Emission line galaxies in the SHARDS Frontier Fields – I. Candidate selection and the discovery of bursty Hα emitters

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ABSTRACT

Emission line galaxies provide a crucial tool for the study of galaxy formation and evolution, providing a means to trace a galaxy’s star formation history or metal enrichment, and to identify galaxies at a range of stellar masses. In this paper, we present a study of emission line galaxies in the Survey for High-redshift Absorption Red and Dead Sources (SHARDS) Frontier Fields (FF) medium-band survey. Through detailed flux calibrations we combine the first results of the SHARDS-FF survey with existing Hubble Frontier Field data to select 1098 candidate emission line galaxies from the Hubble Frontier Filed clusters Abell 370 and MACS J1149.5+2223. Furthermore, we implement this deep medium-band imaging to update photometric redshift estimates and stellar population parameters and discover 38 predominantly low-mass Hα emitters at redshifts 0.24 < z < 0.46. Overall, 27 of these sources have corresponding ultraviolet (UV) data from the Hubble Space Telescope that allow us to distinguish these sources and investigate the burstiness of their star formation histories. We find that more than 50 per cent of our sample shows an enhancement in Hα over UV, suggesting recent bursts in star formation on time-scales of a few to tens of Myr. We investigate these sources and find that they are typically low-mass discy galaxies with normal sizes. Their structures and star formation suggest that they are not undergoing mergers but are bursting due to alternative causes, such as gas accretion.

Key words: galaxies: clusters: general – dark ages, reionization, first stars – ultraviolet: galaxies.

1 INTRODUCTION

Obtaining an accurate picture of galaxy formation and evolution is amongst the most outstanding questions in astrophysics today. There have been many studies examining this process in some detail over the past 30 yr or so, including extensive Hubble Space Telescope (HST) campaigns (e.g. Conselice et al. 2003; Beckwith et al. 2006; Grogin et al. 2011; Duncan et al. 2019) and ground-based imaging studies (e.g. Steidel et al. 2004; Mundy et al. 2017). One of the most critical aspects for studying galaxy formation and evolution is to determine the redshifts of objects such that their evolutionary connections can be made, either through mass or number density selections to connect systems at different points in their evolution (e.g. Mundy, Conselice & Ownsworth 2015).

Two major ways in which galaxy studies progress are through the investigation of galaxies at different redshifts, and by using the emission of light (direct or indirect) from these systems to measure the amount of current star formation and past assembly of stellar mass. The process of star formation is fundamental for understanding the assembly of galaxies and how the Universe was reionized. However, our resulting understanding of the star formation history (SFH) of galaxies is largely based on observations of single integrated light measures of star formation rate (SFR) within entire galaxies, over a variety of redshifts (e.g. Madau & Dickinson 2014). While much work in this area has been done, we are just starting to understand how and why star formation is distributed within galaxies. We also know that the sources of reionization are likely galaxies at z > 6 (e.g. Duncan & Conselice 2015; Robertson et al. 2015), yet we do not know from which types of galaxies, or modes of galaxy formation, ionizing radiation is emitted from. Both of these problems can be addressed in unique ways by searching for and characterizing emission line systems in the distant Universe, and perhaps by examining analogue galaxies at lower redshifts, such as the ‘green peas’ and Lyman α (Lyα) emitters at z ∼ 1.5 (e.g. Izotov, Thuan & Guseva 2017; Matthee et al. 2021).

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There are in general three ways in which galaxies in the distant Universe are discovered. The most reliable method is through spectroscopic surveys, by accurately measuring the wavelengths of a few features in the spectrum of a galaxy, its redshift can be determined with a high accuracy (e.g. Zhou et al. 2019). However, spectroscopy of significant samples is still very difficult to obtain, and only future programs and telescopes such as Multi-Object Optical and Near-infrared Spectrograph (MOONS; Maiolino et al. 2020), WHT Enhanced Area Velocity Explorer (WEAVE; Dalton et al. 2020), and 4-metre Multi-Object Spectroscopic Telescope (4MOST; de Jong et al. 2019) will make significant progress towards obtaining significant numbers of redshifts for galaxies. Furthermore, the future of this field is ‘blind’ spectroscopy, with integral field units (IFUs) such as Multi Unit Spectroscopic Explorer (MUSE), where pre-selection is not required, as it is for most traditional spectroscopic surveys.

Alternatively one can use photometric redshifts to locate the redshifts of distant galaxies by fitting intrinsic spectral energy distributions (SEDs) to stellar population models (e.g. Dahlen et al. 2013). An alternative simplified version of this is to use the Lyman-break dropout method, whereby one finds the Lyman break by searching for galaxies that have a faint or statistically non-existing flux in an observed filter, traditionally the $U$ band (e.g. Koo & Kron 1980; Guhathakurta, Tyson & Majewski 1990; Steidel & Hamilton 1993; Steidel et al. 2004).

The final method is to use line emission as detected in narrow-band imaging. Searching for and examining distant galaxies using line emission through narrow-band imaging has a long history. Traditionally, the Ly$\alpha$ line is used to locate and study distant galaxies (Rhoads et al. 2000; Malhotra & Rhoads 2004; Ouchi et al. 2010; Stark et al. 2010). However, the radiative transfer of Ly$\alpha$ is very complex (e.g. Gronke et al. 2016) as it is a resonant line, such that its photons scatter with neutral hydrogen, and increase the likelihood of dust absorption due to the short wavelengths. Thus, Ly$\alpha$ cannot typically be used to trace the SFR in most galaxies, unless the escape fraction of Ly$\alpha$ photons is known [however, the work of Sobral & Matthee 2019 has calibrated Ly$\alpha$ SFRs with rest-frame equivalent widths (EWs) to within 0.3 dex]. It is often more direct and simpler to use the non-resonant H$\alpha$ (e.g. Geach et al. 2008; Sobral et al. 2013, 2014), or other similar lines such as [O ii] or even [O iii] (e.g. Khostovan et al. 2015). Likewise, if two lines can be measured from the H II regions (such as O III/O II), their ratios give an indication for the content of the radiation coming from these star-forming areas (e.g. Izotov et al. 2017) and/or dust.

1.1 H$\alpha$ emitters

For line emitters, Ly$\alpha$ is ideal line for finding distant galaxies due to its brightness, but it is difficult to use this line for measuring astrophysical quantities from these galaxies (see Sobral & Matthee 2019). The emission from H$\alpha$, [O iii], and [O ii] lines are, on the other hand, much less affected by dust than Ly$\alpha$ or ultraviolet (UV) fluxes. These lines are also good for identifying and characterizing galaxies that may have high dust attenuation and thus very faint Ly$\alpha$ emission. In this paper, we present a general search for very faint line emitters using the Survey for High-z Absorption Red and Dead Sources (SHARDS; Pérez-González et al. 2013) data and describe a detailed analysis of the H$\alpha$ emitters we discover.

There has been much progress in this over the past few years. For example, we know that bright H$\alpha$ emitters are very common at low and intermediate redshifts up to $z \sim 3$ (e.g. Sobral et al. 2012, 2013), but more difficult to find at higher $z$ due to technological limitations, as H$\alpha$ quickly redshifts into the near-infrared (NIR) and redder wavelengths at modest redshifts. We also have not yet probed the lowest mass galaxies at these epochs. These may also be moderate redshift counterparts to the Lyman continuum leaking Green Pea galaxies found in the local Universe (e.g. Jaskot & Oey 2013; Yang et al. 2017). They could also be analogues of the numerous systems that reionized the Universe (e.g. Naidu et al. 2020; Griffiths et al., submitted).

