EFOSC2 spectroscopy of SWIRE-CDFS galaxies

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ABSTRACT
We present the optical spectra of a sample of 34 Spitzer Wide-Area Infrared Extragalactic Survey (SWIRE)-Chandra Deep Field South (CDFS) sources observed with the European Southern Observatory (ESO) Faint Object Spectrograph and Camera (EFOSC2) on the ESO 3.6-m telescope. We have used the spectra and spectroscopic redshifts to validate our photometric redshift codes and spectral energy distribution (SED) template fitting methods. 12 of our sources are infrared luminous galaxies. Of these, five belong to the class of ultraluminous infrared galaxies (ULIRGs) and one to the class of hyperluminous infrared galaxies (HLIRGs), with evidence of both an active galactic nucleus and a starburst component contributing to their extreme infrared luminosity for three, a starburst contributing for one and AGN contributing for two of them.

Key words: techniques: spectroscopic – catalogues – surveys – quasars: emission lines – galaxies: Seyfert – infrared: galaxies.

1 INTRODUCTION
In recent years, extragalactic surveys have revolutionized our view of the high-redshift Universe, showing that the redshift range 0.5 < z < 3.0 witnessed an extraordinary transformation in the demographics of starburst and active galactic nucleus (AGN) activity in galaxies. The factors that drove these changes are, however, unclear. Consequently, the properties of large samples of sources are the current driving force behind modern extragalactic surveys (e.g. Lonsdale et al. 2003; Eales et al. 2010; Oliver et al. 2010). However, either most of the sources in these surveys are too faint for spectroscopic observations, or it is not cost and time effective to acquire large spectroscopic redshift samples using the current facilities. Photometric techniques provide an excellent tool for estimating redshifts, essential for statistical studies of the galaxies’ properties and evolution with only a fraction of the observing time required by spectroscopic surveys. These techniques are faster and can estimate redshifts beyond the spectroscopic limit, with the main handicap of possessing larger errors than spectroscopic techniques. In order to minimize these statistical errors: (i) more bands are needed to be included in the photometric computation and (ii) optical spectroscopic redshifts have to be used to calibrate and validate the photometric redshift codes.

In this paper, we use EFOSC2 on the 3.6-m European Southern Observatory (ESO) telescope to obtain optical spectroscopy of galaxies selected from the SWIRE-CDFS in order to validate our photometric redshift techniques across a wide redshift range, thus allowing more accurate determinations for the whole SWIRE catalogue. In addition, we present the optical spectra and mid infrared (MIR) properties of a sample of luminous infrared galaxies (LIRGs) detected as part of our follow-up. Infrared luminous objects at z > 0.5 are of great importance since they lie at the proposed peak of global starburst activity. They may well be related to the famous submillimetre galaxy population (e.g. Chapman et al. 2005) and be connected to the origin of the cosmic infrared background (Puget et al. 1996). Many questions remain about this population, including the role of AGN in their prodigious luminosities, what their descendants are in the local Universe and what their broader role is in galaxy formation and evolution. Some have claimed, for example, that such far-IR luminous objects can only be incorporated into our general understanding of galaxy formation if they have stellar initial mass functions (IMFs) skewed to high masses (Baugh et al. 2005).

2 OBSERVATIONS
The targets for our EFOSC2 run were selected from the available multi-wavelength data in the SWIRE-CDFS field (Lonsdale et al. 2003). Target lists were prepared from the then latest version of the SWIRE Photometric Redshift Catalogue (Rowan-Robinson et al. 2005), selecting 24 µm sources with r < 21.5. Top priority was given to sources which were of U/LIRG status based on their then estimated photometric redshifts and SED template fits. In total, we targeted 12 prime sources in six pointings. The remaining slits were
assigned to adjacent serendipitous 24 μm sources. We managed to assign an average of 10 slits per mask, resulting in a total of 62 objects observed. Table 1 gives the list of the six observed pointings and a summary of their properties.

The observations were performed in multi-object spectroscopy mode using the ESO Faint Object Spectrograph and Camera (v.2) (EFOSC2) on the ESO 3.6-m telescope at La Silla. In order to obtain full coverage over a large wavelength range, both Grism-3 (3050–6100 Å, 1.5 Å pixel$^{-1}$) and Grism-5 (5200–9350 Å, 2.06 Å pixel$^{-1}$) were used. The width of the slits was 2 arcsec. The observations were carried out during 2006 December 18–19. The exposure time per mask was 2 h, 3600 s per grism. The total time of observations, calibrations, and read out time was 15.6 h or two nights.

