IDENTIFICATION OF LINES IN THE SPECTRUM OF THE QUASAR 0237 – 233

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Abstract. The emission and absorption lines ($\lambda\lambda 3716 - 4290$) in the spectrum of the quasar $0237 - 233$ are identified within the framework of the PLS model. The available evidence indicates that it is a helium star. Similarities between the spectral properties of $0237 - 233$ and the star Upsilon Sagittarii are pointed out. Predictions are made for the absorption-line spectrum which falls outside $\lambda\lambda 3716 - 4290$ and also for an expected discontinuity at $\lambda 2600$.

1. Introduction

The object PKS 0237 – 23 was identified as a quasar by Arp *et al.* (1967). They reported five emission lines in its spectrum and interpreted the spectrum on the redshift hypothesis as having an apparent redshift of $\simeq 2.22$. This quasar has played an important role in the history of quasars. So many absorption lines were found in the spectrum of this quasar that multiple redshift hypothesis was advanced to account for them. In this paper we identify the emission and absorption lines in the spectrum of this quasar on the basis of the plasma-laser star (PLS) model of quasars (Varshni, 1973, 1974, 1975, 1977a, b, 1978, 1979, 1985, 1988a, b; Varshni and Lam, 1976; Varshni and Nasser, 1986). Our theory does away with the artificial assumption of redshifts. Laser action is responsible for the broad emission lines.

2. Emission Lines

2.1. THE DATA

There are several other quasars which belong to the same spectral class (Varshni, 1976) as $0237 - 233$. We summarize the available data on emission lines for all these quasars in Table I. There are a number of other quasars (Hewitt and Burbidge, 1987) which appear to belong to this spectral group but the available data are too poor to make a definite assignment. For each quasar the first row shows the reported wavelengths. Below each wavelength, where known, are shown the characteristics of that line. For three of these quasars, $0237 - 233$, $0029 + 003$, and $1448 - 232$ the available emission line data appear to be better than those for the rest.

   $0237 - 233$. There are only two sets of measurements of the emission lines, one due to Arp *et al.* (1967) and the other due to Burbidge (1967). Arp *et al.* (1967) obtained the spectra (for emission lines) at a dispersion of 600 Å mm^{-1} at the prime-focus of the Lick 120-inch telescope. These authors found five emission lines. Burbidge (1967) also used the Lick 120-inch telescope and the spectrum was obtained at a dispersion of

370 Å mm^{-1} on baked IIaO emulsion. She found two emission lines. There are large differences in the wavelengths of these two lines as given by Arp *et al.* (1967) and by Burbidge (1967).

0029 + 003. This quasar is one of a close pair of quasars. The other member is 0028 + 003; the separation between the two is 62″. Shaver *et al.* (1982) observed the two quasars at low (114 Å mm^{-1}) and intermediate (59 Å mm^{-1}) dispersion with the European Southern Observatory 3.6 m telescope, and at high dispersion (33 Å mm^{-1}) with the Anglo-Australian telescope in October 1981. The line at λ3920 is absent. For other quasars in Table I, in the redshift hypothesis, this line has been identified with Lα. Its absence in 0029 + 003 shows that such redshifts which primarily depend on a line being identified as Lα are highly suspect.

1448 − 232. The best data appear to be that of Chen *et al.* (1983, 1984). Their observations were carried out in 1977, 1979, and 1980 at a dispersion of about 33 Å mm^{-1} with the Anglo-Australian telescope.

2.2. LINE IDENTIFICATIONS

Line No. 1. − Arp *et al.* (1967) give the wavelength as 3930 Å, while Burbidge (1967) gives 3919.8 Å. Arp *et al.* note that their measurement of the λ3930 line was affected by the presence of the mercury night-sky line at λ4046. The better dispersion used by Burbidge (1967) as well as the tracings given in Bahcall *et al.* (1968; hereafter referred to as BGS) favouring Burbidge's value. We identify this line with C II $\lambda\lambda$3919, 3920.7 (mult. 4) which is also known to occur in WR spectra and in nova like stars.

Line No. 2. − There is a considerable spread in the reported wavelengths. Assuming that the one reported by Shaver *et al.* (1982) is closest to the correct value, the identification is with N II λ3995 (mult. 12). The line occurs in Wolf–Rayet and novae spectra.