Ground-based surveys have also used this H$\alpha$ line as a tracer of star formation in distant galaxies (e.g. Sobral et al. 2009, 2012), finding many sources and a steep luminosity function ($\alpha_{\log L} = \sim -1.6$). H$\alpha$ can also be used to investigate the widely variable SFRs of dwarf galaxies predicted by hydrodynamical simulations (e.g. Ceverino et al. 2016a,b; Smit et al. 2016; Sparre et al. 2017; Emami et al. 2019). Dwarf galaxies are not just simple nearby systems, but are the most common galaxy type in the Universe (e.g. Conselice et al. 2019), but these are extremely difficult to locate and study in the distant Universe. Deep emission line surveys remain one of the best ways to find and study these systems outside the very local Universe, with Ly$\alpha$ surveys providing some of the lowest mass galaxies (Oteo et al. 2015; Matthee et al. 2016; Santos et al. 2020).

Dwarf galaxies with stellar masses of $M_\star < 10^{9.5}$ $M_\odot$ typically experience bursty episodes of star formation on time-scales of a few to tens of Myr (Rodighiero et al. 2011; Shen et al. 2014; Sparre et al. 2017). In order to investigate the bursty star formation of these dwarf galaxies, it is necessary to use observables that trace star formation on different time-scales. Hydrogen recombination lines such as H$\alpha$ and H$\beta$ are produced by short-lived O-stars that have lifetimes of a few Myr such that their emission quickly reaches an equilibrium after the star formation is quenched, allowing us to trace galaxy SFRs on these short time-scales. On the other hand, far-ultraviolet (FUV) continuum photons (1300 < $\lambda$ < 2000 Å) are produced by both O- and B-stars that have much longer lifetimes of 100 Myr such that the FUV emission takes much longer to reach equilibrium. Thus, through the comparison of H$\alpha$ and FUV it is possible to determine variations in a galaxy’s SFR on time-scales of less than 100 Myr (e.g. Glazebrook et al. 1999; Iglesias-Páramo et al. 2004; Lee et al. 2009; Weisz et al. 2012; Dominguez et al. 2015; Ceverino, Klessen & Glover 2018). This is crucial to determine how star formation occurs in these most common galaxies, which are also thought to be a dominant production of Lyman-continuum photons that reionized our Universe (e.g. Duncan & Conselice 2015; Griffiths et al., submitted).

In this paper, we describe a survey for these line emitters using the SHARDS Frontier Fields (FF) data set obtained with the Gran Telescopio Canarias (GTC). The SHARDS-HFF survey is a medium-band survey of the FF, which we combine with the existing deep HST imaging. Our data are unique in that our sources are found in this very deep medium-band imaging from the Hubble Frontier Fields (HFF) area. We use this data to search for line emitters and to describe their basic properties and reveal information about their SFHs. The purposes of this paper are twofold: to describe our data and methodology for finding line emitters in the FFs, and to examine the nearest line emitters that are the H$\alpha$ systems. Further papers in this series will describe the other line emitters, including an investigation of the Lyman-continuum emission for systems at $z \sim 2$–3 (Griffiths et al., submitted).

This paper is thus organized as follows. In Section 2, we discuss the SHARDS medium-band observations and data reduction, as well as ancillary data used. Section 2.2 details the photometric calibration of SHARDS imaging matched to the deep HST broadband data. Photometric redshifts and stellar population parameters are calculated in
Section 2.3. We describe corrections of the broad-band continuum colours and the selection of line emitters in Section 3. We present result and investigate the properties of the Hz emission line galaxies in Sections 4 and 5, and draw conclusions in Section 6. Throughout this paper we adopt a Λ cold dark matter (ΛCDM) cosmological model with ΩΛ = 0.7, ΩM = 0.3, and H = 70 km s⁻¹ Mpc⁻¹. All magnitudes are given in the AB system (Oke 1974).

2 OBSERVATIONS AND DATA REDUCTION

The following analysis presented in this paper is based on new medium-band observations of the HFF galaxy clusters (Lotz et al. 2017), Abell 370 and MACS J1149.5+2223 and their corresponding parallel fields. We also utilize the data sets and multiwavelength photometric catalogues made available through the HFF-DeepSpace project (Shipley et al. 2018). We explain the nature of this data and how we use it in our analyses in the following subsections.

2.1 Data sources

2.1.1 Medium-band observational data

Medium-band (MB) optical imaging data of the Abell 370 and MACS J1149.5+2223 clusters (hereafter A0370 and M1149, respectively) and their parallel fields were obtained as part of the SHARDS-FF survey (PI: Pérez-González). The SHARDS-FF (Pérez-González et al., in preparation) survey is an ongoing observation program of two of the HFF galaxy clusters, obtaining subarcsec-seeing imaging in 25 contiguous filters within the wavelength range 5000–9500 Å, reaching an average spectral resolution R ~ 50. Observations are performed using the Optical System for Imaging and low-Intermediate-Resolution Integrated Spectroscopy (OSIRIS) instrument on the 10.4-m GTC at the Observatorio del Roque de los Muchachos, in La Palma. OSIRIS’s 8.5 × 7.8 arcmin² field of view (FOV) covers both the cluster and parallel HST fields in a single pointing. With observations beginning in 2015 December, a total of 240 h observational time was granted for the program. On completion, the observations will reach at least 3σ sensitivity of m ~ 27 in all the 25 contiguous medium-band filters.

Individual images are reduced using a dedicated OSIRIS pipeline (Pérez-González et al. 2013). The pipeline performs bias subtraction and flat-fielding, as well as illumination correction, background gradient subtraction, and fringing removal. Additionally the pipeline implements world coordinate system (WCS) alignment that includes field distortions, two-dimensional calibration of the passband and zero-point, and stacking of individual frames.

In order to search for emission line galaxies at a range of redshifts, we use all available SHARDS data; at the onset of this study, observations of A0370 have been carried out with four SHARDS filters (F517W17, F823W17, F913W25, and F941W33), while M1149 has been observed in three (F883W35, F913W25, and F941W33). Filter data are provided in Table 1 and we show response curves in Fig. 1. We take this opportunity to note that at the time of writing, SHARDS-FF observations of A0370 have recently been completed in all 25 contiguous medium-band filters in which raw data are publicly available as soon as the observations are completed. Reduced images and catalogues will be published in Pérez-González et al. (in preparation) and are available on direct request.

2.1.2 Ancillary observations and catalogues

For differential flux measurements and the selection of emission line galaxies, we require deep broad-band multiband data covering the same wavelengths as the medium-band filters. For this reason we make use of catalogues and imaging data made available as part of the HFF DeepSpace project (Shipley et al. 2018). These data combine up to 17 Advanced Camera for Surveys (ACS)/Wide Field Camera 3 (WFC3) filters with ultradeep Ks-band imaging, and Spitzer/Infrared Array Camera (IRAC), when available. The HFF-DeepSpace data set also includes calibrated catalogues, photometric redshifts, and lensing magnification factors, as well as original imaging data, models and calibration information, providing an ideal ancillary data set for our candidate selection. We note here that HFF-DeepSpace observations cover only a fraction of the ~70 arcmin² area surveyed by SHARDS-FF for each cluster. Considering both the cluster and parallel field, this constitutes roughly ~35 per cent and 38 per cent of the total SHARDS-FF coverage for A0370 and M1149, respectively. In Fig. 2, we show the HFF-DeepSpace detection image FOV for both clusters and their parallel fields overlaid on SHARDS F913W data.

2.2 Photometric calibration

Candidate line emitter selection requires accurate photometric calibration between all observations. This presents a significant challenge when combining ground- and space-based data due to the differences are spatial resolution, point spread functions (PSFs), etc. In order to optimally combine the data it is necessary to avoid the degradation of the HST imaging to the lower resolutions of the ground-based SHARDS observations, while conversely not artificially up-scaling the low-resolution images, likely to provide unreliable flux measurements. To circumvent these issues, we opt to calibrate the medium-band flux measurements following the same procedures used to construct the HST catalogues (Shipley et al. 2018) and examine this methodology in the sections below.

