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Optical spectra and redshifts of 1 Jy, S4 and S5 radio source identifications. V.*

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Abstract. — The results of optical spectroscopy are presented for the optical counterparts of 14 radio sources from the 1 Jy, S4, and S5 radio source catalogues. New redshifts are given for eight sources, three uncertain redshifts have been clarified and the redshifts of two sources were confirmed. The remaining source was confirmed as a BL Lac object showing only a featureless spectrum. Additional direct imaging data are provided for three sources.

Key words: catalogues — radio continuum: galaxies — BL Lac objects: general — galaxies: general — quasars: general

1. Introduction

The 1 Jy (Kühr et al. 1981a), S4 (Pauliny-Toth et al. 1978), and S5 (Kühr et al. 1981b, 1987) radio surveys are complete, large area radio catalogues with consecutive completeness limits at 5 GHz of 1 Jy, and 500 mJy, respectively. The 1 Jy catalogue covers the entire sky outside the galactic plane ($|b| \geq 10°$) and lists 518 radio sources. The S4 and S5 surveys cover the region between $35° \leq \delta \leq 70°$ and $\delta \geq 70°$, containing 269 and 185 sources, respectively.

Although most of the sources from these catalogues with optical counterparts brighter than $m \approx 21$ mag have unambiguously been identified on Sky Survey Plates and, more recently, on CCD images, spectroscopic observations and redshifts are still missing for quite a number of these identifications. Optical spectroscopy and additional direct imaging data for optical counterparts from these surveys had previously been reported by Stickel et al. (1989, 1993a, 1993b) and Stickel & Kühr (1993a, 1993b). As part of this ongoing program to complete the optical identification status of the 1 Jy, S4, and S5 catalogues, we have obtained additional spectroscopic observations for 14 optical counterparts, most of which had as yet either not been observed spectroscopically or had uncertain redshifts. These data allowed the determination of eight new redshifts and confirmed or clarified the redshifts of five sources. For the remaining source, only a featureless optical spectrum was found, confirming its classification as a BL Lac object. For three sources, additional direct imaging data are presented.

2. Observations and data reduction

The observed radio sources are listed in Table 1, which gives for each object its name (Col. 1), other names (Col. 2), the catalogue membership (Col. 3), the radio position (Cols. 4, 5), the magnitude and type of the optical counterpart (Cols. 6, 7), the 5 GHz radio flux (Col. 8) and the two-point radio spectral index α_{11-6} ($S_\nu \propto \nu^\alpha$) between 11 and 6 cm (Col. 9). Finally, Col. 10 gives the references to finding charts.

The spectroscopic data have been obtained during five nights in May and June 1993 with the 2.2 m and 3.5 m telescopes on Calar Alto, Spain. A journal of the observations is given in Table 2, which lists for each object its name (Col. 1), the date the radio source was observed (Col. 2), the telescope used (Col. 3), the integration time (Col. 4), and the spectral scale of the final wavelength calibrated spectra (Col. 5). At the 2.2 m telescope the Boller & Chivens Cassegrain spectrograph together with a Tektronix 1024*1024 CCD (pixel size 24 μm) was used. At the 3.5 m telescope, the Cassegrain Twin spectrograph was utilized, each channel of which was equipped with a Tektronix 1024*1024 CCD (pixel size 24 μm). A 2" wide slit was used throughout the observations.

The obtained two-dimensional data were de-biased and flatfield-corrected using dome-flats. The one-dimensional

* All tables are also available in electronic form: see the Editorial in A&AS 1994, Vol. 103, No. 1

object spectra were extracted according to the algorithm described by Horne (1986). Wavelength calibration was accomplished by fitting a fourth-order polynomial to HeAr comparison spectra, which had been taken immediately after the object exposures. Because non-photometric weather conditions (varying cloudiness and fluctuating seeing between 1.5" and 3") prevailed most of the time, the object spectra could only be approximately flux calibrated with observations of standard stars from the list of Oke (1990), Massey et al. (1988) and Massey & Gronwall (1990), which have been treated in a similar way as the object exposures.

