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The 6C** sample of steep-spectrum radio sources: I – Radio data, near-infrared imaging and optical spectroscopy

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ABSTRACT

We present basic observational data on the 6C** sample. This is a new sample of radio sources drawn from the 151 MHz 6C survey, which was filtered with radio criteria chosen to optimize the chances of finding radio galaxies at $z > 4$. The filtering criteria are a steep-spectral index and a small angular size. The final sample consists of 68 sources from a region of sky covering 0.421 sr. We present VLA radio maps, and the results of K-band imaging and optical spectroscopy.

Near-infrared counterparts are identified for 66 of the 68 sources, down to a 3σ limiting magnitude of $K \sim 22$ mag in a 3-arcsec aperture. Eight of these identifications are spatially compact, implying an unresolved nuclear source. The K-magnitude distribution peaks at a median $K \approx 18.7$ mag, and is found to be statistically indistinguishable from that of the similarly selected 6C* sample, implying that the redshift distribution could extend to $z \gtrsim 4$.

Redshifts determined from spectroscopy are available for 22 (32 per cent) of the sources, over the range of $0.2 \lesssim z \lesssim 3.3$. We measure 15 of these, whereas the other 7 were previously known. Six sources are at $z > 2.5$. Four sources show broad emission lines in their spectra and are classified as quasars. Three of these show also an unresolved K-band identification. Eleven sources fail to show any distinctive emission and/or absorption features in their spectra. We suggest that these could be (i) in the so-called 'redshift desert' region of $1.2 < z < 1.8$, or (ii) at a greater redshift, but feature weak emission line spectra.

Key words: galaxies: active - galaxies: evolution - radio continuum: galaxies - galaxies: high redshift

1 INTRODUCTION

The chief purpose of the 6C** sample was to find radio galaxies at the highest redshifts ($z > 4$) and, based on its data, to directly constrain the co-moving space density of high-redshift radio sources. It is the second of the filtered 6C redshift surveys, being preceded by a pilot sample, namely 6C* (Blundell et al. 1998; Jarvis et al. 2001a,b).

Previous to the 6C and 7C surveys, low-frequency studies of radio sources were based on the revised 3C sample (3CRR; Laing, Riley & Longair 1983). The problem with this sample is that, as with any single flux-limited sample, there is a tight correlation between luminosity and redshift, in the sense that the highest redshift sources in the sample are necessarily the most luminous ones. One obvious im-

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Sample	Flux-density Limits (Jy)	Sky Area (sr)	Number of Sources	Spectroscopic Completeness	Radio Filtering
3CRR	$S_{178} \geq 10.9$	4.24	173	100%	None
6CE	$2.00 \leq S_{151} \leq 3.93$	0.10	58	97%	None
7CRS	$S_{151} \geq 0.5$	0.022	128	90%	None
6C*	$0.96 \leq S_{151} \leq 2.0$	0.13	29	100%	$\alpha_{151M}^{4.85G} \geq 0.981$; $\theta < 15$ arcsec
6C**	$S_{151} \geq 0.5$	0.42	68	32%	$\alpha_{151M}^{1.4G} \geq 1.0$; $\theta < 11$ arcsec

Table 1. Summary of the properties of the 3CRR, 6CE, 7CRS, 6C* and 6C** redshift surveys. Note: spectroscopy has not been attempted yet on all members of the 6C** sample (see Section 3.3).

plication is that based solely on the 3CRR sample, or in any single flux-density limited sample, one cannot distinguish between correlations of source parameters with redshift and with luminosity. The other implication is that the 3CRR sample, being very bright, does not find any objects at $z \gtrsim 2$, due to the rarity of the extremely powerful ($L_{151} \sim 10^{28} - 10^{29}$ W Hz^{-1} sr^{-1}) radio sources.

The 6CE (Rawlings, Eales & Lacy 2001) and 7CRS (Willott et al. 1998, 2002; Lacy et al. 1999a,b) complete samples, with fainter flux-density limits (see Table 1), were designed to address these problems and, in particular, to improve coverage of the 151 MHz luminosity (L_{151}), redshift plane. They were indeed very successful in extending the $L_{151} - z$ plane into lower radio luminosities at low-redshift and into $2 < z < 3$ at high radio luminosity (e.g. Willott et al. 2001). However, the problem with these samples is that the requirement of low flux-density limits could only be achieved, in terms of complete spectroscopic follow-up being feasible, at the expense of the sky area covered. This is particularly dramatic in the case of the 7CRS sample and it very much restricted the number of very high-redshift sources included in these surveys. The need to overcome this limitation, i.e. to have a redshift survey which covers a larger area of sky at flux levels comparable to that of the 7CRS, and thereby probe very high redshift radio sources ($z > 3$) in a statistically meaningful way, provided the main motivation for the construction of the filtered 6C redshift surveys[1].

These surveys, 6C* and 6C**, were both filtered with more selective radio criteria than just a simple flux-density limit (see Table 1). Additional criteria were introduced in order to filter out a large fraction of the sources, mostly at low-redshift, thereby ensuring that optical follow-up would be limited to a manageable number of sources, biased towards high-redshift. The chosen criteria took into account, therefore, the characteristics often seen in very distant radio galaxies, namely steep radio spectral index α and small angular size θ.

The first criterion has been the one most widely used in searches for the highest redshift radio galaxies (e.g. Röttgering et al. 1994; Chambers et al. 1996; Blundell et al. 1998; De Breuck et al. 2000; Cohen et al. 2004). It is based primarily on the convex shape of the radio spectra which flattens below rest-frame $\sim$ 300 MHz. Since higher redshift objects are observed at higher rest-frame frequencies, their measured spectral indices are invariably steeper. The second criterion relies on strong statistical evidence for a negative evolutionary trend of linear size with redshift (e.g. Barthel & Miley 1988; Neeser et al. 1995; Blundell, Rawlings & Willott 1999) although it has been less widely used in targeting high-redshift radio sources.

Both criteria are imperfect in the sense that not all of the sources at low-redshift are eliminated and some fraction at high redshift are actually excluded. Jarvis et al. (2001b) quantified these fractions by comparing the redshift distribution of the 6C* sample with the radio luminosity function model of Willott et al. (2001). They have found that employment of the filtering criteria has reduced the number of $z < 1.5$ sources by $\approx$ 90 per cent, whereas in the redshift range $1.5 \lesssim z \lesssim 3.0$ the fraction excluded varies between $\sim 30 - 70$ per cent. The distribution, as a result, is skewed towards objects at $z \gtrsim 2.0$, and the 6C* sample has a median redshift of $z \sim 1.9$ (cf. 6CE and 7CRS with $\sim$ 1.1 median redshift).

Even though the effects of the filtering criteria introduce difficulties in interpreting the data from filtered samples, namely in assessing which population of sources is filtered out, they are very effective in biasing these samples to objects at high redshift. This has been demonstrated very successfully with the 6C* sample (Jarvis et al. 2001b), which led to the discovery of 6C0140+326 at $z = 4.41$ (Rawlings et al. 1996) – the most distant radio galaxy known at the time of discovery – in a sample of only 29 objects. Nevertheless, the 6C* sample has only two objects at $z > 3$ and, therefore, the $L_{151} - z$ diagram still suffers from small number statistics at high redshift. The 6C** sample, deeper and larger than 6C* (Table 1), aims to ameliorate this problem and, ultimately, to extend the $L_{151} - z$ diagram to even higher redshifts ($z \sim 5$).

The final spectroscopically complete 6C** sample will also potentially supply us with targets with which we can probe the most massive objects in the early Universe. Studies of the host galaxies of radio-loud AGN have shown that all powerful radio sources are associated with the most massive galaxies at every cosmological epoch (Jarvis et al. 2001a; De Breuck et al. 2002; Willott et al. 2003; Zirm et al. 2003). Similarly, it has been shown that the most radio-

[1] A fainter and larger survey, containing $\sim$ 1000 radio sources with $S_{151} > 0.1$ Jy, is also being put together by the groups at Oxford and Texas (Hill & Rawlings 2003). This survey, named the TexOx-1000 (TOOT), aims to probe those radio-loud objects which are more typical at high redshift ($z > 3$), i.e. less luminous than the ones probed by 3CRR, 6CE and 7CRS at the same redshift, which are rare.

loud quasars are those with the most massive black-holes (e.g. Dunlop et al. 2003; McLure & Jarvis 2004). Moreover, recent studies have identified high redshift radio galaxies (HzRGs; $z > 2$) which are associated with the sites of forming proto-clusters (Kurk et al. 2004; Miley et al. 2004; Venemans et al. 2004, 2005), implying that HzRGs are the most likely progenitors of the nearby brightest clusters. Powerful radio sources are therefore key targets for studies of the formation and evolution of massive structures in the early Universe. Also, the discovery of a radio galaxy within the epoch of reionization ($z > 6$) will allow for 21 cm absorption line studies of neutral hydrogen at that epoch (e.g. Carilli, Gnedin & Owen 2002).

Finally, one important characteristic of all the samples mentioned here is that they have been selected at low radio frequencies ($\nu < 200$ MHz). This is a crucial factor in searches for high-redshift sources (e.g. Blundell, Rawlings & Willott 1999, 2000) and strongly determines the content of a sample. Low-frequency surveys typically contain a high proportion of steep-spectrum sources, where the observed emission is dominated by the isotropically emitting radio-lobe components. In high-frequency ($\nu \gtrsim 1$ GHz) surveys, in contrast, core-dominated flat-spectrum sources prevail. Consequently, surveys at high frequency tend to have more objects which are selected above the flux limit because their emission is boosted due to orientation of their jet axes, rather than their intrinsic power. Surveys at low-frequency ($\nu < 200$ MHz), being dominated by isotropic radio emission, provide us, therefore, with much less biased samples of radio sources.

In this paper (hereafter Paper I) we present complete K-band imaging of the 6C** sample, high-resolution radio maps for 42 of the sources, and optical spectroscopy for a sub-sample of the optically identified sources. In a companion paper (Paper II), we will present single-colour (K-band) photometric redshifts for all the sources and investigate the redshift distribution of the sample. The paper is set out as follows. In Section 2 we describe the sample selection criteria. In Section 3 we outline the observing and data reduction procedures. The radio maps, K-band images and photometry, and the redshifts and line parameters are presented in Section 4. In Section 5 we provide notes of each source in the sample with respect to both imaging and spectroscopy. The results are discussed in Section 6 and our main conclusions are summarized in Section 7. Unless otherwise stated, we assume throughout that $H_0 = 70$ km s^{-1}Mpc^{-1}, $\Omega_{\rm M} = 0.3$ and $\Omega_\Lambda = 0.7$. The convention used for radio spectral index is $S_\nu \propto \nu^{-\alpha}$, where S_ν is the flux-density at frequency ν.

2 SAMPLE DEFINITION

The 6C** sample was drawn from Part II and Part III of the 6C survey of radio sources at 151 MHz (Hales et al. 1988, 1990). The region of Right Ascension between $07^{\rm h}\,14^{\rm m}$ and $11^{\rm h}\,50^{\rm m}$ and Declination between $+30^\circ$ and $+58^\circ$ was chosen and, in this area of the sky, all sources with 151 MHz flux density S_{151} less than 0.5 Jy were rejected. Spectral indices were found by cross-correlating the remaining objects with their counterparts (within 120 arcsec) in the NVSS catalogue at 1.4 GHz (Condon et al. 1998). Any object with a spectral index between 151 MHz and 1.4 GHz (i.e., α_{151}^{1400}) that was flatter than 1.0 was then rejected. From the remaining objects only those with angular size, as listed in the NVSS catalogue, smaller than deconvolved 13 arcsec were kept. Fulfilment of the above criteria resulted in a preliminary sample of 158 sources. However, not all of these objects were legitimate members of the 6C** sample.

One disadvantage of the 6C survey is its low spatial resolution (4 arcmin). This means that in a sample like 6C**, with such a relatively low flux-density limit, the problem of source confusion is particularly acute. To ensure that sources with a 6C (integrated) S_{151} resulting from the confusion of two or more radio sources – which if considered individually would fall below the flux-density limit – were rejected, we cross-correlated the NVSS (with 40 arcsec resolution) entries with those in the FIRST survey (with 5 arcsec resolution) at 1.4 GHz (Becker, White & Helfand 1995). Sources which were resolved into two or more independent radio sources in the FIRST catalogue were excluded by eye. Through this procedure we were also able to identify and exclude: (i) sources having an actual angular size larger than the 13 arcsec limit, and (ii) sources which were actually one of the hotspots of a much larger double source.

The final version of the 6C** sample excludes all these identified 'spurious' sources and comprises 68 objects over an area of sky of 0.421 sr. We note also that in this process some sources with sizes between 11 and 13 arcsec were rejected, but not all of them. No sources smaller than approximately 11 arcsec were rejected. Therefore, the sample is only complete at an angular size limit of $\theta < 11$ arcsec. The final selection criteria may be summarized as follows:

(i) $07^{\rm h}14^{\rm m} \leq$ R.A. (B1950) $\leq 11^{\rm h}50^{\rm m}$,
(ii) $30^\circ \leq$ Dec. (B1950) $\leq 58^\circ$,
(iii) $S_{151} \geq 0.5$ Jy,
(iv) $\alpha_{151}^{1400} \geq 1.0$,
(v) $\theta < 13$ arcsec (complete at $\theta < 11$ arcsec).

In Table A1, we list the 6C and NVSS positions and fluxes, and the spectral indices derived from these, for all the members of the 6C** sample.

3 OBSERVATIONS AND DATA REDUCTION

3.1 K-band imaging

3.1.1 UKIRT

All the sources in the 6C** sample have been imaged in K-band (2.2 μm) at the United Kingdom Infrared Telescope (UKIRT). These observations were made over several observing runs, starting in March 1999 up to February 2004, using the UKIRT Fast-Track Imager (UFTI), except for one of the runs. For the observations in January 2003, the UKIRT Imager Spectrometer (UIST) was used. UFTI is a 1-2.5 μm camera with a 1024 × 1024 HgCdTe array and a plate scale of 0.091 arcsec per pixel, giving a field of view of 92″× 92″. UIST is a 1-5 μm imager-spectrometer with a 1024 × 1024 InSb array. In imaging mode there are two plate scales available, 0.12 arcsec per pixel or 0.06 arcsec per pixel. We used the former, giving a field of view of 120″× 120″. All observations were made in photometric conditions with the exception of the ones made on 1999 March 11 or unless otherwise stated, with seeing better than 0.6 arcsec.