2.2.1 Total flux measurements

All observations are first matched to the PSF of the SHARDS F883W filter (~1.0 arcsec). This is done by deriving convolution kernels for each band using the PSFs provided as part of both the SHARDS and HFF-DeepSpace data sets. For all HFF-DeepSpace imaging we use 2 arcsec apertures to recalculate photometry in SEEJECTOR’S dual image mode, utilizing the deep detection images from the HFF-DeepSpace data (see Shipley et al. 2018, section 3.3). We perform aperture photometry for SHARDS bands individually, constructing a final catalogue by matching sources detected in the SHARDS filters to the HFF-DeepSpace IDs.

To correct for flux falling outside of the 2 arcsec apertures, we derive total flux values. Aperture photometry is adjusted by applying a correction factor, derived on a source-by-source basis.
from a reference band (typically F160W). First, for each galaxy the reference band total flux \( f_{\text{ref, tot}} \) is calculated from the SExtractor (Bertin & Arnouts 1996) AUTO flux using a growth curve, in combination with the Kron radius (for full details see Shipley et al. 2018). A conversion factor is then calculated from the ratio of the reference bands total flux to the corresponding 2 arcsec aperture flux \( f_{\text{ref}}(r) \). Following the equation:

\[
    f_{i, \text{tot}} = f_i(r) \frac{f_{\text{ref,tot}}}{f_{\text{ref}}(r)},
\]

where \( r \) is the aperture radius, total fluxes for all other bands \( f_{i, \text{tot}} \) can be derived based on the measure aperture flux, \( f_i(r) \).

It should be noted here that this method of producing our catalogues only provides SHARDS medium-band flux measurements for sources that are also found in the detection of HST images (i.e. sources that are emitting in the continuum). Below we describe how we apply further flux corrections that are required to robustly combine the medium-band imaging with HFF-DeepSpace data.

Typically, when investigating galaxies within the fields of massive clusters such as those in this study, magnifications effects resulting from strong gravitational lensing should be considered. Our H\( \alpha \) sample, the focus of this paper and which is described in Section 3.3, is however situated at or below the cluster redshifts such that corrections for these lensing effects are unnecessary.
In order to obtain consistent measurements between broad- and medium-band photometry, we apply further flux corrections. We correct for galactic extinction, taking values given by the NASA/IPAC Extragalactic Database extinction law calculator\(^1\) for the centre of each field and filter (for a full breakdown of extinctions used for HFF-DeepSpace filters, see table 5 of Shipley et al. 2018). Further, flux values are normalized to a zero-point of 25.

### 2.2.2 Geometric effects

Geometric effects due to incidence angles of the GTC/OSIRIS light beam result in spatially varying effective central wavelengths (CWL) within each filter. This must be corrected for. Sources within each SHARDS observation are detected with similar, but not identical, effective CWL depending on their location within the image. These effects have been calibrated previously in Pérez-González et al. (2013). We also need to include this correction in this work. The variation of the filter’s CWL will affect not only the SED and stellar population synthesis (SPS) fitting, but also the calculations of flux densities, this in turn will induce some shift in the calculated EW and excess significance parameters used for the selection of candidate emitters. Thus, accurate calibration of geometric effects needs to be undertaken.

Here, we present a summary of this calibration procedure that is described in detail in Pérez-González et al. (2013, section 3.3). The CWL calibration is performed through day-time imaging and laboratory obtained spectroscopic data. Using a pinhole mask, spectra are obtained covering the entire FOV, from which the transmission curve is measured. The shape and width of the curve remain relatively constant, while the CWL shows systematic variations around the optical axis (to the left of the FOV). CWL are fit with a function that depends on the distance from the optical axis squared \((r^2)\). Given the source location and the position of the optical axis, the CWL can be computed from the following equation:

\[
\text{CWL}(X, Y) = A + B \left[ (X - X_0)^2 + (Y - Y_0)^2 \right],
\]

where \(X\), \(Y\) and \(X_0\), \(Y_0\) are the pixel locations of the sources and the optical axis, respectively. The values \(A\) and \(B\) are the fitting coefficients, and along with the values of \(X_0\) and \(Y_0\) are filter dependent and do not vary with time. The values of these are presented in table 1 of Pérez-González et al. (2013). Calibrations were tested for repeatability and found to provide robust measurements over different nights.

### 2.3 Updated photometric redshifts and stellar population parameters

We utilize our photometric catalogues combining broad-band data from HFF-DeepSpace with our calibrated medium-band photometry to obtain high-quality photometric redshifts and stellar population parameters for all galaxies within both of the clusters, and their parallel fields. The photometric fitting codes EAZY (Brammer, van Dokkum & Coppi 2008) and FAST (Kriek et al. 2009) are used for this as default parameter files are provided in the HFF-DeepSpace data set. This allows for the most robust comparison to existing catalogue values. For a detailed description of parameter selection and verification, see sections 5.2 and 5.4 of Shipley et al. (2018).

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1. http://ned.ipac.caltech.edu/help/extinction_law_calc.html
2. https://github.com/gbrammer/eazy-photoz/

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**Figure 3.** Comparison of the new photometric redshifts we fit in this study \((z_{\text{phot, mb}})\) to the 502 available spectroscopic measurements. Dotted line shows the one-to-one relation. We find an average scatter of 0.073 and a catastrophic outlier rate of 9 per cent (see text).
to be small (e.g. Banerji et al. 2013), which would especially be the case for lower mass galaxies. A higher solar metallicity may also affect our dust measurements, and if our systems are significantly less than solar metallicity, what has been used previously in the HFF-DeepSpace catalogue. Furthermore, the use of solar metallicity only affects the stellar mass and SFR, respectively. In all of the plots, the subscript ‘mb’ (medium-band) represents estimates obtained in this work, while the subscript ‘ds’ (DeepSpace) denotes the values obtained from the HFF-DeepSpace catalogues.

2.3.2 Stellar population parameters

Stellar population parameters such as stellar mass, SFRs, and ages are estimated for our sample of galaxies with FAST3 (Kriek et al. 2009). For input parameters we again follow the methodology of Shipley et al. (2018); employing a Chabrier initial mass function (IMF; Chabrier 2003), solar metallicity, minimum star formation age of 10 Myr, Calzetti dust attenuation law (Calzetti et al. 2000), 0 < A_v < 6 mag, and exponentially declining SFHs with a minimum e-folding time of log_{10}(τ/yr) = 7. We use a Bruzal & Charlot (2003) SPS model library that includes random bursts (of duration between 3 × 10^7 and 3 × 10^8 yr) superimposed on to models of continuous SFHs with a probability that 50 per cent of galaxies have experienced a burst of the past 2 Gyr. We use a solar metallicity here as this is what has been used previously in the HFF-DeepSpace catalogue. Furthermore, the use of solar metallicity only affects the stellar mass measurements, and if our systems are significantly less than solar this would produce stellar masses that are higher than they should be by +0.3 dex, which is not enough to alter any of our conclusions. A higher solar metallicity may also affect our dust measurements, as the galaxies would be slightly redder when fit and thus would require less dust. FAST models do not currently include emission lines, however their effect on stellar mass estimates has been shown to be small (e.g. Banerji et al. 2013), which would especially be the case for lower mass galaxies.