3. Results of the optical spectroscopy

The optical spectra of the observed 1 Jy, S4, and S5 radio sources are shown in Fig. 1. In each spectrum, the emission lines as well as the absorption lines of the stellar component of the galaxies have been identified. In most of the spectra, atmospheric absorption features and residuals of strong night sky emission lines are also present, but have generally not been marked in Fig. 1.

Since no order separation filter has been used during the 2.2 m observations in order to get the full wavelength coverage, the spectra of the radio sources and the standard stars are contaminated at the red end ($\lambda \gtrsim 7000$ Å) by the second-order spectrum, which will introduce a spurious depression into the continuum of the calibrated object spectra. Although the usage of cool stars rather than hot white dwarfs as standards for the approximate flux calibration lessened the distortion, the continuum depression at $\lambda \gtrsim 7500$ Å can nevertheless clearly be seen in several of the object spectra (e.g. 1216+487, 1606+106).

Redshifts for the emission and absorption features have been derived from the object spectra by fitting single gaussians together with a linear continuum to the calibrated spectra. The results are listed in Table 3, which gives for each object (except 1926+611) its name (Col. 1), the mean redshift derived from all measured spectral features (Col. 2), the identifications of the spectral features (Col. 3), their rest as well as their observed wavelengths (Cols. 4, 5), and their individual redshifts (Col. 6).

4. Notes on individual sources

1216+487: A broad and a narrow emission line is detected in the optical spectrum, which are identified with Mg II λ 2798 and [O II] λ 3727 at $z = 1.071$. The redshifted C III] λ 1909 emission line is probably also present in the rather noisy part of the spectrum near 4000 Å. The Mg II λ 2798 emission line has a FWHM of only ≈ 1300 km/s in the rest frame, making 1216+487 a member of the group of narrow line quasars (Balwin et al. 1988).

The redshift of 1216+487 has previously been given by Kühr (1980), based on a spectrum which also showed the C IV λ 1549 emission line.

1236+842: On POSS, a faint pair of possibly interacting galaxies lies close to the centroid of the radio components (Kühr et al. 1987). A direct CCD image of this field taken in December 1985 with the 2.2 m telescope on Calar Alto shows that the northeastern member proposed as the identification of the radio source is probably an elliptical galaxy while the southwestern galaxy is much more elongated, possibly a disk type galaxy (Fig. 2). It is remarkable that the optical counterpart appears to have a central point source, similar to nearby QSOs and BL Lac objects of low redshift.

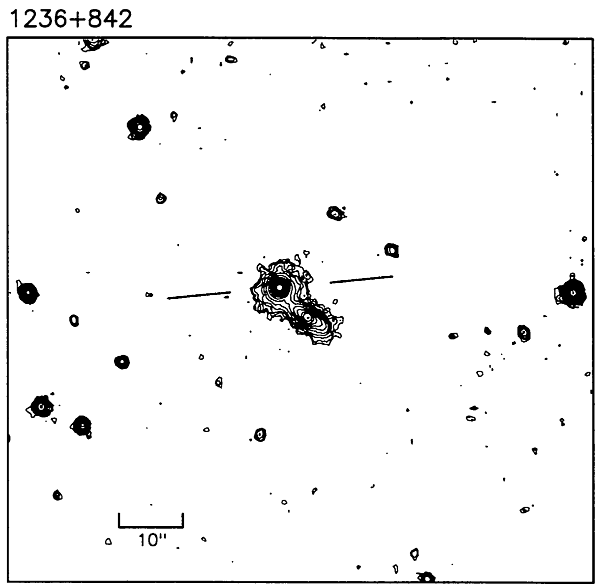

Fig. 2. I - band CCD image of the S5 source 1236+842. North is up and east to the left. The optical counterpart of the radio source is marked

The optical spectrum of the proposed identification reveals only absorption lines characteristic of an early type galaxy at $z = 0.226$, while in the spectrum of the neighbouring galaxy emission lines of [O II] λ 3727 and Hα/[N II] $\lambda\lambda$ 6563, 6584 at the same redshift were detected.