K-BAND				RADIO			
Source Name	Telescope/ Instrument	Dates Observed	Total Exp. (s)	Map Freq. (GHz)	Dates Obs.	Peak Flux (mJy beam^{-1})	RMS (mJy beam^{-1})
6C**0714+4616	UKIRT/UFTI	**2002-01-09**	540	4.9	1996-12-06	22.16	0.36
6C**0717+5121	UKIRT/UFTI	**1999-03-12**	3240	8.4	1996-12-18	1.30	0.10
	UKIRT/UIST	2003-01-28	540				
6C**0726+4938	UKIRT/UIST	**2003-01-28**	540	4.9	1996-12-18	1.29	0.13
6C**0737+5618	UKIRT/UFTI	1999-03-12 1999-03-13	4320				
	UKIRT/UIST	2003-01-28	540				
	Gemini/NIRI	**2004-02-03**	2700	8.4	1996-12-18	0.35	0.09
6C**0744+3702	UKIRT/UFTI	**1999-03-12**	2160	8.4	1996-12-18	0.85	0.09
6C**0746+5445	UKIRT/UFTI	**1999-03-12**	1620	4.9	1996-12-06	0.55	0.12
6C**0754+4640	UKIRT/UFTI	1999-03-13	3000				
	Gemini/NIRI	**2004-02-10**	2460	4.9	1996-12-06	0.48	0.10
6C**0754+5019	UKIRT/UIST	2003-01-28	540				
	Gemini/NIRI	**2004-02-10**	2460	4.9	1996-12-06	8.75	0.21
6C**0801+4903	UKIRT/UFTI	1999-03-11† **2003-12-18**	1080	4.9	1996-12-06	0.52	0.12
	UKIRT/UIST	2003-01-28	540				
6C**0810+4605	UKIRT/UFTI	2002-01-09 **2002-01-13**	2160	4.9	1996-12-06	0.59	0.10
6C**0813+3725	UKIRT/UFTI	2002-01-09 **2003-12-23**	1080	4.9	1996-12-06	0.34	0.08
6C**0824+5344	UKIRT/UFTI	2002-01-09 **2002-01-13**	2160	4.9	1996-12-06	5.56	0.19
6C**0829+3902	UKIRT/UFTI	**1999-03-13**	2640	4.9	1996-12-06	5.96	0.15
6C**0832+4420	UKIRT/UFTI	1999-03-11† **2003-12-15**	1080	4.9	1996-12-06	0.51	0.12
6C**0832+5443	UKIRT/UFTI	**2002-01-09**	540	4.9	1996-12-06	0.37	0.10
6C**0834+4129	UKIRT/UFTI	**2002-01-12**	540	8.4	1996-12-18	3.02	0.13
6C**0848+4803	UKIRT/UFTI	1999-03-11† **2003-12-15**	1620	4.9	1996-12-06	3.68	0.12
6C**0848+4927	UKIRT/UFTI	**1999-03-13**	1080	4.9	1996-12-06	19.77	0.32
6C**0849+4658	UKIRT/UFTI	1999-03-11† **2003-12-15**	1080	8.4	1996-12-18	19.66	0.37
6C**0854+3500	UKIRT/UFTI	**1999-03-12**	540	8.4	1996-12-18	0.49	0.12
6C**0855+4428	UKIRT/UFTI	**2002-01-12**	540	4.9	1996-12-06	3.33	0.15
6C**0856+4313	UKIRT/UFTI	**2003-12-15**	540	4.9	1996-12-06	5.87	0.17
6C**0902+3827	UKIRT/UFTI	2000-04-12 **2003-12-18**	1080	8.4	1996-12-18	8.47	0.18
6C**0903+4251	UKIRT/UFTI	**2000-04-13**	540	8.4	1996-12-18	8.23	0.18
6C**0909+4317	UKIRT/UFTI	**2000-04-12**	3240	4.9	1996-12-06	0.88	0.20
6C**0912+3913	UKIRT/UFTI	**2000-04-13**	540	1.4		26.03	0.37
6C**0920+5308	UKIRT/UFTI	**2002-11-22**	540	4.9	1996-12-06	4.60	0.15
6C**0922+4216	UKIRT/UFTI	**2002-11-22**	540	1.4		199.65	0.13
6C**0924+4933	UKIRT/UFTI	**2002-11-22**	540	4.9	1996-12-06	8.47	0.21
6C**0925+4155	UKIRT/UFTI	2000-04-14 2003-12-18 2003-12-23	1620				
	Gemini/NIRI	2004-02-12†	840				
	Keck/NIRC	**2004-04-30**	1920	1.4		76.41	0.15
6C**0928+4203	UKIRT/UFTI	**2002-11-22**	540	4.9	1996-12-06	8.52	0.24
6C**0928+5557	UKIRT/UFTI	**2000-04-14**	540	4.9	1996-12-06	0.92	0.11
6C**0930+4856	UKIRT/UFTI	**2002-11-22**	540	4.9	1996-12-18	0.79	0.19
6C**0935+4348	UKIRT/UFTI	2000-04-12 2003-12-18 2003-12-23	540				
	Gemini/NIRI	**2004-02-12**	2280	1.4		29.02	0.14
6C**0935+5548	UKIRT/UFTI	**2000-04-13**	540	4.9	1996-12-06	0.72	0.14
6C**0938+3801	UKIRT/UFTI	2000-04-13 **2004-02-09**	1080	8.4	1996-12-18	2.89	0.13
	UKIRT/UIST	2003-01-28	540				
6C**0943+4034	UKIRT/UFTI	**2000-04-14**	540	1.4		56.70	0.13
6C**0944+3946	UKIRT/UFTI	2000-04-14 **2003-12-18**	1080	1.4		53.96	0.13
	UKIRT/UIST	2003-01-28	540				
6C**0956+4735	UKIRT/UFTI	**2002-11-22**	540	4.9	1996-12-06	0.75	0.18
6C**0957+3955	UKIRT/UFTI	**2002-11-22**	540	8.4	1996-12-18	0.77	0.10
6C**1003+4827	UKIRT/UFTI	**2002-11-22**	540	4.9	1996-12-18	2.89	0.21
6C**1004+4531	UKIRT/UFTI	**2002-11-22**	540	4.9	1996-12-06	0.60	0.13
6C**1006+4135	UKIRT/UFTI	**2002-11-22**	540	8.4	1996-12-18	0.43	0.11
6C**1009+4327	UKIRT/UFTI	**2002-11-22**	540	1.4		133.03	0.14
6C**1015+5334	UKIRT/UFTI	**2000-04-14**	540	4.9	1996-12-06	0.58	0.12

Table 2. Log of the *K*-band and radio imaging observations of the sources present in the 6C** sample. The bold lettering indicates the *K*-band images shown in Fig. 1. Columns 5, 6, 7 and 8 list the frequency, observation date, peak flux density and rms noise of the radio maps shown in Fig. 1. The maps at 4.9 GHz and 8.4 GHz were obtained with the VLA in its A-configuration, as described in Section 3.2, with integrations times varying from 2 to 5 minutes. The maps at 1.4 GHz are from the FIRST survey (http://sundog.stsci.edu/first/catalogs.html). Note: the Keck–NIRC image of 6C**0925+4155 was observed through a K_S filter. † signifies that the observation was made under non-photometric conditions.

K-BAND				RADIO			
Source Name	Telescope/ Instrument	Dates Observed	Total Exp. (s)	Map Freq. (GHz)	Dates Obs.	Peak Flux (mJy beam^{-1})	RMS (mJy beam^{-1})
6C**1017+3436	UKIRT/UFTI	**2000-04-14**	540	8.4	1996-12-18	0.48	0.12
6C**1018+4000	UKIRT/UFTI	**2000-04-14**	540	8.4	1996-12-18	0.44	0.11
6C**1035+4245	UKIRT/UFTI	**2000-04-12**	3240	8.4	1996-12-18	0.44	0.11
6C**1036+4721	UKIRT/UFTI	**2002-11-22**	540	1.4		358.25	0.15
6C**1043+3714	UKIRT/UFTI	**2000-04-14**	540	1.4		191.04	0.30
6C**1044+4938	UKIRT/UFTI	2000-04-13 **2000-04-14**	3780	8.4	1996-12-18	1.26	0.17
6C**1045+4459	UKIRT/UIST	**2003-01-28**	540	1.4		45.63	0.14
6C**1048+4434	UKIRT/UIST	**2003-01-28**	540	1.4		86.02	0.14
6C**1050+5440	UKIRT/UFTI	**1999-03-06**	3240	1.4		56.99	0.17
6C**1052+4349	UKIRT/UFTI	**2002-12-20**	540	1.4		45.77	0.13
6C**1056+3303	UKIRT/UFTI	**2002-12-20**	540	1.4		149.92	0.11
6C**1100+4417	UKIRT/UFTI	**2002-01-13**	540	1.4		59.79	0.14
6C**1102+4329	UKIRT/UFTI	2002-01-13 2003-12-18 **2003-12-23**	1620	1.4		81.15	0.13
6C**1103+5352	UKIRT/UFTI	2002-01-13 **2003-12-23**	1080	1.4		256.49	0.14
6C**1105+4454	UKIRT/UFTI	**2002-01-13**	540	1.4		36.60	0.14
6C**1106+5301	UKIRT/UFTI	**2002-05-05**	540	1.4		36.27	0.14
6C**1112+4133	UKIRT/UFTI	**2002-12-20**	540	1.4		11.77	0.13
6C**1125+5548	UKIRT/UFTI	**2002-01-13** 2002-05-05	1080	1.4		24.44	0.14
6C**1132+3209	UKIRT/UFTI	**2002-01-13**	540	1.4		27.52	0.14
6C**1135+5122	UKIRT/UFTI	**2000-04-12**	540	1.4		50.91	0.14
6C**1138+3309	UKIRT/UFTI	2002-01-13 2002-12-20 **2003-12-18**	1620	1.4		36.05	0.11
6C**1138+3803	UKIRT/UFTI	**2002-01-13**	540	1.4		35.34	0.15
6C**1149+3509	UKIRT/UFTI	**2002-12-20**	540	1.4		54.16	0.13

Table 2. *continued*

The observational strategy used in all cases was the standard one when observing with an infrared array. Each object field was observed at nine (or a number multiple of nine) different positions in the array, by offsetting the telescope by about 10 arcsec between each exposure. The offsets were chosen so that they produced a 3 × 3 pointing pattern which allowed for sufficient spatial overlap between the fields, while at the same time ensured that different elements of the array sampled different parts of the field each time. This technique is advantageous in that it provides for good flat-fielding and sky subtraction, it gives a larger field-of-view and it makes it easier to remove cosmic rays and bad pixels. The integration time for each of the multiple exposures was 60 seconds. The total integration time varied between objects in the sample depending on the magnitude of the source and on telescope time constraints. However, most of the sources were observed for at least 9 minutes or a multiple thereof.

3.1.2 Gemini

Five sources that remained undetected after the UKIRT campaign were observed with the Near Infrared Imager (NIRI) on the Gemini North Telescope in February 2004. NIRI comprises a 1024 × 1024 ALADDIN InSb array sensitive from 1 to 5 μm, and three cameras providing 0.022, 0.050, and 0.117 arcsec per pixel plate scales. We used the lowest resolution camera, giving a field of view of $120'' \times 120''$. The sources were observed in K-band using the same observational technique as with UKIRT. In a few cases, individual 60 second exposure frames were corrupted by electronic instability in the detector and these were discarded.

3.1.3 Keck

One of the sources which was not detected with UKIRT was also observed with the Near Infrared Camera (NIRC) on the Keck I Telescope in April 2004. The observations of this source with Gemini were lost due to bad weather conditions. NIRC comprises a 256 × 256 InSb array with a plate scale of 0.151 arcsec per pixel, giving a field of view of $38.4'' \times 38.4''$. The source was observed with the K_S filter for a total of 32 minutes, comprising 10 co-additions of 6 seconds per pointing in two 16-point dither patterns. The seeing was 0.9 arcsec.

A summary of all the K-band observations is given in Table 2.

3.1.4 Data Reduction

The near-infrared imaging data were reduced using a combination of routines within IRAF. The data reduction comprised the following steps: (i) dark-current subtraction; (ii) sky subtraction and flat-fielding, using the multiple exposures of each field to create sky and flat-field frames; and (iii) image co-adding. To combine the images we adopted the following procedure. First, a star common to all the frames in a set of multiple exposures was identified. Its centroid pixel coordinates were then recorded in each frame and used to calculate the relative shifts between frames (the offsets). When it was not possible to identify a suitable object common to the frames, we used the offsets calculated for another set of images in the same night (we found this procedure to be more accurate than using the image header offsets). Each individual frame was scaled by a factor of $10^{(0.4eX)}$, where X is the airmass of the observation and e is the extinction coefficient given in magnitudes per airmass, in order to correct

Source Name	Pointing Position (J2000)		Date	Exposure Time (s)	Slit Width (arcsec)	P.A. (°)
6C**0714+4616	07 17 58.45	46 11 38.9	98Dec17	1x1200B, 1x1200R	2.5	30
6C**0717+5121			98Dec18	1x1800B, 2x900R	2.5	
	07 21 27.31	51 15 49.7	02Dec30	5x900B, 3x1800R	1.0	234
6C**0726+4938	07 30 06.15	49 32 40.7	97Jan09	1x1800B, 2x900R	2.5	135
6C**0737+5618	07 41 15.39	56 11 35.9	97Jan09	1x1800B, 2x900R	2.5	28
			98Dec18	2x1800B, 4x900R	2.5	
	07 41 15.38	56 11 35.8	98Dec19	2x1200B, 4x900R	2.5	208
	07 41 15.39	56 11 35.9	98Dec20	3x1800B, 6x900R	2.5	180
6C**0744+3702	07 47 29.36	36 54 38.0	97Jan09	2x1800B, 4x900R	2.5	0
6C**0746+5445			98Dec18	1x1800B, 2x900R	2.5	
	07 50 24.63	**54 38 07.1**	**02Dec30**	**4x900B, 2x1800R**	**1.0**	**270**
6C**0754+4640	07 58 29.67	46 32 32.7	97Apr08	1x1200B, 2x900R	2.5	14
6C**0754+5019	07 58 06.15	50 11 04.9	97Jan10	1x1800B, 2x900R	2.5	33
6C**0810+4605	08 14 30.28	45 56 39.5	97Jan10	1x379B, 1x395R	3.0	0
6C**0813+3725	08 16 53.72	37 15 54.8	97Jan10	1x1800B, 2x900R	3.0	116
6C**0824+5344	08 27 58.91	53 34 15.0	97Jan10	1x1200B, 2x600R	2.5	137
6C**0829+3902	08 32 45.33	38 52 15.7	97Apr08	2x1200B, 2x900B	2.5	60
	08 32 45.32	38 52 16.1	98Dec17	1x1800B, 2x900R	2.5	60
6C**0832+5443	08 36 10.06	54 33 25.8	97Apr08	1x1500B, 2x750R	2.5	83
	08 36 09.66	**54 33 25.3**	**98Dec17**	**1x1800B, 2x900R**	**2.5**	**83**
6C**0834+4129	08 37 49.23	41 19 53.0	98Dec17	1x1800B, 2x900R	2.5	143
6C**0848+4927	08 52 14.84	49 15 44.7	98Dec20	1x1800B, 2x900R	2.5	177
6C**0854+3500	08 57 15.98	34 48 24.1	02Dec31	2x900B, 1x1800R	1.0	231
6C**0856+4313			98Dec18	1x1800B, 2x900R	2.5	
6C**0902+3827	09 05 13.09	38 14 34.5	97Jan10	1x1800B, 2x900R	2.5	0
6C**0925+4155	09 28 22.12	41 42 23.1	04Dec10	2x1200B, 2x1200R	1.5	31
6C**0928+4203	09 31 38.55	41 49 45.4	98Dec17	1x1800B, 2x900R	2.5	0
6C**0935+4348	09 38 21.41	43 34 37.4	04Dec10	2x1200B, 2x1200R	1.5	90
6C**0938+3801			98Dec18	1x1800B, 2x900R	2.5	
6C**1009+4327	10 12 09.89	43 13 09.1	05Apr14	1x1800B, 2x900R	2.0	30
6C**1036+4721	10 39 15.67	47 05 40.3	03Jan01	1x900B, 1x900R	1.5	93
6C**1045+4459	10 48 32.25	44 44 28.3	97Jan09	1x1800B, 2x900R	2.5	132
6C**1050+5440	10 53 36.30	54 24 41.9	97Jan09	1x1800B, 2x900R	2.5	36
6C**1102+4329	11 05 43.00	43 13 24.6	05Apr14	1x1800B, 2x900R	2.0	90