In order to obtain the most accurate stellar population parameters, we again shift the SHARDS filter response curves on an object-to-object basis to account for variations in CWL and use our updated photometric redshift estimates (see Section 2.3.1). While the inclusion of the SHARDS medium-band photometry is likely to improve estimates of these parameters, only mass-to-light ratios are well constrained due to their dependence on rest-frame optical colours that are covered by the HFF-DeepSpace photometry. We show in the central, and right-hand panels of Fig. 4 that our results on measuring these features with our broad-band and narrow-band imaging are in good agreement with HFF-DeepSpace parameters.

3 EMISSION LINE GALAXY SELECTION

In order to select emission line objects via differential flux measurements, we require overlapping wavelength coverage of both the medium- and broad-band imaging. We utilize F606W and F105W broad-band imaging to match the F517W and F941W medium-band filters, respectively, while F814W is matched to both the F823W and F913W bands (see Fig. 1). We note here that the sky area covered by the F105W band is less than half the size of that covered by the F814W imaging (only ~42 per cent and ~34 per cent the size of the F814W science area for the cluster and parallel fields, respectively). For the robust selection of emission line objects, we employ a two-parameter selection criterion based on emission line EW and having an excess significance, as is well established in previous studies (e.g. Matthee et al. 2015; Santos, Sobral & Matthee 2016; Sobral et al. 2017; Arrabal Haro et al. 2018). This criterion assures that the objects selected show a real colour excess, and not an excess due to random scatter or measurement uncertainties.

3.1 Broad-band continuum

Before applying the two-parameter selection criterion, it is important to note that the medium-band filter profiles are not centrally aligned with the corresponding broad-band filters. Thus, sources with significant intrinsic colour in the continuum can complicate not only the selection of emission line objects, but also result in over or underestimation of line fluxes. In order to correct for this we derive an effective broad-band magnitude (called BB') to account for the slope in the continuum and achieve a mean zero (BB − MB) colour (Sobral et al. 2012, 2013). To obtain the most accurate estimates we first remove all point sources from the catalogue using the STAR_FLAG identifier. A further cut is then performed to select sources within 2σ of the scatter around the median of the broad-band colour. We then perform a linear fit that is used to correct the initial broad-band magnitude of the following form:

\[
(BB' - MB) = (BB - MB) - M(RB - BB) + C,
\]

where RB is the reference band (taken as the closest neighbouring broad-band filter), and M and C are the coefficients of the linear fit. For sources in which one of the broad-band colours is not available, the median correction is applied. We show (BB − MB) colours before

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**Figure 4.** Photometric redshift and stellar population parameter for all objects in both the cluster and their corresponding parallel fields obtained in this work, compared to HFF-DeepSpace catalogue values. Left-hand panel shows a direct comparison of photometric redshifts estimated with EAZY from HFF-DeepSpace catalogues and this work (HFF-DeepSpace+SHARDS filters). The grey dotted line represents a one-to-one ratio. Middle and right-hand panels are similar, but for the FAST estimates of stellar mass and SFR, respectively. In all of the plots, the subscript ‘mb’ (medium-band) represents estimates obtained in this work, while the subscript ‘ds’ (DeepSpace) denotes the values obtained from the HFF-DeepSpace catalogues.

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3 http://w.astro.berkeley.edu/mariska/FAST.html
Figure 5. Colour–colour plot showing broad-band continuum magnitude corrections for all objects in both FF clusters and their corresponding parallel fields. We show object colours before (grey contours) and after (blue contours) corrections have been applied to achieve a mean-zero BB – MB colour.

and after corrections have been applied in Fig. 5. The net effect of this is to reduce our number of candidates significantly. We take a conservative approach here so as to remove as much as possible contamination and to retain a population of certain line emitters.

3.2 Line emitter selection

To carry out a selection for our emission line candidates, first we make a check to determine if the medium-band excess is high enough to be considered an emission line object. This is done by setting a lower limit on EW. The observed EW is the ratio between the flux of an emission line (medium-band) and the continuum (broad-band). We follow the basic procedure used in previous searches and specify a traditional excess criteria of rest-frame EW of 25 Å (e.g. Ouchi et al. 2010). Previous studies (Ouchi et al. 2010) have found that higher EW cuts (>25 Å) help to minimize contamination from low-redshift interlopers, while Sobral et al. (2017) are able to implement much lower cuts through the use of narrower filters. Because of the limited sample size and low expected EW at our modest redshifts, we use the lower limit of 25 Å. To obtain an EW from the observed medium-band excess, magnitudes (mi) is converted to flux densities (fi) for each filter (i) via the equation:

\[ f_i = \frac{c}{\lambda_{i,centre}} \left( \frac{\lambda_{MB}}{\Delta\lambda_{MB}} \right)^{0.4} \left( \frac{m_i}{10} \right) \]

where c is the speed of light and \( \lambda_{i,centre} \) is the filter’s CWL (note that for the medium-band filters, this is taken as the corresponding broad-band CWL as the continuum colour corrections of equation 3 have been applied). Line fluxes and EWs are then computed using

\[ f_{line} = \frac{f_{MB} - f_{BB}}{1 - \Delta\lambda_{MB} / \Delta\lambda_{BB}} \]

\[ EW = \Delta\lambda_{MB} \left( \frac{f_{MB} - f_{BB}}{f_{BB} - f_{MB} \Delta\lambda_{MB} / \Delta\lambda_{BB}} \right) \]

respectively, where \( \Delta\lambda_{MB} \) and \( \Delta\lambda_{BB} \) are the widths of the medium- and broad-band filters, respectively. Here, \( f_{MB} \) and \( f_{BB} \) are the flux densities calculated via equation (4). Depending on the specific filters used, this equation breaks down at certain MB excess when \( \Delta\lambda_{MB} / \Delta\lambda_{BB} \to f_{BB} / f_{MB} \) such that the denominator tends to 0. When this occurs we set the EW of the sources to >1500 Å as this can also be helpful to identify sources that may not be real, or where problems may have arisen.

The second parameter, the excess significance, \( \Sigma \) (e.g. Bunker et al. 1995), is used to quantify the real flux excess compared to an excess due to random scatter. The excess significance can be written as (Sobral et al. 2013)

\[ \Sigma = \frac{1 - 10^{-0.4(EBB-EBM)}}{10^{-0.4(EBB-EBM)} \sqrt{\sigma_{MB}^2 + \sigma_{BB}^2}} \]

where MB and BB are the broad- and medium-band magnitudes, respectively. Here, ZP represents the normalized zero-point (25) and \( \sigma_{ap} \) is the aperture radius in pixels. The root-mean-square (rms) of the background pixel values, \( \sigma_{px} \), is estimated by randomly placing empty apertures across the respective images. A selection criteria of \( \Sigma > 3 \) is used to classify sources as potential line emitters (Sobral et al. 2013).

We show the selection of potential line emitters in Fig. 6. From ~25 000 detected objects across the four fields (two clusters and their respective parallels), 666 candidates are found in the cluster fields with a further 432 in the parallels, providing a total of 1098 candidate line emitters. Through the use of our photometric redshift estimates with the detection filter throughput information, it is possible to assign suspected emissions lines to objects within our sample. This method uses our above criteria and removes a significant number of candidate sources. Ultimately, we are left with only a small fraction that is reliable emitters. One of the main reasons for this is that we are fairly conservative about the line matches with wavelength. This is one of the deepest narrow-band searches yet, and it is also possible that many of the lines are from rare ionization lines that are not the common lines often seen in narrow-band searches, such as Hα, O II, and O III. The comparison of our numbers agrees with the expected uncertainties with previous work such as Sobral et al. (2013). For example; we find 42 robust Hα candidates and 33 O II, 63 O III +Hβ, and three suspected Lyα line emitters. We also find 42 candidate emission line galaxies in the redshifts range 2 < z < 3.5 that we use to investigate escape fractions in Paper II (Griffiths et al., submitted). In Fig. 7, we show the updated photometric redshifts for our candidate emission line galaxies as a function of HFF-DeepSpace photo-z (i.e. without SHARDS medium-band filters) and updated stellar mass (see Section 2.3.2), highlighting a few example emission lines only.