The EFOSC2 data were reduced and calibrated using standard IRAF routines. The data were bias-subtracted and flat-corrected. The

| Target field | α(J2000) | δ(J2000) | Mag. |
|--------------|---------|---------|------|
| EA           | 03h31m26s | −29°05′24″ | 19.96 |
| EB           | 03h35m29s | −28°45′00″ | 21.55 |
| EC           | 03h35m48s | −30°30′79″ | 20.60 |
| ED           | 03h33m17s | −28°36′30″ | 18.65 |
| EE           | 03h28m55s | −28°46′12″ | 18.65 |
| EF           | 03h30m00s | −28°52′12″ | 19.11 |

$^{a}$ Specroscopic redshift.

$^{b}$ Bolometric luminosity in cirrus component.

$^{c}$ Bolometric luminosity in starburst (M82 type) component.

$^{d}$ Bolometric luminosity in starburst (A220 type) component.

$^{e}$ Bolometric luminosity in torus component.

$^{f}$ Bolometric infrared luminosity (1–1000 μm) ($H_\text{0} = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}, \lambda = 0.7$).

$^{g}$ Bolometric optical luminosity.

$^{h}$ Optical template type.

$^{i}$ Visual extinction in magnitudes.

$^{j}$ Dust mass.

$^{k}$ Quality flag of spectroscopic redshift (quality A = multiple detections of strong features, quality B = redshift based on single emission line, or based entirely on several weak, possibly spurious features).
spectra, having been mosaicked, were transformed to a linear wavelength scale. External regions of the 2D spectrum were used to measure the sky background and to subtract it from the final data 1D spectra. Redshifts were determined by visual inspection of the 1D spectra, through identification of emission and absorption features.

3 RESULTS

Our optical spectroscopic sample contains a total of 62 objects. We have selected to present here the 34 sources of this sample which have a counterpart in the latest version of the SWIRE phot-z catalogue (Rowan-Robinson et al. 2008) and for which the redshift determination is secure (see Fig. 2). Sources with very noisy or bad quality spectra have been rejected. The spectra of all the 34 sources are shown in Figs 3, 4, 10 and 11 (later) and their properties are shown in Table 2.

Fig. 1 (left) shows the redshift distribution of the spectroscopic sample. The bulk (85.7 per cent) of the 34 sources targeted lie at $z < 0.6$. The maximum peak in the redshift distribution is found at $z < 0.2$. The source with the highest redshift found is at $z \sim 3.20$. Sources at $z > 2$ have prominent Ly$\alpha$ lines. In the same figure, we show the redshift distribution of the infrared-luminous galaxies in our sample. These galaxies correspond to the higher redshift sources of our sample and their main bulk lie at $0.4 < z < 0.6$.

Fig. 1 (right) shows the $R$-band distribution of the 35 extragalactic sources observed. We have used the Rowan-Robinson et al. (2008) template fitting method to estimate the infrared luminosities of the 35 observed sources using the observed spectroscopic redshifts. Based on the library of infrared templates used, 11 out of 34 sources ($\sim 32.3$ per cent) are fitted with cirrus, 13 ($\sim 38.2$ per cent) are fitted with a starburst, six are fitted with a dust torus ($\sim 17.6$ per cent) and the rest of the sources have single-band infrared excess.

Table 3. Properties of the six LIRGs, five ULIRGs and one HLIRG with available spectra from our sample.