Table 3. Log of the spectroscopic observations obtained for sources in the 6C** sample. When there is more than one observation for one source, the larger bold text represents the observation for the spectra presented in Fig. 3. For the observations made in 1998 December 18 there is no record available of the pointing position nor of the slit position angles. For this reason they do not appear in this table.

for the small effects of atmospheric extinction at K-band. The individual images of each object field were then registered using the offsets and combined into an image with intensity at each pixel equal to the average of the pixels in the individual frames, which excludes pixels more than 4σ away from the median of the distribution. The bad pixels were also excluded. These were flagged by the means of a bad pixel mask and were determined from the flat fields.

3.2 Radio Imaging

Most of the 6C** sources (42 out of 68) were observed with the Very Large Array (VLA) in its A-configuration on various epoch during December 1996. All observations were conducted using two snapshots each typically of a few minutes in duration. For those candidates with a sized quoted in the NVSS catalogue as resolved, the observations were made at 1.4 GHz, while those listed as unresolved were observed at 5 GHz. Data processing was done using standard procedures using the AIPS software including self-calibration for phase corrections, producing radio images with approximately 1 arcsec and 0.35 arcsec resolution, respectively. For those images which were found to be unresolved from these initial observations, we re-observed them in a later epoch at 8 GHz giving 0.2 arcsec resolution.

The respective maps are presented in Fig. 1. The frequencies used and other relevant data are listed in Table 2. Where no high-resolution radio data are available, we present maps from the FIRST survey.

3.3 Optical Spectroscopy

The optical spectra presented in this paper were all obtained with the ISIS long-slit spectrograph on the William Herschel Telescope (WHT). The observations were made over the nights of 1997 January 9–10; 1997 April 8; 1998 December 17–20; 2002 December 30–31, 2003 January 1; 2004 December 10 and 2005 April 14. The observations on 2005 April 14 were part of the WHT service programme. A journal of all these observations is presented in Table 3.

ISIS is a double-beam spectrograph which uses a dichroic to separate the light into two different channels - the blue and red arms. Each of these is equipped with a detector optimized to operate at its respective wavelength range. All the observations were made using both arms. Observational setup details for each night are summarized in Table 4. Slit widths varied between 1 and 3 arcsec, depending on the seeing. Conditions were photometric for all nights except for the run in December 2002 / January 2003. The atmospheric conditions in this run were not photometric since variable cloud cover during each night affected the transparency.

Since all the sources observed were very faint, positioning and centring of the long slit on targets were made by off-setting from a nearby bright star. In the first three runs

(January 1997, April 1997 and December 1998), since most objects had not been previously identified through optical imaging, most spectra were taken by "blind" offsetting to the radio position and by aligning the slit with the radio axis (Rawlings, Eales & Warren 1990). For the observations made after 2002 all of the spectra, except for 6C**0935+4348, were taken at the near-infrared counterpart position.

3.3.1 Data Reduction

Reduction of the raw spectra was carried out using standard routines within the IRAF NOAO packages, particularly the TWODSPEC and ONEDSPEC packages. Data reduction involved the following steps, which were performed separately and in parallel for the red and blue arms: (i) overscan correction and bias subtraction; (ii) flat-fielding, using Tungsten lamp spectra in conjunction with twilight sky spectra; (iii) wavelength calibration and geometrical rectification, using comparison arc lamps and standard stars, respectively; (iv) background subtraction; and, (v) extinction correction. Spectrophotometric standard stars were observed during the course of each night and were used to flux-calibrate the data.

One-dimensional spectra were extracted from the fully-reduced two-dimensional spectra. The extractions were made over an aperture equal to the full-width at zero-intensity (FWZI), making sure that extended emission lines were fully enclosed by it. When more than one exposure of the same object was taken using the same observational setup and slit P.A., the individual one-dimensional spectra were combined using a high-threshold rejection to eliminate cosmic rays. The value of the threshold was set to be slightly higher than the maximum pixel count due to real features in the spectra.

Reduced one-dimensional spectra for all the objects that have obvious emission lines are presented in Fig. 3. For presentation purposes all have been boxcar smoothed over three pixels. Cosmic rays were edited out of the one-dimensional spectra by inspection of the two-dimensional spectra. If features appear in only one arm of the spectrum then the other is not shown. Otherwise, the spectra from the red and blue arms were joined together by averaging over ≈ 50 Å in the overlapping regions.

4 ANALYSIS

4.1 Source Identification and K-band Photometry

4.1.1 Astrometry and identification

Astrometry for each image was achieved by comparing the image with a finding chart from the Second Palomar Observatory Sky Survey. For most fields three or more sources were common to both the image and the finding chart. For these cases the plate solution was obtained using the KARMA–KOORDS task package (Gooch 1996). For cases where fewer than three POSS-II sources were detected on the K-band image, the plate solution for another image with a good fit on the same observing run was used along with the position of one of the detected stars to fix the astrometry. After this procedure, and where possible, we compared star positions in our fields with those from the USNO-A2.0 Catalogue (Monet et al. 1998) and the 2MASS Catalogue (Skrutskie et al. 2006). For most cases we found differences in the range of 0.05 to 0.5 arcsec. Where necessary (thirteen sources) we used stars from these two catalogues to improve the astrometric solution.

Identification of the near-infrared counterparts to the radio sources was accomplished by overlaying the radio contour maps on to the K-band images using the KARMA–KVIS task package (Gooch 1996). The reduced and astrometrized K-band images, with radio contours overlaid, are shown in Fig. 1. All the sources are discussed individually in Section 5.1.

4.1.2 Photometry

We measured magnitudes for all radio source identifications using the IRAF task PHOT and circular apertures with diameters of 3, 5 and 8 arcsec. This is to facilitate comparison with previous work and to make sure that a magnitude is obtained even when there is a nearby object. In Table 5 we present the K-band magnitudes for all of the sources in the 6C** sample.

The photometry was calibrated using observations of standard stars selected from the UKIRT list of faint standards (Hawarden et al. 2001). Two to three different stars were observed over the course of each night with 5 to 20 second exposures (depending on their magnitudes) in mosaics of five positions. The reduction process for these observations is identical to the one outlined in Section 3.1. The following zero-points were obtained: 20.81 ± 0.02 mag for the single night of observations with UIST; in the range of 21.95 – 22.36 mag for the several nights where UFTI was used (the values remained fairly constant throughout individual nights in a given observing run but changed significantly between different runs); and ≈ 23.6 mag for all the observations with NIRI. For the observations made with NIRC at Keck the $K_{\rm S}$ zero-point was 24.66 mag. We used this zero-point to measure the $K_{\rm S}$ magnitude for 6C**0925+4155 (the source observed with NIRC). We do not convert this K_S magnitude to K-band as the correction factor is smaller than the photometric uncertainty. In the remainder of this paper we will refer to it as a K-band magnitude.

4.2 Redshifts and Line Parameters

Sixteen of the sources which have been observed with the WHT show definite and/or plausible emission lines in their spectra. A Gaussian fit was made to all the lines with high enough signal-to-noise to determine the line centre, FWHM and total line flux. Continua were fitted to the data by eye. All measurements were made on the FWZI aperture spectra and prior to the smoothing process described in Section 3.3.1. The emission-line measurements are listed in Table 6.

To determine redshifts and identify the lines we compared our spectra with the composite radio galaxy spectrum of McCarthy (1993), which is based on observations of galaxies with $0.1 \lesssim z \lesssim 3$. Of the objects with identifiable features in their spectra three are classified as quasars (6C**0714+4616, 6C**0928+4203 and 6C**1036+3714) on the basis of broad-lines in the spectrum and/or unresolved K-band emission.

	Dates	1997 Jan 9-10 1997 Apr 8	1998 Dec 17-20	2002 Dec 30-31 2003 Jan 01	2004 Dec 10	2005 Apr 14
	Dichroic	6100	6100	5400	5400	5300
	CCD	TEK5	EEV12	EEV12	EEV12	EEV12
	CCD size	1124x400	720x4200	401x4200	1201x4200	601x2100
	Binning factor	1x1	1x1	1x1	1x1	2x2
Blue	Binned pixel	0.36 arcsec	0.19 arcsec	0.19 arcsec	0.19 arcsec	0.38 arcsec
	Grating	R158B	R158B	R158B / R300B	R300B	R158B
	Spectral scale	2.9 Å pixel^{-1}	1.62 Å pixel^{-1}	1.62 / 0.86 Å pixel^{-1}	0.86 Å pixel^{-1}	3.2 Å pixel^{-1}
	Spectral range	2970 Å	3539 Å	5670 / 3024 Å	3024 Å	3427 Å
	CCD	TEK2	TEK2	MARCONI2	MARCONI2	MARCONI2
	CCD size	1124x400	1124x400	401x4700	1201x4700	501x2350
	Binning	1x1	1x1	1x1	1x1	2x2
Red	Binned pixel	0.36 arcsec	0.36 arcsec	0.19 arcsec	0.19 arcsec	0.38 arcsec
	Grating	R158R	R158R	R158R / R316R	R316R	R158R
	Spectral scale	2.9 Å pixel^{-1}	2.9 Å pixel^{-1}	1.63 / 0.84 Å pixel^{-1}	0.84 Å pixel^{-1}	3.3 Å pixel^{-1}
	Spectral range	2970 Å	2970 Å	4492 / 2302 Å	2302 Å	4637 Å

Table 4. Summary of the observational setup for each optical spectroscopy run.

Figure 1. (a) The K-band images (greyscale) of the 68 6C** sources, with radio contours overlaid. The K-band images have been smoothed with a $\sigma = 1$ pixel Gaussian for presentation purposes, unless otherwise stated. The black/white contours represent the VLA radio emission (with frequencies as given in Table 2, column 5) or, when these are not available, the radio maps from the 1.4 GHz FIRST Survey. Contours are spaced at intervals separated by factors of 2 starting at: 0.4 mJy beam^{-1} for 6C**0714+4616; 0.32 mJy beam^{-1} for 6C**0717+5121; 0.4 mJy beam^{-1} for 6C**0726+4938; and, 0.2 mJy beam^{-1} for 6C**0737+5618.

Figure 1. (b) Contours are spaced at intervals separated by factors of 2 starting at: 0.2 mJy beam^{-1} for 6C**0744+3702; 0.4 mJy beam^{-1} for 6C**0746+5445; 0.2 mJy beam^{-1} for 6C**0754+4640; 0.2 mJy beam^{-1} for 6C**0754+5019; 0.4 mJy beam^{-1} for 6C**0801+4903; and, 0.4 mJy beam^{-1} for 6C**0810+4605. The images of 6C**0744+3702 and 6C**0754+5019 have been smoothed with a $\sigma = 2$ pixel Gaussian.

Figure 1. (c) Contours are spaced at intervals separated by factors of 2 starting at: 0.4 mJy beam^{-1} for 6C**0813+3725; 0.4 mJy beam^{-1} for 6C**0824+5344; 0.32 mJy beam^{-1} for 6C**0829+3902; 0.32 mJy beam^{-1} for 6C**0832+4420; 0.2 mJy beam^{-1} for 6C**0832+5443; and, 0.32 mJy beam^{-1} for 6C**0834+4129. The image of 6C**0832+5443 has been smoothed with a $\sigma = 2$ pixel Gaussian.

Figure 1. (d) Contours are spaced at intervals separated by factors of 2 starting at: 0.2 mJy beam^{-1} for 6C**0848+4803; 0.4 mJy beam^{-1} for 6C**0848+4927; 0.2 mJy beam^{-1} for 6C**0849+4658; 0.4 mJy beam^{-1} for 6C**0854+3500; 0.4 mJy beam^{-1} for 6C**0855+4428; and, 0.4 mJy beam^{-1} for 6C**0856+4313.

Figure 1. (e) Contours are spaced at intervals separated by factors of 2 starting at: 0.32 mJy beam^{-1} for 6C**0902+3827; 0.32 mJy beam^{-1} for 6C**0903+4251; 0.8 mJy beam^{-1} for 6C**0909+4317; 1.28 mJy beam^{-1} for 6C**0912+3913; 0.32 mJy beam^{-1} for 6C**0920+5308; and 0.8 mJy beam^{-1} for 6C**0922+4216.

Figure 1. (f) Contours are spaced at intervals separated by factors of 2 starting at: 0.32 mJy beam^{-1} for 6C**0924+4933; 0.64 mJy beam^{-1} for 6C**0925+4155; 0.4 mJy beam^{-1} for 6C**0928+4203; 0.2 mJy beam^{-1} for 6C**0928+5557; 0.4 mJy beam^{-1} for 6C**0930+4856; and, 0.4 mJy beam^{-1} for 6C**0935+4348.

