THE DEEP SWIRE FIELD. III. WIYN SPECTROSCOPY

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ABSTRACT

We present the results of spectroscopy using HYDRA on the WIYN 3.5 m telescope of objects in the deep SWIRE radio field. The goal of the project was to determine spectroscopic redshifts for as many of the brighter objects in the field as possible, especially those detected in the radio and at 24 \(\mu\)m. These redshifts are primarily being used in studies of galaxy evolution and the connection of that evolution to active galactic nuclei and star formation. Redshifts measured for 365 individual objects are reported. The redshifts range from 0.03 to 2.5, mostly with \(z < 0.9\). The sources were selected to be within the WIYN HYDRA field of approximately 30' in radius from the center of the SWIRE deep field, 10°46′00″, 59°01′00″ (J2000). Optical sources for spectroscopic observation were selected from an \(r\)-band image of the field. A priority list of spectroscopic targets was established in the following order: 20 cm detections, 24 m detections, galaxies with \(r < 20\) and the balance made up of fainter galaxies in the field. We provide a table listing the galaxy positions, measured redshift and error, and note any emission lines that were visible in the spectrum. In practice, almost all the galaxies with \(r < 19\) were observed including all of the radio sources and most of the 24 \(\mu\)m sources with \(r < 20\) and a sample of radio sources which had fainter optical counterparts on the \(r\)-band image.

Key words: cosmology; observations – galaxies: active – galaxies: starburst – infrared: galaxies

Online-only material: color figures, machine-readable tables

1. INTRODUCTION

This paper is the third in a series documenting our study of the deep SWIRE field centered at 10°46′00″, 59°01′00″ (J2000). Paper I (Owen & Morrison 2008) describes the 20 cm VLA observations which produced the deepest 20 cm radio survey to date with 2050 sources and the basic radio properties of the faint \(\mu\)Jy population. Paper II (Owen et al. 2009) details a complementary, deep 90 cm survey and dependence of 20 cm to 90 cm spectral index on radio flux density. These two papers concentrate only on radio properties. What is needed to learn more are the distances to the sources and their properties at other wavelengths. In Paper IV (V. Strazzullo et al. 2009, in preparation), we discuss the absolute radio/optical/NIR properties of the radio sources and their connection to the evolution of galaxies. We accomplish this goal by estimating photometric redshifts for the sources for which we do not possess a spectroscopic redshift, using images of the field from the Galaxy Evolution Explorer (GALEX) UV bands, ground-based UgrizHKJ and the 3.6 and 4.5 \(\mu\)m bands of IRAC on Spitzer. As part of our photometric technique we need spectroscopic redshifts as a training set. The results described in this paper are used in Paper IV, along with redshifts from other projects for this purpose. These spectroscopic redshifts also provide secure, accurate redshifts, and thus distances, for a large fraction of the low-redshift objects in the field.

The results reported here have already been used as calibration data for another photometric redshift study (Rowan-Robinson et al. 2008), which has itself been used for in a number of subsequent studies. A secondary goal of the survey was to observe 24 \(\mu\)m sources and those redshifts were used for a determination of the 24 \(\mu\)m luminosity function (Onyett et al. 2006). Moreover, these spectroscopic and the photometric redshifts from Paper IV are being used for a number of studies of the active galactic nuclei (AGN) versus star formation activity versus redshift. In addition, deep Spitzer MIPS (Multiband Imaging Photometer for Spitzer) imaging is being stacked as a function of radio luminosity and redshift in order to use the radio–FIR relation to indicate the relative evolution of these two properties. The redshifts are also being used with the Chandra survey of this region to study the evolution of the X-ray-loud AGN population and its connection to the radio population (Wilkes et al. 2009). Several other studies that are currently underway are also making use of the WIYN redshifts and the photometric redshifts in order to fold the deep radio data into a more complete picture of galaxy evolution provided at other wavelengths.

2. SELECTION, OBSERVATIONS, AND REDUCTION

The sources were selected to be within the WIYN HYDRA field of view, approximately 30' in radius from the center of the SWIRE deep field, 10°46′00″, 59°01′00″ (J2000). Optical sources for observation were selected from the \(r\)-band image of the field taken for the SWIRE survey with the KPNO 4 m (Lonsdale et al. 2003). The magnitudes were measured using a 2" diameter aperture, which is the same size as the fibers. A preliminary 20 cm radio image from the VLA and a preliminary 24 \(\mu\)m from Spitzer existed at the time of the observation. A priority list of possible sources was established: 20 cm detections, 24 \(\mu\)m detections, galaxies with \(r < 20\), and fainter galaxies (\(r > 20\)) in the field. As described below, sources for observations were optimized for each fiber set.

