, the baryon cycle begins with a galaxy accreting

gas from its surroundings—either in the form of a gas-rich merger or directly from the circumgalactic medium—which in turn triggers star formation in the disk, enriching the local interstellar medium with metals. Ensuing stellar winds and supernovae (SNe) explosions may then expel gas and dust from the disk, creating biconical structures filled with H α -emitting filaments of disk material ([Cooper et al. 2008, 2009](#)). Gas entrained by particularly powerful winds can escape the galaxy’s gravitational potential, and enrich the intergalactic medium, potentially solving the “missing baryons” problem (e.g.,

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Shull et al. 2012). However, in most cases it is expected that the bulk of this material will eventually return to the disk in the form of a “galactic fountain” (Shapiro & Field 1976; Bregman 1980), redistributing metals throughout the disk and providing fuel from which new generations of stars may form.

Powerful winds launched by vigorous star formation manifest as fast outflows of ionised, neutral, and molecular gas (for a comprehensive overview, see Veilleux, Cecil & Bland-Hawthorn 2005). In nearby galaxies such as M82, powerful outflows can be identified by bright, filamentary H α emission in the form of conical structures above and below the disk plane (Lynds & Sandage 1963; Bland & Tully 1988; Shobbell & Bland-Hawthorn 1998; Sharp & Bland-Hawthorn 2010). The emission line profiles indicate strong non-circular motions, comprising multiple distinct kinematic components in addition to broad line widths (McKeith et al. 1995; Westmoquette et al. 2009). Studies of large samples of local galaxies have shown that winds are associated with higher stellar masses and star formation rates (SFRs; Avery et al. 2021), and most strongly with high SFR surface densities (Σ_{SFR} ; Heckman et al. 2002; Roberts-Borsani et al. 2020). More recently, Law et al. (2022) found a strong correlation between the spatially resolved H α velocity dispersion and SFR in local star-forming galaxies, which may be due to increased localised gas turbulence or unresolved broad emission line components at high SFRs.

Many star-forming galaxies do not exhibit winds, but rather thick gas disks that are kinematically distinct from the thin gas disk, which comprises the H II regions. Present in the majority of disk galaxies (Haffner et al. 2009; Levy et al. 2018; Marasco et al. 2019) including our own Milky Way (Reynolds 1991), these thick gas disks—referred to in the literature by a variety of terms, including extraplanar gas or diffuse ionised gas (DIG)—exhibit scale heights of up to a few kpc (Levy et al. 2018, 2019; Marasco et al. 2019; den Brok et al. 2020), and are therefore substantially thicker than the thin gas disk, but typically have a much lower surface brightness than H II regions. They also exhibit vertical velocity gradients of between -10 and $-30 \text{ km s}^{-1} \text{ kpc}^{-1}$ (Swaters et al. 1997; Levy et al. 2018, 2019; Marasco et al. 2019), and therefore exhibit a substantial “lag” in rotational velocity with respect to the thin disk. Thick disks have been observed in both H I and H α , with the two phases sharing similar kinematics (e.g., Spitzer & Fitzpatrick 1993; Reynolds et al. 1995; Swaters et al. 1997; Howk et al. 2003; Fraternali et al. 2004), suggesting they represent the same structure. Similarly to winds, the presence of thick disks is linked to Σ_{SFR} (Rossa & Dettmar 2003; Rueff et al. 2013; Levy et al. 2018).

Fraternali & Binney (2006) proposed that thick ionised gas disks may form via gas return from galactic fountains. Indeed, the kinematics of the thick disk are incompatible with simple hydrostatic equilibrium (Barnabè et al. 2006; Marinacci et al. 2010), and require continuous injection of turbulence to remain stable. Furthermore, recent hydrodynamical simulations suggest that these thick disks may form due to fountains powered by star formation evenly distributed within the disk, whereas centrally concentrated star formation is more likely to produce powerful outflows (Vijayan et al. 2018). Accretion has also been proposed as a mechanism for the formation of thick disks, although this probably only contributes in a small fraction of galaxies at low redshift (Marasco et al. 2019). Understanding the origins of these thick disks, and their relation to winds, therefore provides insight into how gas is cycled in and out of star-forming galaxies.

In high-resolution spectroscopy, winds and thick disks can be identified by the presence of complex emission line profiles. Whilst winds will regularly produce clear “line splitting” and broad emis-

sion line components (e.g., Westmoquette et al. 2009), thick disks present as subtle wings tracing gas at lower rotational speeds than the thin disk (e.g., Marasco et al. 2019). Indeed, Belfiore et al. (2022) proposed that thin and thick disk H α emission can be separated via fitting multiple Gaussian emission line components; this was demonstrated earlier by den Brok et al. (2020), who distinguished thick disk emission in a small sample of local galaxies by fitting multiple Gaussian line profiles to the H α line profiles in low-spectral resolution MUSE observations.

The Sydney-Australian Astronomical Observatory (AAO) Multi-object Integral field spectrograph (SAMI) Galaxy Survey (Bryant et al. 2015; Croom et al. 2021) provides optical integral field spectroscopy (IFS) for 3068 local galaxies. Crucially, the spectral resolution of the red arm of AAOmega ($\sigma_{\text{inst}} = 29.6 \text{ km s}^{-1}$; van de Sande et al. 2017; Scott et al. 2018) is sufficient to resolve individual Gaussian components in the emission lines from ionised gas (e.g., Ho et al. 2014), thereby enabling detailed studies of spectrally resolved winds and thick disks in a large sample of galaxies.

In this work, we use the SAMI Galaxy Survey to determine the underlying galaxy properties associated with complex emission profiles in star-forming galaxies, and therefore the processes that lead to the formation of galactic fountains, winds and thick ionised gas disks. In Section 2 we introduce the sample, and in Section 3 we detail how we identify galaxies with and without complex emission line profiles. In Section 4 we conduct a matched sample analysis to determine the underlying galaxy properties most strongly associated with complex emission line profiles, and in Section 6 we investigate the roles of star formation on both local and global scales. Finally, we discuss our results plus the influence of observational biases in Section 7. For the remainder of this work we assume a flat Λ CDM cosmology with $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_{\text{M}} = 0.3$ and $\Omega_{\Lambda} = 0.7$.

2 THE SAMI GALAXY SURVEY

The SAMI Galaxy Survey (Croom et al. 2012; Bryant et al. 2015) is an IFS survey of 3068 local ($z < 0.095$) galaxies spanning a stellar mass range $10^7 - 10^{12} M_{\odot}$ in field, group and cluster environments. Each target was observed with the Sydney Australian Astronomical Observatory Multi-Object Integral Field Spectrograph (SAMI; Croom et al. 2012) on the 3.9 m Anglo-Australian Telescope at Siding Spring Observatory. SAMI is a multi-object fused-fibre-bundle instrument that feeds the AAOmega spectrograph (Sharp et al. 2006), which has separate blue (3700–5700 Å, $R = 1812$) and red (6300–7400 Å; $R = 4263$) arms. Each fibre bundle, or *hexabundle* (Bland-Hawthorn et al. 2011; Bryant et al. 2014), comprises 61 individual 1.6” diameter optical fibres with a high filling factor of 75 per cent and a total footprint of 14.7”. The observations for each target were dithered on-source to account for gaps between fibres in the hexabundle. The final reduced data cubes have $0.5'' \times 0.5''$ *spaxels* (spatial pixels) with an average effective seeing of 2”.

We used the data products from the third SAMI data release (DR3; Croom et al. 2021)¹, which includes the original data cubes, plus two-dimensional maps of emission line fluxes, gas and stellar kinematics, and other quantities. DR3 also includes tables² containing measurements of additional physical quantities and data quality flags for each galaxy. Spectroscopic and flow-corrected redshifts (z) and stellar masses (M_{\star}) were extracted from the InputCatGAMADR3 (Bryant

¹ Available at <https://docs.datacentral.org.au/sami/>.

² Available at <https://datacentral.org.au/services/schema/#sami>.

et al. 2015), InputCatClustersDR3 (Owers et al. 2017) and InputCatFiller tables. Effective radii (R_e) and axis ratios (b/a) were derived from r -band SDSS, VST and GAMA photometry were computed using the multi-Gaussian expansion (MGE; Emsellem et al. 1994; Cappellari 2002) fits described in D’Eugenio et al. (2021). Inclinations (i) were derived from these axis ratios using eqn. 1 from Poetrodjojo et al. (2021) adopting an intrinsic disk thickness of $q_0 = 0.2$.

To obtain spatially resolved measurements for each galaxy, we used the unbinned (“default”) data products, which include emission line profile fits carried out using LZIFU (Ho et al. 2016a), which first fits and then subtracts the stellar continuum to more accurately fit the emission lines. In this work we use the “recommended” component fits, in which LZCOMP (Hampton et al. 2017a,b), an artificial neural network (ANN), was used to evaluate the best-fitting number of components in each spaxel (i.e., one, two or three components). The components are ordered by velocity dispersion, such that components 1, 2 and 3 refer to the narrow, broad and extra-broad components respectively. For each galaxy, DR3 includes maps of the *total* emission line fluxes in each spaxel—i.e., summed over all Gaussian emission line components—for [O II] $\lambda\lambda 3726, 9$, H $\beta\lambda 4861$, [O III] $\lambda\lambda 4959, 5007$, [O I] $\lambda 6300$, [N II] $\lambda\lambda 6548, 83$, H $\alpha\lambda 6563$ and [S II] $\lambda\lambda 6716, 31$; fluxes for individual components are only provided for H α due to S/N limitations and the lower spectral resolution of the blue arm of AAOmega. The line-of-sight (LoS) ionised gas velocity (v_{gas}) and velocity dispersion (σ_{gas} , corrected for instrumental resolution by LZIFU) are provided for each individual component, however.

We also used the SFR and Σ_{SFR} maps produced by Medling et al. (2018), which were derived using the reddening-corrected H α fluxes from the recommended-component fits assuming a Chabrier (2003) initial mass function (IMF) and the SFR calibration of Kennicutt et al. (1994). We note that these SFR measurements are based on the total H α emission line flux, which may lead to over-estimates of the SFR in cases where broad emission line components are associated with emission from other sources such as shocks or DIG. However, Belfiore et al. (2022) argue that in nearby star-forming galaxies, DIG is predominantly ionised by leaky H II regions, and should therefore be included in SFR estimates; they also concluded that including DIG from evolved stellar populations in these estimates will not lead to a significant over-estimate of the SFR in kpc-resolution data, such as SAMI. None the less, we repeated our analysis using SFR measurements from only the narrow H α component in each spaxel, and found that it made no meaningful difference to our conclusions. Global SFRs and Σ_{SFR} were measured for each galaxy by summing the SFRs in these maps within nuclear apertures of diameter 3 kpc and $2R_e$.

Emission line fluxes were corrected for extinction using the Fitzpatrick & Massa (2007) reddening curve with $R_V = 3.1$ and assuming an intrinsic Balmer decrement of H α /H $\beta = 2.86$ which corresponds to a standard nebular electron temperature and density of 10^4 K and 100 cm^{-3} respectively (Dopita & Sutherland 2003). To ensure reliable extinction correction, this step was only applied to spaxels in which the total flux S/N of both H α and H β exceeded 5. H α equivalent widths (EW(H α)) were computed as the non-extinction-corrected H α flux divided by the mean continuum level in the rest-frame wavelength range 6500–6540 Å.

2.1 Data quality and S/N cuts

Using the DR3 CubeObs table as described in Croom et al. (2021), we identified and removed galaxies with bad sky subtraction residuals (as indicated by WARNKYR and WARNKYB), those with flux calibration

issues (WARNFCAL and WARNFCBR), and those containing multiple objects in the SAMI field-of-view (FoV) (WARNMULT), leaving 2997 galaxies.

To ensure high-quality kinematics and H α fluxes of individual components within individual spaxels, we adopted a minimum flux S/N (defined as the flux divided by the formal uncertainty provided by LZIFU) of 5 in H α in each component, plus a component amplitude-to-noise (A/N) of at least 3, here defined as the Gaussian amplitude of the component divided by the RMS noise in the rest-frame wavelength range 6500 Å–6540 Å. We also required a minimum gas velocity dispersion S/N of 3 in each component as defined by Federrath et al. (2017), which accounts for the uncertainty in measuring the width of individual emission line components that are close to the instrumental resolution. For total emission line fluxes in each spaxel (that is, summed over all emission line components), we required a minimum S/N of 5. Example fits from spaxels meeting these criteria are provided in Appendix A.

2.2 Spectral classification

Spaxels were spectrally classified using the standard optical diagnostic diagrams of Baldwin, Phillips & Terlevich (1981) and Veilleux & Osterbrock (1987), which plot the [O III] $\lambda 5007$ /H β ratio (O3) against the [N II] $\lambda 6583$ /H α (N2), [S II] $\lambda\lambda 6717, 31$ /H α (S2), and [O I] $\lambda 6300$ /H α (O1) ratios.

We used only the O3 vs. N2 and O3 vs. S2 diagrams due to the relative weakness of the [O I] emission line. To ensure reliable classification, only spaxels with a flux S/N of at least 5 in all of H β , H α , [O III] $\lambda 5007$, [N II] $\lambda 6583$, and [S II] $\lambda\lambda 6716, 31$ lines were classified. Due to the lower spectral resolution of the blue arm ($R = 1812$) compared to the red arm ($R = 4236$), blue lines such as [O III] and H β may not have reliable flux measurements for individual components. As a result, DR3 only provides total fluxes for lines other than H α , rather than those of individual components. Spectral classification was therefore performed using the total emission line fluxes in each spaxel. We note that, in cases where multiple emission line components are present that arise from different excitation mechanisms (e.g., a star-forming component plus a shocked component), the classification is naturally weighted towards the component with the highest luminosity.

Each spaxel was assigned one of the following spectral classification:

- **Star-forming (SF)**: lies below the Kauffmann et al. (2003) line in the N2 diagram, and below the Kewley et al. (2001) “extreme starburst” line in the S2 diagram.
- **Composite**: lies above the Kauffmann et al. (2003) line in the N2 diagram but below the the Kewley et al. (2001) “extreme starburst” line in both the N2 and S2 diagrams.
- **LINER**: lies above the Kewley et al. (2001) “extreme starburst” line in both the N2 and S2 diagrams but below the Kewley et al. (2006) LINER/Seyfert line in the S2 diagram.
- **Seyfert**: lies above the Kewley et al. (2001) “extreme starburst” line in both the N2 and S2 diagrams but above the Kewley et al. (2006) LINER/Seyfert line in the S2 diagram.
- **Ambiguous**: inconsistent classifications between the O3 vs. N2 and O3 vs. S2 diagrams; e.g., composite-like in the N2 diagram, but LINER-like in the S2 diagram.
- **Not classified**: low S/N in or missing at least one of H α , H β , [N II], [S II] or [O III] fluxes.