It is of interest to compare the behaviour of 0237 − 233 and 0029 + 003 with respect to Line Nos. 1 and 2. In 0237 − 233, No. 1 occurs but No. 2 does not, while in 0029 + 03, the reverse is the case. Precisely this type of behaviour is expected from laser action in our theory (Varshni, 1975, 1979) for two quasars which lie at certain positions on the n_e, T_e diagram. The redshift hypothesis has no explanation for this behaviour.

Line No. 3. − The recorded values for the wavelength are 4537 Å (Arp *et al.*, 1967) and 4513 Å (Burbidge, 1967). As Burbidge used a better dispersion her value appears to be more accurate. We identify this line with C III $\lambda\lambda$4516, 4517 (mult. 9). This line occurs with good strength in WC spectra. We would like to mention here another possibility also − N III $\lambda\lambda$4511, 4515, 4518 (mult. 3). This line is often quite strong in WN spectra. A detailed study of the structure of the quasar line can help to decide which of the two is the correct identification.

Line No. 4. − We identify this line with N II $\lambda\lambda$4987, 4994 (mult. 24).

Line No. 5. − It appears only as a weak line and its wavelength has considerable uncertainty. We identify this line with C III $\lambda\lambda$5273, 5254 (mult. 4). This line appears in WC spectra.

Line No. 6. − For this line also, there is considerable uncertainty in its wavelength, Arp *et al.* (1967) note that their measurement of λ6141 was affected by the night-sky

TABLE I

Emission line data for quasars. Below each wavelength are given, where available, the characteristics of the line. The symbols have the following meanings. Br – broad; M – medium strength; S – strong; Wk – weak; VWk – very weak. For 0029 + 003, 0046 – 297, and 2228.6 – 395, the second line shows the equivalent widths. For 0244 – 128, 0851 + 197, and 1448 – 132, in the second line, the values in decimals indicate the line to continuum ratios, and the values in Å are the linewidths.

Quasar	V (Mag)	Set	1 λ (Å)	2 λ (Å)	3 λ (Å)	4 λ (Å)	5 λ (Å)	6 λ (Å)	Source
0237 – 233	16.63	(a)	3930		4537	4993	5285	6141	Arp et al. (1967)
			S		M	S	Wk	M	
		(b)	3919.8		4513.7				Burbidge (1967)
0029 + 003	18		absent	3994	4507	4991		6160	Shaver et al. (1982)
				160 Å	21 Å	73 Å		36 Å	
0046 – 297	19.5		3909			4964			Savage et al. (1985)
			200 Å			60 Å			
0135 – 002	19.1		3900			5000			MacAlpine and Lewis (1978)
			M, Br			VWk			
0242 – 410	18.1		3905	3984		4986	5267	6155	Osmer and Smith (1977)
			S	Wk		M	Wk	Wk	
0244 – 128	17.1		3896	(3989)	4480	4952	5253	6120	Jauncey et al. (1984)
			4.46, 70 Å	0.6	0.5, 50 Å	2.07, 50 Å	0.90, 15 Å	1.0, 65 Å	
0254 – 671	18.5			3970		4995			Savage et Wright (1981)
0851 + 197	18		3912		4494	4972			Schmidt (1974)
			S, 150 Å		Wk	Wk			
1225 + 317	15.87		3930			4950			Ulrich (1976)
			S			Wk			
1246 – 057	16.73			3976		4983			Osmer and Smith (1977)
				S		M			
1448 – 232	16.96	(a)	3900	3980	4480	4970		6125	Savage et al. (1976)
			2.5, 60 Å	1.0	0.25	1.0, 45 Å		0.4, 120 Å	
		(b)	3919		4494	4985			Osmer and Smith (1977)
			S		Wk	M			
		(c)	3911	3985	4515	(4981)			Chen et al. (1983, 1984)
1816 + 475	18.2		3928		4508	4986			Walsh et al. (1979)
2228.6 – 395	18.3		3895		4479	4971		6094	Savage et al. (1985)
			340 Å						

line at $\lambda6300$. We identify this line with C III $\lambda\lambda6154, 6155, 6157$ (mult. 13). This line also appears in WC spectra.

The proposed identifications depend, of course, on the assumption that the reported wavelengths are correct. Should future investigations show that the actual values of the wavelengths are substantially different from those given by Burbidge (1967) and Shaver *et al.* (1982), clearly the question of identification will have to be reconsidered.

3. Absorption-Line Spectrum

We have discussed in previous papers (Varshni, 1977, 1978, 1985) the characteristics of the absorption-line spectrum of quasars that are predicted from our model. In particular we shall follow the considerations of our 1985 paper.