3.3 Hα emitter selection

We select Hα emitters, which are the focus of the rest of this paper, from our emission line sample based on a combination of the detected filters and updated photometric redshifts. We utilize filter throughput information for all medium- and broad-band filter combinations to determine the redshift range in which the detected emission line coincides with Hα. When a galaxy is selected as an emission line candidate via the two-parameter selection criterion (as described in Section 3) and its photometric redshift coincides with the Hα emission line for the detection filter combination, the object is marked as an Hα emitter. We find a total of 42 objects meeting this criterion over the four fields (the two clusters and their corresponding parallel
Figure 6. Medium-band excess as a function of F913W medium-band magnitude for the A0370 and M1149 clusters (top left- and bottom left-hand panels, respectively) and their parallel fields (top right- and bottom right-hand panels). The horizontal dashed lines represent a rest-frame EW cut of 25 Å, while solid lines show the average 3.0σ colour significance. All objects are shown as grey points, while galaxies that meet the selection criterion are coloured by photometric redshift.

Figure 7. Left-hand panel: redshift comparison of emission line selected candidates with ($z_{\text{phot, mb}}$) and without ($z_{\text{phot, ds}}$) SHARDS medium-band filters. We show a few example emission lines based on the detected medium-band filter and photometric redshift, other emission line candidates are shown as grey points. Candidates selected from the A0370 and M1149 fields are shown as circles and squares, respectively, while filled and empty points represent the cluster and parallel fields. The redshift of the clusters is shown by dashed vertical lines at 0.375 (A0370) and 0.543 (M1149). The inset shows the same again from the range $2 < z < 7.5$, illustrating the detection of three Ly$\alpha$ emitters. Right-hand panel: stellar mass as a function of photometric redshift for all candidate objects. Coloured points correspond to the same emission line selected candidates as in the left-hand panel.

fields), and summarize the redshift range for all filter combinations in Table 2. Other line emitters will be the focus of future papers.

Given the luminosity functions of Sobral et al. (2013) at $z = 0.4$, we would expect to find roughly four H$\alpha$ emitters within our fields. This is consistent with our results if the overdensity in the A0370 cluster field can be attributed to the sources being cluster members. This is further supported by the work of Stroe et al. (2017) in which ine narrow-band filters are used to select over...
Table 2. Detection filter redshift range and cluster candidate counts of Hα emitters for the MACS J1149.5+2223 (M1149) and Abell 370 (A0370) fields.

| MB   | BB     | Redshift range | # M1149 | # A0370 |
|------|--------|----------------|---------|---------|
| F823W | F814W  | 0.24 < z < 0.27 | –       | 3       |
| F833W | F814W  | 0.32 < z < 0.37 | 2       | –       |
| F913W | F814W  | 0.37 < z < 0.41 | 1       | 19      |
| F941W | F105W  | 0.41 < z < 0.46 | 2       | 11      |

3000 Hα emitters from 19 galaxy clusters and their large-scale environments (beyond 2 Mpc from cluster centre). Their results indicate that cluster fields are overdense in Hα emitters, with the luminosity function showing a strong dependence on the dynamic state of the cluster. Considering recent simulations suggesting A0370 is a merging system (Molnar, Ueda & Umetsu 2020) along with the volume probed by the SHARDS data, our results are consistent with the work of Stroe et al. (2017) finding similar number densities of Hα emitters, considering our deeper depth. This also confirms our approach towards finding these emitters is sound and consistent with previous work.

We also visually inspect all objects that are within a crowded environment or contain contaminating flux from neighbouring sources. In total we find four candidates that cannot be successfully isolated. These objects are excluded from our analysis as the overlapping light profiles have the potential to result in unreliable photometry, as well as systematic shifts in our morphological and structural measurements.

A total of 33 of the remaining 38 candidate galaxies are selected from the A0370 field. This is expected as the redshift of the A0370 cluster (z = 0.38) corresponds to that of our detection range such that we are able to select both foreground galaxies and cluster members. We show the distribution of our Hα candidates within the A0370 field in Fig. 8. However, as M1149 is at the slightly higher redshift of z = 0.54 we are unable to probe the cluster population with our permitted filter combinations. This is a strong indication that our Hα emitters are located mostly within dense environments.

We note here that this process is undertaken for all chosen emission lines; however, a full analysis of all these emitters is beyond the scope of this paper and will be discussed in future publications.

3.3.1 Correction for [N II] line contamination

Calculations of Hα emission line fluxes and EWs must take into consideration the contribution of flux from neighbouring [N II] lines at λrest = 6548 and 6583 Å. As these lines are situated in close proximity to Hα, their flux is typically included in photometric measurements, acting to artificially increase line fluxes and EWs measured. To account for this, we implement a correction based on the work of Villar et al. (2008) where it was found that the fractional contribution of the [N II] flux decreases with increasing EW due to lower metallicities. The flux ratio, $F_{\text{N II}} / F_{\text{Hα}}$, and equivalent width, EW(Hα+[N II]), are related by

$$\log \left( \frac{F_{\text{N II}}}{F_{\text{Hα}}} \right) = -5.78 + 7.63x - 3.37x^2 + 0.42x^3,$$

(8)

where the value ‘x’ is log(EW[Hα+[N II]]). We use this relation to correct all Hα fluxes in this study whereby we find a median correction of $\sim$25 per cent. The range of masses for our sample overlaps with the range of masses for which this criterion was measured and determined.

3.3.2 Extinction correction

The Hα emission line is much less affected by dust obscuration than other common lines such as Lyα or [O ii], however dust effects are non-negligible and should be accounted for. This is particularly the case when deriving SFRs. When spectroscopy is available for individual sources, the amount of extinction can be estimated by comparing the intrinsic Balmer decrement with that observed. As spectroscopy of each individual sources is often unfeasible, dust extinctions can also be estimated via the comparison of Hα and far-infrared (FIR)-based SFRs (Ibar et al. 2013; Koyama et al. 2013).

There are many ways in which to account for dust extinction in our sample, some of which we explore below, and throughout the paper. Some studies employ a simple approach of applying a constant value of dust extinction throughout a galaxy. As determined by Kennicutt (1992), a 1 mag extinction of Hα can be adopted, and is often a good approximation for the true extinction (e.g. Ly et al. 2007; Geach et al. 2008; Sobral et al. 2009). However, this extinction has been found to be stellar mass dependent in the local Universe (Garn & Best 2010), in clusters (Sobral et al. 2016), and at high redshift (Sobral et al. 2012), so it must be used with care.

However, as SEDs are readily available for our galaxy candidates, we estimate dust attenuation based on stellar $E(B-V)$ values derived during fitting (see Section 2.3) and the assumption of $A_V = 0.44A_{\text{gas}}$ found in local starburst galaxies (Calzetti et al. 2000). This is a major assumption we are making, and we later investigate how our results would differ if we were to assume other relationships, such as equality between the stellar and gaseous components. We find all galaxies have a dust content such that $0 < E(B-V) < 0.7$ with mean, median, and dispersion values for our dust corrections of 0.16, 0.06, and 0.20, respectively.
We also investigate the situation whereby we make the assumption that $A_{\text{V, stars}} = A_{\text{V, gas}}$, which in some higher redshift situations is more likely the case (e.g. Reddy et al. 2015). We describe in detail how this assumption would change our results when we discuss the effects of star formation. The net effect is that the measured SFR in the UV would be $\sim 1.85$ times lower with this equality in the dust extinction. This produces a change of $\sim 0.26$ dex when plotting features in log space. As we discuss later, this affects in no significant way the conclusions we draw from this study. This shows that these galaxies are overall not very dusty systems, which fits in with them typically being low-mass galaxies.