1244+492: An uncertain redshift based on a single emission line at 4500 Å identified with [O II] λ 3727 has been listed by Walsh et al. (1979). Our spectrum confirms the identification of this line and shows in addition emission lines of [O III] $\lambda\lambda$ 4959, 5007, Hα/[N II] $\lambda\lambda$ 6563, 6584 and [S II] λ 6724 as well as stellar absorption features at $z = 0.206$.

1345+736: Broad Balmer emission lines as well as narrow [O III] $\lambda\lambda$ 4959, 5007 at $z = 0.290$ are detected in the optical spectrum.

1504+377: The optical counterpart of 1504+377 has been identified by Fugmann et al. (1988) as an unresolved quasistellar object. A deeper R band CCD image taken in June 1993 with the 3.5 m telescope on Calar Alto, however, shows that the optical counterpart is clearly extended without a noticeable central point source (Fig. 3). It has therefore been classified as a galaxy in Table 1. The derived optical magnitude of $m_R = 20.8$ mag is consistent with the value of $m_r = 21.2$ mag given by Fugmann et al. (1988).

The optical spectrum of the galaxy shows only narrow emission lines at $z = 0.674$, superposed on a weak optical continuum (Fig. 1). The spectrum of the galaxy lying ≈ 20" northeast does not show any emission lines; its optical continuum was too weak to detect absorption features. However, it is likely that this galaxy together with the galaxies surrounding 1504+377 form a physical group, where the radio source is located in the brightest group member.

1520+725: The redshift of $z = 0.799$ is based on several narrow emission lines of neon and oxygen as well as a broad emission line identified with Mg II λ 2798.

1606+106: The optical spectrum shows two broad emission lines identified with C III] λ 1909 and Mg II λ 2798 at $z = 1.226$. Since the FWHM of the Mg II λ 2798 emission line is only ≈ 1200 km/s in the rest frame, 1606+106 is also a member of the group of narrow line quasars (Baldwin et al. 1988). The source is surrounded by a number of galaxies (Fig. 3), which are likely to be foreground objects because of the high redshift of the quasar.

Wills et al. (1973) previously noted that the optical counterpart had spectroscopically been confirmed as a quasar, but no redshift had been given. A preliminary redshift of $z = 1.24$ has been listed by Biermann et al. (1987), which was based on spectroscopic observations of one of us (H.K.) with the Steward Observatory 90" telescope on Kitt Peak.

1726+769: Three broad emission lines are detected in the optical spectrum of 1726+769, which have been identified with Mg II λ 2798, Hγ λ 4340 and Hβ λ 4861 at $z = 0.680$. Remarkably, no narrow [O III] $\lambda\lambda$ 4959, 5007 emission lines appear to be present. Nevertheless, the identification of the broad emission lines seems fairly certain because of the characteristic continuum depression redward of Mg II λ 2798, which can also be seen in the spectra of 1520+725 and 1606+106.

1746+712: Only a rather short exposure of 1746+712 has been obtained (Table 2), which nevertheless shows the presence of five emission lines identified with [O II] λ 3727, [O III] $\lambda\lambda$ 4959, 5007, Hα λ 6563 and [S II] λ 6724 at a redshift of $z = 0.216$.

1856+737: A number of broad and narrow emission lines at $z = 0.460$ are detected in the optical spectrum of