There have been a number of investigations on the absorption-line spectrum of $0237 - 233$. We summarize these investigations here.

A spectrum of 195 Å mm^{-1} obtained by Arp *et al.* (1967) at the prime focus of the 200-inch telescope showed the presence of many absorption lines. These authors listed 33 absorption lines in the interval $\lambda\lambda3526 - 5096$ and attempted to identify them on the redshift hypothesis with $z = 2.20$. Burbidge (1967) obtained a spectrum of $0237 - 23$ on baked IIaO emulsion with the conventional prime-focus spectrograph on the Lick 120-inch telescope, with the camera-grating combination giving a dispersion of 370 Å mm^{-1}. She listed 20 lines in the interval $\lambda\lambda3444 - 4613$ and attempted to identify some of the lines at $z \simeq 1.95$. Greenstein (cf. Greenstein and Schmidt, 1967) obtained two spectra of $0237 - 233$ at a higher resolution. They were obtained at 89 Å mm^{-1} in the first order with the Palomar prime-focus spectrograph. About 150 possible absorption features were measured. Of these, as described by Greenstein and Schmidt (1967), a highly selected list of 40 lines was published in their Table I. It is not clear how many strong lines were left unmentioned. Greenstein and Schmidt (1967) assigned most of these 40 lines to two redshift systems, $z_1 = 2.2020$ and $z_2 = 1.9555$. Thus was born the multiple-redshift hypothesis for the absorption lines of quasars.

Meanwhile several more spectrograms were obtained by Greenstein and Sargent (BGS) and a list of 49 absorption lines in the range $\lambda\lambda3346 - 4493$ was analyzed in collaboration with Bahcall using the multiple-redshift hypothesis. Twenty-eight of the forty-nine lines were claimed to have been identified by five redshifts. These were $z = 2.2015, 1.6704, 1.6560, 1.5132,$ and 1.3642. However, many of the strong lines were unidentified, even with five redshift systems. It is not without significance that after this work on $0237 - 233$, Greenstein, a very experienced stellar spectroscopist, quit quasars altogether and years later wrote 'as for me, after a few parting shots on multiple-absorption-line systems in quasars, I abandoned the field in 1967 without regret' (Greenstein, 1984). Parenthetically we note that it was not for the lack of telescope time, because as he himself notes, he had been assigned 20 to 30 nights a year (1952–1979) at the 200-inch (Greenstein, 1984). Greenstein's work on a similar star is noted in Section 5.

Burbidge *et al.* (1968; hereafter BLS) obtained spectra of $0237 - 233$ at Lick and Kitt

Peak observatories and they list a total of 92 absorption lines in the interval $\lambda\lambda 3205 - 6630$. Comparing their results with those of Greenstein and Schmidt (1967), Burbidge *et al.* commented: "However, it is clear that the present material does not support a contention that the majority of the absorption features in PKS 0237 – 23 can be explained on the basis of the two suggested redshifts. Furthermore, the present authors take issue with many of the identifications made by Greenstein and Schmidt...". BLS proposed an additional redshift, $z = 1.365$. Grueff (1969) claimed that eleven absorption lines of strong and medium intensity can be identified with lines of sulphur ions at a redshift of 2.4516.

The investigations of BLS and BGS were based on conventional image-tube and photographic spectrograms which were near the limits of the resolution, about 2.3 Å, then available on large telescopes.

Boksenberg and Sargent (1975) used the University College London image photon counting system (IPCS) at the Coudé focus of the Palomar telescope to obtain the spectrum of 0237 – 233 at a resolution of 0.71 Å. They give a list of 75 absorption lines in the wavelength range $\lambda\lambda 3737 - 4270$. Boroson *et al.* (1978, hereafter BSBC) carried out further observations on 0233 – 233 with the IPCS and these observations were combined with the older data of Boksenberg and Sargent (1975). These authors tabulated wavelengths and equivalent widths of 193 absorption lines in the spectral range $\lambda\lambda 3716 - 4289$. BSBC claimed that many of these lines are due to C IV $\lambda\lambda 1548.20$, 1550.77 at various redshifts. A total of 45 redshifts were claimed. Varshni (1981) examined these supposed identifications and showed that the number of redshift systems based on C IV doublets differs insignificantly from what would be expected from chance coincidences. Consequently, these systems and their z-values seem devoid of any physical significance.

