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PKS 0528−250: A NEUTRAL STELLAR OBJECT AT $z = 2.812$, WITH NO EMISSION LINES AND A RICH ABSORPTION-LINE SPECTRUM

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ABSTRACT

Image-tube dissector scanner observations of the 19th mag neutral stellar object identified with the radio source PKS 0528−250 show that it possesses a rich absorption-line spectrum similar to that expected from an intervening galaxy at $z = 2.812$. The object is unusual in having no emission lines but strong Lα absorption at 4635 Å.

Subject headings: galaxies: redshifts — radio sources: general

I. INTRODUCTION

A program of optical spectroscopy of southern QSOs from the Parkes 2.7 GHz radio survey is being undertaken (Peterson *et al.* 1976; Wright *et al.* 1977; Jauncey *et al.* 1978), using the 4 m Anglo-Australian telescope (Wampler 1975).

An especially interesting result is reported here for the source PKS 0528−250. This source was previously classified III-S, i.e., a single stellar object of neutral color, in good agreement with the radio position (Bolton, Shimmins, and Wall 1975). No identification was claimed at that time, but the accuracy of the Parkes radio position, about 7″ rms in each coordinate, showed that an earlier suggested identification (Gearhart *et al.* 1972) was incorrect. Subsequently, accurate radio positional measurements with the NRAO three-element interferometer[1] (Condon, Hicks, and Jauncey 1977) confirmed that the 19th mag stellar object noted by Bolton *et al.* was indeed the correct identification, and a comparison of the red and blue images on the Palomar Sky Survey established the neutral color. The positions (1950) are: radio, R.A. $05^{h}28^{m}05^{s}.24 \pm 0^{s}.08$, decl. $-25°05'43''.0 \pm 1''.8$; optical, R.A. $05^{h}28^{m}05^{s}.19 \pm 0^{s}.07$, decl. $-25°05'45''.2 \pm 0''.9$. A finding chart for the identification is given by Condon, Hicks, and Jauncey (1977). The source is unresolved on the 2.1 km baseline of the NRAO interferometer at 8.085 GHz, indicating an angular size of less than 2″.

Scanner observations of this object made on the 4 m Anglo-Australian telescope revealed a very rich and deep absorption-line spectrum but failed to show any significant emission-line features (Wright *et al.* 1977).

II. THE RADIO SPECTRUM

Flux density measurements for PKS 0528−250 covering the range 408 MHz to 10.7 GHz have been plotted in Figure 1. The measurements include observations at 1.4, 3.2, 6.6, and 10.7 GHz by Andrew *et al.* (1973); at 2.7 and 5.0 GHz by Bolton, Shimmins, and Wall (1975); at 408 MHz with the Molonglo Cross by A. G. Little (1976, private communication); and by the authors at 2.29 and 8.42 GHz with the NASA 64 m telescope at Tidbinbilla, Australia, at 5.0 GHz at Parkes, and at 2.695 and 8.085 GHz with the NRAO three-element interferometer. PKS 0528−250 has a peaked radio spectrum with a maximum near 3 GHz.

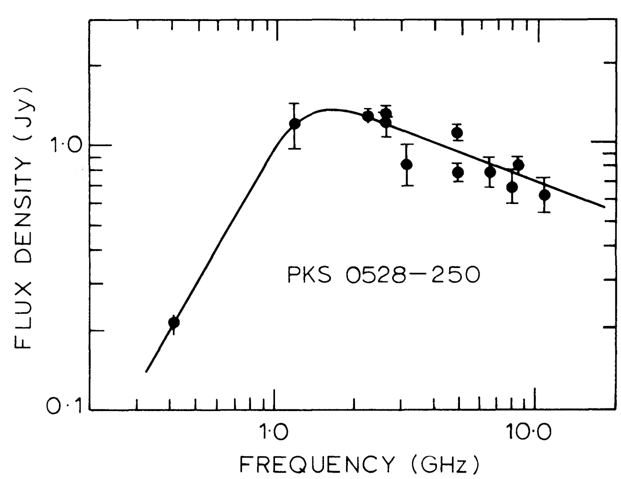

FIG. 1.—The radio spectrum of PKS 0528−250.