| Object                      | RA       | Dec.      | $z^{a}$ | $R$  | $S_{34}^{b}$ | log($L_{IR}^{c}$) | Optical$^{d}$ | IR$^{e}$ | alp$^{f}$ | alp$^{g}$ |
|-----------------------------|----------|-----------|---------|------|-------------|------------------|---------------|----------|-----------|-----------|
| SWIRE3-J033523.29-284827.2 | 53.84701 | −28.80756 | 0.195   | 18.61| 3156.71     | 11.12            | Sbc           | M82      | 1         | 0         |
| SWIRE3-J033529.55-284559.2 | 53.87317 | −28.76646 | 0.297   | 17.42| 0           | 11.20            | Sbc           | M82      | 1         | 0         |
| SWIRE3-J033227.95-293122.6 | 53.11647 | −29.52299 | 0.374   | 20.27| 875.16      | 11.11            | Scd           | M82      | 1         | 0         |
| SWIRE3-J033528.00-284500.3 | 53.86671 | −28.7510  | 0.404   | 19.60| 444.40      | 11.23            | Scd           | A220     | 1         | 0         |
| SWIRE3-J033233.17-293004.8 | 53.13818 | −29.50138 | 0.453   | 20.78| 2920.02     | 11.56            | QSO           | A220     | 1         | 0         |
| SWIRE3-J033357.46-284354.0 | 52.90610 | −28.73170 | 0.769   | 21.48| 700.66      | 11.64            | Scd           | M82      | 1         | 0         |
| SWIRE3-J033234.23-293450.8 | 53.14263 | −28.58084 | 0.529   | 19.80| 2200.28     | 12.11            | Scd           | M82      | 1         | 0         |
| SWIRE3-J033541.23-283414.0 | 53.92179 | −28.57058 | 0.579   | 20.60| 6248.21     | 12.44            | Scd           | M82      | 0.65      | 0.35      |
| SWIRE3-J033352.19-284801.1 | 53.88404 | −28.80030 | 0.807   | 21.55| 10805.76    | 12.98            | E             | M82      | 0.55      | 0.45      |
| SWIRE3-J033220.88-293140.5 | 53.08703 | −28.52793 | 1.180   | 19.81| 2486.48     | 12.20            | QSO           | Torus    | 0         | 1         |
| SWIRE3-J033528.91-283203.6 | 53.87048 | −28.53434 | 1.962   | 19.32| 1294.57     | 12.53            | QSO           | Torus    | 0         | 1         |
| SWIRE3-J033144.54-290505.6 | 52.93562 | −29.08486 | 3.200   | 19.96| 1740.18     | 14.16            | QSO           | M82      | 0.85      | 0.15      |

$^{a}$Spectroscopic redshift.
$^{b}$Observed 24 $\mu$m fluxes in mJy.
$^{c}$Bolometric infrared luminosity (1–1000 $\mu$m) ($H_0 = 72$ km s$^{-1}$ Mpc$^{-1}$, $\lambda = 0.9$).
$^{d}$Optical SED best fit.
$^{e}$Infrared SED best fit.
$^{f}$Fraction of starburst contribution at 8 $\mu$m.
$^{g}$Fraction of AGN contribution at 8 $\mu$m.
According to the optical templates five sources are fitted with a quasi-stellar object (QSO) template. Of the remaining 29 galaxies, four (~13.3 per cent) are classified as ellipticals and 25 (~86.7 per cent) as spirals.

According to the estimated bolometric infrared luminosities, among the 34 sources there are six LIRGs \((L_{IR} > 10^{11} L_\odot)\), five ultraluminous infrared galaxies (ULIRGs) \((L_{IR} > 10^{12} L_\odot)\) and one hyperluminous infrared galaxy (HLIRG) \((L_{IR} > 10^{13} L_\odot)\). Table 3 summarizes the main properties of these IR-luminous objects and Fig. 3 (later) shows their spectra. Seven of the 12 H/ULIRGs are fitted with a spiral optical template, one is fitted with an elliptical template and four are fitted with a QSO optical template (one LIRG, two ULIRGs and one HLIRG). According to the infrared templates, two ULIRGs are fitted with a dust torus, eight sources are fitted with an M82 starburst (four LIRGs, three ULIRGs and one HLIRG) and two LIRGs appear to be Arp 220 starburst fitted. Two of the IR-luminous sources seem to contain a powerful AGN, seven seem to be powered by a starburst and the remaining three seem to be powered by both a starburst and an AGN. Half of the IR-luminous sources with \((L_{IR} > 10^{12} L_\odot)\) are powered by both a starburst and an AGN. These results are consistent with previous studies of 24 \(\mu\)m selected ULIRGs (Trichas et al. 2009, 2010). The only HLIRG of our sample is powered by both a starburst and an AGN with a major contribution of a starburst. Below, we summarize the properties of the five ULIRGs and one HLIRG found. The U/HLIRG spectra are given in Figs 3 and 4.