Varshalovich and Levshakov (1981) analyzed the absorption line data reported by BSBC and claimed to have found 12 redshift systems containing CO lines and they tabulate five of these. Varshni (1983) examined this claim also and showed that the number of redshifted CO absorption-line systems that are found in the spectrum of 0237 – 233, using the rules of Varshalovich and Levshakov, differs insignificantly from what would be expected from chance coincidences. Consequently, the CO systems proposed by Varshalovich and Levshakov also seem to have no physical reality.

It is obvious from the above summary that the redshift hypothesis has been singularly unsuccessful in explaining the absorption-line spectrum of 0237 – 233. Before coming to the identifications on the basis of our theory, we shall first consider the quality of the available data. Certain problems whih were encountered in the case of 0805 + 046 (Varshni, 1985) are also present here.

With the improvement in observational techniques, the number of observed lines has been rapidly increasing. This can be seen in the number density of lines observed. Most of the reported observations of 0237 – 233 are shortward of 5100 Å, and in this region the number of lines per 100 Å for the various investigators are as follows: Arp *et al.* (1967) – 2.10, BLS (1968) – 4.51 (Kitt Peak spectrum) and 4.45 (Lick spectrum), BGS (1968) – 4.27, Boksenberg and Sargent (1978) – 13.70, BSBC (1978) – 33.68. The

resolution obtained by BSBC was only 0.7 Å (corresponds to 52 km s^{-1}). Now it is possible to obtain much better resolution in quasar spectra (Chaffee *et al.*, 1983, 12 km s^{-1}; York *et al.*, 1984, 10 km s^{-1}). If 0237 – 233 is studied with a resolution of 10 km s^{-1}, we expect the number density of lines to increase by a factor of about 2.5. The incompleteness of the BSBC data has to be borne in mind while considering the number of lines of any element which are identified as against the expected number of lines, and also as regards the completeness of multiplets in the identifications.

As noted earlier, the estimated resolution in the BSBC data is 0.71 Å. However, a close inspection of enlargements of Figures 1 and 2 of BSBC shows that many lines are wider than 0.7 Å and many of them are blends. BSBC state "The wavelengths of the lines are probably accurate to 0.3 Å except in the case of blended lines, where the error may be twice as large". Allowing for these various factors a value of 1 Å appears to be a reasonable guiding value for the tolerance: i.e., the discrepancy between the observed and identified wavelengths. When the line is very wide (blended) clearly a larger value is acceptable.

As regards the relative intensities of lines, again the situation is similar to that of 0805 + 046. We would give here only two examples. For the lines λ3886.70 and λ3891.8, Boksenberg and Sargent (1975) give the intensities as 3 and 5, respectively, while BSBC give 1.9 and 0.9, respectively. Similarly for λ3905.5 and λ3909.8, Boksenberg and Sargent's (1975) values are 3 and 2, while BSBC give 0.9 and 0.1, respectively. Clearly the recorded equivalent widths can only be taken as a qualitative guide and no more.

Identifications for most of the absorption lines in the range $\lambda\lambda$3716 – 4290 reported by BSBC are presented in Table II. The reported equivalent widths of lines by BSBC appear to indicate that in some cases, besides the proposed identifications, there is blending due to unknown components. The average value of $|\lambda_{obs} - \lambda_{iden}|$ for all the identifications is 0.49 Å which is quite satisfactory. Next we consider the evidence bearing on the presence of some of the atoms and ions.

He I. Present. Mult. 2, 5, 16, and 18 are present. The only line missing is λ3868, which could be weak, or blended with λ3869.70. The weakness of λ3889 is rather surprising.

Mg I. Appears to be present though weakly.

Si II. Present. Multiplets 1 and 3 are present, which are the only important ones expected.

Ca II. Present. Part of the equivalent widths of K and H lines is expected to be interstellar.

Sc II. Possibly represented weakly by the line λ4247.

Ti II. Present. Most members of multiplets 11, 13, 34, 72, and 105 are present.

Cr II. Represented by many lines.

Fe I. Many lines are present.

Fe II. Represented by many lines.

Sr II. Multiplet 1 is present.

There is no positive evidence for the presence of hydrogen in the available data. Clearly the quasar is highly deficient in hydrogen. It will be noticed that most of the lines which we have not been able to identify are common with unidentified lines in the star v Sgr.

TABLE II

Identification of lines in the spectrum of 0237−233. $\delta = \lambda_{obs} - \lambda_{lab}$. λ_{obs}, W_λ, λ_{lab}, and δ all are in Å.