3 DEFINING 1- AND MULTI-COMPONENT GALAXIES

Our aim is to determine the fundamental differences between star-forming galaxies exhibiting large numbers of spaxels with complex emission line profiles—that is, containing multiple components—and those without, which we refer to as “multi-component galaxies” and “1-component galaxies” respectively. Here, we describe our method for classifying SAMI galaxies into these two categories.

We begin by defining a parent sample. For a galaxy to be included, it must contain at least 50 spaxels that can be spectrally classified after making the data quality and S/N cuts detailed in Section 2.1; this requirement removes galaxies that are poorly resolved and those with overall low emission line S/N and therefore less reliable multi-component fits. In this work, we are primarily interested in winds and outflows associated with star formation. Because active galactic nuclei (AGN) can also contribute to these phenomena, we remove possible AGN hosts from our sample by requiring at least 80 per cent of spectrally-classified spaxels to be star-forming, and that all but one spaxel within 2” of the nucleus must be star-forming, unclassified, or have $EW(H\alpha) < 3$, where this last criterion allows for spaxels where the dominant photoionisation mechanism is evolved stars (Singh et al. 2013; Belfiore et al. 2016; Byler et al. 2019). We also remove galaxies containing any spaxels classified as Seyfert. Our final parent sample of star-forming galaxies contains **655** objects.

From this parent sample, we select “1-component” and “multi-component” galaxies according to the following criteria: 1-component galaxies are those in which over 99 per cent of all spaxels with emission line components that pass our S/N and data quality cuts contain only 1 component, and multi-component galaxies are those in which at least 15 per cent of all such spaxels contain 2 or more components. Objects in which 1–15 per cent of spaxels contain multiple components are not classified as either 1- or multi-component galaxies.

Figure 1 shows examples of 1- and multi-component galaxies. SDSS images are shown, alongside maps displaying the number of emission line components fitted in each spaxel, spectral classifications, and the LoS velocity of the narrow and broad components. Note that we do not base our classification on the number of 3-component spaxels due to their rarity: of all spaxels containing emission lines exceeding our S/N requirements, approximately 6.8 per cent contain 2 components whereas only 0.7 per cent contain 3 components. That said, our multi-component galaxy sample contains objects with appreciable numbers of spaxels containing 3 components, e.g., galaxy 53770 as shown in Fig. 1.

Although our choice of 15 per cent is somewhat arbitrary, we find that shifting this threshold does not meaningfully change our results; 15 per cent strikes a good balance between having a sufficiently large multi-component galaxy sample to conduct statistical analysis, and having a large enough number of multi-component spaxels within each galaxy to ensure our multi-component sample is not contaminated by spaxels with unreliable 2 or 3-component fits. Our criteria result in **266** 1-component galaxies and **133** multi-component galaxies.

Note that our selection criteria for multi-component galaxies do not explicitly take into account the origin of the broad-line emission, and as such includes systems in which the broad component is due to beam smearing, winds/outflows, thick disks and other processes such as mergers and stripping. For example, as shown in Fig. 1, the broad component in galaxy 491457 exhibits smooth rotation similar to that of the narrow component, whereas that in galaxy 53770 is clearly blueshifted, and likely represents a wind.

A drawback of spatially resolved data in comparison with in-

tegrated spectra is the lower S/N. We therefore repeated our 1- and multi-component classification process using velocity-subtracted $1R_e$ aperture spectra to check whether there are any galaxies with low surface-brightness broad line emission that is not detectable in the spatially resolved data. As detailed in Appendix B, there were no galaxies classified as 1-component using the resolved data that were classified as multi-component in the aperture spectra. In fact, 20 galaxies classified as multi-component using the resolved data were classified as 1-component using the aperture spectra, possibly due to beam smearing effects “washing out” faint broad components in individual spaxels. We therefore rely only upon the resolved classifications for the remainder of this paper.

3.1 General properties of 1- and multi-component galaxies

Figures 2a and 2b show the distributions of various physical and observational galaxy properties respectively in the 1- and multi-component samples. The 2-sample Kolmogorov-Smirnoff (KS) and Anderson-Darling (AD) tests, both of which estimate the likelihood that both samples are drawn from the same parent distribution, were applied to the 1- and multi-component galaxy distributions in each quantity. In all quantities except for R_e , the p -values are far below the significance threshold of $p = 0.05$, suggesting fundamental differences between the 1- and multi-component galaxies. Both tests are employed in order to more robustly judge whether distributions are significantly different or not; in cases where one test has $p > 0.05$ and the other has $p < 0.05$, we judge the distributions as being substantially different only at a tentative level.

As shown in Fig. 2a, the multi-component galaxies are more massive, and have significantly higher mean SFRs and Σ_{SFR} measured within $1R_e$ (SFR_{R_e} and Σ_{SFR, R_e} , respectively) as well as higher specific SFRs (sSFRs) than 1-component galaxies. In particular, there is essentially no overlap in the distributions in Σ_{SFR} measured within 3 kpc ($\Sigma_{\text{SFR}, 3 \text{ kpc}}$) of the 1- and multi-component systems; however, $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ may not reflect the true Σ_{SFR} within the galaxy in systems with $R_e < 3$ kpc, which represents a significant fraction of our galaxies. For this reason, we primarily rely on R_e -based measurements for the remainder of this work. The multi-component galaxies also have higher values of $\log_{10}(M_*/R_e)$ and $\log_{10}(M_*/R_e^2)$, which are proxies for gravitational potential and stellar surface density respectively, and slightly redder $g - i$ colours than 1-component galaxies. They also have clumpier star formation distributions on average, as evidenced by their higher Gini coefficients (G , Gini 1936), which are computed using

$$G = \frac{1}{2n^2\bar{s}} \sum_{i=1}^n \sum_{j=1}^n |s_i - s_j| \quad (1)$$

where s_i is the Σ_{SFR} (or equivalently SFR) in spaxel i , n is the total number of spaxels where the Σ_{SFR} can be measured and \bar{s} is the average Σ_{SFR} in the galaxy. $G = 0$ corresponds to perfect equality, i.e., every spaxel has the same Σ_{SFR} , whereas $G = 1$ corresponds to maximal inequality, i.e., all star formation is concentrated in a single spaxel. Gini coefficients are discussed further in Section 6.

Figure 2b shows the distribution in various observational quantities in the 1- and multi-component samples.

In the leftmost panel we show $\log_{10}(H\alpha A/N)_{3\text{kpc}}$, the mean $H\alpha$ A/N measured within a 3 kpc aperture. Here, and for the remainder of this paper, $H\alpha$ A/N is defined within each spaxel as the peak amplitude of the $H\alpha$ line profile (directly measured from the spectrum, and therefore not corrected for stellar absorption) relative to the mean continuum level in the rest-frame wavelength range 6500 Å–6540 Å

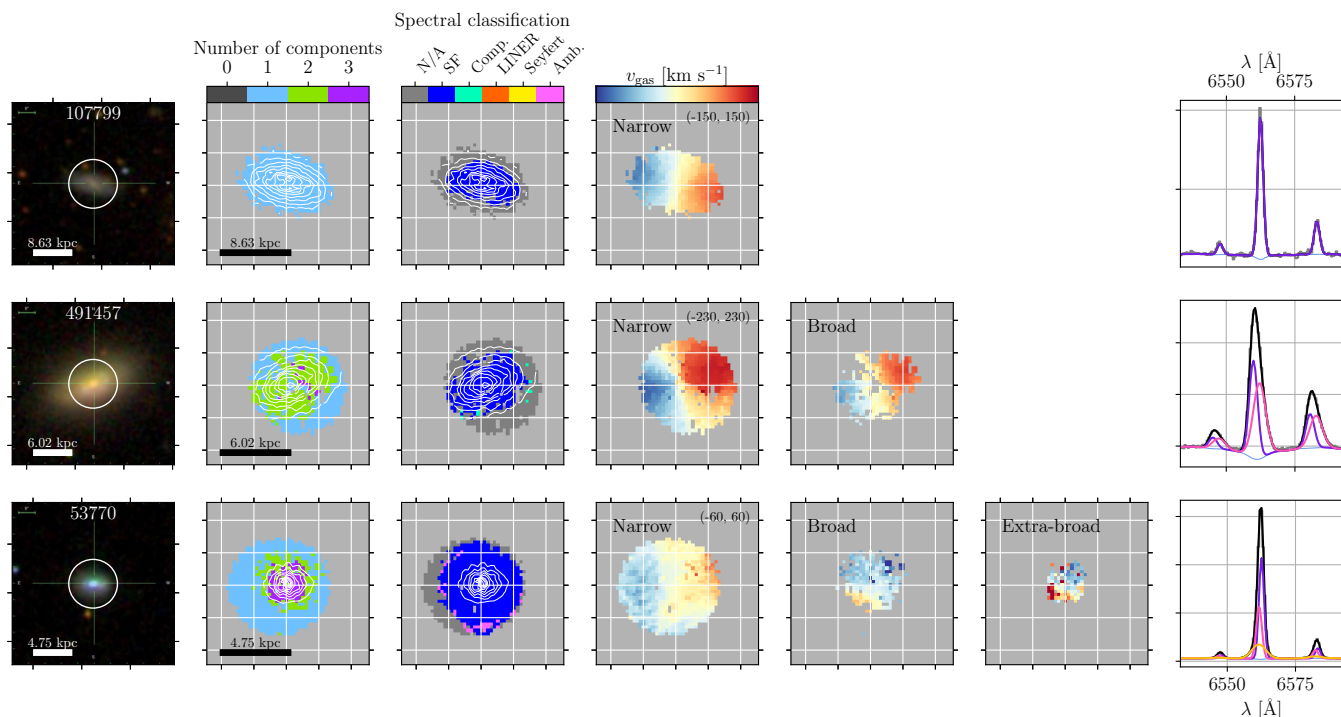


Figure 1. Example 1-component (top row) and multi-component (bottom two rows) galaxies. The leftmost column shows the SDSS image, where the white circle represents the SAMI FoV. The middle five columns show maps of the number of components, spectral classification, and LoS velocities of the ionised gas in each spaxel, where the white contours represent the logarithmically-scaled stellar continuum, and the black bar shows the angular scale. The minimum and maximum velocity scaling values for each galaxy are shown in the upper-right corner. The rightmost column shows the rest-frame H α and [N II] $\lambda\lambda$ 6548, 83 emission line profiles in grey, overlaid with the LZIFU fits, extracted from an individual spaxel in the nucleus of each galaxy. The blue line represents the stellar continuum fit; the purple, pink and orange lines represent the first (narrow), second (broad) and third (extra-broad) Gaussian components respectively, and the black line represents the combined fit.

divided by the RMS noise measured in the same range. We opt to use A/N rather than flux S/N as the latter is based on the fluxes and formal uncertainties provided by LZIFU, and may not be representative of the true S/N in cases of bad fits. The multi-component galaxies exhibit higher mean H α A/N than the 1-component galaxies.

They also tend to be more distant, although this could result from SAMI’s stepped sample selection function, in which all essentially all galaxies with $\log_{10} M_* < 9$ are located at $z \lesssim 0.03$ (see fig. 3 of Croom et al. 2021). Compared to the 1-component galaxies, multi-component galaxies are slightly over-represented at intermediate inclinations and under-represented at high inclinations, which is contrary to expectations if the presence of multiple components is a consequence of beam smearing alone. Potential explanations for this over-representation are discussed in Section 7.2.

The locations of the 1- and multi-component galaxies on the star-forming main sequence (SFMS) are shown in the upper panel of Fig. 3. At stellar masses below approximately $10^{10} M_\odot$, multi-component galaxies sit along the upper envelope of the SFMS, having elevated SFRs for their mass, whilst at higher masses they exhibit a wider range of SFRs. The bottom panel, which shows Σ_{SFR, R_e} as a function of stellar mass, shows that the multi-component galaxies typically have $\Sigma_{\text{SFR}} \gtrsim 10^{-2} M_\odot \text{ yr}^{-1} \text{ kpc}^{-2}$.

The R_e measurements were derived using r -band photometry (for details see D’Eugenio et al. 2021) which includes the H α emission line for galaxies at $z \lesssim 0.066$, representing the majority of galaxies in our sample (see Fig. 2b). In galaxies with high SFRs, R_e may be biased towards smaller values by bright H α emission in the nuclear regions, thereby no longer representing the stellar extent of the galaxy

and in turn elevating Σ_{SFR, R_e} . A 10 per cent H α contribution to the r -band flux corresponds to an emission line EW(H α) of approximately 150 \AA ; within $1R_e$, the average EW(H α) exceeds this amount in only 3 and 2 of our 1- and multi-component galaxies respectively, indicating that only a very small fraction of our sample is likely to have biased R_e measurements. We therefore conclude that the R_e measurements are not significantly biased by this effect and use R_e -aperture measurements for the remainder of this work. Plots made using the 3 kpc circular (“round”) aperture measurements are shown in Appendix C for comparison.

4 MATCHED SAMPLE ANALYSIS

As shown by Fig. 2, the 1- and multi-component galaxies have statistically significantly different distributions in a number of physical properties, including stellar mass and SFR; they also differ in observational properties such as inclination and S/N . Identifying the processes that cause complex emission line profiles therefore requires careful treatment due to underlying correlations between various parameters. For example, the multi-component galaxies have higher stellar masses and higher SFRs; however, because stellar mass is itself correlated with SFR (Fig. 3), this alone does not indicate whether the presence of complex emission line profiles is driven by stellar mass or SFR.