Figure 1. (g) Contours are spaced at intervals separated by factors of 2 starting at: 0.4 mJy beam^{-1} for 6C**0935+5548; 0.32 mJy beam^{-1} for 6C**0938+3801; 0.4 mJy beam^{-1} for 6C**0943+4034; 0.4 mJy beam^{-1} for 6C**0944+3946; 0.8 mJy beam^{-1} for 6C**0956+5735; and, 0.2 mJy beam^{-1} for 6C**0957+3955. The image of 6C**0938+3801 has been smoothed with a $\sigma = 2$ pixel Gaussian.

Figure 1. (h) Contours are spaced at intervals separated by factors of 2 starting at: 0.8 mJy beam^{-1} for 6C**1003+4827; 0.32 mJy beam^{-1} for 6C**1004+4531; 0.4 mJy beam^{-1} for 6C**1006+4135; 1.28 mJy beam^{-1} for 6C**1009+4327; 0.64 mJy beam^{-1} for 6C**1015+5334; and, 0.32 mJy beam^{-1} for 6C**1017+3436. The image of 6C**1009+4327 has been smoothed with a $\sigma = 2$ pixel Gaussian.

Source Name	NIR Position (J2000) RA	DEC	Magnitude 3" diameter	Magnitude 5" diameter	Magnitude 8" diameter	Detector
6C**0714+4616†	07 17 58.48	+46 11 39.3	16.705 ± 0.022	16.565 ± 0.039	16.316 ± 0.069	UFTI
6C**0717+5121	07 21 27.23	+51 15 50.3	18.148 ± 0.033	17.788 ± 0.047	nbo	UFTI
			18.081 ± 0.070	17.804 ± 0.098	nbo	UIST
6C**0726+4938	07 30 06.20	+49 32 41.2	18.991 ± 0.220	18.711 ± 0.395	18.168 ± 0.497	UIST
6C**0737+5618	–	–	> 21.8	> 21.5	> 21.1	NIRI
6C**0744+3702	07 47 29.36	+36 54 37.9	19.708 ± 0.142	19.667 ± 0.220	19.440 ± 0.753	UFTI
6C**0746+5445	07 50 24.63	+54 38 06.9	18.423 ± 0.061	nbo	nbo	UFTI
6C**0754+4640(a)	07 58 29.70	+46 32 34.0	20.138 ± 0.049	19.971 ± 0.082	nbo	NIRI
6C**0754+4640(b)	07 58 29.43	+46 32 30.8	20.162 ± 0.051	19.907 ± 0.079	nbo	NIRI
6C**0754+5019	07 58 06.06	+50 11 03.1	21.519 ± 0.186	20.629 ± 0.265	nbo	NIRI
6C**0801+4903	08 04 41.26	+48 54 58.3	19.979 ± 0.433	19.855 ± 1.529	nbo	UFTI
6C**0810+4605	08 14 30.31	+45 56 39.8	16.405 ± 0.010	16.123 ± 0.016	15.993 ± 0.030	UFTI
6C**0813+3725	08 16 53.70	+37 15 54.8	20.018 ± 0.450	19.574 ± 0.540	18.798 ± 0.684	UFTI
6C**0824+5344	08 27 58.87	+53 34 15.4	19.720 ± 0.231	19.719 ± 0.328	19.392 ± 0.721	UFTI
6C**0829+3902	08 32 45.32	+38 52 16.7	19.427 ± 0.108	19.413 ± 0.227	nbo	UFTI
6C**0832+4420	08 35 27.84	+44 09 52.4	18.896 ± 0.105	19.149 ± 0.266	18.915 ± 0.406	UFTI
6C**0832+5443	08 36 09.87	+54 33 25.8	19.604 ± 0.230	19.283 ± 0.441	nbo	UFTI
6C**0834+4129	08 37 49.25	+41 19 54.6	19.571 ± 0.192	19.396 ± 0.460	19.378 ± 0.717	UFTI
6C**0848+4803	08 52 17.86	+47 52 21.4	18.581 ± 0.077	18.169 ± 0.108	17.828 ± 0.161	UFTI
6C**0848+4927	08 52 14.83	+49 15 44.8	18.577 ± 0.078	18.354 ± 0.134	18.222 ± 0.263	UFTI
6C**0849+4658†	08 53 09.47	+46 47 00.9	17.689 ± 0.037	17.500 ± 0.058	17.319 ± 0.099	UFTI
6C**0854+3500	08 57 15.99	+34 48 24.9	18.388 ± 0.101	18.273 ± 0.141	18.121 ± 0.177	UFTI
6C**0855+4428	08 58 38.57	+44 16 26.6	18.315 ± 0.086	18.485 ± 0.202	nbo	UFTI
6C**0856+4313	08 59 20.19	+43 02 00.8	18.568 ± 0.072	18.234 ± 0.094	17.999 ± 0.119	UFTI
6C**0902+3827	09 05 13.10	+38 14 34.5	19.544 ± 0.224	19.290 ± 0.358	nbo	UFTI
6C**0903+4251	09 06 26.15	+42 39 04.2	16.947 ± 0.029	16.648 ± 0.046	16.615 ± 0.090	UFTI
6C**0909+4317	09 13 00.80	+43 05 20.1	18.977 ± 0.066	18.784 ± 0.123	18.635 ± 0.235	UFTI
6C**0912+3913	09 16 05.11	+39 00 19.3	18.695 ± 0.146	18.032 ± 0.180	17.595 ± 0.304	UFTI
6C**0920+5308	09 23 47.60	+52 56 44.8	14.982 ± 0.004	14.707 ± 0.006	14.526 ± 0.009	UFTI
6C**0922+4216†	09 25 59.28	+42 03 37.7	15.035 ± 0.005	15.961 ± 0.008	15.928 ± 0.015	UFTI
6C**0924+4933	09 27 55.66	+49 21 16.3	15.446 ± 0.007	15.126 ± 0.009	14.955 ± 0.015	UFTI
6C**0925+4155‡	09 28 22.18	+41 42 24.9	20.080 ± 0.078	20.279 ± 0.192	nbo	NIRC
6C**0928+4203	09 31 38.56	+41 49 44.8	18.691 ± 0.129	18.661 ± 0.256	18.448 ± 0.403	UFTI
6C**0928+5557	09 32 17.64	+55 44 42.5	17.824 ± 0.055	17.285 ± 0.064	nbo	UFTI
6C**0930+4856	09 34 14.55	+48 42 46.0	18.843 ± 0.215	18.950 ± 0.584	18.903 ± 1.164	UFTI
6C**0935+4348	–	–	> 21.7	> 21.6	> 20.9	NIRI
6C**0935+5548	09 39 04.73	+55 35 09.0	18.951 ± 0.390	18.649 ± 0.273	18.325 ± 0.348	UFTI
6C**0938+3801	09 41 52.27	+37 47 24.9	19.244 ± 0.318	18.552 ± 0.279	18.132 ± 0.338	UFTI
			18.946 ± 0.081	18.353 ± 0.100	18.038 ± 0.160	UFTI
6C**0943+4034	09 46 27.45	+40 20 33.1	18.098 ± 0.069	17.724 ± 0.100	17.592 ± 0.199	UFTI

Table 5. The K-band magnitudes for the 6C** sample in three different apertures. Columns 2–3 list the position of the near-infrared identification for each source. In columns 4–6 'nbo' denotes that the radio galaxy is too close to a nearby object to measure the magnitude reliably. Note: ‡6C**0925+4155 was observed through a K_S filter and therefore the magnitude presented here is a K_S magnitude (see also the text in Section 4.1). † signifies that the source has an unresolved near-infrared identification.

Figure 1. (i) Contours are spaced at intervals separated by factors of 2 starting at: 0.32 mJy beam^{-1} for 6C**1018+4000; 0.32 mJy beam^{-1} for 6C**1035+4245; 0.64 mJy beam^{-1} for 6C**1036+4721, 1.6 mJy beam^{-1} for 6C**1043+3714; 1.28 mJy beam^{-1} for 6C**1044+4938; and, 0.64 mJy beam^{-1} for 6C**1045+4459.

Figure 1. (j) Contours are spaced at intervals separated by factors of 2 starting at: 0.8 mJy beam^{-1} for 6C**1048+4434; 0.8 mJy beam^{-1} for 6C**1050+5440; 0.4 mJy beam^{-1} for 6C**1052+4349; 0.8 mJy beam^{-1} for 6C**1056+5730; 0.64 mJy beam^{-1} for 6C**1100+4417; and, 1.6 mJy beam^{-1} for 6C**1102+4329. The images of 6C**1050+5440 and 6C**1102+4329 have been smoothed with a $\sigma = 2$ pixel Gaussian.

Figure 1. (k) Contours are spaced at intervals separated by factors of 2 starting at: 0.64 mJy beam^{-1} for 6C**1103+5352; 1.6 mJy beam^{-1} for 6C**1105+4454; 0.64 mJy beam^{-1} for 6C**1106+5301; 0.8 mJy beam^{-1} for 6C**1112+4133; 1.28 mJy beam^{-1} for 6C**1125+5548; and, 0.64 mJy beam^{-1} for 6C**1132+3209. The images of 6C**1103+5352 and 6C**1125+5548 have been smoothed with a $\sigma = 2$ pixel Gaussian. The image of 6C**1132+3209 has not been smoothed.

Source Name	NIR Position (J2000) RA	DEC	Magnitude from 3" diameter	Magnitude from 5" diameter	Magnitude from 8" diameter	Detector
6C**0944+3946	09 47 49.16	+39 33 10.4	19.605 ± 0.214	18.938 ± 0.399	19.088 ± 0.981	UFTI
6C**0956+4735	09 59 18.81	+47 21 13.4	17.799 ± 0.049	17.458 ± 0.063	17.192 ± 0.090	UFTI
6C**0957+3955	10 00 46.12	+39 40 45.5	18.571 ± 0.107	18.462 ± 0.187	18.264 ± 0.317	UFTI
6C**1003+4827†	10 06 40.55	+48 13 09.6	17.304 ± 0.033	17.092 ± 0.052	16.950 ± 0.092	UFTI
6C**1004+4531	10 07 42.82	+45 16 07.6	17.998 ± 0.061	17.539 ± 0.080	17.183 ± 0.115	UFTI
6C**1006+4135	10 09 27.47	+41 20 46.3	19.268 ± 0.167	19.825 ± 0.433	nbo	UFTI
6C**1009+4327	10 12 09.88	+43 13 09.0	20.513 ± 0.596	nbo	nbo	UFTI
6C**1015+5334	10 18 29.93	+53 19 33.6	19.159 ± 0.188	18.797 ± 0.289	18.516 ± 0.595	UFTI
6C**1017+3436	10 20 05.70	+34 21 19.8	19.314 ± 0.185	18.999 ± 0.247	18.972 ± 0.389	UFTI
6C**1018+4000	10 21 28.70	+39 45 45.3	18.568 ± 0.097	18.245 ± 0.130	18.434 ± 0.258	UFTI
6C**1035+4245	10 38 41.03	+42 29 51.9	17.463 ± 0.016	17.269 ± 0.024	17.250 ± 0.048	UFTI
6C**1036+4721†	10 39 15.67	+47 05 40.5	17.099 ± 0.025	17.100 ± 0.043	16.967 ± 0.065	UFTI
6C**1043+3714	10 46 11.91	+36 58 44.5	17.579 ± 0.016	nbo	nbo	UFTI
6C**1044+4938	10 47 47.86	+49 22 36.1	19.096 ± 0.319	18.685 ± 0.286	nbo	UFTI
			19.024 ± 0.312	18.645 ± 0.278	nbo	UFTI
6C**1045+4459	10 48 32.4	+44 44 28.0	18.581 ± 0.140	18.438 ± 0.202	nbo	UIST
6C**1048+4434	10 51 26.52	+44 18 21.2	18.805 ± 0.147	18.628 ± 0.210	nbo	UIST
6C**1050+5440	10 53 36.29	+54 24 42.3	20.605 ± 0.224	20.164 ± 0.216	19.715 ± 0.264	UFTI
6C**1052+4349†	10 55 37.35	+43 33 37.0	17.238 ± 0.026	17.142 ± 0.042	17.081 ± 0.074	UFTI
6C**1056+5730†	10 59 14.91	+57 14 47.3	17.701 ± 0.041	17.562 ± 0.067	17.295 ± 0.101	UFTI
6C**1100+4417	11 03 33.54	+44 01 26.2	18.656 ± 0.100	18.334 ± 0.133	18.095 ± 0.196	UFTI
6C**1102+4329	11 05 43.12	+43 13 24.7	19.794 ± 0.740	19.793 ± 0.950	19.661 ± 1.297	UFTI
6C**1103+5352	11 06 14.93	+53 36 00.5	20.379 ± 0.374	20.142 ± 0.388	nbo	UFTI
6C**1105+4454	11 08 45.96	+44 38 17.7	18.153 ± 0.048	18.086 ± 0.087	17.729 ± 0.127	UFTI
6C**1106+5301	11 09 49.10	+52 45 18.4	17.996 ± 0.071	17.609 ± 0.088	17.354 ± 0.129	UFTI
6C**1112+4133	11 15 09.82	+41 17 02.4	18.779 ± 0.098	18.435 ± 0.128	18.044 ± 0.162	UFTI
6C**1125+5548	11 28 26.82	+55 33 07.1	19.636 ± 0.250	19.680 ± 0.695	nbo	UFTI
6C**1132+3209	11 35 26.69	+31 53 32.7	14.505 ± 0.003	nbo	nbo	UFTI
6C**1135+5122	11 38 27.77	+51 05 56.2	18.767 ± 0.119	18.554 ± 0.172	nbo	UFTI
6C**1138+3309	11 41 25.98	+32 52 11.8	18.574 ± 0.092	18.421 ± 0.142	18.014 ± 0.182	UFTI
			18.779 ± 0.111	18.435 ± 0.150	18.145 ± 0.244	UFTI
6C**1138+3803†	11 41 30.24	+37 46 53.0	17.351 ± 0.028	nbo	nbo	UFTI
6C**1149+3509	11 51 50.75	+34 53 01.6	19.240 ± 0.170	18.800 ± 0.247	18.729 ± 0.585	UFTI

Table 5. *continued.*

Figure 1. (l) Contours are spaced at intervals separated by factors of 2 starting at: 0.64 mJy beam^{-1} for 6C**1135+5122, 0.8 mJy beam^{-1} for 6C**1138+3309; 0.8 mJy beam^{-1} for 6C**1138+3803; and, 0.64 mJy beam^{-1} for 6C**1149+3509.