### 3.3.3 Star formation rates

A galaxy’s star formation activity changes throughout its lifetime due to various physical processes such as major/minor mergers, gas accretion, and supernovae feedback. These fluctuations all contribute to the luminosity of the Hα emission line, which is sensitive to instantaneous star formation on time-scales of the order $\sim 10$ Myr (e.g. Kennicutt 1998). The burstiness of star formation activity can be investigated through the direct comparison of Hα-derived SFRs with those estimated via UV continuum emission, which provides time-averaged SFRs over a much longer $\sim 100$ Myr period (e.g. Kennicutt 1998). It is also the case that the Hα EW is a good indicator for the specific star formation rate (sSFR; Khostovan et al. 2021).

As the UV continuum traces star formation over a wider range of stellar ages than that of Hα, our calibrations must trace a galaxy’s SFR history for at least the last 100 Myr. As such, we derive UV SFRs from rest-frame 1600 Å emission ($L_{1600}$) for our Hα sample. The UV flux corresponds to the F275W band, which is provided in the HFF-DeepSpace data set for both clusters. The luminosities for these galaxies are first corrected for reddening using the stellar $E(B-V)$ values derived from SED fitting before SFRs are obtained from the Kennicutt (1998) relation adapted from a Salpeter to Chabrier (2003) IMF following Muzzin et al. (2010):

$$\text{SFR} \left( \frac{M_\odot}{\text{yr}^{-1}} \right) = 0.8 \times 10^{-28} L_{1600} \left( \text{erg s}^{-1} \text{Hz}^{-1} \right).$$

To provide a consistent set of calibrations, we convert corrected Hα luminosities into SFRs using the standard calibration of Kennicutt (1998), again modified to a Chabrier (2003) IMF following Muzzin et al. (2010):

$$\text{SFR} \left( \frac{M_\odot}{\text{yr}^{-1}} \right) = 4.5 \times 10^{-22} L_{\text{H}_\alpha} \left( \text{erg s}^{-1} \right),$$

assuming case B recombination at $T_e = 10^4$ K and continuous star formation. All measurements are based on line luminosities in which the [N II] contamination has been accounted for and dust attenuation is assumed to follow $A_{V, \text{stars}} = 0.44 A_{V, \text{gas}}$, as discussed in Section 3.3.2. While this calibration assumes continuous star formation on time-scales of over 100 Myr, it is relatively robust to variations in recent SFH (if it has been fairly continuous when averaged over periods of tens of Myr, for more discussion see Kennicutt 1998).

We use these SFRs to investigate the possibility of bursty SFHs of these galaxies at moderate redshifts. We note that estimates based on equations (9) and (10) assume a constant SFR for more than 100 Myr. However, for a robust comparison of Hα and UV SFRs in this analysis, the absolute SFR scale is less important than a consistent set of calibrations. As Hα and UV luminosities depend on the shape of the upper IMF for a given age, we expect the Hα to UV ratio to vary no more than 30 per cent for typical IMF slopes (e.g. Glazebrook et al. 1999).

### 3.4 Structure and morphologies

We have used the MORFOMETRYKA application (Ferrari, de Carvalho & Trevisan 2015) version 8.2 to measure the structure, non-parametric morphology, and Sersic profiles of the sources investigated here in the HST/F814W band (Lotz et al. 2017). We briefly describe how MORFOMETRYKA works below; refer to Ferrari et al. (2015) for full details.

MORFOMETRYKA takes as input the galaxy stamp image and the related PSF, then segments it and measures basic geometric parameters (e.g. centre, axis length, and position angle). Next, it quantifies the radial light distribution $I(R)$ from which the Petrovian radius $R_p$ (Petrosian 1976) and the half-light radius are estimated. For subsequent measurements, a Petrovian region with the same geometric parameters as the galaxy and with a radius of 1.5 $R_p$ is used. We also use this region to measure classic non-parametric morphology indicators, like the concentration–asymmetry–smoothness (CAS) system parameters (Conselice 2003, 2014). Additionally, our method fits an 1D Sersic profile (Sersic 1968) for the quantified $I(R)$ and uses the retrieved initial parameters to fit a 2D Sersic profile directly to the image of the central source. The structural and morphological measurements used in Section 4.4 are summarized in Table 3, including errors estimated for the Sersic index, asymmetry, concentration, and half-light radius.

### 4 RESULTS

#### 4.1 Emission line candidates

Using the methods outlined in Section 3, we select emission line candidates based on the differential flux measurements using medium- and broad-band data. SHARDS fluxes are calibrated to match broad-band HST measurements, and are corrected for filter geometric effects (equation 2) and broad-band continuum colour (Fig. 5). We then implement a two-parameter selection criterion, based partially on agreement of line identification with photometric redshift, in order to minimize contamination from low-redshift interlopers and the effects of random scatter. This selection process yields our candidate emission line galaxies from both cluster and their parallel fields (see Fig. 6 and Section 3.2).

One of the ways we identify correctly emission lines is by updating photometric redshift estimates through integrating all available SHARDS medium-band data. Using the SED fitting code EAZY (Brammer et al. 2008) on a source-by-source basis, SHARDS filter response curves are shifted to the effective CWL of each object, allowing for robust photometric redshift estimates (see Fig. 4). In a similar manner, we update HFF-DeepSpace stellar population parameters using the FAST (Kriek et al. 2009) code.

Our updated photometric redshift estimates allow for the identification of the emission lines responsible for the observed flux excess, as shown in Fig. 7. Our sample is dominated by [O II] and [O III] + Hβ emitters, as described earlier in the paper. The photometric redshift criteria, along with the line emitter criteria, ensure that our sample is a pure one with minimal contamination. It may also appear that there is a continuous distribution of values, but this selection is done before we narrow down our targets, and many of these systems on the right-hand side of Fig. 7 are from rarer emission lines that are not often seen in shallower surveys. Furthermore, we do find a concentration of objects at the expected common line emitter redshifts, and gaps at other redshifts, such as around $z \sim 1.1$.

While we find only three Lyα candidates, one of which is a previously unknown $z \sim 7$ object, which we will explore in future
works. As mentioned, this paper focuses on the Hα emitters. The reason for this is that the Hα emitters are the closest systems to us and due to being the reddest emission line are affected less by dust and redshift effects. They therefore are easier to study, and give us some idea for how line emitters in the relatively nearby Universe behave, which we can then compare with the higher redshift emitters.

In the next subsections we explore the properties of these Hα emitters and give some idea of their origin. This includes characterizing their physical properties and comparing these to other known line emitters and field galaxies. Specifically, we explore the SFH of these objects and their structure, arguing that they are a population late time infall into cluster galaxies with induced star formation.

4.2 Star formation main sequence

First, we investigate the SFRs of our Hα emitters and how these correlate with other properties. A crucial tool for understanding galaxy evolution is the star-forming main sequence, or SFR–stellar mass relation. We present in Fig. 9, Hα-derived SFRs as a function of stellar mass. These Hα SFRs are calculated using the Kennicutt (1998) conversion factor following corrections as detailed in Section 3.3, while stellar masses are measured using the SPS fitting code, fast (Kriek et al. 2009). The green line in Fig. 9 shows the z = 0 (redshift of our sample) main-sequence parametrization of Speagle et al. (2014), derived from rest-frame UV-continuum-based SFRs.

In Fig. 9, we also show the SFRₜₜₜₚₗ₋ₘₛ relation for the z = 0.4 Hα emitter sample selected from the narrow-band High-z Emission Line
Survey (HiZELS; Sobral et al. 2013) in blue, and from the study of the rich cluster Cl 0939+4713 (Koyama et al. 2013) in orange.