Observational biases must also be controlled for. For instance, the multi-component galaxies have higher H α A/N ; a scenario in which *all* galaxies would exhibit multiple emission line components

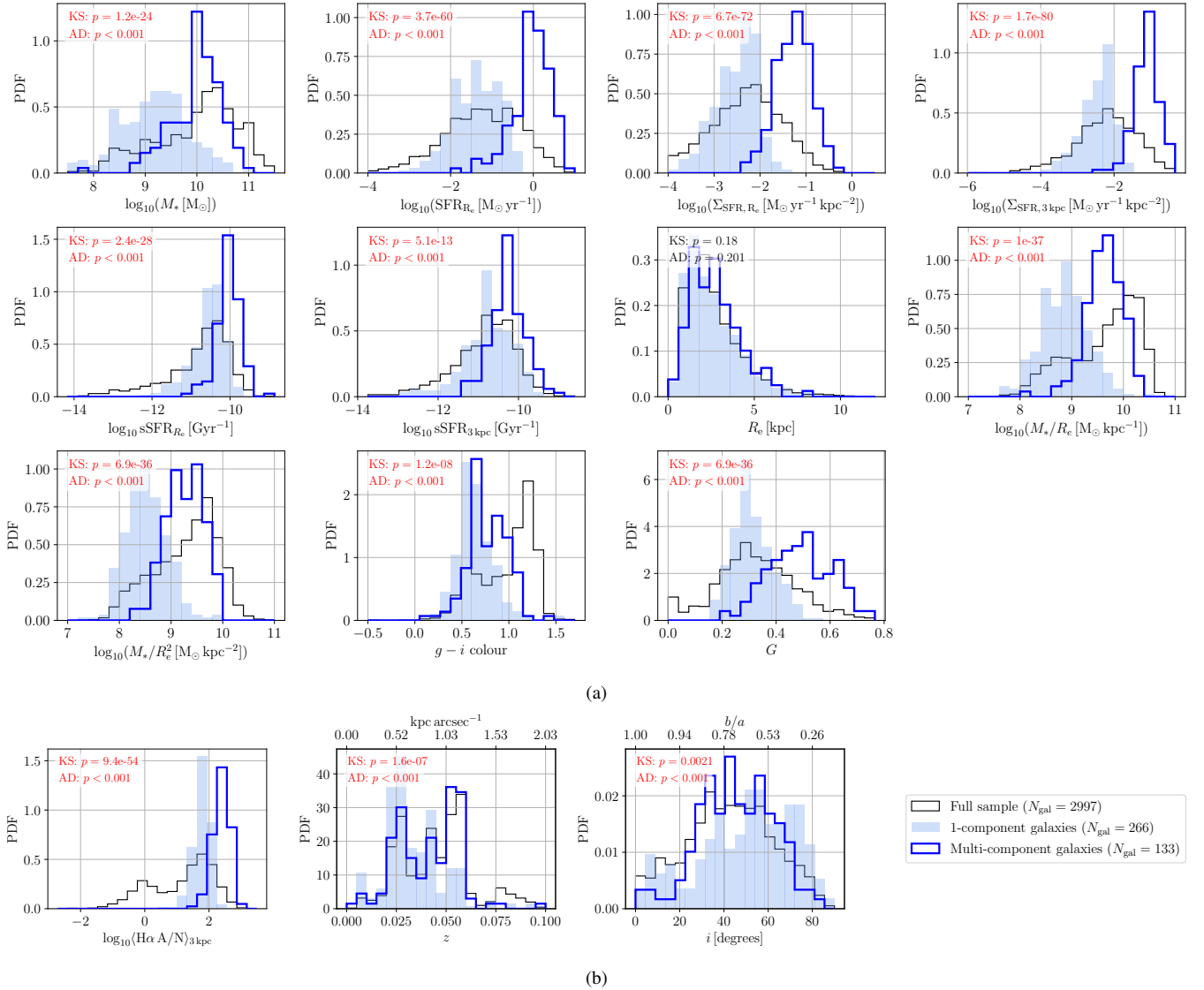


Figure 2. Probability distribution functions (PDFs) in various *physical* galaxy properties (a) and *observational* quantities (b) shown for our different sub-samples. In each panel we show the distribution in the full SAMI sample of 2997 galaxies (thin black line), the 1-component galaxy sample (shaded blue histogram), and multi-component galaxy sample (thick blue line). In (b), the top axis ticks of the bottom right-most panel show the axis ratios b/a corresponding to the measured inclinations assuming an intrinsic disk thickness $q_0 = 0.2$ (Poetrodjojo et al. 2021). The text in the upper left corner shows the p -values of the KS and AD tests applied to the 1- and multi-component samples. In all quantities except for R_e , the very low p -values indicate that the samples are highly unlikely to be drawn from the same parent sample, suggesting the two samples have fundamentally different distributions in all quantities shown here.

given sufficient A/N could therefore be consistent with these observations. However, the multi-component galaxies also have higher SFRs, meaning that at a fixed redshift they will have brighter H α emission, and therefore higher A/N . The offset in A/N could therefore also occur if SFR is the fundamental driver of multiple emission line components.

To control for the effects of observational and physical parameters on the presence of multiple emission line components, we perform a matched sample analysis (e.g., Kaasinen et al. 2017) using an adaptive threshold matching technique as follows:

(i) For each multi-component galaxy, we identify all unmatched 1-component galaxies within some matching threshold Δ of the quantity Q being matched.

(ii) If this is successful, we select the 1-component galaxy from this subset that is closest to the multi-component galaxy in Q , and

subsequently remove both galaxies from the lists of unmatched galaxies.

(iii) Otherwise, if there are no 1-component galaxies within $\pm\Delta$ of Q , the multi-component galaxy remains unmatched and we repeat step (i) for the next unmatched multi-component galaxy.

(iv) Once we have attempted to match all multi-component galaxies, we terminate the process if at least 80 per cent of all multi-component galaxies have been matched. Otherwise, we increment the matching threshold by $+\Delta$ and repeat the matching process (step (i)) on all of the unmatched multi-component galaxies.

(v) If necessary, steps (i)–(v) are repeated once more with a match threshold of 3Δ , after which the process is terminated.

Δ was set to the typical uncertainty for quantities in which measurement uncertainties were available; Δ values for other parameters were chosen to provide sufficiently large matched samples to enable

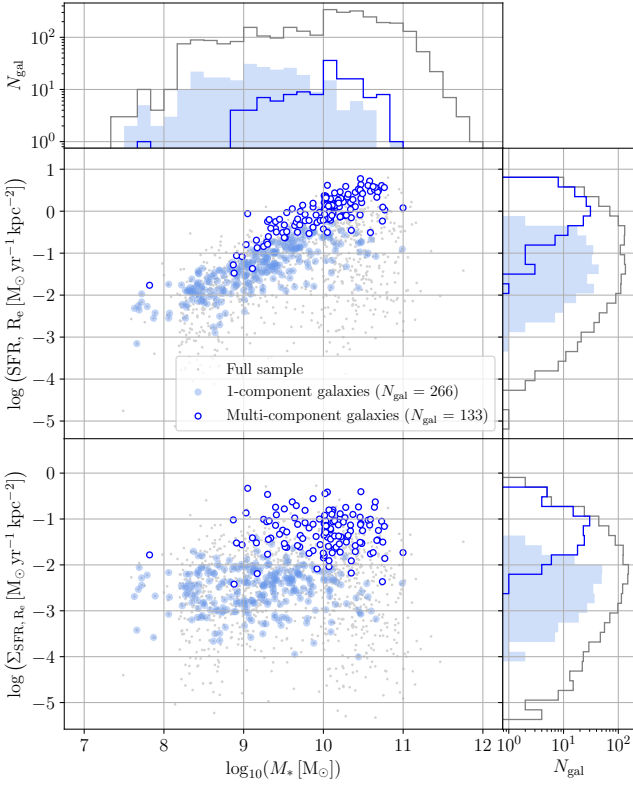


Figure 3. Star-forming main sequence (top) and Σ_{SFR} main sequence (bottom) for the full SAMI sample (grey points), 1-component galaxies (blue filled circles) and multi-component galaxies (blue open circles). Distributions in M_* , SFR_{R_e} and Σ_{SFR, R_e} for each subsample are shown in the top and right-hand panels.

Table 1. Match thresholds Δ used for the matched sample analysis (Section 4).

Quantity	Δ
$\log_{10}(M_* [M_\odot])$	0.1
$\log_{10}(\text{SFR}_{R_e} [M_\odot \text{ yr}^{-1}])$	0.0085
$\log(\Sigma_{\text{SFR}, R_e} [M_\odot \text{ yr}^{-1} \text{ kpc}^{-2}])$	0.0085
$G(\text{SFR})$	0.025
R_e [kpc]	0.2
$\log_{10}(M_*/R_e [M_\odot \text{ kpc}^{-1}])$	0.1
$\log_{10}(M_*/R_e^2 [M_\odot \text{ kpc}^{-2}])$	0.1
i [degrees]	2
kpc arcsec^{-1}	0.1
$\log_{10}\langle \text{H}\alpha \text{ A/N} \rangle_{3 \text{ kpc}}$	0.05

fair comparison whilst ensuring reasonable similarity in the matched quantity between 1- and multi-component galaxies. The values of Δ used are given in Table 1.

Validity of the final matched 1- and multi-component galaxy samples was determined using the 2-sample KS and AD tests as in Section 3.1; when matching, we required $p > 0.05$ in both of these tests to ensure that the matched samples were valid. To ensure stability of our results, we repeated steps (i) to (v) 1000 times for each matched quantity, each time randomly sorting the list of multi-component galaxies, and inspecting the distribution of p -values. In all matched quantities the p -values exceeded 0.05 in both KS and AD tests over 99 per cent of the time, indicating stable results.

4.1 Matched sample analysis results

Figure 4 shows violin plots representing kernel density estimates (KDEs) of the distributions in various parameters for the 1- and multi-component galaxy samples matched in M_* , SFR_{R_e} , Σ_{SFR, R_e} and G . To control for observational biases, we also show samples simultaneously matched with these physical quantities and in succession with $\log_{10}\langle \text{H}\alpha \text{ A/N} \rangle_{3 \text{ kpc}}$, angular scale and inclination.

To control for observational biases, we also show samples matched with these physical quantities simultaneously in $\log_{10}\langle \text{H}\alpha \text{ A/N} \rangle_{3 \text{ kpc}}$, angular scale and inclination. The results of KS and AD 2-sample tests are indicated for each violin plot; text in red represent $p < 0.05$, indicating a statistically significant likelihood that the samples are not drawn from the same underlying distribution. Results for matched samples in other combinations of parameters are summarised in Fig. C1.

We first match in M_* (first four columns of Fig. 4). When controlling for M_* (column 1), the multi-component galaxies have smaller R_e and significantly higher SFR_{R_e} ; in particular, they exhibit mean Σ_{SFR, R_e} and $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ nearly 1.0 dex higher than those of the matched 1-component galaxies. They also have significantly higher values of G , indicating clumpier and/or more centrally-concentrated SFR distributions, much higher average $\text{H}\alpha \text{ A/N}$ and have distinct distributions in angular scale and inclination. However, when controlling for $\text{H}\alpha \text{ A/N}$, angular scale and inclination by matching in these quantities simultaneously with M_* (columns 2–4), the multi-component galaxies still exhibit significantly higher SFR_{R_e} , Σ_{SFR} and G , and tend to be more compact.

We now consider SFR_{R_e} (columns 5–8 of Fig. 4). When matched in SFR_{R_e} alone (column 5), the multi-component galaxies have a significantly different distribution in M_* , being less massive than the 1-component galaxies; however, when controlling for $\text{H}\alpha \text{ A/N}$, angular scale and inclination this difference disappears. Rather, when accounting for these observational effects, the multi-component galaxies are differentiated by being more compact and having higher Σ_{SFR} than 1-component galaxies at the same SFR_{R_e} ; they also exhibit higher Gini coefficients.

As shown in Fig. 3, there is some overlap between the 1- and multi-component galaxies on the SFMS and the Σ_{SFR} main sequence. To determine what distinguishes the two samples in the overlapping regions of these parameter spaces, in the 4th column of Fig. C1 we match in both M_* and SFR_{R_e} , which yields similar results to matching in SFR_{R_e} alone: the matched multi-component galaxies have significantly higher Σ_{SFR, R_e} and $\Sigma_{\text{SFR}, 3 \text{ kpc}}$, and are more compact than the 1-component galaxies. Note that we do not simultaneously match in observational parameters as the resulting sample sizes become too small to perform statistical analysis; however, this is unlikely to bias our results, having just shown that the multi-component galaxies exhibit elevated Σ_{SFR} when matched in M_* and SFR_{R_e} even when controlling for $\text{H}\alpha \text{ A/N}$, angular scale and inclination. In the 5th column of Fig. C1, we match in both M_* and Σ_{SFR, R_e} . In this case, the matched 1-component galaxies have similar SFR_{R_e} , suggesting that Σ_{SFR} is more fundamental than SFR in determining the presence of complex emission line profiles in these galaxies.

We now match in Σ_{SFR, R_e} (columns 9–12 of Fig. 4). Note that the nearly disjoint distributions of the 1- and multi-component galaxies in Σ_{SFR, R_e} (as shown in Fig. 2b) results in a relatively small sample size of 18 when matching in this quantity, and that the matched 1-component galaxies may not be representative of the overall sample. None the less, at a fixed Σ_{SFR, R_e} , the multi-component galaxies are significantly larger, more massive and have higher SFR_{R_e} than the 1-component galaxies; these trends persist when controlling for $\text{H}\alpha$

A/N, angular scale and inclination. Although the multi-component galaxies have a median $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ over 0.5 dex higher than those of the matched 1-component galaxies, this may not be representative of the true Σ_{SFR} within the galaxy itself due to their small size. For this reason, we do not match in $\Sigma_{\text{SFR}, 3 \text{ kpc}}$. Rather, we propose that these high- Σ_{SFR} 1-component systems may harbour the same underlying physical phenomena that manifest as complex emission line profiles in more massive systems (e.g., winds) but that it may not be possible to detect them at the spectral resolution of SAMI; these high- Σ_{SFR} 1-component galaxies are discussed further in Section 4.1.1.

As is clear from Fig. 4, the multi-component galaxies exhibit significantly higher Σ_{SFR} than the 1-component values regardless of which quantity is held constant, even when controlling for observational biases. We therefore conclude that Σ_{SFR} is the most important physical parameter in determining the presence of complex emission line profiles in star-forming galaxies. However, H α A/N, spectral resolution and inclination effects may play a secondary role; these are discussed further in Sections 4.1.1, 7.2.2 and 7.2.3.

4.1.1 High- Σ_{SFR, R_e} 1-component galaxies

As shown in columns 9–12 of Fig. 4, our sample contains a small population of 1-component galaxies with high Σ_{SFR} .