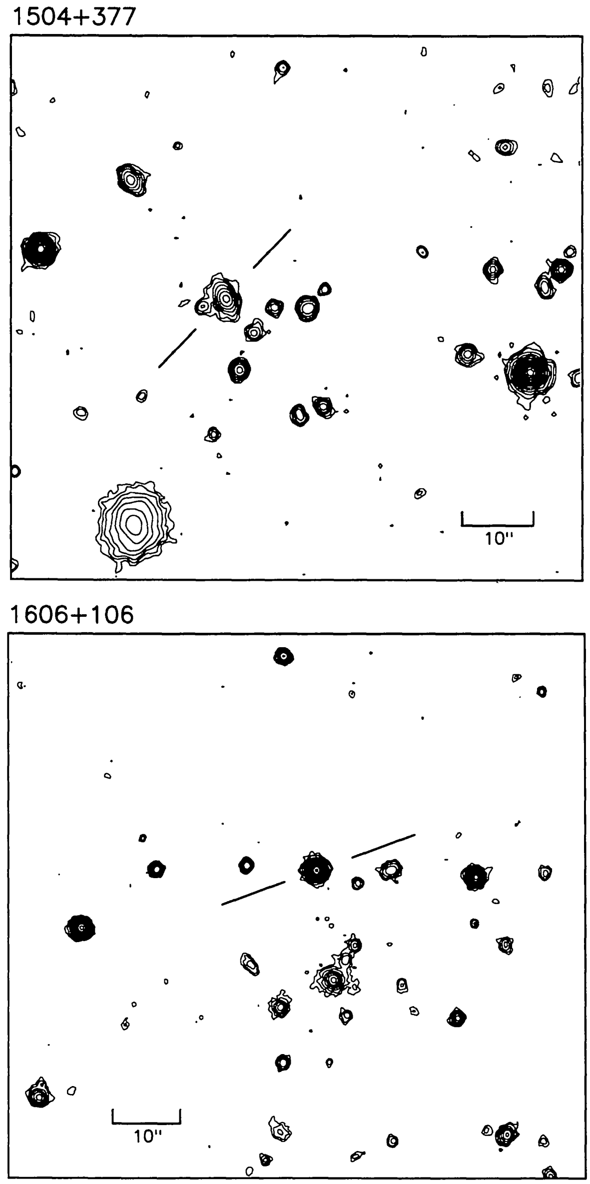

Fig. 3. R - band CCD images of the 1 Jy sources 1504+377 and 1606+106. North is up and east to the left. The optical counterparts of the radio sources are marked

1856+737. It is remarkable that the Balmer lines are much broader than the Mg II λ 2798 emission lines, and appear to have a central narrow component.

1926+611: No obvious emission or absorption features can be seen in the optical spectrum of 1926+611, in agreement with the observations reported by Stickel & Kühr (1993a) and Xu et al. (1993). There is indication of a very weak broad emission feature near 5600 Å, which is also present in our previously obtained spectrum shown in Stickel & Kühr (1993a). Since it lies close to the overlapping region of the two spectrograph channels, it cannot be excluded that it is a spurious result of the flux calibration procedure. The dip of the continuum blueward of 4000 Å is due to galactic Ca II $\lambda\lambda$ 3933, 3968 absorption.

2053−201: No emission lines are detected in the optical spectrum of 2053−201; the redshift of $z = 0.156$ is derived from the stellar absorption features alone.

2255+416: The optical spectrum shown in Fig. 1 confirms the presence of a broad emission line near $\approx$ 6000 Å, which has already been detected in a previous observation (Stickel & Kühr 1993a). The measured wavelengths of this emission line agree remarkably well in the two spectra, and its identification with Mg II λ 2798 at $z = 1.149$ seems fairly certain, particularly because in the first spectrum an emission feature has been seen close to the position of the redshifted C III] λ 1909 emission line.

As long as no other emission lines have unambiguously been detected, the redshift of $z = 1.149$ derived from the Mg II λ 2798 emission line is adopted for 2255+416. This value is in obvious contrast to the redshift given by Xu et al. (1993). Their redshift is based on several emission lines, which are not present in any of our spectra.

2356+385: There are several broad emission features present in the optical spectrum of 2356+385, which have been identified with Lyα/N V $\lambda\lambda$ 1216, 1240, Si IV λ 1402, CIV λ 1549 and C III] λ 1909 at $z = 2.704$. The Lyα line appears to be nearly completely absorbed, leading to a rather broad emission feature near 4550 Å. The uncertain redshift suggested by Wills et al. (1992) is apparently based on the incorrect identification of this broad emission feature with Mg II λ 2798.