As can be seen, we find a strong SFR$_{H\alpha}$ enhancement of more than a factor of 2 for almost all galaxies in our sample over the Speagle et al. (2014) parametrization. This is indicative of a recent starburst in our galaxy sample’s SFH, the excess in SFR$_{H\alpha}$ is further enhanced at low masses if one is to consider the Whitaker et al. (2014) parametrization, which finds a steep low-mass slope and has been shown to be consistent with not only UV and IR star formation indicators, but also that of H$\alpha$. We note here however that care should be taken when making assumptions based on the Whitaker et al. (2014) parametrization as it is only constrained down to log(M/$\odot$/M$_\odot$) = 8.4. Regardless, it is clear that these systems all have very large SFRs for their mass and can be considered to be actively star-forming galaxies, as expected given their identification as line emitters. We later compare this H$\alpha$ SFR to the UV measured SFR to locate galaxies that exhibit ‘bursty’ SFHs. Note that as in Section 3.3.2, if we consider an equivalence between the extinction in stars and gas, rather than the 0.44 factor, we would obtain a decrease in 0.26 dex in the log SFR axis. This would, however, not change the results discussed above.

4.3 Bursty star formation

From the previous sections it is clear that we have discovered a highly star-forming population of moderate to low-mass galaxies at moderate redshifts. The nature of these objects is however a mystery, and in the next sections we determine the properties of these systems, including their possible bursting nature, as well as their structure, environment, and other properties.

4.3.1 Comparison of H$\alpha$- and UV-derived SFRs

In this section, we discuss the SFR history for our sample by comparing the H$\alpha$ to FUV fluxes. Ideally, these two SFRs should be the same if they measure the same aspects of star formation. However, for galaxies in which the SFR is more episodic or bursting, the measured H$\alpha$ SFR will often be higher than that measured from UV. The reason for this is that during a star formation episode, the SFR measured with H$\alpha$ will be higher during the initial burst than the UV measured star formation as detailed in Section 1. After some time, the H$\alpha$ measured star formation will become more similar to the UV measured one, especially for more constant SFHs.

In Fig. 10, we present a comparison of SFRs derived from H$\alpha$ and UV luminosities in order to provide a direct visualization of possible bursty star formation activity. The H$\alpha$ line fluxes are initially computed via equation (5) to account for a non-zero continuum before we apply corrections for dust extinction and [N ii] line contamination. UV luminosities are derived directly from reddening corrected rest-frame 1600 Å emission, corresponding to the F275W band at $z \sim 0.4$. In order to obtain SFRs from H$\alpha$ and UV corrected luminosities we use the method described in Section 3.3.3. To gain further insight into our sample and the possibility of bursty SFHs, we include the evolutionary track of two example galaxies modelled with STARBURST994 (Leitherer et al. 1999).

In yellow, we show the evolutionary track of an individual stellar population model of initial mass $10^6$ M$_\odot$, undergoing a single burst of star formation, while model ages of 1, 5, and 10 Myr are represented by the yellow points. While in green we show the evolutionary track of a model stellar population with a constant rate of star formation of 1 M$_\odot$ yr$^{-1}$ (green line), and indicate the SFR at ages of 1, 10, and 100 Myr by the green points.

For simulated galaxies with a constant SFH, H$\alpha$-derived SFRs usually match closely to values derived from the UV. In Fig. 10, we show the one-to-one ratio of H$\alpha$ and UV SFRs, representing the equilibrium value of a constant SFR. The 0.3 dex margin accounts for variations around the main sequence due to changes in star formation.

4http://www.stsci.edu/science/starburst99/
feedback (Tacchella et al. 2016). We include two stellar population models typical scatter in star formation activity due to mergers, gas flows, or AGN.

Figure 10. Comparison of the H\(\alpha\) and UV SFRs for our sample of H\(\alpha\) emitters. H\(\alpha\) line fluxes are corrected for dust extinction and \([\text{N}\,\text{II}]\) line contamination, while the UV luminosities are dust corrected using stellar \(E(B-V)\) values derived from SED fitting. See the text for alternative parametrizations of these factors. Candidates from this study are marked by blue and orange points and green crosses (as described in Fig. 9). Black dotted line shows a one-to-one ratio with a 0.3 dex margin, accounting for typical scatter in star formation activity due to mergers, gas flows, or AGN feedback (Tacchella et al. 2016). We include two stellar population models from STARBURST99 (Leitherer et al. 1999) for reference. The green track shows a model stellar population with a constant SFH of 1 M\(_\odot\) yr\(^{-1}\), with ages of 1, 10, and 100 Myr marked by green points. While the yellow track shows a burst of star formation for a single stellar population with an initial mass of 10\(^6\) M\(_\odot\) and ages of 1 and 5 Myr shown as yellow points. Note that these models would need to be scale up in both directions to match the mass of individual galaxies in our sample by a factor of mass that is larger than 10\(^6\) M\(_\odot\).

Further sources of uncertainty arise from possibly more complicated dust parametrizations (Kewley et al. 2002) and \([\text{N}\,\text{II}]\)/H\(\alpha\) flux ratios. However, low-mass galaxies such as those in our sample are less affected by dust than higher redshift systems (Reddy et al. 2015), while luminosity to SFR conversions and variations in \([\text{N}\,\text{II}]\)/H\(\alpha\) line ratios are not sufficient to account for the excess in H\(\alpha\)-derived SFRs of our sample.

Figure 11. sSFRs derived from H\(\alpha\) and UV luminosities. These H\(\alpha\) line fluxes are corrected for dust extinction and \([\text{N}\,\text{II}]\) line contamination (Section 3.3), while UV luminosities are dust corrected using stellar \(E(B-V)\) values derived from SED fitting. Stellar masses used in the calculation of the sSFR are obtained through SPS modelling (see Section 2.3.2). Candidates from this study are marked by blue and orange points and green crosses (as described in Fig. 9). We include two stellar population models from STARBURST99 (Leitherer et al. 1999) for reference. The green track shows a model stellar population with a constant SFH of 1 M\(_\odot\) yr\(^{-1}\), with ages of 1, 10, and 100 Myr and 1 Gyr marked by green points. While the yellow track shows a single burst of star formation of a single stellar population and an initial mass of 10\(^6\) M\(_\odot\) and ages of 1, 5, and 10 Myr shown as yellow points.

There are however some important caveats in the direct comparison of SFRs, including the dust assumptions as already mentioned. First, the conversion from luminosities to SFRs induces uncertainties due to unknown factors, such as the IMF, stellar populations, and metallicities (Boselli et al. 2009). Uncertainties in the IMF arise as a result of galaxies with a less abundant population of high-mass stars to ionize hydrogen, these objects will have similarly low ratios of H\(\alpha\)-to-FUV as those undergoing bursty star formation (Lee et al. 2009). For low-mass galaxies, these effects become particularly important, and luminosity to SFR conversions are expected to differ from the standard Kennicutt (1998) prescriptions (Ly et al. 2016). Further sources of uncertainty arise from possibly more complicated dust parametrizations (Kewley et al. 2002) and \([\text{N}\,\text{II}]\)/H\(\alpha\) flux ratios. However, low-mass galaxies such as those in our sample are less affected by dust than higher redshift systems (Reddy et al. 2015), while luminosity to SFR conversions and variations in \([\text{N}\,\text{II}]\)/H\(\alpha\) line ratios are not sufficient to account for the excess in H\(\alpha\)-derived SFRs of our sample.