Matching in Σ_{SFR, R_e} alone yields 18 compact, low-mass 1-component galaxies with high Σ_{SFR, R_e} that have significantly lower $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ than the matched multi-component galaxies. This could indicate that $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ is fundamentally more important than Σ_{SFR, R_e} ; however, it is also possible that $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ is not a reliable estimate of the true Σ_{SFR} within these galaxies due to their small sizes, as stated in Section 3.1. However, matching in both M_* and Σ_{SFR, R_e} (5th column of Fig. C1) reveals a sample of 1-component galaxies with similar masses and sizes to the matched multi-component galaxies. Notably, these galaxies have lower $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ by around 0.4 dex but have similar sizes to the matched multi-component galaxies, suggesting the offset in $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ is not an artefact of small galaxy sizes.

The lack of complex emission line profiles in the high- Σ_{SFR, R_e} 1-component systems may be a spectral resolution effect: as discussed in Section 7.2.2, we may be unable to resolve multiple emission line components in low-mass systems at the spectral resolution of the SAMI instrument. Higher-resolution observations may therefore reveal complex emission line components in these unusual objects.

5 CORRELATION ANALYSIS

In Fig. 5, we plot F_{R_e} , the fraction of spaxels within $1R_e$ containing two or three components within an individual galaxy, as a function of global Σ_{SFR, R_e} for star-forming SAMI galaxies. Note that although the pixel size of SAMI is $0.5''$, the effective number of resolution elements across the SAMI FoV is approximately 60, meaning that values of $F_{R_e} < 1/60$ may represent artefacts, which may explain the increase in scatter at low values of F_{R_e} ; this threshold is indicated by the shaded grey region. There is a strong and statistically significant correlation between F_{R_e} and Σ_{SFR, R_e} as indicated by the Spearman's rank correlation coefficient of 0.862 ($p \ll 0.05$). Moreover, galaxies with $F_{R_e} = 0$ have markedly lower global Σ_{SFR} than those with $F_{R_e} > 0$, as indicated by the pink shaded region. A similarly strong correlation is observed between $F_{3 \text{ kpc}}$ and $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ (Fig. C2). This trend is consistent with the finding from our matched sample analysis that Σ_{SFR} is the parameter that is most strongly correlated with the presence of complex emission line profiles; however, Figs. 5 and C2

Table 2. Spearman's rank-order correlation coefficients S and associated p -values computed for correlations between the fraction of multi-component spaxels (F_{R_e}) and the quantities given in the leftmost column for the 655 star-forming galaxies in our sample. The strongest correlations, highlighted in bold, are between F_{R_e} and Σ_{SFR, R_e} and $\Sigma_{\text{SFR}, 3 \text{ kpc}}$. To enable a fair comparison, for quantities indicated by the daggers, the correlation was computed for $F_{3 \text{ kpc}}$ instead of F_{R_e} .

Parameter	Correlation coefficient	p -value
$\log_{10}(M_* [M_\odot])$	0.423	8.646×10^{-29}
$\log_{10} \text{SFR}_{R_e}$	0.718	1.412×10^{-101}
$\log_{10} \Sigma_{\text{SFR}, R_e}$	0.862	2.615×10^{-189}
$\log_{10} \Sigma_{\text{SFR}, 3 \text{ kpc}}$	0.858	2.877×10^{-183}
$\log_{10} \text{sSFR}_{R_e}$	0.549	7.941×10^{-51}
$\log_{10} \text{sSFR}_{3 \text{ kpc}}$	0.404	7.664×10^{-26}
R_e [kpc]	-0.049	0.2165
$\log_{10}(M_*/R_e [M_\odot \text{ kpc}^{-1}])$	0.590	2.284×10^{-60}
$\log_{10}(M_*/R_e^2 [M_\odot \text{ kpc}^{-2}])$	0.675	6.025×10^{-85}
$g - i$ colour	0.259	4.151×10^{-11}
G	0.644	9.921×10^{-76}
$\log_{10} \langle \text{H}\alpha \text{ A/N} \rangle_{3 \text{ kpc}}$	0.729	2.368×10^{-106}
z	0.258	4.265×10^{-11}
kpc arcsec $^{-1}$	0.258	4.265×10^{-11}
i [degrees]	-0.126	0.001479

also reveal that the association between F and Σ_{SFR} is continuous in nature, albeit with significant scatter.

For completeness, correlation strengths between F_{R_e} and parameters other than Σ_{SFR} are shown in Table 2; amongst the parameters considered, Σ_{SFR, R_e} indeed shows the strongest correlation with F_{R_e} (with a strength of 0.862), followed by $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ (0.858). However, there is also a strong correlation between F_{R_e} and the mean H α A/N measured within a 3 kpc aperture (0.729).

To determine whether A/N is responsible for the correlation between Σ_{SFR} and F_{R_e} , we compute partial correlation coefficients (PCCs) in order to examine the influence of confounding variables such as A/N and angular scale upon this correlation. These values are shown in Table 3, and were calculated using the `partial_corr` function from the PYTHON package PINGOUIN (Vallat 2018). In all cases, $p \ll 0.05$, indicating statistically a significant correlation between Σ_{SFR} and F_{R_e} when controlling for all confounding variables considered here. Of all variables, H α A/N has the strongest impact on the correlation between F_{R_e} and Σ_{SFR, R_e} , confirming that A/N does play a role in determining the fraction of spaxels within any given galaxy that exhibit multiple components. However, when controlling for this effect, the correlation between F_{R_e} and Σ_{SFR, R_e} remains strong at approximately 0.69, indicating that indeed Σ_{SFR} is the variable that is most strongly associated with the presence of complex emission line profiles, and that the higher A/N associated with multi-component spaxels is most likely due to elevated H α fluxes resulting from more concentrated star formation. This is consistent with our matched sample analysis, which showed that multi-component galaxies exhibit elevated Σ_{SFR} compared to 1-component galaxies when matched in A/N (Section 4). We therefore conclude that the correlation shown in Fig. 5 is unlikely to be driven purely by A/N.

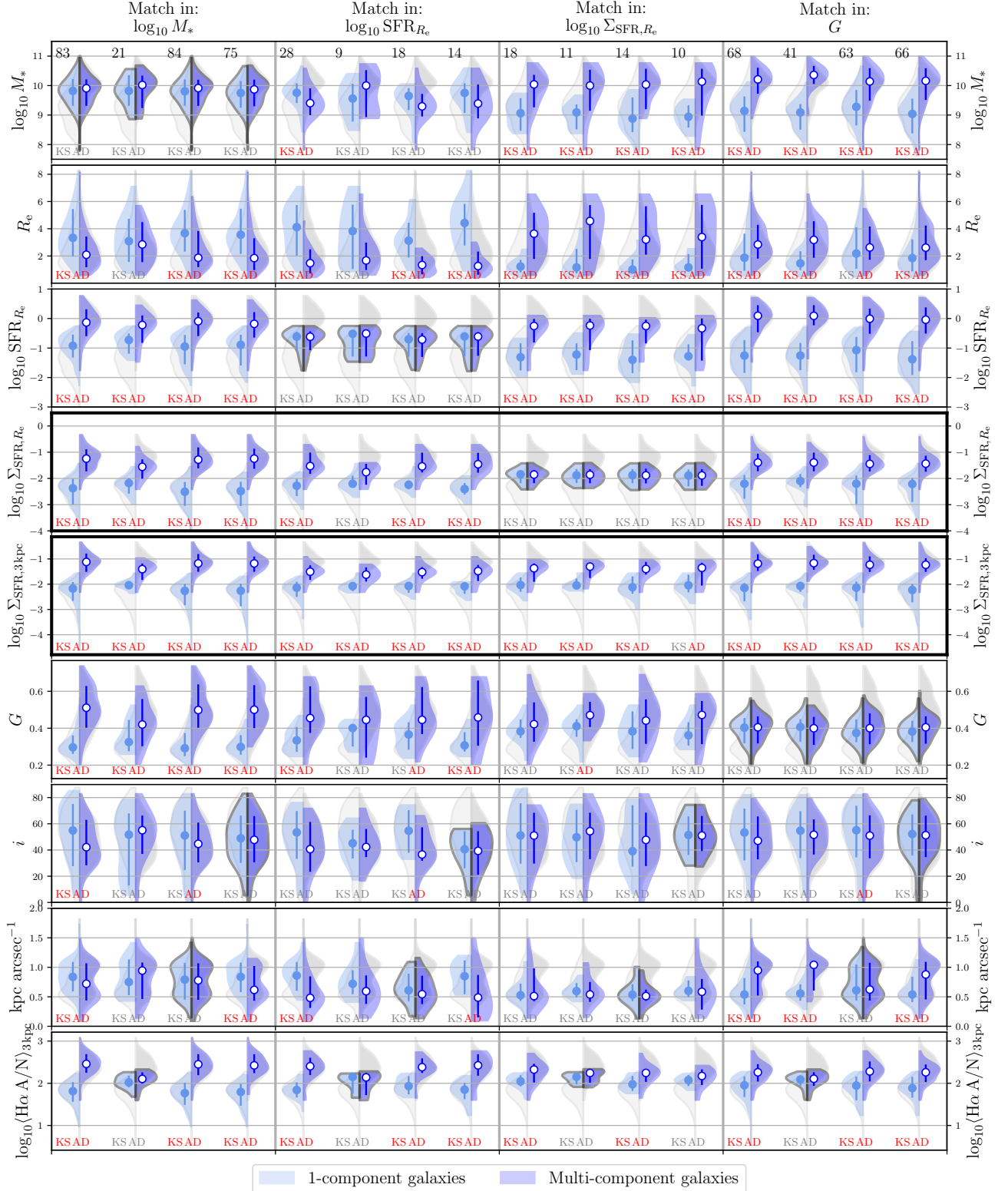


Figure 4. Violin plots showing KDEs representing the distributions in various properties for the 1-component (light blue, left) and multi-component (dark blue, right) matched samples. The full distributions are also shown in grey for reference. Each row shows the distributions in the matched samples in various quantities, and each column shows the distributions matched in the quantity indicated by thick grey outlines around violin plots. The figure is divided into four sub-groups representing samples matched in the quantity shown at the top of the figure: M_* , SFR_{R_e} , Σ_{SFR, R_e} and Gini coefficient G . Within each sub-group, the leftmost column of violin plots represents samples matched only in that quantity, and the other three columns represent samples matched in that quantity simultaneously with (from left to right) mean $\text{H}\alpha A/N$ within 3 kpc, angular scale, and inclination. In each violin plot, the circular points and error bars show the mean and interquartile ranges (IQRs) of the 1- and multi-component matched samples, and the number of galaxies in each matched sample is shown in the upper left. The text at the bottom of each plot represents the result of KS and AD 2-sample tests; text in red represents a p -value less than 0.05, indicating a statistically significant likelihood that the distributions of the matched sample in that quantity are not drawn from the same parent distribution.

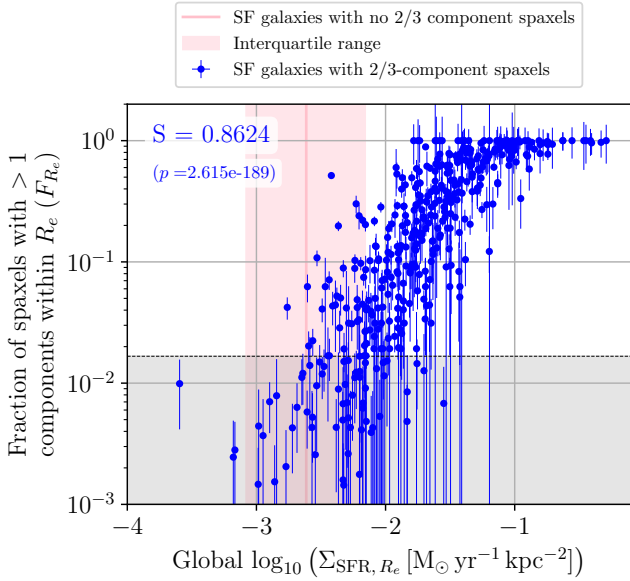


Figure 5. Fraction of spaxels within $1R_e$ containing multiple components (F_{R_e}) as a function of Σ_{SFR, R_e} . Star-forming galaxies with $F_{R_e} > 0$ are shown in blue, where the vertical error bars represent 1σ Poisson errors. The pink vertical line and shaded region indicate the mean and interquartile ranges of global Σ_{SFR, R_e} of galaxies containing only 1-component spaxels. Spearman’s rank correlation coefficients and associated p -values computed for star-forming galaxies with $F_{R_e} > 0$ are shown in the upper left-hand corner. The horizontal dashed line represents the minimum reliable value for F_{R_e} , corresponding to one resolution element containing multiple components as discussed in Section 6. Values below the horizontal dashed may be unreliable due to resolution effects. A version of this figure made using measurements from a 3 kpc aperture is shown in Fig. C2.

Table 3. Partial Spearman’s rank correlation coefficients between $\log_{10} \Sigma_{\text{SFR}, R_e}$ and F_{R_e} when controlling for various parameters. Corresponding p -values are not shown as they are $\ll 0.05$ in all cases.