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Table 1. Observed radio source identifications

Object (1)	other Names (2)	Catal. (3)	RA (1950) (4)	Dec (1950) (5)	m (6)	type (7)	S_{5GHz} (8)	α_{11-6} (9)	FC (10)
1216 + 487	ON+428	1 Jy, S4	12 16 38.58	+48 46 35.2	18.5	QSO	1.080	+0.30	1
1236 + 842		S5	12 36 17.53	+84 13 36.4	19.5	Gal	0.286	−0.76	0,3
1244 + 492	4C+49.25, ON+474	S4	12 44 49.00	+49 16 39.9	17.7	Gal	0.580	−0.52	2
1345 + 736		S5	13 45 14.84	+73 35 50.2	17.4	QSO	0.452	−0.48	3
1504 + 377	OR+306, MG1506+3730, B2	1 Jy, S4	15 04 12.95	+37 42 23.6	21.2	Gal[a]	1.100	+0.14	0,8
1520 + 725		S5	15 20 56.79	+72 35 46.4	16.5	QSO	0.486	−0.87	3,7
1606 + 106	4C+10.45, OS+111, PKS DA401, MG1608+1029	1 Jy	16 06 23.40	+10 36 59.9	18.5	QSO	1.490	+0.42	0,4
1726 + 769		S5	17 26 09.48	+76 55 43.6	19.2	QSO	0.339	−0.11	3
1746 + 712		S5	17 46 26.42	+71 16 49.5	18.8	Gal	0.268	−0.69	3
1856 + 737		S5	18 56 07.00	+73 47 19.5	17.5	QSO	0.407	−0.02	3
1926 + 611		S4	19 26 49.65	+61 11 21.1	17.5	BL	0.721	−0.09	11
2053 − 201	PKS, MSH 20 − 214	1 Jy	20 53 12.83	−20 08 06.0	17.5	Gal	1.020	−0.69	5
2255 + 416	4C+41.45, OY+492, DA589	1 Jy, S4	22 55 04.66	+41 38 13.2	20.9	QSO	1.000	−0.55	9,10
2356 + 385	OZ+395	S4	23 56 59.83	+38 34 00.2	19.0	QSO	0.636	+0.27	6

[a] revised type, see notes on individual sources

References : 0) this paper; 1) Kühr (1977); 2) Cohen et al. (1977); 3) Kühr et al. (1987); 4) Bolton et al. (1968); 5) Hazard (1972); 6) Johnson (1974); 7) Riley (1989); 8) Fugmann et al. (1988); 9) Rieke et al. (1979); 10) Stickel & Kühr (1993a); 11) Kapahi (1981)

Table 2. Journal of the observations

Object (1)	Date (2)	Telescope (3)	Int.Time [sec] (4)	Spectral Scale [Å/pixel] (5)
1216 + 487	May 30, 1993	2.2m	2700	3.3
1236 + 842	June 27, 1993	3.5m	3000	3.5/3.9
1244 + 492	May 28, 1993	2.2m	4000	3.3
1345 + 736	May 30, 1993	2.2m	3000	3.3
1504 + 377	June 26, 1993	3.5m	4000	3.5/3.9
1520 + 725	May 31, 1993	2.2m	1800	3.3
1606 + 106	May 29, 1993	2.2m	2900	3.3
1726 + 769	May 31, 1993	2.2m	2700	3.3
1746 + 712	May 29, 1993	2.2m	700	3.3
1856 + 737	May 31, 1993	2.2m	1800	3.3
1926 + 611	June 28, 1993	3.5m	3600	3.5/3.9
2053 − 201	May 29, 1993	2.2m	3400	3.3
2255 + 416	June 27, 1993	3.5m	2500	3.5/3.9
2356 + 385	May 31, 1993	2.2m	3000	3.3