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

III. THE OPTICAL SPECTRUM

The optical spectrum was first observed by us on the night of 1976 January 27–28 under excellent (<1″) seeing conditions, with the image-tube dissector scanner (Robinson and Wampler 1972) at the f/15 focus of the 4 m Anglo-Australian telescope. The scans covered the spectral range 3600 to 8000 Å at about 10 Å resolution, and were distinguished by numerous deep absorption lines and a wide absorption band from 4600 to 4650 Å that was clearly black even on a few minutes' integration on the monitor attached to the scanner. This object shows the deepest and richest absorption-line spectrum that we have observed at this resolution with the dissector scanner.

On the night of February 21–22 further scans were taken at about 5 Å resolution. Figure 2 shows the January and February scans corrected for the instrumental response. Although the continuum in Figure 2 is not smooth, there are no clear emission features that appear on both scans. The optical image appears stellar both on the Palomar Sky Survey prints and on the television finder attached to the 4 m telescope.

PKS 0528−250 is an optical variable. Our magnitude estimate from the Sky Survey is 19.0 ± 0.5, while the

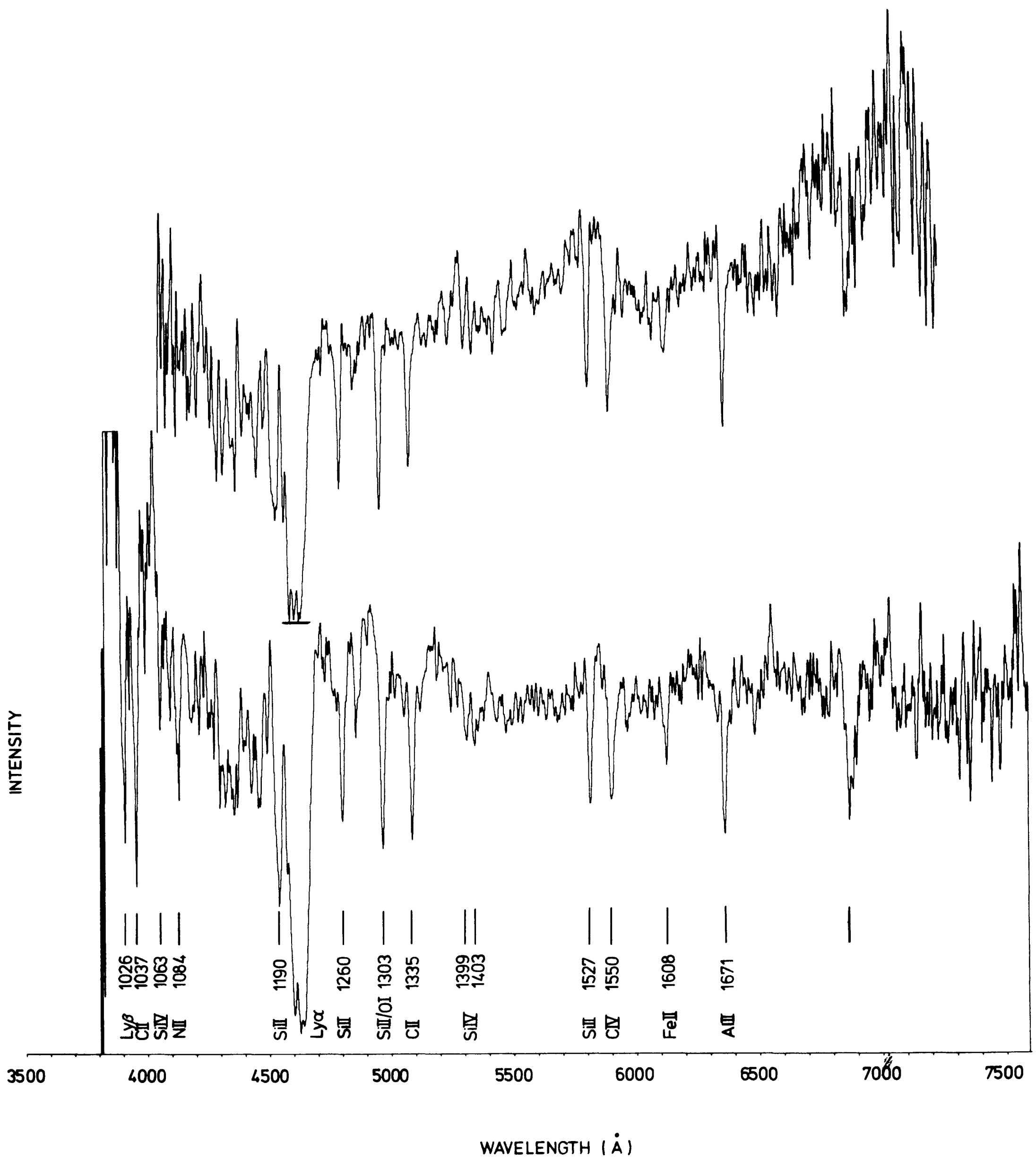

FIG. 2.—IDS scans of PKS 0528−250 taken in 1976 January and February. The January scan (*lower*) was taken with 10 Å resolution; the February scan (*upper*) with 5 Å resolution. The stronger absorption features listed in Table 1 have been marked, together with the identifications in the $z = 2.812$ absorption system.

January and February scanner counts show it to have been significantly brighter, 17.5 ± 0.5. Further observations were attempted in 1976 September, but no additional spectroscopic information was obtained because the source was much fainter at 19.5 ± 0.7.

a) The Absorption-Line Spectrum

After identification of the deep absorption band between 4600 and 4650 Å with Lα, the other deep absorption lines were easily identified as ground-state lines of the more abundant metals all at the same redshift of 2.812. Table 1 lists all the absorption features that are common to both the January and February scans, together with their wavelengths as derived from the higher-resolution February scan. Also given are our line identifications and their rest wavelengths and redshifts for the individual identified lines. Nearly all the strong absorption features have been identified with absorbing material at the redshift of 2.812.