Parameter	Partial correlation coefficient
$\log_{10}(M_* [M_\odot])$	0.845
$\log_{10} \text{SFR}_{R_e}$	0.731
$\log_{10} \text{sSFR}_{R_e}$	0.795
$\log_{10} \text{sSFR}_{3 \text{ kpc}}$	0.837
R_e [kpc]	0.878
$\log_{10}(M_*/R_e [M_\odot \text{ kpc}^{-1}])$	0.794
$\log_{10}(M_*/R_e^2 [M_\odot \text{ kpc}^{-2}])$	0.726
$g - i$ colour	0.852
G	0.758
$\log_{10}(\text{H}\alpha A/N)_{3 \text{ kpc}}$	0.686
z	0.853
kpc arcsec $^{-1}$	0.853
i [degrees]	0.868

6 IS THE PRESENCE OF MULTIPLE EMISSION LINE COMPONENTS DRIVEN BY STAR FORMATION ON LOCAL OR GLOBAL SCALES?

As shown in Sections 4 and 5, galaxies containing complex emission line profiles are associated with higher Σ_{SFR, R_e} and $\Sigma_{\text{SFR}, 3 \text{ kpc}}$, i.e., *global* Σ_{SFR} , even after controlling for both physical and observational effects. However, because the global Σ_{SFR} is a measure of

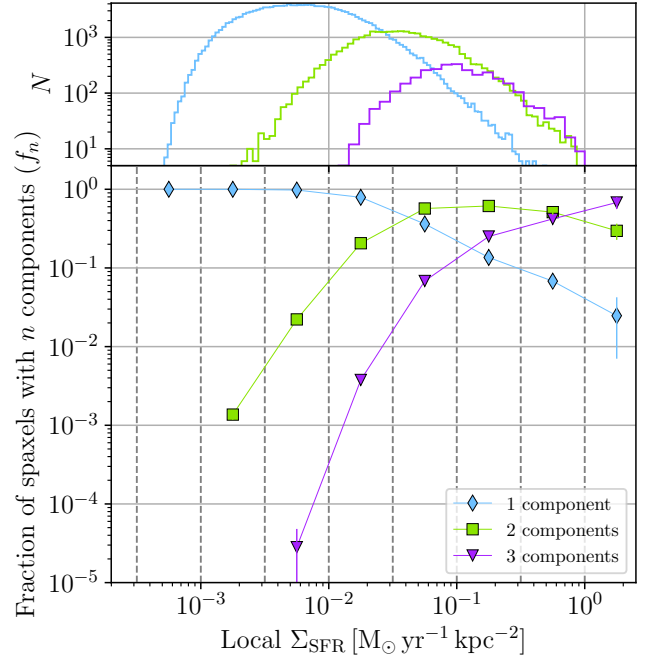


Figure 6. Fraction f_n of star-forming spaxels in the SAMI Galaxy Survey containing 1 (f_1 , blue diamonds), 2 (f_2 , green squares) and 3 (f_3 , purple triangles) emission line components as a function of spaxel-scale (i.e., *local*) Σ_{SFR} . 1σ Poisson errors in f_n are indicated by the vertical black error bars. The log-scaled histogram in the top panel shows the distribution of 1, 2 and 3-component spaxels in Σ_{SFR} . Vertical dashed lines indicate bin edges.

the average Σ_{SFR} within individual spaxels, it is unclear whether the presence of complex emission line profiles—and therefore winds, outflows and/or thick ionised gas disks—are associated with star formation on local, or global (i.e., *galaxy-wide*) scales. We now leverage the spatially resolved nature of the SAMI data set to determine whether star formation on local or global scales is the underlying driver of the presence of multiple emission line components.

In Fig. 6 we show f_n , or the fraction of star-forming spaxels in the full SAMI data set containing n components, as a function of *local* Σ_{SFR} (i.e., that measured within individual spaxels), representing the spatially-resolved analogue of Fig. 5. Before continuing, we note that although the spaxel size of SAMI is $0.5''$, the effective spatial resolution is approximately $2''$, corresponding to a median physical scale of approximately 1 kpc for the galaxies in our sample (Fig. 2). f_1 and f_2 increase smoothly as a function of Σ_{SFR} such that 2- and 3-component spaxels begin to dominate at $\Sigma_{\text{SFR}} \gtrsim 10^{-1.5} M_\odot \text{ yr}^{-1} \text{ kpc}^{-2}$. Together, Figs. 5 and 6 indicate that both local and global effects play a role in determining whether or not complex emission line profiles are present.

To further investigate the relationship between f_n and the roles of local versus global star formation, in Fig. 7 we plot f_n as a function of local Σ_{SFR} in our sample of star-forming galaxies, but in bins of host galaxy Σ_{SFR, R_e} . At a fixed local Σ_{SFR} , spaxels residing in galaxies with higher global Σ_{SFR} are much more likely to exhibit multiple emission line components. This effect is even stronger when $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ is used as a measure of the global Σ_{SFR} (Fig. C3a). The likelihood of detecting multiple emission line components in any given spaxel is therefore affected not only by the local Σ_{SFR} , but by star formation occurring on scales larger than the spatial resolution of SAMI. This illustrates that care must be taken when studying gas

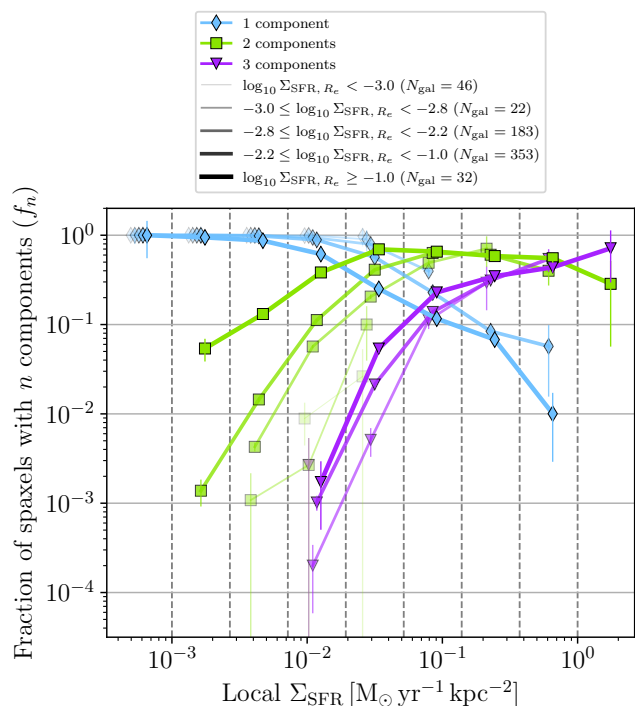


Figure 7. Same as Fig. 6, where spaxels have been binned by the Σ_{SFR, R_e} (i.e., global Σ_{SFR}) of their host galaxies. Thicker lines indicate spaxels residing in galaxies with higher global Σ_{SFR, R_e} . Within each bin of local Σ_{SFR} , the points have been slightly shifted in x for clarity. In the legend, N_{gal} refers to the number of galaxies in each Σ_{SFR, R_e} bin. Vertical dashed lines indicate bin edges. The likelihood of a spaxel exhibiting complex emission line profiles therefore depends not only upon the local Σ_{SFR} , but on the global Σ_{SFR} of its host galaxy.

kinematics within individual spaxels when divorced from their host galaxy properties.

To investigate the influence of observational biases on this result, in Figs. C3b and C3c we show f_n vs. Σ_{SFR} in spaxels binned by their host galaxy’s inclination and angular scale. At a fixed Σ_{SFR} , the relative enhancement in f_2 and f_3 in galaxies at different angular scales and inclinations tends to be smaller than that in galaxies with different global Σ_{SFR} , indicating that these observational biases do not primarily drive the splitting between low- and high- Σ_{SFR} galaxies shown in Fig. 7. We do note, however, that spaxels in more face-on galaxies are more likely to exhibit multiple emission line components than those in edge-on systems; this is most likely due to off-planar emission being present as a single emission line component when viewed in a near-edge-on system. The effects of inclination are discussed further in Section 7.2.3.

Under certain circumstances, beam smearing can produce artificial broad emission line components due to smearing of a steep velocity gradient by seeing effects (Marasco et al. 2019; Concas et al. 2022). SFR profiles tend to peak in the nuclei of galaxies, meaning that spaxels with high Σ_{SFR} are more likely to be affected by beam smearing. To determine whether the increase in f_n with Σ_{SFR} could be partially due to artificial broad line components caused by beam smearing, in Fig. C3d we plot f_n as a function of local Σ_{SFR} binned by projected spaxel radius. At a fixed local Σ_{SFR} , spaxels located within the seeing disc (approximately $2''$) are marginally more likely to exhibit multiple emission line components, but this effect is far smaller than the offsets seen between spaxels in galaxies with differ-

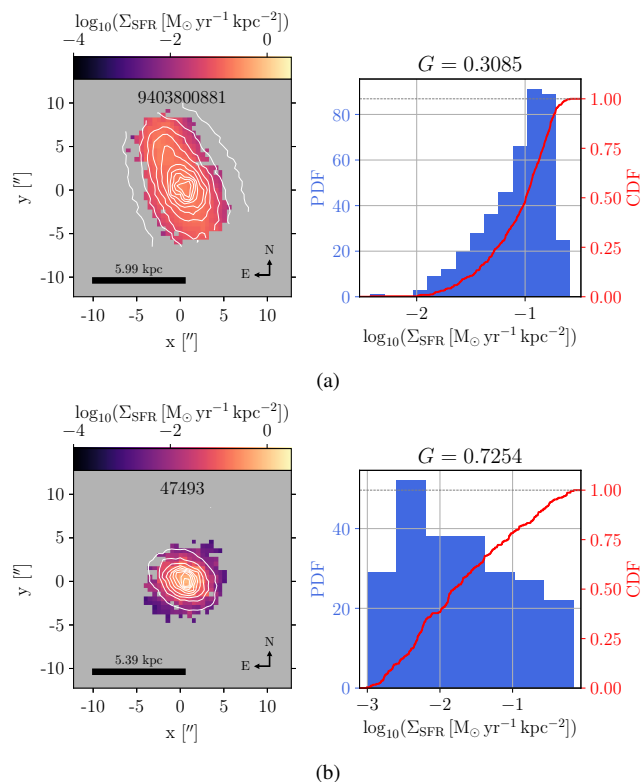


Figure 8. Maps, PDFs and cumulative distribution functions (CDFs) in $\log_{10} \Sigma_{\text{SFR}}$ for (a) galaxy 9403800881, which has a low Gini coefficient of 0.3085, and (b) 47493, which has a high Gini coefficient of 0.7254.

ent global Σ_{SFR} in Fig. 7. We therefore conclude that the correlation between global Σ_{SFR} and the presence of complex emission line profiles has a physical origin, and that star formation taking place on global scales can affect the kinematics of gas on smaller scales as seen in IFS observations.

6.1 How important is clumpiness?

To further investigate the contributions from Σ_{SFR} on local and global scales, we now consider the clumpiness of the star formation distribution within individual galaxies. As shown in Fig. 5, there is considerable vertical scatter in F_{R_e} versus Σ_{SFR, R_e} . If star formation on local, rather than global, scales is the fundamental driver of multiple emission line components, then galaxies with similar global Σ_{SFR} , but clumpier SFR distributions (i.e., containing spaxels with higher local Σ_{SFR}), should have a larger F , whereas if global Σ_{SFR} is more important, then all galaxies should have similar values of F regardless of local variations in Σ_{SFR} . That is, we would expect clumpiness to contribute to the vertical scatter in the relation shown in Fig. 5.

To quantify the clumpiness of star formation we employ the Gini coefficient (Gini 1936), a parameter originally developed to quantify wealth inequality that has previously been applied to parametrise the clumpiness of galaxy morphologies by Lotz et al. (2004) and Bloom et al. (2017). Gini coefficients for each galaxy were computed from the SFR maps using Eqn. 1. Figure 8 shows Σ_{SFR} maps and corresponding Gini coefficients for two SAMI galaxies; galaxy 9403800881 has a much smoother Σ_{SFR} distribution and therefore a much lower Gini coefficient ($G = 0.3085$) than 47493 ($G = 0.7254$), which has centrally-concentrated star formation.

As shown in Fig. 2, multi-component galaxies have higher aver-

age G than 1-component galaxies, implying clumpier and/or more centrally concentrated star formation, although there is substantial overlap between the two distributions. multi-component galaxies also have higher median G when matched in stellar mass, SFR, and other quantities as shown in Fig. 4. However, as shown in Table 3, the correlation between F_{R_e} and Σ_{SFR, R_e} remains very strong at 0.7578 when controlling for G , suggesting that at the spectral and spatial resolution of SAMI, global Σ_{SFR} is more important than local variations in Σ_{SFR} within galaxies in determining the presence of complex emission line profiles.

7 DISCUSSION

7.1 Physical interpretation

In Section 4, we showed that multi-component galaxies have systematically higher Σ_{SFR, R_e} than the 1-component galaxies. We also determined in Section 6 that the presence of multiple emission line components is driven by Σ_{SFR} on both global and local scales. Observational biases do not explain these results, indicating an underlying physical mechanism.

Complex emission line profiles in star-forming galaxies are most often interpreted as winds (e.g., McKeith et al. 1995; Westmoquette et al. 2009; Ho et al. 2014) or thick ionised gas disks (also referred to as extraplanar gas, or DIG; e.g., den Brok et al. 2020; Belfiore et al. 2022); both of these phenomena can be interpreted as manifestations of galactic fountains (Fraternali & Binney 2006; Barnabè et al. 2006; Marinacci et al. 2010). Although some SAMI galaxies exhibit complex gas kinematics due to processes such as mergers or ram-pressure stripping (e.g., Quattropiani et al., *in prep.*), visual inspection of SDSS imaging indicates that only approximately 10 per cent of our multi-component galaxies are undergoing a major merger. We therefore assume that the presence of complex emission line profiles in the star-forming galaxies in our sample indicates the presence of galactic fountains in the form of winds or thick disks. Detailed kinematic analysis of the multi-component galaxies, including consideration of the differences between galaxies harbouring winds and those with thick disks, is deferred to a future work.

Our finding that Σ_{SFR} is the parameter most strongly associated with complex emission line profiles and winds is consistent with previous findings using SAMI data. Ho et al. (2016b) found that edge-on systems with winds have systematically higher Σ_{SFR} than those without. Tescari et al. (2018) additionally found that extraplanar gas in simulated galaxies with higher Σ_{SFR} tend to exhibit high- σ tails, which the authors interpreted as increased outflow activity due to star formation. More recently, in a sample of star-forming SAMI galaxies, Varidel et al. (2020) found the vertical gas velocity dispersion correlates more strongly with Σ_{SFR} than with SFR.

Recent studies using MaNGA (Bundy et al. 2015) have also found strong links between Σ_{SFR} and winds. Avery et al. (2021) found that galaxies with star formation-driven outflows (as identified by the presence of broad H α components in aperture spectra) tend to have overall $\Sigma_{\text{SFR}} \gtrsim 10^{-2} \text{ M}_{\odot} \text{ yr}^{-1} \text{ kpc}^{-2}$. Earlier, Roberts-Borsani et al. (2020) found that neutral outflows (as traced by interstellar NaD absorption) are only detected in galaxies with $\Sigma_{\text{SFR}} \gtrsim 10^{-2} \text{ M}_{\odot} \text{ yr}^{-1} \text{ kpc}^{-2}$. These thresholds are remarkably similar to that we find between the 1- and multi-component galaxies (Fig. 2).