The redshifts listed on Table 6 are based on the strongest and cleanest line (i.e. a line profile not affected by absorption) in each spectrum. In the case of quasars the redshifts are based on narrow lines if possible. The redshifts of six objects (6C**0726+4938, 6C**0746+5445, 6C**0832+5443, 6C**1009+4327, 6C**1045+4459 and 6C**1102+4329) are based on a single emission-line identification. In five of these cases we associate it with Lyα, due to its structure and strength. Redshifts based on the Lyα line alone may not be the most accurate because in some cases, either (i) absorption blueward of the line occurs shifting the measured line centre to the red; or (ii) the line profile is severely disturbed by strong absorption making redshift determination difficult (van Ojik et al. 1997; Jarvis et al. 2003). If there are other high signal-to-noise lines present in the spectrum, the Lyα line is not used to estimate redshifts.

We have estimated the spatial extent of some of the lines with higher signal-to-noise ratio, typically: Lyα, CIV and in three cases [OII]. These were estimated by evaluating the full-width zero-intensity of a cross-cut through the emission line, deconvolved from the seeing (as in Rawlings, Eales & Lacy 2001; Jarvis et al. 2001b). The values are presented in Table 6.

Using the NASA Extragalactic Database[2] (NED) we have searched for known spectroscopic redshifts for the members of the 6C** sample. We have found spectroscopic redshifts in the literature for seven of the 6C** sources, one of which we have also obtained in this paper (6C**0714+4616; Section 4.2). The results of our search are summarized on Table 7.

4.3 Sources without a redshift

For eleven of the sources which have been observed spectroscopically it is not possible to determine a redshift. Nine sources (6C**0737+5618, 6C**0744+3702, 6C**0754+4640, 6C**0813+3725, 6C**0829+3902, 6C**0848+4927, 6C**0925+4155, 6C**0938+3801 and 6C**1050+5440) do not show any reliable continuum or emission lines in their spectra; whilst, two other sources

[2] http://nedwww.ipac.caltech.edu/

(6C**0717+5121 and 6C**0902+3827) show weak red continuum but no obvious emission or absorption features in their spectra.

Although in most of these cases spectroscopy was taken "blind" we are confident that, with one possible exception, the respective near-infrared counterpart for each source was encompassed by the slit. The exception here is 6C**0754+4640. Its spectrum was taken pointed at the centre of the radio source with the slit aligned along the radio axis. If the radio source is identified by source (a) in our K-band image (Fig. 1), then the slit would have certainly targeted it. However, if the true identification is source (b), then that would have not been the case. Deeper spectroscopy with the slit passing through both K-band components will be necessary to establish their nature and relationship to the radio source.

5 NOTES ON INDIVIDUAL SOURCES

5.1 Near-infrared imaging

In this section we present notes on all individual sources in the 6C** sample. These refer to the images presented in Fig. 1. A summary of the sources with unresolved K-band emission is given in Table 9. These are most likely to be quasars.

6C0714+4616** (z = 1.466) Our K-band image shows a bright unresolved identification co-spatial with the radio core, as is expected for a quasar. This object, a highly polarized red quasar, is discussed in great detail in De Breuck et al. (1998).

6C0717+5121** A bright K-band identification is co-spatial (within the astrometric uncertainty) with the southern lobe of a small radio source. There is another source ≈ 4.5 arcsec to the west of our identification which contaminates the photometry in an 8-arcsec diameter aperture.

6C0726+4938** ($z = 1.203$?) A faint, diffuse K-band identification is co-spatial with the midpoint of the radio lobes for this small radio source.

6C0737+5618** This is a compact radio source. We have a total of 2700 seconds integration with NIRI on Gemini on this source with no apparent ID down to a limiting 3σ magnitude of $K = 21.8$ mag in a 3-arcsec diameter aperture. This is consistent with the results of De Breuck et al. (2002), who have also imaged this source, both in K- and R-band with NIRC on Keck and Kast on the the Lick 3m, respectively. Their R-band magnitude lower limit is $R > 24$ mag in a 4-arcsec diameter aperture.

6C0744+3702** (z = 2.992) Our K-band image shows a faint identification co-spatial (within the astrometric uncertainty) with a double-lobed radio source. The K-band emission is diffuse and shows sub-structure. Our K-band magnitude is consistent with the one reported by De Breuck et al. (2002).

6C0746+5445** (z = 2.156) Our K-band image shows a two-component (a, b) faint identification associated with the double-lobed radio source. The K-band emission appears to be highly aligned with this radio source. At the redshift of this object the Hα emission line is redshifted into the K-band. Therefore, it is possible that the extended emission is associated with the emission line gas. There is also another source (c) ≈ 3 arcsec to the north-west of our identification which may be contributing some flux to the K-band magnitude. This could plausibly be a companion galaxy to the system. It has a K-band magnitude of 19.0 in a 3-arcsec diameter aperture.

6C0754+4640** There are three possible faint K-band identifications for this radio source present in our NIRI image. One (a) is associated with the northern lobe along the radio axis, another one (b) lies ≈ 2.5 arcsec to the south-west of the centre of the radio source, and yet another one (c) is associated (within astrometric uncertainty) with the southern lobe. The K-band magnitudes of (a) and (b) are very similar. Faint diffuse emission surrounding both objects and features suggestive of tidal tails in object (b), one of which seeming to reach towards object (c), are indicative that the system may be undergoing a major merger. The K-band magnitudes of both object (a) and (b) are given in Table 5. Given their similarity, the distribution in K-band magnitude of the sample is not affected significantly by choosing one counterpart over the other. We assume for the remainder of this paper that source (a) is the ID, as it lies along the radio axis. However, further long-slit spectroscopy, with the slit running through both objects, is required to confirm this.

6C0754+5019** (z = 2.996) The extremely faint identification (a) is situated between the two radio lobes and it has been confirmed spectroscopically (see notes on spectrum, Section 5.2). There is also another source (b) ≈ 4 arcsec to the east of our identification which contaminates the photometry in an 8-arcsec diameter aperture, and which could plausibly be a companion galaxy.

6C0801+4903** There is a faint, diffuse identification co-spatial with the radio source. Another slightly brighter source (K = 19.1 mag in a 5-arcsec aperture) ≈ 4.0 arcsec to the north-west west of our identification, which could also be the ID, contaminates the photometry in an 8-arcsec diameter aperture.

6C0810+4605** ($z = 0.620$) The K-band identification of this small double-lobed radio source is a bright galaxy with an apparently disturbed morphology.

6C0813+3725** Our faint K-band identification is co-spatial (within the astrometric uncertainty) with a small radio source.

6C0824+5344** (z = 2.824) This source has a double-lobed radio morphology, with a diffuse faint K-band identification coincident with the radio core.

6C0829+3902** We find a faint K-band identification at the position of the northern radio component. There is also another source (b) ≈ 4 arcsec to the south-west of our identification which contaminates the photometry in an 8-arcsec diameter aperture.

6C0832+4420** The faint K-band identification for this source lies between the two radio lobes, along the radio axis but closer to the north-eastern one.

6C0832+5443** ($z = 3.341$) The faint K-band identification for this source lies between the two radio lobes but closer to the western lobe. There is another bright source ≈ 4 arcsec to the north of our identification which contaminates the photometry in an 8-arcsec diameter aperture.

6C0834+4129** ($z = 2.442$) We find a faint K-band identification co-spatial (within the astrometric uncertainty) with a small radio source.

6C0848+4803** A bright K-band identification is co-spatial (within the astrometric uncertainty) with the radio core of a small double-lobed radio source.

6C0848+4927** A compact radio source with a faint K-band identification at its centre.

6C0849+4658** Our K-band image shows a bright unresolved identification co-spatial with a small double radio source. It is possibly a quasar.

6C0854+3500** ($z = 2.382$) We find a faint K-band identification co-spatial (within the astrometric uncertainty) with a small radio source.

6C0855+4428** The K-band identification of this source lies at the radio core. There is a close brighter source ($K = 17.1$ in an 5-arcsec aperture) ≈ 4 arcsec to the south-west, which is probably a foreground object and contaminates the photometry in an 8-arcsec diameter aperture.

6C0856+4313** ($z = 1.761$) We find a faint K-band identification co-spatial (within astrometric uncertainty) with a small double radio source. The K-band emission appears to consist of a few knots of emission.

6C0902+3827** We find a faint K-band identification at the centre of this double radio source. There is a brighter object ≈ 5 arcsec to the south of our ID, which contaminates the photometry in an 8-arcsec diameter aperture.

6C0903+4251** ($z = 0.907$) Our K-band image shows a bright identification co-spatial with the radio core. A knot of emission (b) is apparent in the image and it is most likely associated with the system, e.g. a tidal tail. Fuzzy emission around the source and hints of a disturbed morphology suggest that it is the result of, or is currently undergoing, a merger event.

6C0909+4317** The faint K-band identification (a) is situated between the two radio lobes towards the north-eastern lobe. Towards the north-east of the identification there is a faint diffuse component (b), which is most likely part of the system and could possibly be a remnant of a merger, or a satellite object.

6C0912+3913** Our image shows a faint K-band identification lying in between the radio lobes of this double radio source. The identification is close to a much brighter object, making magnitude estimation difficult.

6C0920+5308** This source has a double-lobed radio morphology co-spatial with a bright resolved K-band ID. Apparent to the south-west of the host-galaxy is a knotty string of emission which is most likely a tidal tail, remnant of a major merger. Faint diffuse emission around the source is also consistent with this picture.

6C0922+4216** ($z = 1.750$) The near-infrared identification for this source is the bright resolved object ≈ 5 arcsec to the north-west of the radio centroid. This source has been identified as a quasar at $z = 1.750$ by Vigotti et al. (1990).

6C0924+4933** The radio source is co-spatial with a bright, resolved K-band identification.

6C0925+4155** Our NIRC image shows a faint near-infrared identification co-spatial with the centre of this marginally resolved radio source.

Figure 2. A cut-out of the Gemini–NIRI K-band image of 6C**0935+4348. The horizontal lines mark the width (to scale) and orientation of the 1.53-arcsec slit used in the optical spectroscopic observations of this source. The pointing position of spectroscopy and the approximate position of the spectrum along the slit are also marked. The distance between the pointing position and that of the spectrum is about 3.5 arcsec (from the astrometry on the 2D spectrum). The distance between the source marked with an A and the centre of the slit is 1.79 arcsec.

6C0928+4203** ($z = 1.664$) The K-band identification for this source is coincident with the southern lobe.

6C0928+5557** Our K-band image shows a bright identification co-spatial with the radio source. Another K-band object ≈ 5 arcsec to the south-east of our ID, with very similar K-band magnitude is plausibly a true companion galaxy. There is faint diffuse emission surrounding the two objects and the radio jet seems to reach towards the south-eastern object. These two sources may well be in the process of merging, although spectroscopy would be required to confirm such hypothesis. Another possibility is that the south-eastern object is the result of jet-induced star formation (e.g. Bicknell 2002).

6C0930+4856** This small double source reveals a sub-structured K-band identification, with two peaks of emission.

6C0935+4348** ($z = 2.321$?) This source has a slightly extended[3] radio morphology, centred at $\alpha = 09{:}38{:}21.41$, $\delta = +43{:}34{:}37.3$. We have a total of 2280 seconds integration with NIRI on Gemini on this source, with no apparent identification around that position down to a limiting 3σ magnitude of $K = 21.7$ in a 3-arcsec diameter aperture. Astrometry from our two-dimensional spectrum places Lyα emission at a position ~ 3.5 arcsec to the west of the centre of the radio source, along a slit (with a width of 1.53 arcsec) which was centred at the radio source, with a position angle of 90° (see Fig. 2). The infrared object ≈ 5.8 arcsec to the north-west (at $\alpha = 09{:}38{:}20.99$, $\delta = +43{:}34{:}39.2$) cannot be ruled out as the ID because, although the slit does not pass through that object (marked with an A in Fig. 2), the Lyα emission can be more extended than the K-band emission (e.g. Kurk et al. 2002).

6C0935+5548** We find a faint K-band identification at the position of the eastern radio lobe.

6C0938+3801** Our K-band image shows an object with a high-degree of sub-structure lying between the two radio lobes, but closer to the north-western one.

6C0943+4034** We find a faint K-band identification coincident with the centre of the radio source.

6C0944+3946** We find a faint K-band identification at the centre of the radio source.

6C0956+4735** ($z = 1.026$) Our K-band image shows a bright identification co-spatial with the radio core.

6C0957+3955** The K-band identification for this source lies between the two radio lobes.

6C1003+4827** We find a bright, unresolved K-band identification associated with the radio core, suggestive of a quasar. The radio structure of this source is also consistent

[3] Deconvolved major axis of 5.1 arcsec, with a P.A. of $\sim 90°$ in the FIRST catalogue (http://sundog.stsci.edu/cgi-bin/searchfirst).

with that of a quasar, in that it shows a bright radio core and a one-sided jet.

6C1004+4531** We find a bright K-band identification coincident with the position of the radio core. Towards the eastern lobe there is a fainter clump of emission that is most probably associated with the host galaxy, e.g. a region of enhanced star formation induced by the jet (e.g. Bicknell 2002). This region is contributing to the K-band flux.

6C1006+4135** We find a faint K-band identification at the position of the north-western radio lobe.

6C1009+4327** ($z = 1.956$) The extremely faint identification (a) is situated between the two radio lobes and it has been confirmed spectroscopically. There is also another source (b) ≈ 3 arcsec to the north of our identification, which contaminates the photometry in apertures of 5-arcsec diameter and larger. Source (b) has similar K-band magnitude ($K = 20.44$ in 3-arcsec aperture) and could plausibly be a true companion galaxy.

6C1015+5334** A faint diffuse K-band identification is co-spatial with the southern lobe of a double-lobed radio source.

6C1017+3436** The K-band identification for this source lies between the two radio lobes.

6C1018+4000** The K-band identification for this source is coincident with the radio core.

6C1035+4245** This small double-lobed radio source is co-spatial with a bright resolved K-band identification .

6C1036+4721** ($z = 1.758$) A bright unresolved K-band identification lying at the centre of the radio source, as is expected for a quasar.

6C1043+3714** ($z = 0.789$) Our K-band image shows a bright identification coincident with the centre of the radio source. There is also a fainter source ≈ 2 arcsec to the south-west, which could be contributing some flux to the K-band magnitude. The faint diffuse emission surrounding the two objects suggests that they could be in the process of merging. The optical spectrum of Allington-Smith et al. (1985) shows an asymmetric extended region of [O II] λ 3727Å emission, which the authors interpreted as suggestive of interaction with a nearby companion (although no companion was visible in their optical images). Our K-band image is consistent with this scenario.

6C1044+4938** The faint K-band identification (a) is co-spatial with a small double radio source. There are also two other faint sources close to the identification. Both object (b) ≈ 4 arcsec to the south-west, and (c) ≈ 5 arcsec to the north-west of our identification may contribute some flux to the K-band magnitude in apertures > 5 arcsec. Source (b) has similar K-band magnitude to source (a), source (c) is much fainter.

