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More redshifts of powerful equatorial radio sources from the Best, Röttgering & Lehnert sample

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ABSTRACT

A new sample of very powerful radio sources, defined from the Molonglo Reference Catalogue, was recently compiled by Best, Röttgering & Lehnert. These authors provided redshifts for 174 of the 178 objects in the sample, making the sample 98 per cent spectroscopically complete. Here, redshifts for three of the remaining galaxies are presented, confirming the optical identifications and raising the spectroscopic completeness of the sample to 99.5 per cent; only 1059−010 (3C 249) is currently without redshift.

Key words: catalogues – galaxies: active – galaxies: distances and redshifts.

1 INTRODUCTION

Radio sources have many important roles to play in astrophysical and cosmological studies (e.g. see McCarthy 1993 for a review). In order to provide a large, spectroscopically complete sample of luminous radio sources accessible to both northern radio interferometers such as the Very Large Array (VLA) and large southern telescope facilities, such as the Very Large Telescope, Gemini South, and the Atacama Large Millimetre Array (ALMA), Best, Röttgering & Lehnert (1999) recently defined a new sample of very powerful equatorial radio sources from the Molonglo Reference Catalogue (MRC; Large et al. 1981), according to the criteria (see Best et al. for details) $S_{408\,\mathrm{MHz}} \geqslant 5\,\mathrm{Jy}$, $-30° \leqslant \delta \leqslant +10°$, $|b| \geqslant 10°$. This sample (hereafter the BRL sample) consists of 178 objects and, following radio imaging, optical imaging and spectroscopic observations, spectroscopic redshifts were provided for 174 of these in the original paper. The host galaxies of the remaining four sources were all optically identified, but no spectroscopic redshifts were obtained.

In this paper, spectroscopic redshifts are derived from new observations of three of these remaining four objects, 1413−215, 1859−235 and 1953−077 (3C 404). In Section 2, details of the observations and data reduction are provided. The reduced spectra are presented and discussed in Section 3. The reader is referred to Best et al. (1999) for a complete description of the sample and its properties.

2 OBSERVATIONS AND DATA REDUCTION

Long-slit spectra of 1859−235 and 1953−077 were taken using the dual-beam ISIS spectrograph on the William Herschel Telescope (WHT) in photometric conditions during service time on the night of 1999 July 5 (see Table 1 for details). The observations were made using the 5700-Å dichroic and the R158B and R158R gratings in the blue and red arms of the spectrograph. In the blue arm this provided a spatial scale of 0.19 arcsec pixel^{-1} and a spectral resolution of about 19 Å, and in the red arm a spatial scale of 0.36 arcsec pixel^{-1} and a spectral resolution of about 12 Å.

The data were reduced using standard packages within the IRAF NOAO reduction software. After subtraction of the bias level, the spectroscopic data were flat-fielded using observations of internal calibration lamps, and the sky background was removed. The two exposures of each galaxy were combined, removing cosmic ray events, and one-dimensional spectra were extracted from an angular extent of 2.9 arcsec along the slit. The extracted spectra were wavelength-calibrated using observations of CuNe and CuAr arc lamps, and flux calibration was achieved using observations of the spectrophotometric standard star Kopff 27. The determined fluxes were corrected for any atmospheric extinction arising from the non-unity airmass of the observations.

1413−215 was observed at the Keck II telescope in photometric conditions during evening twilight on 1999 July 11 (see Table 1). The observations were made using the Low-Resolution Imaging Spectrograph (LRIS; Oke et al. 1995) with the 150 line mm^{-1} grating (7500-Å blaze), providing a spatial pixel scale of 0.21 arcsec and a spectral resolution of about 25 Å. The galaxy was shifted 10 arcsec along the slit between two separate observations to reduce fringing effects. Data reduction followed essentially the same procedure as outlined for the WHT observations, except that the spectrum was extracted from an angular extent of 2.1 arcsec along the slit (because of a smaller spatial extent of the object). Feige 110 and HZ44 were used for flux calibration.

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Table 1. Details of the spectroscopic observations.

Source	Observ. date	Tele.	Exp. time (s)	Slit width (arcsec)	Slit PA (°)
1413−215	11/07/99	Keck	2×600	1.5	350
1859−235	05/07/99	WHT	2×900	2.5	90
1953−077	05/07/99	WHT	2×900	2.5	340

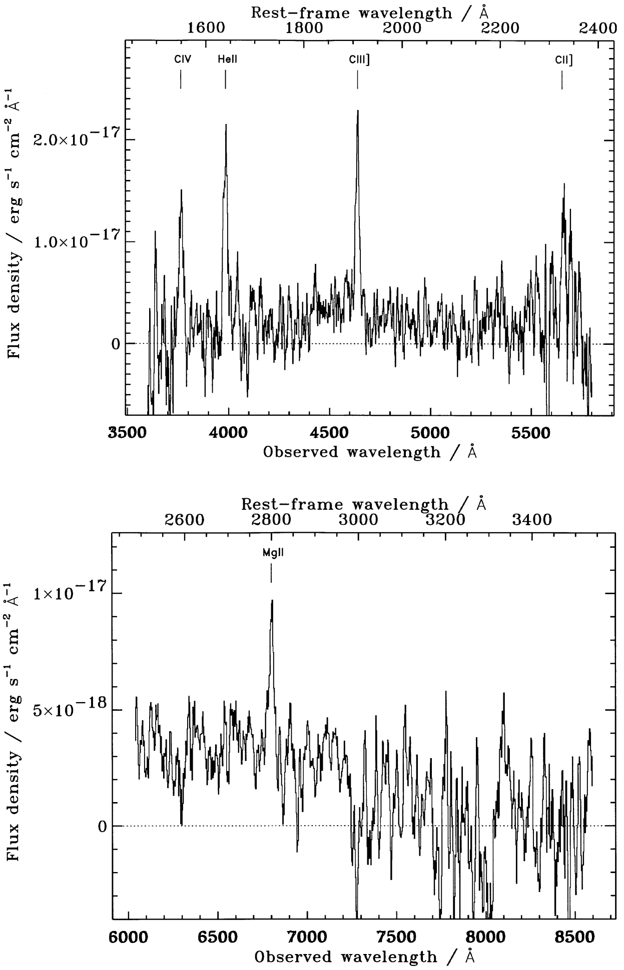

Figure 1. The WHT ISIS blue arm (left) and red arm (right) spectra of 1859−235.