Similar trends have been found between the presence of thick ionised gas disks and Σ_{SFR} . Rossa & Dettmar (2003) detected extraplanar gas only in galaxies above a certain Σ_{SFR} threshold, and

using a small sample of galaxies, Rueff et al. (2013) found that DIG becomes brighter and more filamentary as Σ_{SFR} increases. More recently, Belfiore et al. (2022) found that the velocity dispersions of DIG-dominated spaxels (identified by enhanced forbidden line emission) only become significantly larger than the velocity dispersions in H II region-dominated spaxels in galaxies with high global SFRs. This suggests that at sufficiently low SFRs, it may not be possible to resolve DIG from H II region emission using our spectral decomposition technique. Together with the correlation between stellar mass and SFR (Fig. 3), this may explain why there are few multi-component galaxies with $M_{*} \lesssim 10^9 \text{ M}_{\odot}$. These and other spectral resolution considerations are discussed in Section 7.2.2.

It is therefore possible that these thick gas disks may be present in most of the star-forming galaxies in our sample, but that they are only detectable with SAMI above a certain Σ_{SFR} and/or stellar mass threshold. Unresolved thick gas disks could explain the population of high- Σ_{SFR} 1-component galaxies as discussed in Section 4.1.1: as shown in Fig. 4, these systems have low stellar masses and low SFRs, but are very compact and so have high Σ_{SFR, R_e} . Confirming this scenario would require higher spectral resolution observations.

As shown in Fig. 7, spaxels residing in galaxies with higher Σ_{SFR, R_e} are more likely to exhibit multiple emission line components regardless of their local Σ_{SFR} . An analogous effect was found by Law et al. (2022), who found global SFR to correlate more strongly with the H α velocity dispersion than the local Σ_{SFR} . This trend can be explained by projection effects. A hot wind originating from a high- Σ_{SFR} region of a galaxy will accelerate cloud fragments from the disk outwards in a spherical fashion (Cooper et al. 2008, 2009), forming dramatic biconical structures such as that observed in M82 (Lynds & Sandage 1963; Bland & Tully 1988; Shopbell & Bland-Hawthorn 1998). Due to orientation effects, H α -emitting filaments in the wind may therefore intersect lines of sight towards lower- Σ_{SFR} regions of the galaxy that are not involved in launching the wind; this would also apply to gas returning to the disk via a galactic fountain, in the process forming a thick ionised gas disk. Evidence for these LoS effects has been observed in the Large Magellanic Cloud, in which highly ionised winds, traced by broad [O VI] absorption, can be seen along lines of sight towards both locations of active star-formation and quiescent regions (Howk et al. 2002; Barger et al. 2016). Our results suggest that spectral decomposition may be a viable way to detect this phenomenon in unresolved systems.

7.2 Observational biases

Here, we discuss several sources of observational bias which may be important to consider when carrying out any study relying on multi-component emission line fits.

7.2.1 Reliability of component identification

As detailed in Hampton et al. (2017a), LZCOMP, the ANN used to classify spaxels as containing 1, 2 or 3 emission line components, is trained using human observers; as such, its reliability as a function of S/N is unclear. Due to our conservative S/N and data quality cuts on the 2nd and 3rd kinematic components within each spaxel (as detailed in Section 2.1), we assume that our sample of 2- and 3-component spaxels is unlikely to contain misclassified 1-component spaxels. However, our sample of 1-component spaxels may contain misclassified spaxels that in fact contain 2 (or more) components; here, we perform two tests to determine the degree of contamination within our 1-component spaxel sample. 3-component spaxels are not

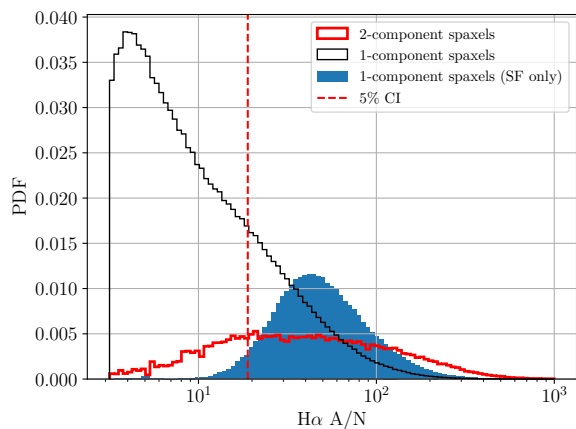


Figure 9. PDFs of $H\alpha$ A/N in all 2-component spaxels (red), all 1-component spaxels (black) and SF 1-component spaxels (blue). The vertical dashed line shows the 5% confidence interval for the 2-component spaxels.

discussed due to their rarity (representing < 1 per cent of all spaxels; see Section 3).

First, we investigate the impact of A/N on the classification process, where A/N is defined as the peak amplitude of the $H\alpha$ line (measured directly from the spectrum, and therefore not corrected for stellar absorption) relative to the mean continuum level within the rest-frame wavelength range 6500 Å–6540 Å divided by the RMS noise within the same range. We assume that LZCOMP begins to misclassify multi-component spaxels as 1-component below some A/N threshold, which we define as the 5 per cent confidence interval of the A/N distribution of the 2-component spaxels that pass our S/N and data quality cuts. In Fig. 9 we show distributions in A/N in all 2-component spaxels (red), all 1-component spaxels (black) and SF 1-component spaxels (blue). The vertical dashed line shows the 5% confidence interval for the 2-component spaxels of approximately 19. Whilst over 40% of all 1-component spaxels have A/N below this threshold, fewer than 2% of SF spaxels fail this criterion. Under the assumption that A/N is an important factor influencing the ANN, this implies that the SF 1-component spaxels, which are the focus of this work, are unlikely to be contaminated by a significant amount of low-S/N 2-component spaxels.

We now check the reliability of the ANN classification by inspecting the velocity dispersions of components measured within 1- and 2-component spaxels. When 2-component spaxels are fitted with a single component, the width of the best-fit Gaussian tends to be broader by an average of around 10 km s^{-1} than that of the narrow component in the 2-component fit, as shown in Fig. 10. We therefore compare the measured velocity dispersions in 1- and 2-component spaxels to estimate the contamination of misclassified multi-component spaxels in our sample of 1-component spaxels.

First, we consider all spaxels in the SAMI sample. In the top panel of Fig. 11a, we show σ_{gas} distributions for 1-component spaxels (shaded blue), σ_{narrow} and σ_{broad} of the 2-component spaxels (open purple and open pink respectively), and of σ_{gas} from the 1-component fits to the 2-component spaxels (shaded orange). The corresponding means, standard deviations, medians and interquartile ranges (IQRs) are reported in Table 4. If there were a significant population of 2-component spaxels contaminating the sample of 1-component spaxels, then the blue histogram would be skewed towards values similar to the orange histogram. This is indeed the case: the IQR of the 1-component spaxels is skewed to larger values of σ_{gas} compared to the narrow component in 2-component spaxels.

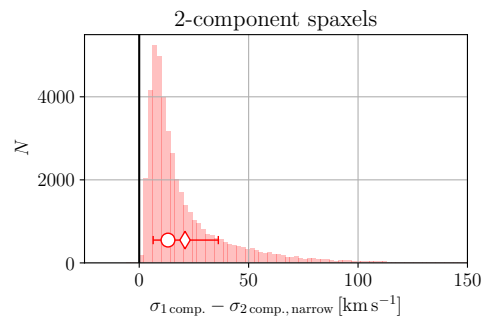


Figure 10. Distribution in the difference between the velocity dispersion of the 1-component fit and the narrow component in the 2-component fit for 2-component spaxels. The median and mean in the distribution are indicated by the white circle and diamond respectively, where the horizontal error bar represents the interquartile range.

However, as shown in the bottom panel of Fig. 11a, among the SF spaxels, which are the focus of this work, the distribution in σ_{gas} of the 1-component spaxels is similar to that of σ_{narrow} in the 2-component spaxels, whereas the distribution in σ_{gas} of the 1-component fits to the 2-component spaxels is markedly offset by approximately 10 km s^{-1} . The purple histogram is in fact skewed towards higher values of σ_{gas} than the blue histogram, and the two distributions are statistically significantly different according to the KS and AD tests with p -values $\ll 0.05$ for both tests. This would be consistent with there being only minimal contamination by 2-component spaxels amongst the SF 1-component spaxels. We also note that among both the 1-component SF spaxels and the narrow component of the 2-component SF spaxels, the average velocity dispersion $\sigma_{\text{gas}} \approx 30 \pm 10 \text{ km s}^{-1}$, which is similar to that of the “dynamically cold” ionised gas component associated with SF regions identified by Law et al. (2021); meanwhile, the typical velocity dispersions of the broad component in 2-component SF spaxels is similar to that of their “dynamically hot” component.

We now consider how contamination of misclassified 2-component spaxels may affect our galaxy classification (Section 3). In Fig. 11b, we compare the σ_{gas} of 1-component spaxels in 1-component galaxies (open dashed blue histogram) to σ_{narrow} in the 2-component spaxels in multi-component galaxies (open purple). In comparison with Fig. 11a, there is a larger difference between the two distributions, such that the purple histogram is even more skewed towards higher values. This is consistent with our hypothesis that there is only minimal contamination of misclassified 2-component spaxels within the 1-comp. galaxies. Meanwhile, the 1-component spaxels in multi-component galaxies (shaded blue histogram) are much broader than the narrow component in the 2-component spaxels, and have a distribution skewed towards that of the 1-component fits to the 2-component spaxels, suggesting that some 1-component spaxels in the 2-component galaxies may represent misclassified 2-component spaxels.

From these two tests, we conclude that our analysis is unlikely to be affected by misclassified multi-component spaxels. Although our multi-component galaxies may contain significant numbers of broad 1-component spaxels that may be misclassified multi-component spaxels, this effect is probably minimal in the 1-component galaxies, indicating that our galaxy classification scheme is robust against contamination of misclassified multi-component spaxels.

Table 4. Means, standard deviations, and percentiles for the velocity dispersion distributions shown in Fig. 11. 3-component spaxels are not included due to their rarity compared to 2-component spaxels. All values are in units of km s^{-1} .

Quantity	Mean	Std. dev.	16th percentile	Median	84th percentile
All spaxels					
σ of 1-comp. spaxels	40.54	27.76	22.31	31.79	57.14
σ_{narrow} of 2-comp. spaxels	34.08	16.22	21.82	29.79	45.33
σ_{broad} of 2-comp. spaxels	101.34	61.91	62.93	87.90	134.04
σ of 1-comp. fit to 2-comp. spaxels	55.00	32.14	30.94	44.69	79.60
SF spaxels					
σ of 1-comp. spaxels	29.24	11.38	20.40	26.37	37.45
σ_{narrow} of 2-comp. spaxels	30.19	11.03	20.96	27.61	39.32
σ_{broad} of 2-comp. spaxels	86.81	42.53	59.83	80.98	109.49
σ of 1-comp. fit to 2-comp. spaxels	44.88	18.79	29.52	39.74	60.07
SF spaxels in 1-component galaxies					
σ of 1-comp. spaxels	24.94	6.19	19.30	23.92	30.53
SF spaxels in multi-component galaxies					
σ of 1-comp. spaxels	38.74	15.61	25.87	34.31	51.37
σ_{narrow} of 2-comp. spaxels	30.43	9.82	21.65	28.26	39.23
σ_{broad} of 2-comp. spaxels	86.10	27.03	63.81	81.63	105.68
σ of 1-comp. fit to 2-comp. spaxels	45.12	17.55	30.62	40.20	59.34

7.2.2 Spectral resolution limitations

In general, individual emission line components cannot be resolved by a spectrograph with resolution σ_{inst} if the difference between the LoS velocities of the broad and narrow components $v_{\text{broad}} - v_{\text{narrow}} := \Delta v \lesssim \sigma_{\text{inst}}$ and the difference in the velocity dispersions $\sigma_{\text{broad}} - \sigma_{\text{narrow}} := \Delta\sigma \lesssim \sigma_{\text{inst}}$.

The inability of SAMI to detect multiple emission line components closely spaced in both velocity and velocity dispersion is demonstrated in Fig. 12, where we plot all 2-component spaxels in the $\Delta v - \Delta\sigma$ plane. Again, we do not consider 3-component spaxels here due to their rarity in comparison with 2-component spaxels. There is a “hole” roughly defined by $\Delta\sigma \lesssim \sigma_{\text{inst}}$ and $|\Delta v| \lesssim \sigma_{\text{inst}}$, at which point multiple emission line components can no longer be distinguished at the spectral resolution of SAMI. If $\Delta\sigma \lesssim \sigma_{\text{inst}}$ but $|\Delta v| \gg \sigma_{\text{inst}}$, i.e. the two components have similar widths, but are sufficiently separated in LoS velocity, then the two components can be distinguished. Conversely, if $|\Delta v| < \sigma_{\text{inst}}$ but $\Delta\sigma \gg \sigma_{\text{inst}}$, i.e. the two components have similar LoS velocities but have substantially different widths, then the two components can be distinguished as well. The spaxels lying closest to the “forbidden” region of the parameter space tend to reside in less massive galaxies; we therefore conclude that with SAMI we may be unable to reliably detect DIG/thick ionised gas disks using this method in low-mass systems, as discussed in Section 7.1.

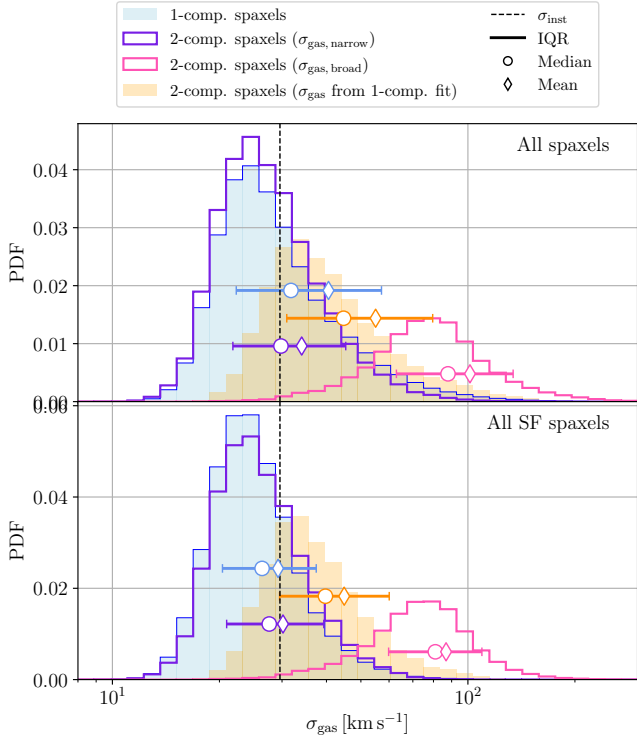
In Fig. 12 we also indicate the spectral resolution of MaNGA (approximately 70 km s^{-1} ; e.g., Law et al. 2022) by the dotted lines. As shown by the black contours, which trace the distribution of 2-component spaxels in the $\Delta v - \Delta\sigma$ plane, approximately 53 per cent of 2-component spaxels that can be detected with SAMI have $\Delta v < \sigma_{\text{inst, MaNGA}}$, indicating that typical broad emission line components in local galaxies cannot be resolved with MaNGA using the standard spectral decomposition technique employed here. This demonstrates the importance of high spectral resolution when conducting detailed studies of gas kinematics.