The strong line at 4490 Å, corresponding to 1177.9 Å at $z = 2.812$, is too far in wavelength from the metastable C III 1175.7 line and too strong to be identified with it. This strengthens the suggestion by Strittmatter and Williams (1976) that there is probably an unidentified resonance line near 1175 Å. The absorption line at 6873 Å remains as the *only* unidentified strong absorption line in the spectrum of PKS 0528−250. This line appears to show structure but the wavelength agreement is incompatible with Si II 1807.5. PKS 0528−250 is unusual among high-redshift objects in having so many of the strong absorption lines accounted for by one absorption system.

The absorption spectrum of PKS 0528−250 shows no evidence for absorption from the Si II fine-structure levels. The upper limit on the equivalent widths of the Si II fine-structure lines at 1265 Å and at 1533 Å is 0.7 Å. This upper limit implies that the cloud of absorbing material is more than ~100 pc from the continuum source and that the electron density in the cloud is less than 10^2 cm^{-3} (Bahcall 1967; Bahcall and Wolf 1968).

The width of the Lα absorption band in PKS 0528−250 is very similar to that found in PHL 957 (Beaver *et al.* 1972) and in 1331+170 (Carswell *et al.* 1975) and implies a high H I column density if the line is saturated. If it is, the column density can be estimated from the width, $\Delta\lambda$, of Lα absorption feature at an optical depth of 0.3 in the wings of the absorption line, namely,

$$N_{\mathrm{H\,I}} = 10^{20}\left(\frac{\Delta\lambda}{16}\right)^2 \mathrm{cm}^{-2}\,.$$

With $\Delta\lambda = 100/(1+z) = 26.2$ Å for 0528−250, we infer a column density for H I of 3×10^{20} cm^{-2}.

The equivalent widths of the absorption lines of the singly ionized metals, C II λ1335, Si II λ1527, and Fe II λ1608, are about 5 times greater than those found in the spectrum of ζ Oph (Morton 1975). Assuming that the main contribution to the equivalent widths comes from the damping wings, we find that the column densities in PKS 0528−250 would be about twice