Table 3. Identified emission and absorption line features

Object (1)	z (2)	ID (3)	λ_{rest} (4)	λ_{obs} (5)	z_{ind} (6)
1216 + 487	1.076	Mg II	2798	5799	1.072
		[O II]	3727	7753	1.080
1236 + 842	0.226	Ca II	3933	4820	0.225
		Ca II	3968	4860	0.225
		'G'	4303	5271	0.226
		Mg I	5175	6350	0.227
1244 + 492	0.206	[O II]	3727	4500	0.207
		Ca II	3933	4741	0.205
		Ca II	3968	4789	0.207
		'G'	4303	5195	0.207
		[O III]	4959	5983	0.206
		[O III]	5007	6045	0.207
		Mg I	5175	6248	0.207
		Na I	5893	7108	0.206
		Hα	6563	7906	0.205
		[N II]	6584	7938	0.206
		[S II]	6724	8100	0.205
1345 + 736	0.290	Hγ	4340	5605	0.292
		Hβ	4861	6283	0.293
		[O III]	4959	6385	0.287
		[O III]	5007	6446	0.287
		Hα	6563	8457	0.289
1504 + 377	0.674	[Ne V]	3426	5737	0.675
		[O II]	3727	6239	0.674
		[Ne III]	3869	6477	0.674
		Hβ	4861	8138	0.674
		[O III]	4959	8299	0.674
		[O III]	5007	8379	0.673
1520 + 725	0.799	Mg II	2798	5033	0.799
		[Ne V]	3426	6164	0.799
		[O II]	3727	6703	0.798
		[Ne III]	3869	6952	0.797
1606 + 106	1.226	C III]	1909	4234	1.218
		Mg II	2798	6249	1.233
1726 + 769	0.680	Mg II	2798	4697	0.679
		Hγ	4340	7304	0.683
		Hβ	4861	8158	0.678
1746 + 712	0.216	[O II]	3727	4531	0.216
		[O III]	4959	6040	0.218
		[O III]	5007	6097	0.218
		Hα	6563	7975	0.215
		[N II]	6584	7990	0.214
		[S II]	6724	8164	0.216
1856 + 737	0.460	Mg II	2798	4076	0.457
		[O II]	3727	5442	0.460
		[Ne III]	3869	5651	0.461
		[Ne III]	3968	5796	0.461
		Hδ	4102	6006	0.464
		Hγ	4340	6351	0.463
		[O III]	4363	6369	0.460
		Hβ	4861	7103	0.461
		[O III]	4959	7234	0.459
		[O III]	5007	7303	0.459
2053 − 201	0.156	Ca II	3933	4546	0.156
		Ca II	3968	4584	0.155
		'G'	4303	4978	0.157
		Mg I	5175	5986	0.157
		Na I	5893	6813	0.156
2255 + 416	1.149	Mg II	2798	6014	1.149
2356 + 385	2.704	Lyα	1216	4510	2.709
		N V	1240	4604	2.704
		Si IV	1402	5206	2.713
		C IV	1549	5724	2.695
		C III]	1909	7057	2.697