7.2.3 Inclination effects

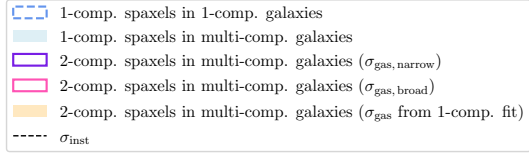
As discussed in Section 3 and as shown in Fig. 2b, multi-component galaxies are under-represented at near-face-on and near-edge-on inclinations. Additionally, at a fixed local Σ_{SFR} , spaxels residing in galaxies at higher inclinations are less likely to exhibit multiple components (Fig. C3b). There are several possible explanations for this.

At higher inclinations, extraplanar gas or winds above and below the disk plane may not share a LoS with gas in the thin disk, and would therefore be visible as a single, but broad, component. In a subset of edge-on SAMI galaxies, Ho et al. (2016b) identified wind-dominated and DIG-dominated systems by assuming that winds should exhibit higher velocity dispersions and greater asymmetry in the velocity field beyond the disk plane compared to DIG. Of their 15 wind-dominated systems, two are present in our 1-component sample, and two of our multi-component galaxies are found. Meanwhile, their sample of DIG-dominated edge-on systems contains 7 of our 1-component galaxies and no multi-component galaxies. This suggests that the presence of multiple emission line components may be an unreliable method for detecting winds and DIG in edge-on systems. However, their sample of edge-on galaxies was chosen to have axis ratios $b/a < 0.26$, corresponding to only 23 galaxies in our parent sample of 655 galaxies, indicating that our spectral decomposition technique is unlikely to be missing a large number of wind- and DIG-dominated galaxies in our sample due to edge-on inclination effects. Of the 18 high- Σ_{SFR} 1-component galaxies discussed in Section 4.1.1, only two have $b/a < 0.26$, indicating that the lack of observed complex line profiles in these objects is unlikely to result from inclination effects.

The lack of high-inclination multi-component galaxies may also be due to spectral resolution limitations. In Fig. 13 we plot the velocity dispersions of the narrow and broad components (σ_{narrow} and σ_{broad} respectively), plus $\Delta\sigma$, as a function of inclination. σ_{narrow} is weakly correlated with inclination, most likely due to the artificial broadening of emission lines in more highly-inclined systems due to rotation, whereas σ_{broad} is anticorrelated. The observed trends



(a)



(b)

Figure 11. Velocity dispersion distributions within different subsets of spaxels. Panel (a) shows normalised velocity dispersion distributions for 1-component spaxels (pale blue outlined histogram), the narrow component in 2-component spaxels (purple outlined histogram) and that of 1-component fits to 2-component spaxels (shaded orange histogram) for all spaxels (top panel) and for SF spaxels only (bottom panel). Panel (b) shows velocity dispersion distributions for subsets of SF spaxels within 1- and multi-component galaxies. 1-component spaxels in 1- and multi-component galaxies are represented by the dashed blue and shaded pale blue histograms respectively. The narrow and broad components in 2-component spaxels in multi-component galaxies are shown in the purple and pink outlined histograms respectively, and the shaded orange histogram represents the 1-component fit to the 2-component spaxels. Corresponding medians and means are indicated by the circles and diamonds respectively, and IQRs are shown by the error bars; values are given in Table 4. The SAMI instrumental resolution is indicated by the black dashed line.

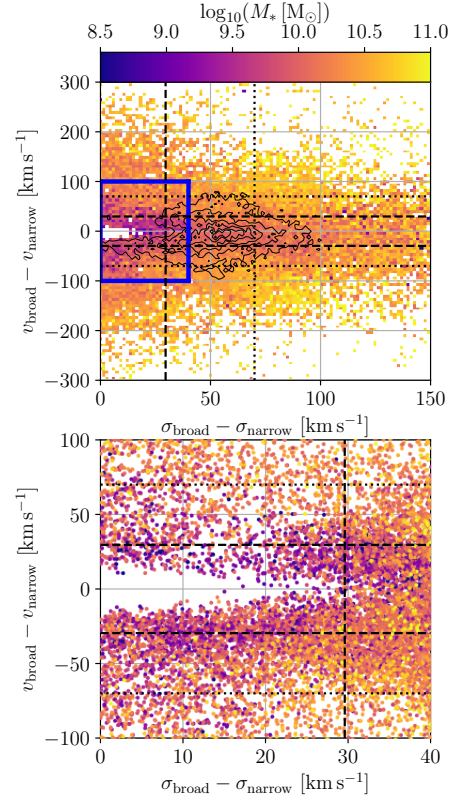


Figure 12. Δv vs. $\Delta\sigma$ for individual spaxels with two components, coloured by the stellar mass of their host galaxy. In the upper panel, the data is represented as a 2D histogram, in which the colour of each cell represents the median M_* of all spaxels falling within that cell, and the black contours show the number distribution of spaxels on a log scale. The lower panel shows an inset view of the left-hand plot (indicated by the blue rectangle), where spaxels are shown individually as circles. The dashed lines represent the spectral resolution of SAMI (29.6 km s^{-1}) and the dotted lines represent the MaNGA spectral resolution (approximately 70 km s^{-1}), indicating that MaNGA would be unable to spectrally resolve approximately 53 per cent of the multi-component spaxels identified in this work.

may arise if the vertical component of the velocity dispersion σ_{zz} is larger than the azimuthal or radial components $\sigma_{\phi\phi}$ and σ_{rr} . Such anisotropy may be expected in the presence of galactic winds (Marinacci et al. 2010) where material is preferentially launched out of the disk plane. However, this explanation contradicts the findings of Law et al. (2022), who found that $\sigma_{zz} < \sigma_{\phi\phi}, \sigma_{rr}$ in a sample of local star-forming galaxies, although their analysis is based upon the $\text{H}\alpha$ velocity dispersion measured from single Gaussian fits to lower-resolution MaNGA data.

Rather, the anticorrelation between σ_{broad} and inclination most likely originates from observational effects. Galactic fountains may lead to the formation of a thick ionised gas disk which has a negative vertical velocity gradient resulting in a slower circular velocity than the thin disk (Swaters et al. 1997; Levy et al. 2018, 2019; Marasco et al. 2019). In this configuration, the LoS velocity separation between the thin and thick disks increases as a function of inclination, whilst in face-on systems $\Delta v \sim 0 \text{ km s}^{-1}$. Referring to Fig. 12, SAMI is unable to resolve multiple emission line components when $\Delta v \lesssim \sigma_{\text{inst}}$ and $\Delta\sigma \lesssim \sigma_{\text{inst}}$. Therefore, in face-on systems, we may only spectrally resolve broad emission line components from thick disks if $\Delta\sigma > \sigma_{\text{inst}}$, whereas in highly inclined systems, spaxels with $\Delta\sigma < \sigma_{\text{inst}}$ may be resolved as long as $\Delta v > \sigma_{\text{inst}}$. As a

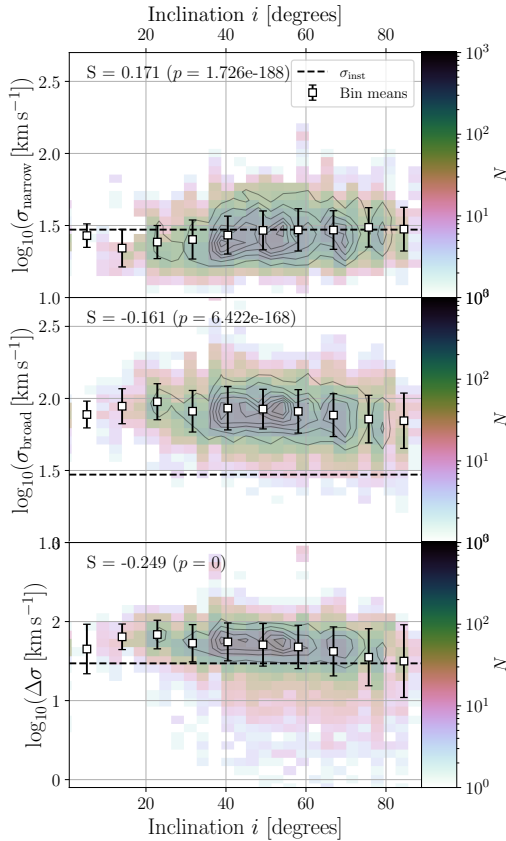


Figure 13. Distribution of all 2-component spaxels in σ_{narrow} , σ_{broad} and $\Delta\sigma$ as a function of inclination. The white squares show median values and the error bars represent the standard deviation in different inclination bins. The horizontal dashed lines represent the SAMI instrumental resolution of 29.6 km s^{-1} . The Spearman’s rank-order correlation coefficient and accompanying p -value is shown in the upper right-hand corner.

result, at low inclinations, we can only detect thick disks in which $\Delta\sigma > \sigma_{\text{inst}}$, whereas at higher inclinations we may detect thick disks with a wider range of velocity dispersions. Our inability to spectrally resolve face-on thick disks may therefore explain the lack of spaxels with $\Delta\sigma < \sigma_{\text{inst}}$ at inclinations $\lesssim 20^\circ$.

In wind-dominated systems, we can expect $\Delta v \gg 0 \text{ km s}^{-1}$ in low-inclination systems, meaning that in principle it would be possible to resolve a broad component with $\Delta\sigma < \sigma_{\text{inst}}$. However, winds typically have $\Delta\sigma \gg \sigma_{\text{inst}}$ due to large turbulent motions and outflow velocities; this is therefore consistent with the lack of spaxels with $\Delta\sigma < \sigma_{\text{inst}}$ at low inclinations.

Finally, it is also possible that multi-component galaxies are intrinsically “puffier” than their 1-component counterparts, biasing inclination measurements towards lower values due to our assumption of a fixed disk thickness of $q_0 = 0.2$.

8 CONCLUSIONS

We applied a spectral decomposition technique to distinguish line emission from the star-forming thin disk and winds and/or thick disks in star-forming galaxies from the SAMI Galaxy Survey. Our conclusions are as follows:

(i) The presence of complex emission line profiles in star-forming galaxies is strongly correlated with the global Σ_{SFR} of the host galaxy,

even when controlling for sample biases in stellar mass and SFR, and observational effects such as inclination, angular scale and A/N. This correlation is consistent with previous studies that have found a strong connection between Σ_{SFR} and both thick ionised gas disks and winds. In fact, virtually all galaxies in our sample that contain a significant fraction of spaxels with complex emission line profiles have $\Sigma_{\text{SFR}} \gtrsim 10^{-2} \text{ M}_\odot \text{ yr}^{-1} \text{ kpc}^{-2}$, which is remarkably similar to the value found by Roberts-Borsani et al. (2020).

(ii) Whilst *global* Σ_{SFR} , measured via Σ_{SFR, R_e} , is the quantity that is most strongly correlated with the fraction F_{R_e} of multi-component spaxels within individual galaxies within $1R_e$, the fraction f_n of individual spaxels containing multiple components is also strongly dependent on the local Σ_{SFR} measured within individual spaxels. We also find that, at a fixed local Σ_{SFR} , spaxels in galaxies with higher global Σ_{SFR} are more likely to exhibit multiple components. This illustrates the importance of considering global galaxy properties when conducting studies of individual spaxels in IFS surveys.

(iii) There is a strong residual correlation between Σ_{SFR, R_e} and F_{R_e} when controlling for Gini coefficient G , suggesting that global Σ_{SFR} is more important than clumpiness in dictating the presence of widespread complex emission line profiles within a galaxy.

(iv) The strong correlation between Σ_{SFR} and the presence of complex emission line profiles is consistent with the findings of previous studies that have employed different techniques to identify winds and thick ionised gas disks. This indicates that the spectral decomposition technique is an effective means of identifying these phenomena in local galaxies.

(v) SAMI is currently the only IFS survey with sufficient spectral resolution to resolve multiple emission line components in local galaxies using the spectral decomposition technique employed here. However, SAMI is likely unable to detect broad emission line components in low-mass galaxies, where the LoS velocity and velocity dispersion offsets between the narrow and broad components are smaller than the instrumental resolution. Hector (Bryant et al. 2020), the successor to SAMI, will have a comparable spectral resolution, enabling similar studies to be carried out on a much larger sample of over 10,000 galaxies.

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The majority of this research was carried out on the traditional lands of the Ngunnawal and Ngambri people, and the observations presented in this work were gathered at Siding Spring Observatory, located on the traditional lands of the Gamilaraay/Kamilaroi people.

DATA AVAILABILITY

The data used in this paper is from the SAMI Galaxy Survey Data Release 3 which is available at <https://docs.datacentral.org.au/sami/>. SPAXELSLEUTH, the PYTHON package used to carry out all analysis in this work, is available at <https://github.com/hzovaro/spaxelsleuth>.

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APPENDIX A: EXAMPLE LZIFU FITS

Example emission line fits to a selection of randomly-chosen 1, 2 and 3-component spaxels is shown in Fig. A1.

APPENDIX B: UNRESOLVED SELECTION CRITERIA

As discussed in Section 3, we repeated our 1- and multi-component galaxy classification using aperture spectra to see whether there are any galaxies with low surface-brightness broad emission lines not detected in individual spaxels, but present in aperture spectra.