SWIRE3-J033234.23-293450.8. It is one of the strongest 24 \(\mu\)m emitters among all H/ULIRGs of our sample and also the one with the lowest redshift \((z = 0.529)\). It has been detected in all Infrared Array Camera (IRAC) and Multiband Imaging Photometer (MIPS) bands. Balmer lines, \([\text{O}_\text{II}]\) and \([\text{O}_\text{III}]\) doublet are detected in its spectra. Both optical and IR SED fitting imply the presence of a starburst. The starburst’s presence is also visible but weaker. A weak and broad Mg \(\text{II}\) line is also visible in the blue spectrum. These lines indicate the presence of AGN events. The source lies at \(z = 0.807\). Optical SED fitting implies the presence of a young elliptical galaxy and the IR SED fitting an AGN dust torus.

SWIRE3-J033532.19-284801.1. The R-band magnitude of this source is \(R = 21.55\). It is the strongest 24 \(\mu\)m emitter of our sample with detections in all IRAC and MIPS bands. As can be seen by its spectra there is a strong \([\text{O}_\text{II}]\) line. H\(\beta\) and \([\text{O}_\text{III}]\) doublet lines are also visible but weaker. A weak and broad Mg \(\text{II}\) line is also visible in the blue spectrum. These lines indicate the presence of AGN events. The source lies at \(z = 0.579\). SWIRE3-J033520.88-293140.5. It is the strongest 24 \(\mu\)m emitter among all five ULIRGs, with detections in all IRAC bands and at 24 \(\mu\)m. The R-band magnitude of this source is \(R = 19.81\). We have detected two strong broad lines, C\(\text{II}\) and Mg \(\text{II}\). The presence of these lines makes the presence of a very strong AGN, which is also identified by optical and IR SED fitting, almost certain. This source lies at \(z = 1.180\).

SWIRE3-J033528.91-283203.6. This ULIRG is the brightest one of our sample with R-band magnitude \(R = 19.32\). It has been detected in all IRAC bands and at 24 \(\mu\)m. As can be seen by its spectra there are three strong and broad detected lines, Ly\(\alpha\), C\(\text{iv}\) and C\(\text{iii}\). Both optical and IR SED fitting imply the presence of an AGN with significant starburst contribution. The redshift of this source is \(z = 1.962\).

SWIRE3-J033144.54-290505.6. This is the only HLIRG in our sample with bolometric infrared luminosity \(L_{IR} > 10^{13} L_\odot\). This is one of the brightest \((R = 19.96)\) sources at the highest redshift \((z = 3.2)\) in this sample. It has been detected in all IRAC and MIPS bands except 160 \(\mu\)m. This source exhibits four broad lines, Ly\(\alpha\), N\(\text{v}\), Si\(\text{iv}\) and C\(\text{iv}\). The clear detection of these lines indicates the presence of a QSO in agreement with the SED fitting.

### 3.1 Photo-z/spec-z comparison

We have compared the spectroscopic redshifts obtained with EFOSC2 with the photometric redshifts calculated using the latest version of the ISoZ code (Rowan-Robinson et al. 2008). The results are given in Fig. 2. Reliability and accuracy of the photometric redshifts are measured via the fractional error \(\Delta z/(1+z)\) for each source, examining the mean error \(\overline{\Delta z}/(1+z)\), the rms scatter and the rate of ‘catastrophic’ outliers \(\eta\), defined as the fraction of the full sample that has \(|\Delta z/(1+z)| > 0.15\). Fig. 2 shows a comparison of \(\log(1+z_{\text{spec}})\) versus \(\log(1+z_{\text{spec}})\) for the sample of 34 sources with available spectroscopy. For the whole sample, the total rms scatter, \(\sigma \cdot \mu\), is 0.121, with \(\Delta z/(1+z) = 0.013\), and the number of outlier sources is 4. 3/4 of the outliers are fitted with a QSO template and one with a galaxy template. Redshift estimation for all the outliers is based on the detection of at least three lines making their spec-z highly reliable. From the four sources which were fitted with a QSO optical template the number of outliers is three. From the three sources with \(z_{\text{spec}} > 1.5\), all of them fitted with a QSO optical template, there are two ‘catastrophic’ outliers.

### 4 EMISSION-LINE DIAGNOSTICS

A suite of emission-line diagnostic diagrams has been used extensively in order to classify the dominant energy sources in

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**Figure 2.** Photometric versus spectroscopic redshift for all sources with available spectroscopic redshifts in our sample. The straight lines represent a 10 per cent accuracy in \(\log(1+z)\). Red triangles are sources fitted with a QSO template and black triangles are sources fitted with a galaxy template.
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Figure 3. Optical spectra of the six LIRGs found in our sample. Blue and red colours represent spectra taken with Grism-3 and -5, respectively.

emission-line galaxies (Baldwin, Phillips & Terlevich 1981). These diagrams are based on various optical line ratios. We have used the following three: [O III]/Hβ, [N II]/Hα and [S II]/Hα. The reason behind this selection is that these ratios are not affected by reddening and spectrophotometric effects even in the case of non-flux calibrated spectra.