6C1045+4459** ($z = 2.571$) The faint K-band identification (a) lies between the radio lobes, closer to the south-eastern one. There is also another source (b) ≈ 5 arcsec to the north-west of our identification which may contribute some flux to the K-band magnitude. Although the K-band magnitudes of both sources are very similar, our spectroscopy shows that source (b) is a foreground galaxy at $z = 0.883$ (if the line we detect is [O II]; see notes on spectrum of this source, Section 5.2).

6C1048+4434** Our K-band image shows three bright sources associated with the radio source. We take the source lying in between the radio lobes at the centre and along the radio axis to be our plausible identification. The other two sources, lying to south-west of the radio centroid, especially its nearest neighbour, cannot be ruled out as the host-galaxy. All three sources have similar K-band magnitudes.

6C1050+5440** Our K-band image shows a very faint identification coincident with the centre of the radio source.

6C1052+4349** We find a bright, unresolved K-band identification co-spatial with the centre of the radio source. This is possibly a quasar.

6C1056+5730** This is a double-lobed radio structure with a bright unresolved K-band identification close to its centre. This is possibly a quasar.

6C1100+4417** We find a faint K-band identification at the centre of the radio source.

6C1102+4329** ($z = 2.734$) This source has an extremely faint K-band identification, which lies in a position which is consistent with the centre of the radio source.

6C1103+5352** This source has an extremely faint K-band identification lying at the centre of the radio map. The identification is close to a much brighter object, making the magnitude estimation difficult.

6C1105+4454** We find a bright K-band identification lying towards the north-western radio lobe.

6C1106+5301** This source has a faint K-band identification lying at the centre of a slightly elongated radio source.

6C1112+4133** We find a faint K-band identification at the centre of the double-lobed radio structure.

6C1125+5548** The faint K-band identification (a) lies at the position of the southern radio lobe. There is also another source (b) ≈ 5 arcsec to the north-west of our identification, which contributes the photometry in an 8-arcsec diameter aperture. This source has a very similar K-band magnitude and could also be associated with the radio source. Spectroscopic observations will be needed to confirm this.

6C1132+3209** ($z = 0.231$) This is the brightest K-band source in our sample. Its K-band identification appears to be a complex system of interacting galaxies. It is not clear from Fig. 1 but there are three peaks of emission along the radio axis. The Nasa Extragalactic Database associates this source with the MACS J1135.4+3153 galaxy cluster (Edge et al. 2003).

6C1135+5122** We find a faint K-band identification at the centre of the radio source. Another source ≈ 4.5 arcsec to the north-west contaminates the photometry in an 8-arcsec diameter aperture.

6C1138+3309** This source has a faint K-band identification lying near the centre of an elongated radio source.

6C1138+3803** A bright, unresolved K-band identification lies towards the west of the radio centre. This is possibly a quasar.

6C1149+3509** This source has a faint K-band identification lying at the centre of the radio source.

5.2 Optical Spectroscopy

In this section we present notes for all sources for which a redshift has been obtained. These refer to the spectra presented in Fig. 3.

Source	z	Line	$\lambda_{\rm rest}$ (Å)	$\lambda_{\rm obs}$ (Å)	FWHM (km s^{-1})	Flux (Wm^{-2})	$\log_{10} L_{\rm line}$ (W)	Extent (arcsec / kpc)	Galaxy / Quasar
6C**0714+4616	1.466	CIV	1549	3820 ± 1	0 – 1200	8.3E-19 ± 13%	36.05	< 3.5 / 30	Q
		MgII	2799	6897 ± 1	1150 – 1300	2.1E-19 ± 14%	35.45		
6C**0726+4938	1.203?	[OII]?	3727	8209 ± 1	450 – 750	1.7E-19 ± 13%	35.15	5 / 41	G
6C**0746+5445‡	2.156	Lyα	1216	3838 ± 1	∼ 1200	5.2E-19 ± 24%		< 2.5 / 21	G
6C**0754+5019	2.996	Lyα	1216	4858 ± 1	1100 – 1500	8.3E-20 ± 22%	35.81	< 3 / 23	G
		HeII	1640	6557 ± 1	1000 – 1300	1.0E-19 ± 20%	35.89		
6C**0810+4605	0.620	MgII	2799	4527 ± 1	1600 – 2100	1.1E-18 ± 11%	35.25		G
		[OII]	3727	6039 ± 1	1150 – 1550	9.1E-18 ± 13%	36.17	6 / 41	
		[NeIII]	3869	6264 ± 1	900 – 1300	6.9E-19 ± 20%	35.05		
		[NeIII]	3968	6436 ± 1	300 – 1000	4.5E-19 ± 20%	34.86		
		Hγ	4340	7034 ± 1	1000 – 1400	6.1E-19 ± 18%	34.99		
		[OIII]	4959	8026 ± 1	250 – 800	8.5E-19 ± 34%	35.14		
		[OIII]	5007	8110 ± 1	900 – 1200	3.3E-18 ± 14%	35.73		
6C**0824+5344	2.824	Lyα†	1216	4650 ± 1	0 – 1000	1.3E-18 ± 5%	36.94	8 / 63	G
6C**0832+5443	3.341	Lyα	1216	5279 ± 1	950 – 1400	4.8E-19 ± 11%	36.68	< 3 / 22	G
6C**0834+4129	2.442	Lyα	1216	4185 ± 1	0 – 1100	4.8E-19 ± 13%	36.35	5 / 41	G
		CIV	1549	5335 ± 1	1250 – 1600	3.2E-19 ± 35%	36.18		
6C**0854+3500‡	2.382	Lyα	1216	4113 ± 1	∼ 2100			< 2 / 16	G
		CIII]	1909	6456 ± 1	∼ 1000				
6C**0856+4313	1.761	Lyα	1216	3358 ± 1	0 – 1650	1.3E-18 ± 24%	36.44	< 3 / 25	G
		CIV	1549	4279 ± 1	0 – 900	9.0E-20 ± 22%	35.28		
6C**0928+4203	1.664	Lyα	1216	3240 ± 1	2300 – 2800	4.9E-18 ± 6%	36.95	4.5 / 38	Q
		CIV	1549	4128 ± 1	800 – 1500	4.0E-19 ± 6%	35.87	4 / 34	
		HeII	1640	4368 ± 1	1150 – 1650	2.3E-19 ± 22%	35.63		
		CIII]†	1909	5070 ± 1	2000 – 2200	3.7E-19 ± 12%	35.83		
		CII]	2326	6206 ± 1	2150 – 2300	3.3E-19 ± 16%	35.78		
		MgII	2799	7447 ± 8	∼ 5600	1.1E-18 ± 11%	36.31		
6C**0935+4348	2.321?	Lyα?	1216	4021 ± 1	∼ 1600	1.2E-18 ± 18%	36.70	8 / 65	G
		NV?	1240	4118 ± 1	< 500	2.4E-19 ± 20%	36.00		
6C**1009+4327	1.956	Lyα	1216	3595 ± 1	2000	1.6E-19 ± 17%	35.64	7.0 / 59	G
6C**1036+3714‡	1.758	Lyα	1216	3337 ± 1	> 1900	2.8E-18 ± 11%		< 4 / 34	Q
		SiIV+OIV]	1402	3867 ± 1	> 800	6.5E-19 ± 14%			
		MgII	2799						
6C**1045+4459	2.571	Lyα	1216	4341 ± 1	1600 – 1900	6.6E-19 ± 9%	36.55	10 / 80	G
(foregr. obj.)	0.883?	[OII]?	3727	7017 ± 1	750 – 1000	1.8E-19 ± 17%	34.84	5 / 40	G
6C**1102+4329	2.734	Lyα	1216	4541 ± 1	1200	6.8E-19 ± 2%	36.62	6.5 / 51	G

Table 6. Redshifts and emission line properties for the sources in the 6C** radio sample. The '?' symbol denotes an uncertain line identification. The † symbol means that the line is contaminated by a cosmic ray. The ‡ symbol means that the source was observed under non-photometric conditions. For many of the uncertain lines in sources with known redshifts the line diagnostics are not presented because of the low signal-to-noise. For sources with redshifts based on uncertain lines, we present the emission line data for the emission lines which are likely to be real. Errors on the line fluxes represent the 1σ uncertainty expressed as a percentage of the best line-flux estimate, for the strongest lines these are dominated by roughly equal contributions from uncertainties in fixing the local continuum level, and from the absolute flux calibration (including plausible slit losses). Line widths were estimated from the FWHM of the best-fitting Gaussian to each line, the lower value of a range assumes the line-emitting region fills the slit, and the higher value assumes that it is broadened only by the seeing. The spatial extent of the emission lines were estimated by evaluating the full-width zero-intensity of a cross-cut through the emission line, deconvolved from the seeing. There are no emission line fluxes available for 6C*0854+3500 due to the lack of a spectrophotometric standard for the spectrum presented. We do not measure the line parameters for MgII in 6C**1036+3714 as the line is severely extinguished by telluric absorption (see notes on this source). We none the less present line-flux measurements for the sources with non-photometric data (6C**0746+5445 and 6C**1036+4721) but caution that these should only be used to evaluate relative fluxes.

6C0714+4616** Optical spectroscopy of this source has been reported previously by De Breuck et al. (2001). Definite CIVλ1549 Å and MgIIλ2799 Å at $z = 1.466$ in our spectrum are in good agreement with this previous observation. The HeIIλ1640 Å line has FWHM < 10 Å and could well be spurious. Infrared spectroscopy and spectropolarimetric observations have shown that this is a highly polarized red quasar (De Breuck et al. 1998). Based solely on our spectrum it would have been difficult to classify this source as a quasar given that, although MgIIλ2799 Å has a hint of a broad base, the narrow component has a width of only about 1150–1300 km s^{-1}. However, this source has a very bright ($K = 16.3$ in an 8-arcsec diameter aperture) unresolved identification (Fig. 1), as is expected for a quasar.

6C0726+4938** This source displays an almost featureless faint continuum. However, a definite line is detected in the far-red at 8209 Å, and we take it to be [OII]λ3727 Å at $z = 1.203$. This redshift is consistent with the K-band magnitude for this object ($K = 18.2$ in an 8-arcsec aperture), but the lack of any confirming features renders its value insecure.

6C0746+5445** The spectrum of this source contains a single double-peaked line, which we take to be Lyα at $z = 2.156$. The double-peaked structure is most probably due to HI absorption associated with the host galaxy. The projected linear size of the radio emission is small ($D \approx$ 26 kpc). This is consistent with the results of van Ojik et al. (1997) and Wilman et al. (2004), in which small (< 50 kpc) radio sources are more likely to show strong associated HI absorption. The spectrum presented in Fig. 3 was taken under non-photometric conditions. The observations made in December 1998 yielded a blank field from which it was not possible to extract a spectrum.

6C0754+5019** A blind spectrum was taken pointed at the centre of the radio source with the slit aligned along the radio axis. The position of the line along the slit is consistent with the position of our near-infrared identification (source (a) in Fig. 1). We detect a weak-emission line spectrum where the most prominent features are Lyα and HeIIλ1640 Å at $z = 2.996$. Somewhat unusual is that we measure very similar fluxes for both of the lines. Comparison of the Lyα and HeII line fluxes for radio galaxies using the ratios of McCarthy (1993) gives a Lyα to HeII ratio of 10:1. The strength of Lyα relative to HeII in our spectrum could be indicative of strong Lyα attenuation, possibly by dust or HI. Objects with anomalously low Lyα emission have been observed before. Dey, Spinrad & Dickinson (1995) reported a radio galaxy (MG 1019 + 0535) at $z = 2.76$ showing a similarly weak Lyα to HeII ratio, which has been explained by strong attenuation of Lyα by dust. However more relevant than the Lyα line ratios, which are sensitive to neutral hydrogen absorption, could be the NV/HeII and NV/CIV line ratios, which are indicative of the nitrogen abundance (Villar-Martin et al. 1999; De Breuck et al. 2000). According to the interpretation of the NV/HeII vs. NV/CIV diagram of Fosbury et al. (1999), the nitrogen abundance could be indicative of the level of chemical enrichment of the interstellar medium produced by a stellar population composed of massive stars. Our spectrum shows a hint of the NV line but it could also be a spurious feature. A deeper and higher resolution spectrum will be needed to confirm the reality of this line, and constrain the NV/CIV and NV/HeII ratios. Our object is also one of the faintest sources in the sample, with $K = 20.6$ in a 5-arcsec diameter aperture, which is unusually faint for this redshift. Again, this is suggestive of a dusty screen. Sub-millimetre photometry would be helpful in establishing the nature of this source.

6C0810+4605** We detect strong [OII]λ3727 Å at $z = 0.620$. Several other lines: MgIIλ2799 Å, [NeIII]λ3869 Å, [NeIII]λ3968 Å, Hγ, [0III]λ4959 Å, [0III]λ5007 Å and possible Hβ, confirm this redshift. This source shows a low level of ionization, as indicated by a [OII]/[OIII] ratio of about 2.8.

Name	z	Other Name	Gal./ Quasar	Ref.
6C**0714+4616	1.462	WN J0717+4611	Q	1
6C**0744+3702	2.992	WN J0747+3654	G	1
6C**0903+4251	0.907	B3 0903+428	G	2
6C**0922+4126	1.750	B3 0922+422	Q	3
6C**0956+4735	1.026	4C +47.31	G	2
6C**1043+3714	0.789	4C +37.28	G	4
6C**1132+3209	0.231	2MASX J11352669+3153324	G	5

Table 7. Spectroscopic redshifts from the literature. REFERENCES: 1. De Breuck et al. (2001); 2. McCarthy (1990); 3. Vigotti et al. (1990); 4. Allington-Smith et al. (1985); 5. Brinkmann et al. (2000).

This, together with the indication from our K-band image that this source could be undergoing a major merger, suggests that shock heating may be the dominant excitation mechanism operating in this source. The close alignment between the optical structure and the radio source is also consistent with this picture (Tadhunter 2002). It is possible that jet-induced shocks are driving a starburst over the whole galaxy.

6C0824+5344** We find a strong line at 4650 Å, which we take to be Lyα at $z = 2.824$. Probable HeIIλ1640 Å and CIII]λ1909 Å, and the K-band magnitude ($K = 19.4$ in a 8-arcsec diameter aperture) are consistent with this redshift. The single blue arm exposure containing the Lyα emission has a cosmic ray in close proximity to the line, which may contribute to the flux measurement in Table 6.

6C0832+5443** There is just one emission feature and no continuum in the spectrum of this object. The emission line shows a double-peaked structure. From its wavelength, the lack of continuum and structure we take it to be Lyα at $z = 3.341$. Again, the structure of the line is probably due to HI absorption in the host galaxy, and the size of the radio source ($D \approx 48$ kpc) is within the 50 kpc limit of van Ojik et al. (1997).