Following Avery et al. (2021), aperture spectra were created by summing spaxels within $1R_e$ after having the LoS velocity subtracted (measured from the DR3 1-component fits to the resolved data), to minimise the effects of beam smearing on the final line widths. 1- and 2-component emission line fits were carried out using LZIFU (Ho et al. 2016a).

We classified multi-component galaxies as those for which the likelihood ratio test (LRT) described in Ho et al. (2014) preferred the 2-component emission line fit to the 1-component fit at a statistical significance of $p < 0.05$; 1-component galaxies were those not meeting this criterion, but in which the 1-component fit was preferred to a stellar continuum-only fit at $p < 0.05$. In addition to these, we required that the spectral classification be star-forming (using the total fluxes summed over all fitted components); in all fitted components, both $H\alpha$ and $[N\text{II}]\lambda 6583$ must have flux $S/N > 5$, flux $A/N > 3$, and σ S/N of 3 as per Section 2.1. This resulted in 746 1-component galaxies and 125 multi-component galaxies.

The unresolved scheme identified over twice as many 1-component galaxies (746 versus 266), likely due to the inclusion of galaxies with fewer than 50 spaxels with sufficient emission line S/N to be classified using the resolved data. However, there was considerable disagreement between the resolved and unresolved classification schemes. Of the galaxies classified as 1- and multi-component using the resolved criteria, 31 and 42 respectively were unclassified using the aperture spectra; and of those classified as 1- and multi-component using the aperture spectra, 496 and 50 were unclassified using the resolved criteria. Only 222 1-component and 68 multi-component galaxies had consistent classifications using both methods.

Interestingly, there were no multi-component galaxies identified by the unresolved criteria that were classified as 1-component galaxies using the spatially resolved data, suggesting that there are no galaxies with faint broad components that can only be observed in aperture spectra extracted using this technique. In fact, there were 20 galaxies classified as multi-component using the resolved data that were classified only as 1-component galaxies using the aperture spectra.

There are several potential explanations for this; firstly, faint broad components that are detectable in individual spaxels may be overwhelmed by very strong narrow-component emission from other

spaxels when summed to create the aperture spectra. Additionally, the LoS velocity subtraction was carried out using the single-Gaussian component fits in DR3, which are heavily biased towards the narrow component, as it is generally much stronger than any broad components. Whilst this step minimises the effects of beam smearing on the narrow component, the broad component may be significantly affected by beam smearing as it traces a distinct structure with separate kinematics. This may reduce its amplitude relative to the narrow component to the extent that it falls below the A/N criterion, meaning these galaxies will not be classified as multi-component galaxies. Lastly, any multi-component spaxels located at $r > R_e$ would not be included in the aperture spectra. These factors demonstrate the utility of spatially resolved spectroscopy for analysing detailed gas kinematics. We therefore opted to use only the resolved data for this work.

APPENDIX C: ADDITIONAL PLOTS AND TABLES

Fig. C1 shows a ‘‘punnet square’’ plot showing the median offsets between various parameters between the 1- and multi-component samples matched in a number of quantities.

Fig. C2 shows the counterpart of Fig. 5 made using $\Sigma_{\text{SFR}, 3\text{kpc}}$ rather than Σ_{SFR, R_e} .

Fig. C3 shows f_n as a function of local Σ_{SFR} binned by $\Sigma_{\text{SFR}, 3\text{kpc}}$, host galaxy inclination, angular scale, and projected spaxel radius.

This paper has been typeset from a $\text{\TeX}/\text{\LaTeX}$ file prepared by the author.

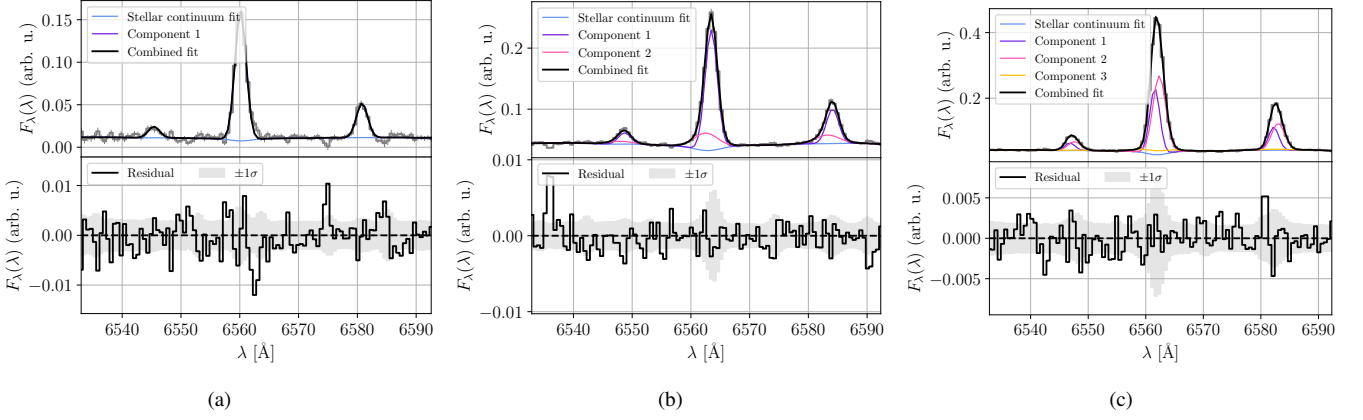


Figure A1. Example LZIFU fits to the H α and [N II] $\lambda\lambda$ 6548, 83 lines from randomly chosen spaxels with one (a), two (b) and three (c) components meeting the S/N and data quality cuts discussed in Section 2.1. In each figure, the upper panel shows the data plus 1σ errors in grey, the stellar continuum fit in light blue, and individual Gaussian components for the narrow, broad and extra-broad components in purple, pink and orange respectively, plus the total fit in black. The lower panel shows the residual in black with $\pm 1\sigma$ errors indicated in grey.

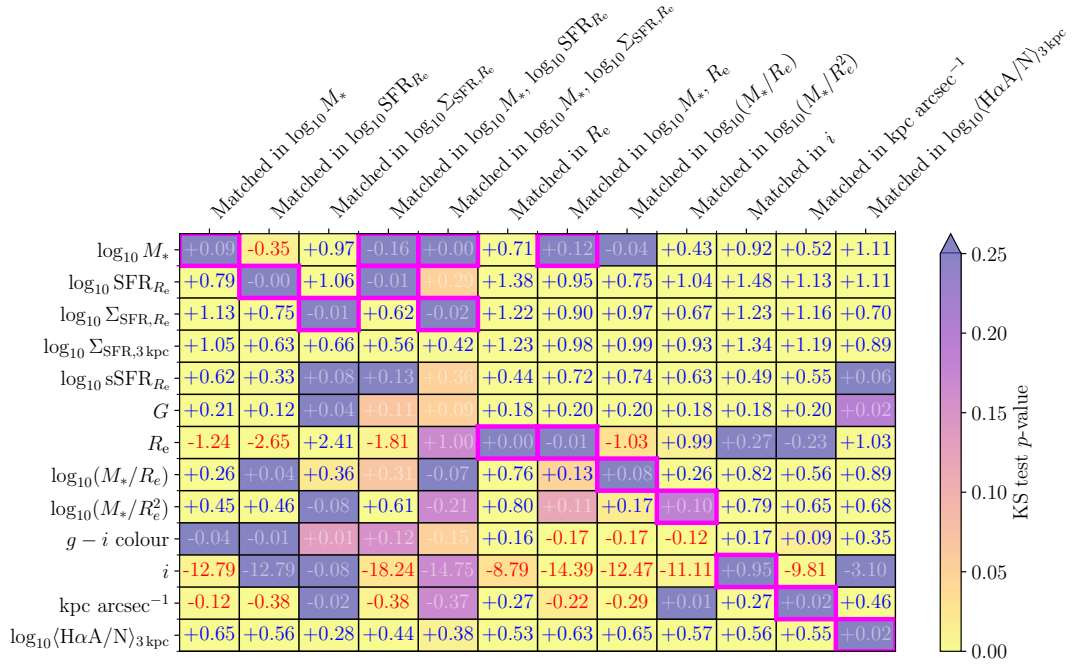


Figure C1. Results from the matched sample analysis in Section 4. Each cell compares the distributions in the *row* quantity between the 1- and multi-component galaxies when matched in the *column* quantity. The cell colour represents the p -value from the two-sample KS applied to the matched samples measured in the *row* quantity; in dark-coloured cells the distributions are similar, whereas pale colours indicate that the distributions are highly unlikely to be drawn from the same parent sample, i.e., that the 1- and multi-component matched samples are significantly different. The number in each cell represents the difference in the median values of the row quantity between the 1- and multi-component matched samples. Cells in which the p -value is below the significance threshold of 0.05 are indicated by coloured text, where red values indicate a *lower* median value and blue values a *higher* median value in the multi-component matched sample than the 1-component matched sample. For example, when matched in SFR (2nd column), the stellar mass distributions of the 1- and multi-component galaxies (top row) are significantly different, as indicated by the bold text and pale cell colour, and the matched multi-component galaxies have a median stellar mass 0.35 dex lower than that of the 1-component galaxies. Meanwhile, the matched samples have similar distributions in $\log_{10}(M_*/R_e)$ (8th row) as indicated by the dark cell colour.

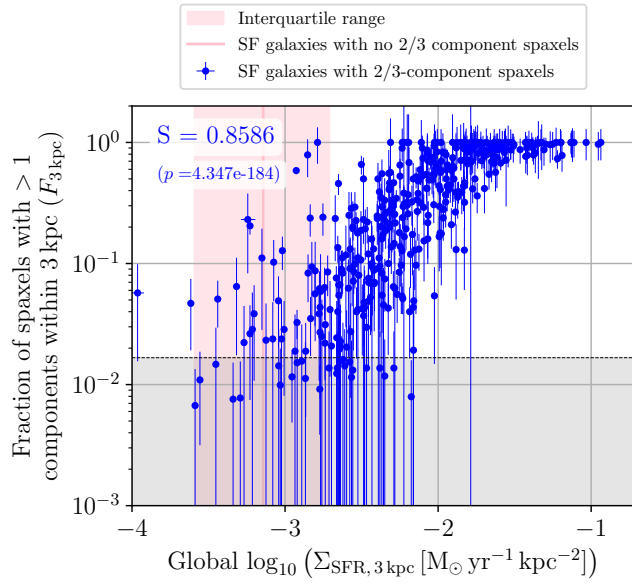


Figure C2. Same as Fig. 5 with $\Sigma_{\text{SFR}, 3 \text{ kpc}}$ substituted for Σ_{SFR, R_e} .

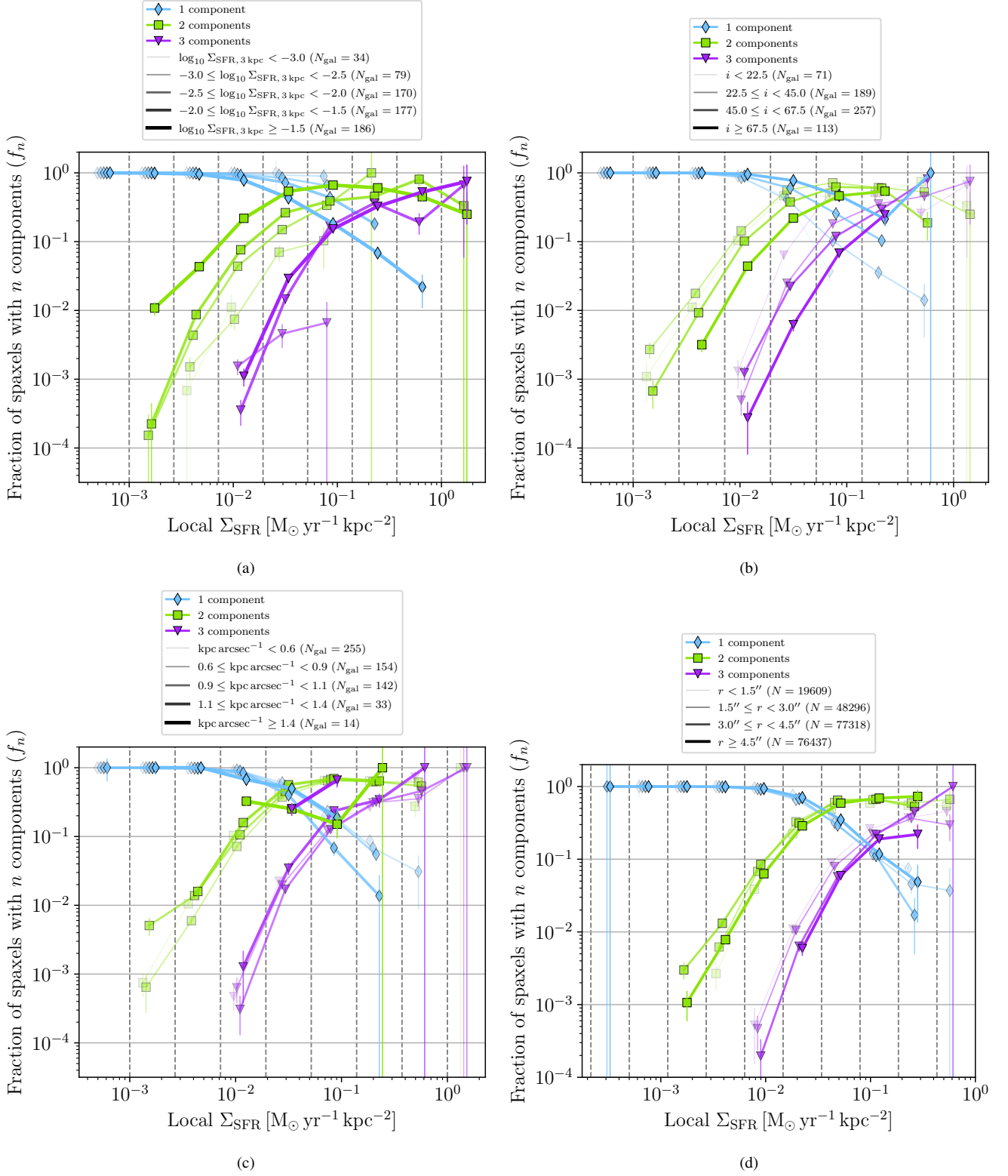


Figure C3. Same as Fig. 7 but binned by (a) $\Sigma_{\text{SFR}, 3 \text{ kpc}}$, (b) host galaxy inclination, (c) angular scale and (d) projected spaxel radius.