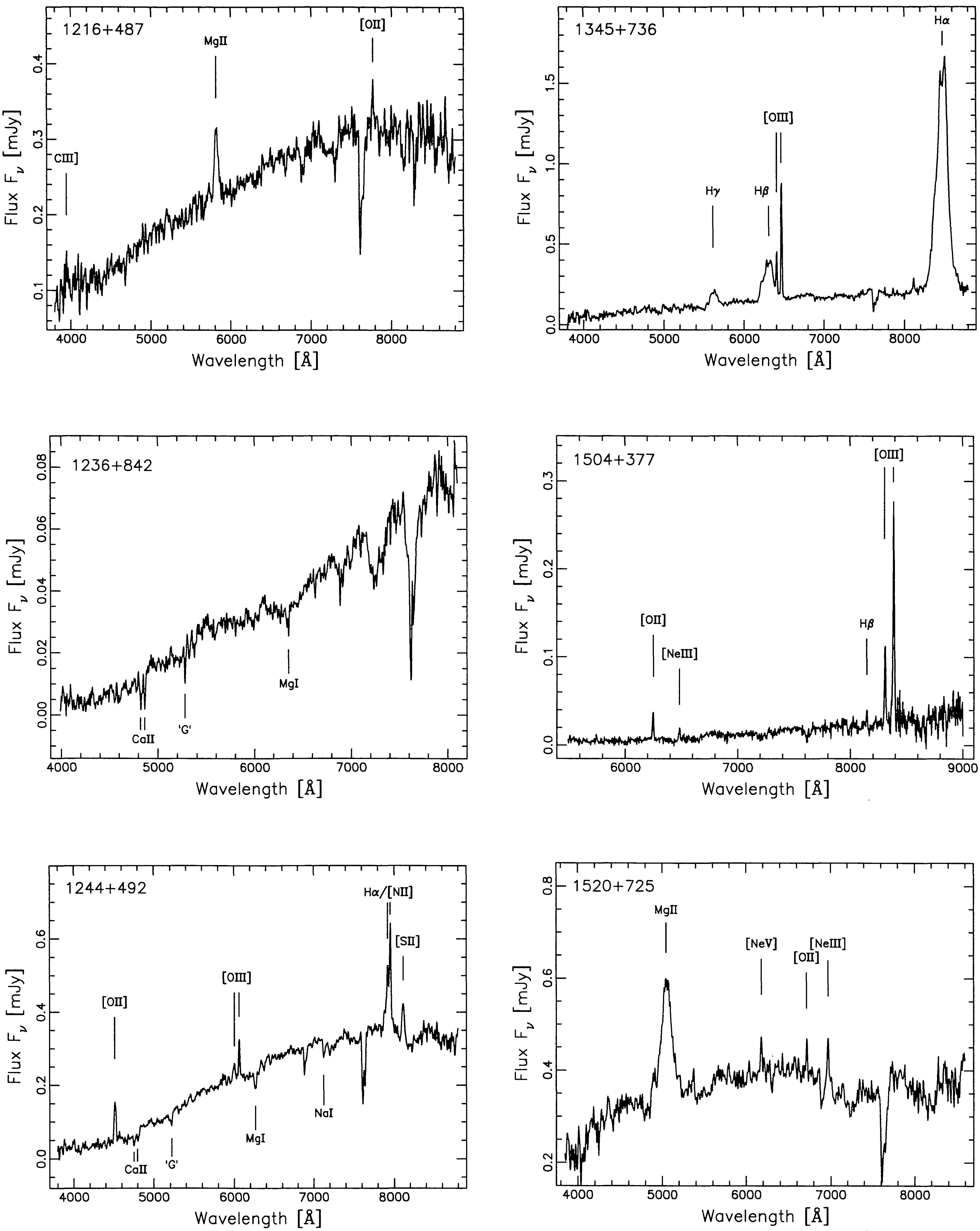
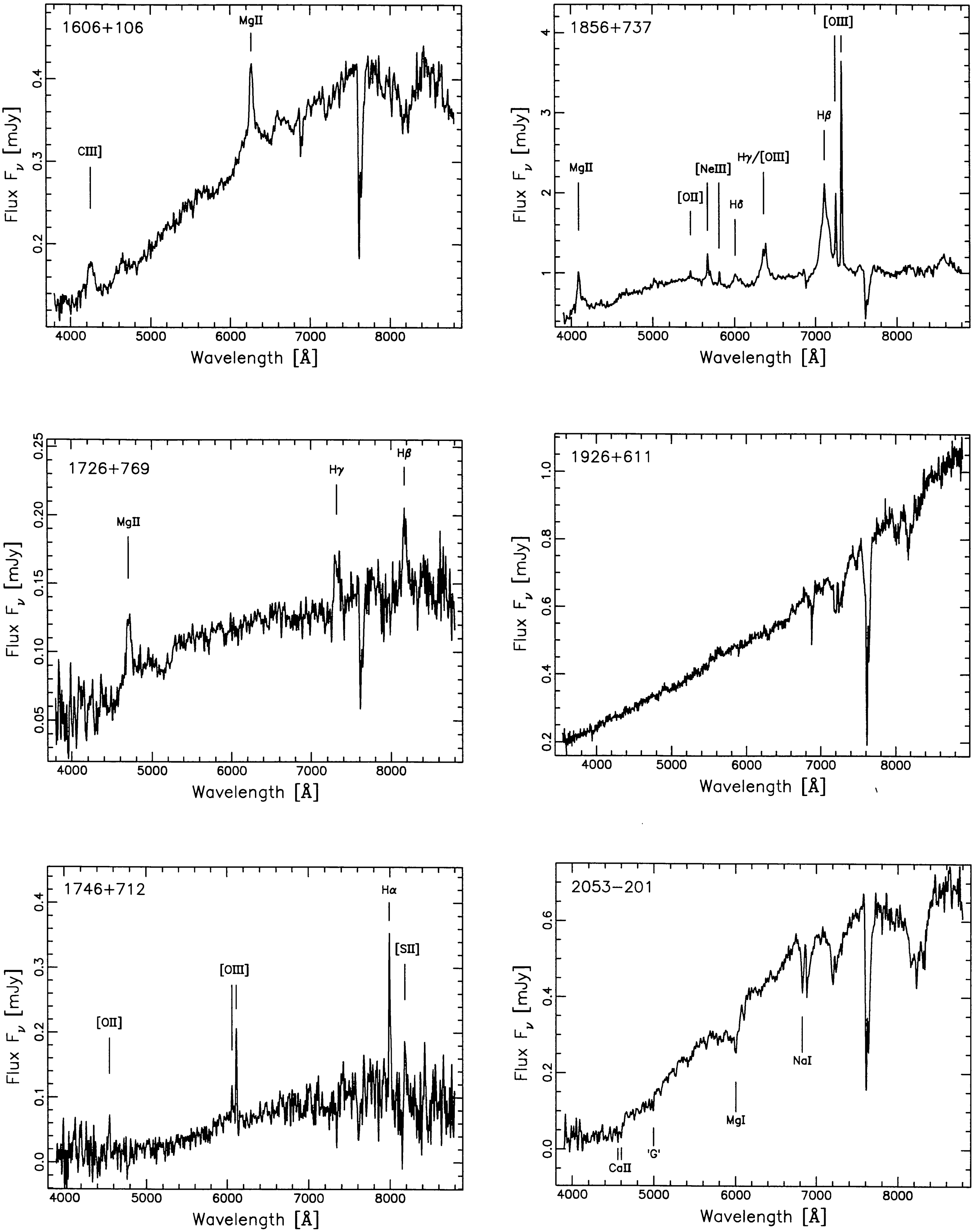