6C0834+4129** The spectrum shows a clear emission line at 4185 Å, which we identify with Lyα at $z = 2.442$. Further faint lines corresponding to CIVλ1549 Å and probable HeIIλ1640 Å confirm this redshift.

6C0854+3500**
The presence of Lyα and CIII]λ1909 Å in our spectrum confirm this as a radio galaxy at $z = 2.382$. Again, we detect a double-peaked line structure associated with a very small radio source ($D \simeq 9$ kpc). The lack of a spectrophotometric standard for the set-up used to take this spectrum makes it impossible to flux calibrate it. Hence, the flux-density scale presented in Fig. 3 can only be used to estimate relative fluxes.

6C0856+4313** Strong Lyα, along with weak CIVλ1549 Å, possible NVλ1240 Å and CIII]λ1909 Å confirm this as a radio galaxy at $z = 1.761$.

6C0928+4203** This source has a rich emission-line spectrum. Six definite emission lines place it at $z = 1.664$. The spectrum shows broad MgIIλ2799 Å (~ 5600 km s^{-1}), but our K-band image (Fig. 1) shows a faint ($K = 18.4$ in an 8-arcsec diameter aperture) resolved source, hence we classify this source as reddened quasar. The redshift we obtain is consistent with the K-band magnitude and well within

Figure 3. (a) Spectra of the 6C** WHT–ISIS targets with definite or possible spectral features. Uncertain (possible) emission lines are marked with a '?'. The synthetic aperture used to extract 1D spectra from the 2D data was defined by the full-width at zero-intensity of a cross-cut through the data, excepting the cases of 6C**0726+4938 and 6C**0754+5019 for which a full-width at half-maximum aperture was used. The shadowed region in the spectrum of 6C**0810+4605 shows the wavelengths affected by severe fringing in the CCD. The flux density scale for the spectrum of 6C**0854+3500 is measured in W m^{-2} $Å^{-1}$ with arbitrary normalisation, due to the lack of a spectrophotometric standard. The observations of 6C**0746+5445 and 6C**1036+4721 were made under non-photometric conditions.

Figure 3. (b)*continued*

the scatter of the $K - z$ relation for radio galaxies. The broad MgII emission could therefore be a scattered quasar component.

6C0935+4348** We detect Lyα and NVλ1240 Å in our high-resolution ($\sim$ 5.5 Å) spectrum. Before we proceed to discuss it, we caution that these line identifications are uncertain, and the near-infared identification for this source is not secure (see note on Section 5.1). The Lyα to NV ratio is particularly low in this source (5:1), when compared with the much higher ratio (20:1) derived by McCarthy (1993) for radio galaxies. Albeit this line ratio is suggestive of a quasar, the observed width of the Lyα line (of about 1600 km s^{-1}) is characteristic of a radio galaxy. Similar cases of high NV to Lyα ratios have been found before in radio galaxies at $z \sim 2 - 3$, such as TX 0211-122 (van Ojik et al. 1994) and TXS J2353-0002 (De Breuck et al. 2001). TX 0211-122 has been explained as a dusty galaxy, possibly undergoing a massive starburst based on the similarity of its spectrum to that of the $z = 2.286$ ultraluminous IRAS galaxy F10214+4724 (Rowan-Robinson et al. 1991). It has been argued the starburst would produce the dust responsible for attenuating the Lyα emission and a relative overabundance of nitrogen. Another important feature in the spectrum of our source is the absence of CIVλ1549 Å, which we would expect to be present at around 5144 Å. This is indicative of a high NV/CIV ratio, which is a better indicator of nitrogen overabundance (see also the notes for 6C**0754+5019).

6C1009+4327** The only emission line present in the spectrum of this object is detected in the far-blue. We take it to be Lyα at $z = 1.956$. We detect continuum emission in both the red and blue arm exposures but no other identifiable features. The position of the line along the slit is consistent with the position of our near-infrared counterpart (source (a) in Fig. 1), which is unusually faint ($K = 20.5$ in a 3-arcsec diameter aperture) for this redshift.

6C1036+4721** This is a reddened quasar at $z = 1.758$. We find strong Lyα in the far-blue of the spectrum, along with fainter SiIV + OIV]λ1402 Å and MgIIλ2799 Å. The blue wing of the MgII emission line is severely extinguished by the 7600 Å A-band telluric absorption line system. Telluric absorption is also found at $\sim$ 6821 Å. Because of the strong absorption it is not possible to derive accurate line parameters for the MgII line. Moreover it is not possible to estimate its width, although the line seems to have a broad base. We none the less classify this source as a quasar, given that its K-band identification is a bright ($K = 17.0$ in an 8-arcsec diameter aperture) unresolved source. We note also that the optical spectroscopic observations of this source were made under non-photometric conditions.

6C1045+4459** A blind spectrum was taken pointed at the centre of the radio source with the slit aligned along the radio axis. The spectrum shows no continuum and only a single strong, spatially extended line which we associate with Lyα at $z = 2.571$. The position of the line along the slit is consistent with the position of our near-infrared identification (source (a) in Fig. 1). We also detect the object $\approx$ 5 arcsec to north-west of the radio galaxy ($K = 18.73$ in a 5 arcsec aperture), which is visible in our K-band image (source (b) in Fig. 1). A strong emission line at 7017 Å, which we associate with [OII]λ3727 Å, and the blue continuum present in the spectrum of this object (also shown in Fig. 3) leads us to conclude that it is a foreground galaxy at $z = 0.883$, and is not associated with the radio emission.

6C1102+4329** Another object for which there is just one emission feature and no continuum in the spectrum. From its wavelength and the lack of continuum we take it to be Lyα at $z = 2.734$.

6 DISCUSSION

6.1 Number of chance coincidences expected among the near-infrared identifications

We have identified all but two of the sources in the 6C** sample, down to a limiting magnitude of $K \sim 21$ mag (8-arcsec diameter aperture). Note, however, the caveat that one of the non-detected sources (6C**0935+4348) has an uncertain identification (see notes on this source in Section 5.1). Using K-band number counts from Gardner, Cowie & Wainscoat (1993) and assuming an average search radius of 2.5 arcsec, we now estimate the number of chance coincidences expected inside the matching area. This is a function of K-band magnitude reached.

Deep infrared surveys (e.g. Gardner, Cowie & Wainscoat 1993) have shown that there are about 7.8×10^4 galaxies per square degree brighter than $K = 21$ mag. Therefore, we expect 0.12 chance coincidences within a 2.5 arcsec matching radius in the fields imaged with NIRI and NIRC. With UFTI we reach $K \sim 19.5$ mag (8-arcsec diameter aperture) with the shortest exposures (540 sec.) and $K \sim 20$ mag (8-arcsec diameter aperture) with the deepest ones (3240 sec.). The K-band number counts are down to $\sim 2.9 \times 10^4$ and $\sim 4.0 \times 10^4$ per square degree, respectively, and the chance coincidences expected within the same matching radius are 0.06 and 0.04. Finally, with UIST we reach $K \sim 19$ mag (8-arcsec diameter aperture), to which the number counts are $\sim 2.0 \times 10^4$ per square degree. Therefore, we expect 0.03 chance coincidences between a radio and near-infrared source within a 2.5 arcsec matching radius.

Figure 3. (c)*continued*

Figure 4. Histogram of the K-band magnitudes, measured in a 3-arcsec diameter aperture, of the 6C** sample (solid line) and the 6C* sample (dashed line). The dotted line represents the distribution of K-band magnitudes, measured in a 5-arcsec aperture, for the sources in the 7C-I and 7C-II regions of the 7C Redshift Survey. The bin width in each histogram is $\Delta K = 0.5$ mag. The non-detected sources (6C**0737+5618 and 6C**0935+4348) are represented by arrows.

6.2 K-band magnitude distribution

In Fig. 4 we compare the distribution of K-magnitudes of the 6C** sample with those of the similarly selected 6C* sample (Jarvis et al. 2001a) and of the 7C-I and 7C-II regions of 7CRS (Willott et al. 1998, 2002, 2003). The later were selected at the same flux level as 6C** but without any filtering.[4]. The median K-band magnitude of the 6C** sample is ≈ 18.7 mag (3-arcsec diameter aperture), with a maximum magnitude of $\gtrapprox 21.7$ mag, while the 6C* sample has a median K-band magnitude of ≈ 18.8 mag in the same aperture, with the faintest magnitude being ≈ 20 mag. It can be seen that although the distributions of both samples peak at the same median magnitude, that of the 6C** sample extends both to brighter and fainter magnitudes, with a slightly asymmetrical tail extending towards bright magnitudes ($K \simeq 14.5$ mag). A Kolmogorov-Smirnov test shows that the two datasets are consistent with being drawn from the same underlying distribution with probability $p = 0.51$. Therefore, we expect the 6C** sample to have a similar redshift distribution to that of the 6C* sample. The 6C* sample has a median redshift of $z \simeq 1.9$, with a minimum redshift of 0.513 and maximum redshift of 4.410 (Jarvis et al. 2001b). The median K-band magnitude of the combined 7-CI and 7C-II regions is ≈ 17.4 mag (5-arcsec aperture). This shows that the filtering criteria employed to select the 6C** sample is being effective in biasing the sample towards fainter sources, and possibly higher redshifts. A full derivation of redshift estimates for the members of the 6C** sample, based on their K-band magnitudes, will be presented in Paper II, along with a detailed analysis of their space density.

6.3 Sources without a redshift

We now discuss the sources for which we could not determine a redshift from optical spectroscopy (listed in Table 8). It is likely that some of the these sources lie in the redshift range $1.2 < z < 1.8$, where it is difficult to measure redshifts, due to the absence of the strongest lines of the radio galaxy spectrum in the optical wavelength region (e.g. Lacy et al. 1999b). Moreover, some may have SEDs which are similar to those of the $1 < z < 2$ EROs, found in the 7CRS redshift survey (Willott et al. 1999), which may be counterparts to radio galaxies which lack strong emission lines in their spectra. Other sources will be at $z > 1.8$, but have a weak emission line spectrum, which falls below our detection limit ($\sim 5 \times 10^{-20}$ W m^{-2} in ~ 30 min. exposures).

[4] The 7C-I region covers an area of sky of 0.0061 sr and contains 37 sources with $S_{151} > 0.5$ Jy. The 7C-II region cover an area of sky 0.0069 sr and contains 38 sources with $S_{151} > 0.5$ Jy.

Name	K (mag)	Comments
6C**0717+5121	17.79(5)	Faint red continuum, no lines
6C**0737+5618	> 21.8(3)	Blank
6C**0744+3702	19.44(8)	Blank
6C**0754+4640	20.09(5)	Blank
6C**0813+3725	18.50(8)	Blank
6C**0829+3902	19.41(5)	Blank
6C**0848+4927	18.22(8)	Blank
6C**0902+3827	19.29(5)	Faint red continuum, no lines
6C**0925+4155	20.30(5)	Blank
6C**0938+3801	18.13(8)	Blank
6C**1050+5440	19.71(8)	Blank

Table 8. Attempted spectroscopic observations not yielding a redshift.

Name	K (mag)	z
6C**0714+4616	16.3(8)	1.466
6C**0849+4658	17.3(8)	–
6C**0922+4216	15.9(8)	1.750
6C**1003+4827	16.9(8)	–
6C**1036+4721	17.1(8)	1.758
6C**1052+4349	17.1(8)	–
6C**1056+5730	17.3(8)	–
6C**1138+3803	17.3(3)	–

Table 9. Summary of unresolved K-band sources. We assume that these sources are quasars based on their unresolved continuum emission. Redshifts are given for sources where spectroscopy is available. We note that in all these cases spectroscopy has confirmed the source as a quasar.

For all the sources with no measured redshifts it is possible that deeper spectroscopy will enable redshift determination. Indeed, this is the case of 6C**0744+3702, which is not detected in our one hour exposure spectrum (on WHT), but for which Keck spectroscopy (De Breuck et al. 2001) finds a weak-emission-line spectrum at $z = 2.992$ (see also Table 7). However, as found by De Breuck et al. (2001) some steep-spectrum radio galaxies are not detected even in long exposures ($\simeq 1 - 2$ hrs) with 8-10 metre class telescopes. These sources seem to be preferentially characterised by compact radio morphologies ($\theta \lesssim 2 - 3$ arcsec).

One of the objects we targeted (6C**0737+5618) has these characteristics, and is also one of the faintest ($K > 21.8$ mag in a 3-arcsec aperture) objects in our sample. Several attempts in different observing runs were made at obtaining optical spectroscopy for this object. Different position angles and increasingly higher exposure times were used each time. None the less this source remained undetected in our WHT spectra. Its K-band magnitude suggests a very high redshift, which could well be above the optical detection limit at $z \gtrsim 6.5$, if the $K-z$ relation holds to such high redshifts. Moreover, if a source is at $z \gtrsim 6$, i.e. within the epoch of reionization, it may have its Lyα emission severely suppressed by the intervening intergalactic medium (IGM, Gunn & Peterson 1965, Becker et al. 2001). However, it is possible that Lyα remains visible even when it is embedded in a neutral IGM (e.g. Haiman 2002; Santos 2004; Furlanetto, Zaldarriaga & Hernquist 2006). Another possibility is that 6C**0737+5628 is at a lower redshift but heavily obscured (e.g. like WN J0305+3525 in Reuland et al. 2003), possibly due to it being observed shortly after the jet-triggering event.

Given the nature of our selection criteria, i.e. a small radio angular size, the galaxies which are at high-redshift ($z \gtrsim 2$) in our sample are preferentially young and seen shortly after the jet-triggering event (Blundell & Rawlings 1999). The projected linear size of the radio emission, which may be used as an age indicator for the radio source, (Blundell, Rawlings & Willott 1999) is also found to anti-correlate with the 850 μm flux-density (Willott et al. 2002), which in turn is an indicator of the dust content of a galaxy. We speculate that the spectra for some of the sources for which we could not obtain a redshift may be similar to those of 6C**0754+5019 and 6C**0935+4348, with higher or lower degrees of Lyα suppression and/or chemical enrichment indicators as dictated by their evolutionary stage (Vernet et al. 2001).