For the [S II]/Hα versus [O III]/Hβ and [N II]/Hα versus [O III]/Hβ diagrams the theoretical work of Kewley et al. (2001) provided a maximum starburst line and clear division between AGN and star-forming (SF) galaxies, with all galaxies lying above this line dominated by an AGN. The work of Kauffmann et al. (2003) provided a cleaner delineation between AGN and SF galaxies due to
Figure 4. Optical spectra of the five ULIRGs and the one HLIRG found in our sample. Blue and red colours represent spectra taken with Grism-3 and -5, respectively.

the large sample of Sloan Digital Sky Survey (SDSS) galaxies. The result was an empirical relation dividing pure SF galaxies from Seyfert–H II composite objects whose spectra contain significant contributions from both AGN and star formation. In the [S II]/Hα versus [O III]/Hβ diagram, the AGNs lie on two branches: on the upper one lie Seyfert galaxies while LINERs lie on the lower one. The division between the two AGN branches takes effect via the Seyfert–LINER classification line (Kewley et al. 2006).

In order to recreate the BPT diagrams for our sample, we have plotted all narrow-line sources with detections in all five lines:
Figure 5. Left: the [N\textsc{ii}] λ6583/H\textalpha versus [O\textsc{iii}] λ5007/H\textbeta diagnostic emission-line diagram for our sample of 15 sources with available lines. The black-dashed line is the pure SF line (Kauffmann et al. 2003) and the black-solid line is the extreme SF line (Kewley et al. 2001). The red-dashed lines are the Seyfert/low-ionization nuclear emission-line region (LINER) lines (Ho et al. 1997). Green, blue and red asterisks represent the star-forming, the composite and the Seyfert sources based on the [N\textsc{ii}] λ6583/H\textalpha versus [O\textsc{iii}] λ5007/H\textbeta diagnostic. Orange asterisks are LINERs based on the [S\textsc{ii}] λ6716+λ6731/H\textalpha versus [O\textsc{iii}] λ5007/H\textbeta diagnostic. Open black squares are U/LIRGs of our sample with available lines. Right: the [S\textsc{iii}] λ6716+λ6731/H\textalpha versus [O\textsc{iii}] λ5007/H\textbeta diagnostic emission-line diagram for the sample of 15 sources. The black-solid line is the AGN/starburst line (Baldwin et al. 1981) and the black-dashed line is the Seyfert/LINER line (Kewley et al. 2006). We keep the same colours for the sources.

Galaxies that lie below the pure SF lines are H\textalpha region-like galaxies. Galaxies that lie in between the two classification lines, extreme and pure SF lines, are known as composite objects, being on the AGN–H\textalpha mixing sequence. Composite galaxy spectra are likely to contain significant contributions from a metal-rich stellar population plus an AGN. Everything that lies above the solid line (Kewley et al. 2001) is classed as AGN. Ho, Filippenko & Sargent (1997) defined a new classification scheme which is represented by the red-dashed lines. Adding these lines

Table 4. The [N\textsc{ii}]/H\textalpha versus [O\textsc{iii}]/H\textbeta and [S\textsc{ii}]/H\textalpha versus [O\textsc{iii}]/H\textbeta diagrams for all the 15 sources with available lines.