TABLE 1

ABSORPTION FEATURES IN PKS 0528-250

Observed wavelength	Identification	Emitted wavelength	Redshift	Comments
3905	Lyβ	1025.7	2.807	
3952	CII	1036.3	2.814	
4054	S IV	1062.7	2.815	
4130	NII	1084.0	2.810	
4217	FeII	1106.4	2.811	
4253				
4273				
4323	NI	1134.5	2.810	
4352	FeII	1142.3	2.810	Wide absorption band possibly due to FeII lines from 1142.3 to 1144.9 Å.
4462				
4490	(CIII)	1175.7	(2.819)	Identification with CIII λ1175 probably incorrect (see text).
4524				
4540	SiII	1190.4	2.814	
4550	SiII	1193.3	2.813	
4575	NI	1199.9	2.813	
4598	SiIII	1206.5	2.811	
4635	Lyα	1215.7	2.813	
4730	NV	1238.8	2.818	
4803	SiII	1260.4	2.811	Possibly blended with FeII 1260.5.
4968	{SiII / OI}	{1304.4 / 1302.7}	2.811	Probably a blend of SiII 1304.4 and OI 1302.7.
5089	CII	1334.5	2.813	
5251				
5315	SiIV	1393.8	2.813	
5348	SiIV	1402.8	2.812	
5483				Broad.
5819	SiII	1526.7	2.811	
5907	CIV	1549.5	2.812	Broad, CIV 1548.2 and 1550.8 not quite separated.
6132	FeII	1608.4	2.812	
6371	AlII	1670.8	2.813	
6873				Broad.

those in ζ Oph, or $\sim 10^{17}$ cm^{-2} for C II, $\sim 10^{15}$ cm^{-2} for Si II, and $\sim 10^{15}$ cm^{-2} for Fe II. The equivalent width of the blended C IV 1549 doublet is about 200 times greater than the upper limit for C IV absorption in the spectrum of ζ Oph, thus indicating a higher degree of ionization in the cloud in front of PKS 0528−250 than in the interstellar medium along the line of sight to ζ Oph. The relatively low density and high ionization imply a photoionization mechanism. Thus the absorption spectrum of PKS 0528−250 is remarkably similar to that expected from the interstellar medium in an intervening galaxy.

b) *Lack of Emission Lines*

The most remarkable feature of the spectrum of PKS 0528−250 is the lack of any prominent emission lines. We note, however, that the continuum in Figure 2 is not smooth and that there is a weak, broad feature at $\sim$5850 Å which appears on both scans. We believe this feature is not C IV 1549 at $z_{\rm em} \sim z_{\rm abs}$, since then L$\alpha$ and C III] 1909 should be present as strong broad lines in emission, and Si IV 1393, 1402, and O IV] 1406 might be seen as medium intensity lines. No such lines can be seen in Figure 2. One possibility is that this feature may be weak Lα emission, but we believe that further observations are necessary to confirm the reality of the feature.

Two explanations are possible for the apparent lack of emission lines: either (*a*) the object is intrinsically lineless; or (*b*) it is a QSO with a redshift such that no strong emission lines are present in the observed regions of the spectrum. If $z_{\rm em} \gtrsim z_{\rm abs}$, then the absence of L$\alpha$ emission suggests a minimum emission redshift $z_{\rm em} \gtrsim 4.7$.

The characteristics of PKS 0528−250 do not lead to a clear-cut identification of the object as a QSO. The lack of emission lines, the presence of absorption lines, the neutral color, the radio spectrum, and the optical variability suggest that 0528−250 may be best put in a category with the BL Lacertae objects. If so, then it would be the highest-redshift and most luminous BL Lacertae object yet discovered, with the continuum source lying at some redshift $z \geq 2.8$. If it is a BL Lacertae object, the absorption lines may be formed in the nebulosity often associated with such objects.

A continuous range of objects with very weak or no emission lines suggests itself: at the lowest redshift, objects like BL Lacertae; then, with increasing redshift, absorption-line objects like AO 0235+164, intermediate-redshift QSOs with very weak emission lines like 4C 28.25 (Schmidt 1974), and then high-redshift objects like PKS 0528−250.

IV. IDENTIFICATION OF SIMILAR OBJECTS

One important consequence of the lack of emission lines and the deep absorption features is the difficulty of identifying such objects in most radio source optical identification programs. The deep absorption shortward of 4650 Å means that similar objects may not appear blue on the Palomar Sky Survey and may also lack an ultraviolet excess. Consequently they can be discovered by identifying radio sources with optical objects *only* when accurate, $\sim 1''$, position measurements are available for both the radio and optical objects. Furthermore, if such objects have radio spectra, like PKS 0528−250, then they will be most uncommon in low-frequency radio surveys and would be found predominantly in the short-wavelength radio surveys (see Condon and Jauncey 1974).

Objects with optical spectra, like PKS 0528−250, will also elude the optical surveys. With colors essentially indistinguishable from those of normal stars, these objects are impossible to identify with the usual multicolor searches. Moreover, the absence of emission lines greatly reduces the chances of finding similar objects in objective-prism surveys (see Smith 1975).

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