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The observations were made on 2004 February 11–15 using the HYDRA fiber spectrograph on the WIYN 3.5 m telescope at KPNO. The 316@7.0 grating was used with the Bench Spectrograph and the red fiber cables. The G4 $GG – 420$ blocking filter was used which after calibration yielded a usable spectral region of 4400 Å–9700 Å with some second-order contamination beyond 8800 Å. Two CuAr comparison lamp exposures were taken for each wavelength calibration, one with 10 times the integration time of the other, and were observed before and after each fiber set. These data showed that the wavelength response of the bench spectrograph setup was very stable. Standard stars were observed each night through single fibers to allow a rough relative spectral calibration to be obtained. Radial velocity standards were also observed to check the stability and accuracy of the redshift measurements. These observations demonstrated that the overall calibration of our unknown sources was limited by other considerations than the calibration, mainly $S/N$ (signal-to-noise).

The fiber setup was done using whydra. A large number of runs of the program with slightly different parameters were used to obtain the best fiber setup for each observation. Typically, 20 sky fibers, 5 FOPS (guide stars), and 65 objects fibers were used. Depending on observing conditions different criteria were used to prioritize the setup, e.g., brighter objects were observed preferentially when the transparency and/or seeing was poorer.
estimates for multiple lines in quadrature with 50 km s$^{-1}$, the upper limit to the error in the absolute spectral calibration derived from the scatter in velocity derived for observations of radial velocity standard stars.

In Figure 1, we show six examples of spectra we used to determine the results in tables. These spectra are picked to cover the range of different types of objects in our sample from broadline, high-redshift AGN to pure absorption-line spectra. One can see the increasing importance of night sky features at longer wavelengths but that strong emission lines can still be seen in the red. After completing the reductions out of 1063 objects in our original sample, 548 had at least one reduced spectrum. Of these we obtain reliable redshifts for 365 objects. For the remaining 183 we could not measure a robust redshift. In most of these cases the signal in the spectrum was too weak to be usable due to poor observing conditions. In Table 1, we summarize the statistics of the observed sources as a function of $r$ magnitude.

### 3. RESULTS

In Table 2, we give the first 10 columns of the online table containing J2000 positions and $r$ magnitudes of the objects for which we obtained successful spectra from WIYN. In Table 3, we present the first 10 columns of the online table containing the results of the WIYN spectroscopy. In Columns 1 and 2, we give the J2000 coordinate name and the radio source name. If Column 2 is blank that means that the galaxy was not detected in the 5$\sigma$ 20 cm catalog given in Paper I. Columns 3 and 4 contain the redshift and error. In Column 5 we give the “notes” on the results, including either the spectral line(s) and/or the “FXCOR” if the redshift was obtained by cross-correlation with an absorption-line template. When a photometric redshift is used to confirm a one line redshift we add the note “photoz.” If the source was detected at 20 cm at the 3$\sigma$ level we also note in Column 5. Finally, we give the number of the galaxy in the input file for the WIYN observation for future reference and requests for individual spectra.

Of the 365 total objects for which we measured a redshift, 267 of the objects have emission lines; 249 have two or more lines. For the 18 objects with only one line, the identity of the emission line (usually O ii) is confirmed by an absorption-line redshift in nine cases and in the other nine cases by a photometric redshift from V. Strazzullo et al. (2009, in preparation). 98 objects have measured redshifts from absorption lines only. 249 of the measured redshifts are for radio-detected objects. 229 are published in the 5$\sigma$ catalog in Paper I. Ten are detected at the 4$\sigma$ level and 10 more at 3$\sigma$. 286 24 m$\mu$ sources had their redshifts determined (Onyett et al. 2006). In Figure 2 we show the redshift distribution. The largest peak contains 53 objects with 0.11 < $z$ < 0.12 suggesting we are looking through an organized structure at this redshift, although no concentrated cluster is obvious in the images. Eight objects not shown have redshifts > 1.

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