| Object                | z   | S1 | S2 | S3 | SC1 | SC2 |
|-----------------------|-----|----|----|----|-----|-----|
| SWIRE3-J033152.82-290647.1 | 0.079 | −0.8240 | −0.1677 | −0.0962 | Star-forming | LINER |
| SWIRE3-J033148.59-290643.1 | 0.119 | −0.2180 | −0.5677 | 0.7244 | AGN | AGN |
| SWIRE3-J033145.66-290728.0 | 0.245 | −0.0971 | −0.1584 | −0.1121 | Composite | LINER |
| SWIRE3-J033142.11-290551.9 | 0.158 | −0.2765 | −0.1253 | −0.8868 | Star-forming | Star-forming |
| SWIRE3-J033535.68-284714.2 | 0.123 | −0.8131 | −0.3639 | 0.2009 | Star-forming | Star-forming |
| SWIRE3-J033523.29-284827.2 | 0.195 | −0.4371 | −0.1988 | 0.5581 | AGN | AGN |
| SWIRE3-J033536.42-283309.5 | 0.105 | −0.1468 | −0.4471 | 0.0645 | Composite | Star-forming |
| SWIRE3-J033552.56-283051.1 | 0.077 | −0.5036 | −0.3016 | 0.7621 | AGN | AGN |
| SWIRE3-J033529.98-283344.4 | 0.225 | −0.1783 | −0.3706 | −0.0500 | Composite | Star-forming |
| SWIRE3-J033234.23-293450.8 | 0.529 | −0.1029 | −0.1649 | 0.0700 | Composite | LINER |
| SWIRE3-J033555.74-290742.4 | 0.222 | −0.1365 | −0.1936 | 0.0584 | Composite | LINER |
| SWIRE3-J033552.63-290535.6 | 0.189 | −0.3475 | −0.4514 | 0.0045 | Composite | Star-forming |
| SWIRE3-J033555.43-290758.9 | 0.190 | −1.0127 | −0.4227 | −0.2384 | Star-forming | Star-forming |
| SWIRE3-J033551.15-290735.6 | 0.195 | −0.5292 | −0.3433 | 0.1401 | Star-forming | Star-forming |
| SWIRE3-J033008.28-285400.3 | 0.217 | −0.7703 | −0.6176 | 0.2039 | Star-forming | Star-forming |

\( a \) Spectroscopic redshift.

\( b \) Spectroscopic classification according to the [N\textsc{ii}]/H\textalpha versus [O\textsc{iii}]/H\textbeta diagnostic.

\( c \) Spectroscopic classification according to the [S\textsc{ii}]/H\textalpha versus [O\textsc{iii}]/H\textbeta diagnostic.

\( d \) \( \log_{10}(\text{N}\textsc{ii}/\text{H}\alpha) \).

\( e \) \( \log_{10}(\text{S}\textsc{ii}/\text{H}\alpha) \).

\( f \) \( \log_{10}(\text{O}\textsc{iii}/\text{H}\beta) \).
to the previous two classification lines, we separate the classification scheme into four parts. As ‘HII region’ are classified the sources which lie below the Kewley line and left from the red-dashed line, Seyfert sources lie at the upper-left box and the LINERs at the lower-right box. Fig. 5 (right) shows the \([\text{S}\ II]/\text{H}\alpha\) versus \([\text{O}\ III]/\text{H}\beta\) diagnostic emission-line diagram for the 15 sample sources. The black-solid line (Baldwin et al. 1981) provides an upper limit to the SF sources on this diagram. The black-dashed line (Kewley et al. 2006) provides a division between Seyfert and LINER sources. The red-dashed lines represent the Ho et al. (1997) classification line in the \([\text{N}\ II]/\text{H}\alpha\) versus \([\text{O}\ III]/\text{H}\beta\) diagram.

Based on both diagnostic diagrams, we found six pure SF galaxies of which one appears as a LINER on the \([\text{S}\ II]/\text{H}\alpha\) versus \([\text{O}\ III]/\text{H}\beta\) diagram, three Seyfert galaxies and six composite objects of which three appear as SF objects and three as LINERs on the \([\text{S}\ II]/\text{H}\alpha\) versus \([\text{O}\ III]/\text{H}\beta\) diagram. The spectra of these objects are available in Fig. 10 (later).

**Figure 6.** IRAC colour–colour plot (Lacy et al. 2004) of all 34 sources of our sample with detections in all IRAC bands. Green, blue, orange and red colours represent the star-forming, composite, LINER and Seyfert narrow-line emission sources based on \([\text{N}\ II]/\text{H}\alpha\) versus \([\text{O}\ III]/\text{H}\beta\) and \([\text{S}\ II]/\text{H}\alpha\) versus \([\text{O}\ III]/\text{H}\beta\) diagrams. Red diamonds are broad-line QSOs. Black asterisks represent all the remaining sources. The red solid line is the AGN area as defined by Lacy et al. (2004). Open black squares represent the H/U/LIRGs of our sample.