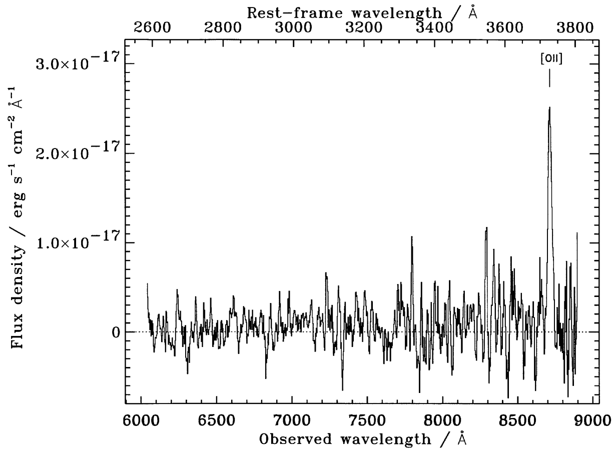

Figure 2. The WHT ISIS red arm spectrum of 1953−077.

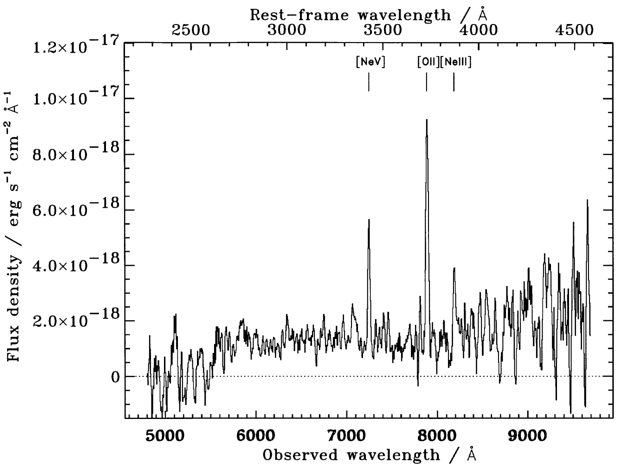

Figure 3. The Keck LRIS spectrum of 1413−215.

3 RESULTS AND DISCUSSION

The extracted spectra of the three galaxies are provided in Figs 1, 2 and 3, and details of the emission-line properties are provided in Table 2. Emission lines are detected for all three objects, confirming the identifications proposed in the paper by Best et al. (1999). For 1859−235 and 1413−215, several emission lines are detected, providing unambiguous redshift measurements. For

Table 2. Emission-line properties of the galaxies. In addition to the derived galaxy redshifts, the integrated fluxes of the emission lines are given, together with their deconvolved velocity full width at half-maxima and their rest-frame equivalent widths. These properties were calculated in the manner described in Best et al. (1999).

Source	Redshift	Line	Line flux (10^{-16} erg s^{-1} cm^{-2})		FWHM (deconv.) (km s^{-1})		Eq. width (Å)	
1413−215	1.116 ± 0.001	[Ne v]	1.0	±0.1	<390		33	±5
		[O II]	2.5	0.3	760	±280	99	19
		[Ne III]	0.6	0.2	730	590	18	6
1859−235	1.430 ± 0.001	[C IV]	3.4	0.6	<1300		103	5
		He II	4.6	0.6	1230	800	173	6
		C III]	4.7	0.5	800	410	75	14
		C II]	6.7	1.1	<1950		142	4
		Mg II	1.8	0.3	1180	480	24	4
1953−077	1.338 ± 0.002	[O II]	7.6	1.2	880	410	195	10

1953−077 only a single strong emission line is detected, at 8714 Å. This emission line is assumed to be [O II] 3727 for a number of reasons: (i) if this were [O III] 5007 or Hα (or any other weaker line), then the lack of any other strong emission lines between 3500 and 9000 Å would be very surprising; (ii) weak continuum emission is detected in the red-arm observations down to about 6000 Å, ruling out the possibility that the line is Lyα; (iii) if the line is [O II] 3727 then, given the R magnitude of the source ($R = 22.90$), the derived redshift places it in the middle of the R–z diagram of the other radio galaxies (cf. fig. 51 of Best et al. 1999). It appears fairly secure, therefore, that this emission line is [O II] 3727.

Following these results, the BRL sample is now 99.5 per cent complete. The only object without a spectroscopic redshift in the sample is 1059−010 (3C 249), the very faint R magnitude of which ($R = 24.20$; Best et al. 1999) suggests a minimum redshift of 1.5. Spinrad, Stern & Dey (private communication) have attempted, without success, to obtain a redshift for this object using the Keck Telescope, and Rawlings (private communication) has carried out near-infrared spectroscopy with UKIRT in the J band and between 1.6 and 2.2 μm, detecting the continuum but no lines. Obtaining the final redshift in the sample may prove difficult.

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