Fig. 1. Optical spectra of the counterparts of the 1Jy, S4, and S5 radio sources. The identified spectral features are indicated



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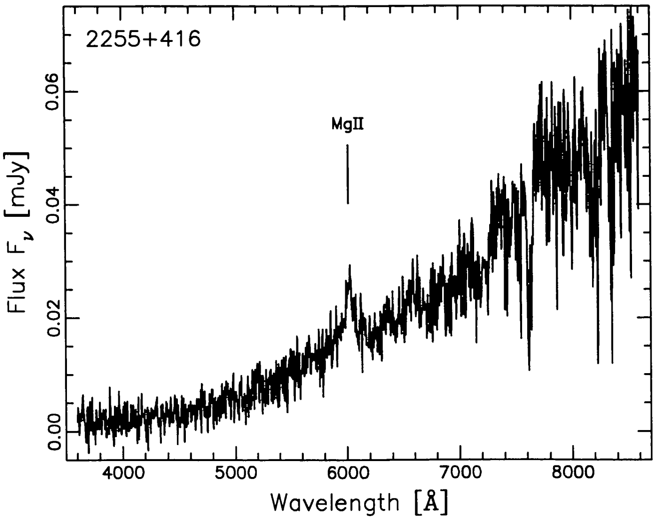

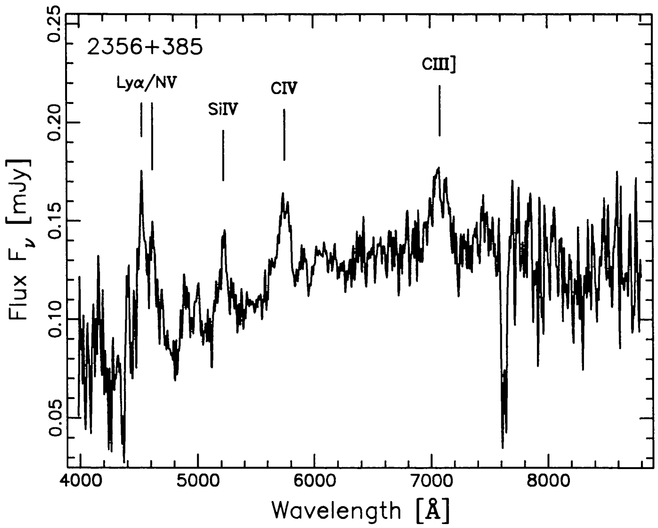

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