**Figure 7.** IRAC–MIPS colour–colour plot of 31 sources of our sample with detections in 3.6 \(\mu\)m, 5.8 \(\mu\)m and 24 \(\mu\)m bands. The red solid line distinguishes between AGN and SF galaxies (Lacy et al. 2004). Colours and symbols are the same as in Fig. 6.

**Figure 8.** IRAC colour–colour plot (Stern et al. 2005) of 34 sources of our sample with detections in 3.6 \(\mu\)m, 4.5 \(\mu\)m, 5.8 \(\mu\)m and 8.0 \(\mu\)m bands. Red solid lines follow empirical criteria to separate AGNs from other sources (Stern et al. 2005). Colours and symbols are the same as in Fig. 6.

**Figure 9.** SEDs for the nine galaxies with \(z > 0.5\). Two are fitted with an M82 starburst, one with an Arp 220 starburst, two with an AGN dust torus and four are composite M82 starburst+AGN dust torus. All three with QSO optical templates have AGN dust tori (the long-dashed curves).
5 MIR COLOURS

For the Lacy et al. (2004) diagnostic we require sources to have detections in all four IRAC bands, 3.6 µm, 4.5 µm, 5.8 µm and 8 µm, a total of 29 sources. For the remaining five, we have used SWIRE limits for each band. Sources that lie within the Lacy wedge are those expected to be AGN dominated from the mid-infrared colours.

Figure 10. A sample of spectra with available [S ii], Hα, [O iii], Hβ, [N ii] lines used to estimate line ratios. The redshift of these sources is from 0.077 to 0.529. The two U/LIRGs of this sample are plotted in Figs 3 and 4.
Fig. 6 shows the IRAC colour–colour plot combined with information obtained from the spectroscopic diagnostics. In our sample we detect four broad-line objects which are fitted with a QSO optical template and all of them lie within the AGN wedge (red diamonds). In the case of the narrow emission lines, all the star-forming sources (green asterisks) lie outside the AGN region and specifically on the top-left of the diagram. In the same region with SF sources lie the LINER sources at a rate of 2/3 (orange asterisks) and all the composite sources (blue asterisks). Only one of the three narrow-line AGNs we found in our sample (based on BPT diagrams) lies within the AGN wedge. All the H/ULIRGs of our sample lie within the AGN region in contrast with LIRG sources.
which lie outside the AGN wedge at a rate of 5/6. In Fig. 7, we plot an IRAC–MIPS colour–colour diagram using the sources with detection in IRAC’s 3.6 and 5.8 µm bands and MIPS’s 24 µm band. This requirement limits the number of our sample to 31. Even if the larger wavelength difference between 8 and 24 µm makes the interpretation of the MIPS/IRAC colour–colour plots more complicated, all the QSO fitted sources lie within the AGN region (right of the red line). The rate of LIRG sources that lie within this region has been increased at 4/6. Fig. 8 shows the IRAC colour–colour diagnostic diagram from Stern et al. (2005). Again, all the broad-line objects lie within the AGN region and 1/3 Type II Seyferts. Fig. 9 shows the SEDs of the 13 sources with $z > 0.5$. All of them are fitted with the standard infrared templates of Rowan-Robinson et al. (2008).

6 SUMMARY

We present the optical spectra of 34 sources within SWIRE-CDFS, observed using EFOSC-2 in MOS mode on the ESO 3.6-m telescope. We have compared the observed spectroscopic redshift values to those estimated using our photo-$z$ methods and the agreement is very good especially in the case of galaxies. With respect to QSO photo-$z$ agreement and taking into consideration the problems photo-$z$ methods face when dealing with quasars, our sample is too small to extract safe results. Among our sources we found six LIRGs, five ULIRGs and one HLIRG. All H/ULIRGs are broad-line objects at $z > 1.0$, in excellent agreement with our SED template fitting method which fitted all of them with a QSO optical template. All the broad-line objects in our sample are fitted with a QSO optical template and show evidence of a strong dust
torus component in the MIR in excellent agreement with MIR colour–colour plots. In the case of narrow emission-line objects, based on emission diagnostic diagrams for the 15 sources (their spectra are available in Fig. 10) with the necessary lines, we found six pure SF galaxies, three Seyfert galaxies, six composite objects of which three appear as SF objects and three as LINERs based on the [S\(\text{II}\)/H\(\alpha\) versus [O\(\text{III}\)/H\(\beta\) diagram. In Fig. 11 can be found the original spectra of the rest of the nine objects of our sample.
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