4.3.2 Specific star formation rates

The relatively high SFR\(_{\text{H}\alpha}/SFR_{\text{UV}}\) ratios present in our sample can be attributed to bursts of star formation, in which H\(\alpha\) flux from short-lived O-stars is boosted with respect to that of the UV. However, it can also be explained by the assumption of predominantly young galaxies formed in a single burst of star formation. As can be seen in Fig. 10, models with a bursting star formation are able to match these values better than a constant SFR, except for the bursts that have a higher H\(\alpha\)-based SFR.

In order to further investigate the origin of the observed enhancement in SFR\(_{\text{H}\alpha}\), we present the H\(\alpha\) specific star formation rate (sSFR) as a function of UV sSFR in Fig. 11. The sSFR is defined as the measured SFR divided by the stellar mass. It gives some idea of the whether the star formation ongoing when a galaxy is observed is an important component of its mass formation. Again, we show
the evolutionary tracks of two STARBURST99 models as discussed in Fig. 10 and Section 4.3.1.

As shown by the evolutionary tracks in Fig. 11, the sSFRs of a galaxy undergoing constant star formation (green line) eventually settles into equilibrium with little deviation. This is however not the case for a young galaxy formed under a single burst of star formation (yellow track), in which an enhancement in Hα is expected for the first \( \sim 5-10 \) Myr, but rapidly decreases with age as star formation is shut off. Thus, for a recent burst of star formation we would expect galaxies to be above the one-to-one relation of sSFR_{Hα} to sSFR_{UV}. After some time these sources with ages \( > 10 \) Myr after the burst would drop below this high excess. For our sample as a whole, we find no reason to favour young galaxy ages over bursty SFHs as deviations from the one-to-one relation are typically within the margins expected due to perturbations such as gas flows or mergers. We note that \( \sim 15\) per cent of our sources exhibit a deficit in sSFR_{UV} over that of Hα that could be attributed to young ages, but is more likely due to those galaxies being in the post-burst phase. These results would not change if we considered the alternative formalism for the dust extinction in gas compared to stars, as described in the previous section.

As can be seen in Fig. 11, our bursty sample, as defined by having a significantly larger SFR in Hα than in the UV, is not well fit by either the constant star formation or the single burst. However, if we consider the alternative equivalence between extinction in stars and gas, these points do approach the constant SFH models. This is however likely due to the fact that the bursts we see are occurring on top of an existing stellar mass. From Fig. 11, we can see that the difference is about a factor of \( \sim 3 \), showing that the burst ongoing is about \( \sim 3 \) per cent of the galaxies mass, which would be consistent with an older system that is undergoing a new burst of star formation.

4.4 Structure and sizes

We use the methodology explained in Section 3.4 to measure the structures and sizes of our galaxies to better understand their origin in more detail. From the previous sections we know that these Hα systems are undergoing star formation, with a small number undergoing bursts. The sizes and structures of these systems may illuminate how the star formation within these systems triggered.

In Fig. 12, we show the distribution of the sizes versus mass for our sample. As can be seen, these systems are similar in size to galaxies of similar mass based on the size–mass relation for nearby galaxies (from Lange et al. 2015). We also compare our objects to the size–mass relations derived from HiZELS (Sobral et al. 2013). From these size–mass relations (dotted and dash–dot lines in Fig. 12), we show that (with the exception of ID:4080) our galaxies are similar to typical Hα emitters of corresponding mass and redshifts.

In terms of other aspects of the structure, we find that there are a range of Sersic indices for our systems, but that most of them have values of around \( n = 1 \), suggesting that these systems are more disc like, rather than spheroidal like. This can also be gleaned by investigating the visual morphologies of these systems shown in Fig. 13 where most of them appear to be disc-like objects rather than ellipticals.

Furthermore, the bursting galaxies, quite interestingly, do not show any signs of being mergers. They are not found in the merger space of the concentration–asymmetry diagram (Fig. 14), and do not appear to have a merger morphology when examined by eye (see Fig. 15).

This implies that these systems do not have their star formation triggered directly by merging activity. In fact, the bursts themselves are amongst the lowest asymmetry objects in the early-type galaxy region. This is a strong sign that other mechanisms, besides merging, are responsible for producing the star formation within these systems.
and later confirmed by the simulations of Bekki & Couch (2003). More recent simulations propose large-scale, low pressure shocks induced by merger processes could trigger star formation in cluster galaxies (Roediger et al. 2014).

When we examine the morphologies of these galaxies (Fig. 13) we find that most of them appear to disc-like, which is consistent with their low stellar masses. One of the burst galaxies appears to be a spiral (ID:4080), which may have recently fallen into the cluster, but the other three do not seem to have any detailed substructure. However, as we show and discuss in Section 4.4, these systems are of typical size for their mass. We conclude that therefore these systems are likely in some type of evolutionary stage whereby infalling field galaxies are undergoing rapid star formation, likely due to the cluster environment triggering this. On the other hand, they could be galaxies stripped of mass by the cluster environment, but it is unlikely that this process would be efficient enough to produce so many systems. Future observations of these galaxies, through e.g. spectroscopy, should help us to better understand the origins of these systems that appear to be a new class of low-mass galaxy.

6 CONCLUSIONS

In this paper, we investigate the selection of emission line galaxies from two of the HFF clusters using SHARDS medium-band imaging. Our Major findings are as follows.

I. With the full suite of SHARDS observations now available (for A0370), we carry out an investigation to discover and study emission line selected galaxies over a wide redshift range. While lacking the wide area coverage studies such as this typically use, deep imaging through the full set of 25 contiguous medium-band filters combined with the strong lensing potential of the FF clusters provides an essential tool for the identification and study of line emitters at a variety of redshifts. Particularly those at high redshifts that would typically be too faint to be detected in field observations or observations carried out with smaller ground-based telescopes.

II. We identify 1098 candidate emission line galaxies based on a modified version of a well-established two-parameter selection criterion. SHARDS photometry is calibrated to match HST images and used to update photometric redshift estimates and stellar population parameters. Using a strict criterion, we are able to match a fraction of these to well-known emission lines, such as Hα, the focus of this paper. Many of the other sources are likely from more obscure emission lines.

III. We discover 38 predominantly mid- to low-mass Hα emitters, which is the focus of the latter parts of this paper. After correcting for dust extinction and [N II] line contamination, we derive Hα-based SFRs. Overall, 27 of these candidates have corresponding HST UV data that enable us to investigate potential bursts of star formation in our galaxies recent histories by comparing the two indicators. Most of our Hα emitters are undergoing star formation at high enough values such that these galaxies fall above the main-sequence relation between star formation and stellar mass.

IV. We investigate bursty SFHs for these star-forming galaxies using different star formation indicators that trace different timescales. We find a significant enhancement (>0.3 dex) of SFR\textsubscript{Hα} over that of SFR\textsubscript{UV} for four of our candidates. This fact implies a recent burst in star formation within these systems. These systems are likely within the foreground FF clusters, and thus their bursty star formation is probably induced by cluster processes. This result is robust to different considerations of the dust extinction we use to correct the Hα-based SFRs.
V. Enhancements in the Hα SFR are typically attributed to bursty star formation, but can also result from a young population of galaxies. In order to differentiate we compare the Hα and UV sSFR to the evolutionary tracks of two model galaxies. We find no reason to favour a young first generation population for the majority of our sample, but note that up to 10 per cent of our galaxies show a tentative indication of young ages over bursty SFHs.

We conclude that SHARDS imaging combined with deep HST data set can successfully identify emission line galaxies over a wide range of redshifts. Future papers will investigate the higher redshift emitters in a similar way. These methods coupled with the strong lensing potential of the FF clusters enable the identification of a population of low-mass, faint galaxies likely undergoing a burst in star formation. These objects are fairly unique and should be followed up as they are likely tracing important processes in the formation of galaxies within dense environments.

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DATA AVAILABILITY
The data underlying this paper will be shared on reasonable request to the corresponding author.

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