7 SUMMARY

- We have defined a sample of 68 sources from the 6C catalogue by applying spectral index and angular size criteria to the sources with $S_{151} > 0.5$ Jy in a 0.421 sr patch of sky.
- An extensive programme of deep K-band imaging of all the 68 members of the 6C** sample has been presented. High-resolution VLA radio images have been also presented for 42 of the sources. We find K-band identifications for all but two of the sources, down to a 3σ limiting magnitude of $K \sim 22$ mag in a 3-arcsec aperture.
- The distribution of K-band magnitudes of the 6C** sample is found to be similar to that of 6C*, peaking at the same median K-magnitude of 18.7 mag in a 3-arcsec aperture. Moreover, we find that the two distributions are statistically indistinguishable, suggesting similar redshift distributions.
- We have also presented the results of optical spectroscopy of 27 sources in the 6C** sample. The 15 new redshifts presented here together with 7 others found in the literature bring the total number of redshifts in the 6C** sample to 22 out of 68 (32 per cent) sources. The redshift content of the 6C** sample is therefore not complete. For the remaining sources, we will present redshift estimates based on detailed modelling of the $K-z$ diagram (Paper II).
- We find two sources without any distinctive emission or absorption features and nine other sources which did not yield any optical continuum or line emission. Some of these may be in the 'redshift desert' region of $1.2 < z < 1.8$. Others, will have $z > 1.8$ but feature a weak emission line spectra and/or different levels of Lyα suppression.
- Eight of the optically identified sources are spatially compact, implying an unresolved nuclear source. From our spectroscopy we find that two of these sources show broad lines in their spectra, confirming them as quasars. Two other of these sources are confirmed as quasars in the literature, and bring the number spectroscopically identified quasars in the 6C** sample to four.

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APPENDIX A: THE SURVEY FLUX DENSITIES OF THE 6C** SOURCES

In this appendix we list the 6C and NVSS flux densities and positions for all the members of the final 6C** sample (Table A1). The spectral indices derived from these values are also listed.

6C Source Name	6C Position J2000 R.A.	Dec.	NVSS Position J2000 R.A.	Dec.	6C Flux 151 MHz (Jy)	NVSS Flux 1.4 GHz (Jy)	α_{151}^{1400}
6C0714+4616	07 17 58.3	+46 11 24	07 17 58.5	+46 11 39	1.65 ± 0.04	0.1020 ± 0.0032	1.25 ± 0.02
6C0717+5121	07 21 28.5	+51 15 49	07 21 27.3	+51 15 51	1.24 ± 0.04	0.1050 ± 0.0032	1.11 ± 0.02
6C0726+4938	07 30 05.8	+49 32 25	07 30 06.1	+49 32 41	0.61 ± 0.04	0.0432 ± 0.0014	1.19 ± 0.03
6C0737+5618	07 41 11.8	+56 11 29	07 41 15.4	+56 11 35	0.74 ± 0.04	0.0429 ± 0.0014	1.28 ± 0.03
6C0744+3702	07 47 30.3	+36 54 42	07 47 29.4	+36 54 38	0.64 ± 0.04	0.0343 ± 0.0011	1.31 ± 0.03
6C0746+5445	07 50 25.4	+54 38 05	07 50 24.7	+54 38 06	0.53 ± 0.04	0.0523 ± 0.0017	1.04 ± 0.04
6C0754+5019	07 58 06.3	+50 11 01	07 58 06.1	+50 11 04	1.05 ± 0.04	0.0958 ± 0.0030	1.07 ± 0.02
6C0754+4640	07 58 29.5	+46 32 28	07 58 29.6	+46 32 33	0.69 ± 0.04	0.0630 ± 0.0020	1.07 ± 0.03
6C0801+4903	08 04 40.6	+48 54 56	08 04 41.3	+48 55 00	1.08 ± 0.04	0.0871 ± 0.0027	1.13 ± 0.02
6C0810+4605	08 14 30.4	+45 56 39	08 14 30.3	+45 56 39	10.26 ± 0.04	1.0800 ± 0.0332	1.01 ± 0.07
6C0813+3725	08 16 54.3	+37 15 47	08 16 53.7	+37 15 53	0.50 ± 0.04	0.0316 ± 0.0010	1.24 ± 0.04
6C0824+5344	08 27 58.7	+53 34 20	08 27 58.9	+53 34 15	0.88 ± 0.04	0.0821 ± 0.0025	1.06 ± 0.02
6C0829+3902	08 32 44.6	+38 52 21	08 32 45.3	+38 52 16	0.51 ± 0.04	0.0388 ± 0.0012	1.16 ± 0.04
6C0832+4420	08 35 26.2	+44 09 47	08 35 27.5	+44 09 52	0.52 ± 0.04	0.0412 ± 0.0013	1.14 ± 0.04
6C0832+5443	08 36 10.4	+54 33 11	08 36 09.6	+54 33 25	0.60 ± 0.04	0.0613 ± 0.0019	1.02 ± 0.03
6C0834+4129	08 37 48.0	+41 19 28	08 37 49.2	+41 19 54	0.50 ± 0.04	0.0539 ± 0.0017	1.00 ± 0.04
6C0848+4927	08 52 16.0	+49 15 50	08 52 14.8	+49 15 44	0.94 ± 0.04	0.0950 ± 0.0029	1.03 ± 0.02
6C0848+4803	08 52 19.1	+47 52 04	08 52 17.9	+47 52 20	0.71 ± 0.04	0.0425 ± 0.0013	1.26 ± 0.03
6C0849+4658	08 53 09.1	+46 46 57	08 53 09.4	+46 47 00	3.50 ± 0.04	0.3530 ± 0.0108	1.03 ± 0.01
6C0854+3500	08 57 13.8	+34 48 46	08 57 16.0	+34 48 24	0.87 ± 0.04	0.0812 ± 0.0025	1.06 ± 0.02
6C0855+4428	08 58 38.2	+44 16 34	08 58 38.5	+44 16 25	0.94 ± 0.04	0.0887 ± 0.0028	1.06 ± 0.02
6C0856+4313	08 59 19.9	+43 02 04	08 59 20.1	+43 02 01	0.59 ± 0.04	0.0630 ± 0.0020	1.00 ± 0.03
6C0902+3827	09 05 11.3	+38 15 31	09 05 13.0	+38 14 35	1.60 ± 0.04	0.1590 ± 0.0049	1.04 ± 0.02
6C0903+4251	09 06 25.2	+42 39 04	09 06 26.1	+42 39 05	3.14 ± 0.04	0.2820 ± 0.0087	1.08 ± 0.01
6C0909+4317	09 13 00.5	+43 05 16	09 13 00.8	+43 05 21	3.36 ± 0.04	0.3550 ± 0.0110	1.01 ± 0.01
6C0912+3913	09 16 05.8	+39 00 35	09 16 05.1	+39 00 23	0.56 ± 0.04	0.0580 ± 0.0018	1.02 ± 0.03
6C0920+5308	09 23 55.1	+52 56 02	09 23 47.6	+52 56 44	0.56 ± 0.04	0.0570 ± 0.0018	1.03 ± 0.03
6C0922+4216	09 25 59.3	+42 03 42	09 25 59.6	+42 03 36	2.70 ± 0.04	0.2570 ± 0.0079	1.06 ± 0.01
6C0924+4933	09 27 56.6	+49 20 53	09 27 55.6	+49 21 15	0.93 ± 0.04	0.0888 ± 0.0027	1.05 ± 0.02
6C0925+4155	09 28 22.6	+41 42 21	09 28 22.2	+41 42 22	0.91 ± 0.04	0.0961 ± 0.0030	1.01 ± 0.02
6C0928+4203	09 31 38.2	+41 49 46	09 31 38.5	+41 49 44	2.04 ± 0.04	0.1350 ± 0.0041	1.22 ± 0.02
6C0928+5557	09 32 17.3	+55 44 36	09 32 17.5	+55 44 41	0.58 ± 0.04	0.0570 ± 0.0018	1.04 ± 0.03
6C0930+4856	09 34 16.6	+48 43 12	09 34 14.7	+48 42 44	0.66 ± 0.04	0.0686 ± 0.0023	1.02 ± 0.03
6C0935+4348	09 38 19.8	+43 34 29	09 38 21.4	+43 34 37	1.09 ± 0.04	0.0523 ± 0.0021	1.36 ± 0.02
6C0935+5548	09 39 05.3	+55 35 03	09 39 04.5	+55 35 10	0.90 ± 0.04	0.0941 ± 0.0029	1.01 ± 0.02

Table A1. The survey flux densities of the 6C** sources in Jy and the spectral indices derived from these. Spectral indices are determined by: $\alpha_{151}^{1400} = -(\log_{10} S_{1400} - \log_{10} S_{151})/(\log_{10} 1400 - \log_{10} 151)$. Error analysis on Parts II and III of the 6C catalogue shows that ∼ 60 per cent of the sources have flux densities within ± 40 mJy of their true value (Hales et al. 1988, 1990) - thus we take 40 mJy as the typical error for the 6C flux densities quoted here.

6C Source Name	6C Position J2000 R.A.	Dec.	NVSS Position J2000 R.A.	Dec.	6C Flux 151 MHz (Jy)	NVSS Flux 1.4 GHz (Jy)	α_{151}^{1400}
6C0938+3801	09 41 51.6	+37 47 43	09 41 52.4	+37 47 22	1.03 ± 0.04	0.0836 ± 0.0027	1.13 ± 0.02
6C0943+4034	09 46 27.2	+40 20 29	09 46 27.3	+40 20 32	0.99 ± 0.04	0.0929 ± 0.0029	1.06 ± 0.02
6C0944+3946	09 47 47.8	+39 32 44	09 47 49.1	+39 33 11	0.66 ± 0.04	0.0705 ± 0.0022	1.00 ± 0.03
6C0956+4735	09 59 18.8	+47 21 18	09 59 18.7	+47 21 14	6.13 ± 0.04	0.4930 ± 0.0152	1.13 ± 0.01
6C0957+3955	10 00 46.9	+39 41 01	10 00 46.1	+39 40 45	0.62 ± 0.04	0.0650 ± 0.0020	1.01 ± 0.03
6C1003+4827	10 06 40.9	+48 13 11	10 06 40.5	+48 13 09	6.88 ± 0.04	0.6030 ± 0.0186	1.09 ± 0.01
6C1004+4531	10 07 40.7	+45 16 27	10 07 42.9	+45 16 07	0.70 ± 0.04	0.0738 ± 0.0023	1.01 ± 0.03
6C1006+4135	10 09 29.5	+41 21 14	10 09 27.5	+41 20 46	0.52 ± 0.04	0.0545 ± 0.0017	1.01 ± 0.04
6C1009+4327	10 12 10.2	+43 13 09	10 12 09.7	+43 13 06	2.89 ± 0.04	0.1880 ± 0.0058	1.23 ± 0.01
6C1015+5334	10 18 29.8	+53 19 26	10 18 30.0	+53 19 34	1.44 ± 0.04	0.1400 ± 0.0043	1.05 ± 0.02
6C1017+3436	10 20 05.8	+34 21 26	10 20 05.7	+34 21 21	1.17 ± 0.04	0.1150 ± 0.0035	1.04 ± 0.02
6C1018+4000	10 21 29.0	+39 45 24	10 21 28.6	+39 45 46	0.53 ± 0.04	0.0546 ± 0.0017	1.02 ± 0.04
6C1035+4245	10 38 40.7	+42 29 46	10 38 41.0	+42 29 51	1.89 ± 0.04	0.1080 ± 0.0033	1.28 ± 0.02
6C1036+4721	10 39 15.6	+47 05 37	10 39 15.7	+47 05 40	3.70 ± 0.04	0.3700 ± 0.0114	1.03 ± 0.01
6C1043+3714	10 46 11.6	+36 58 25	10 46 11.9	+36 58 45	2.62 ± 0.04	0.2590 ± 0.0079	1.04 ± 0.01
6C1044+4938	10 47 47.4	+49 22 40	10 47 47.9	+49 22 36	1.66 ± 0.04	0.1490 ± 0.0046	1.08 ± 0.02
6C1045+4459	10 48 31.3	+44 44 06	10 48 32.2	+44 44 27	0.95 ± 0.04	0.0809 ± 0.0025	1.11 ± 0.02
6C1048+4434	10 51 26.1	+44 18 18	10 51 26.5	+44 18 22	1.51 ± 0.04	0.1540 ± 0.0047	1.02 ± 0.02
6C1050+5440	10 53 36.0	+54 24 36	10 53 36.3	+54 24 42	0.93 ± 0.04	0.0647 ± 0.0020	1.20 ± 0.02
6C1052+4349	10 55 38.3	+43 33 17	10 55 37.4	+43 33 36	0.51 ± 0.04	0.0510 ± 0.0016	1.03 ± 0.04
6C1056+5730	10 59 14.9	+57 14 46	10 59 15.0	+57 14 45	2.66 ± 0.04	0.2190 ± 0.0068	1.12 ± 0.01
6C1100+4417	11 03 34.5	+44 01 10	11 03 33.5	+44 01 26	0.72 ± 0.04	0.0639 ± 0.0020	1.09 ± 0.03
6C1102+4329	11 05 42.6	+43 13 21	11 05 42.9	+43 13 24	1.11 ± 0.04	0.0990 ± 0.0031	1.08 ± 0.02
6C1103+5352	11 06 14.9	+53 35 57	11 06 14.9	+53 36 00	2.67 ± 0.04	0.2700 ± 0.0082	1.03 ± 0.01
6C1105+4454	11 08 45.6	+44 38 16	11 08 46.1	+44 38 14	0.83 ± 0.04	0.0874 ± 0.0028	1.01 ± 0.03
6C1106+5301	11 09 47.9	+52 45 20	11 09 48.9	+52 45 17	0.77 ± 0.04	0.0617 ± 0.0019	1.13 ± 0.03
6C1112+4133	11 15 11.2	+41 17 36	11 15 09.8	+41 17 02	0.54 ± 0.04	0.0282 ± 0.0009	1.33 ± 0.04
6C1125+5548	11 28 30.7	+55 31 30	11 28 26.9	+55 33 11	0.63 ± 0.04	0.0404 ± 0.0013	1.23 ± 0.03
6C1132+3209	11 35 26.2	+31 53 11	11 35 26.7	+31 53 33	0.63 ± 0.04	0.0622 ± 0.0020	1.04 ± 0.03
6C1135+5122	11 38 26.2	+51 06 07	11 38 27.8	+51 05 56	0.66 ± 0.04	0.0570 ± 0.0018	1.10 ± 0.03
6C1138+3309	11 41 23.7	+32 52 58	11 41 25.8	+32 52 14	0.93 ± 0.04	0.0618 ± 0.0019	1.22 ± 0.02
6C1138+3803	11 41 29.1	+37 46 54	11 41 30.4	+37 46 54	0.51 ± 0.04	0.0487 ± 0.0015	1.05 ± 0.04
6C1149+3509	11 51 48.7	+34 53 00	11 51 50.6	+34 53 02	0.61 ± 0.04	0.0576 ± 0.0018	1.06 ± 0.03

Table A1. *continued*