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
3716.90	0.6	3715.45	Cr II	145	1.45
		3717.53	Mn II	8	−0.63
3721.70	0.3	3721.63	Ti II	13	0.07
3722.80	0.9	3722.56	Fe I	5	0.24
		3723.40	Cr II	144	−0.60
3726.50	0.9	3727.04	Fe II	192	−0.54
		3727.35	V II	21	−0.85
		3727.37	Cr II	117	−0.87
		3727.62	Fe I	21	−1.12
3737.80	0.5	3736.90	Ca II	3	0.90
		3737.13	Fe I	5	0.67
		3738.38	Cr II	20	−0.58
3739.40	0.6	3739.53	Fe I		−0.13
3741.90	0.2	3741.63	Ti II	72	0.27
3742.60	0.3	3742.64	v Sag		
3743.30	0.5	3743.36	Fe I	21	−0.06
3746.00	0.1	3745.56	Fe I	5	0.44
		3745.81	V II	15	0.19
		3745.90	Fe I	5	0.10
		3746.56	Fe II	14	−0.56
3747.40	1.1	3748.01	Ti II	107	−0.61
3748.80	0.2	3748.26	Fe I	5	0.54
		3748.49	Fe II	154	0.31
		3748.50	Fe I	5	0.30
		3748.68	Cr II	11	0.12
3750.30	0.2	3750.56	Cr II		−0.26
		3750.88	V II	21	−0.58
3751.60	0.4	3751.22	V II	100	0.38
3754.20	0.4	3753.61	Fe I	73	0.59
		3754.59	Cr II	20	−0.39
3758.30	0.2	3757.68	Ti II	72	0.62
		3758.23	Fe I	21	0.06
3759.60	0.8	3759.29	Ti II	13	0.31
		3759.46	Fe II	154	0.14
		3760.24	V II	21	−0.64
3761.10	0.3	3761.32	Ti II	13	−0.22
		3761.69	Cr II	11	−0.59
		3761.90	Cr II	11	−0.80
3762.80	0.3	3762.89	Fe II	192	−0.09
3763.80	0.2	3763.79	Fe I	21	0.01
		3764.09	Fe II	29	−0.29
3767.80	0.8	3767.19	Fe I	21	0.61
3773.30	0.5	3773.66	v Sag		
		3773.77	48 Lib		
3776.30	0.2	3776.06	Ti II	72	0.24
3777.50	1.8	3778.36	V II	21	−0.86

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
3777.50	1.8	3778.37	Fe II	192	− 0.87
3788.00	0.5	3787.23	V II	100	0.76
		3787.88	Fe I	21	0.12
3789.20	0.1	3789.31	Pleione		
3790.60	1.1	3790.06	48 Lib		
		3791.43	ε Aurigae		
3792.30	0.5	3791.41	Si III	5	0.89
3795.10	0.2	3795.00	Fe I	21	0.10
3799.20	0.3	3798.36	Fe II	14	0.84
		3799.55	Fe I	21	− 0.35
		3799.81	Ti II	13	− 0.61
3803.60	0.3				
3804.70	0.5	3805.34	Fe I	608	− 0.65
		3805.40	α Cygni		
3807.40	0.1	3806.70	Fe I	607	0.70
		3806.82	Fe II	153	0.58
3810.90	0.3	3810.41	Pleione		
		3810.48	ε Aurigae		
3811.90	0.1	3812.96	Fe I	22	− 1.06
3821.70	0.1	3820.43	Fe I	20	1.27
		3821.92	Fe II	14	− 0.22
3826.90	0.1	3825.88	Fe I	20	1.02
		3827.08	Fe II	153	− 0.18
		3827.82	Fe I	45	− 0.92
3831.20	0.1	3832.30	Mg I	3	− 1.10
3838.50	1.2	3838.29	Mg I	3	0.21
3840.00	0.5	3840.44	Fe I	20	− 0.44
		3841.05	Fe I	45	− 1.05
3842.50	0.1	3843.00	Sc II	1	− 0.50
		3843.03	Zr II	7	− 0.53
3845.20	0.1	3845.18	Fe II	127	0.02
3854.40	0.3	3853.66	Si II	1	0.74
		3853.95	Fe II	127	0.45
3857.30	0.3	3856.02	Si II	1	1.28
		3857.53	υ Sag		
3861.70	1.4	3860.92	Fe II		0.78
3862.60	0.8	3862.59	Si II	1	0.01
		3863.40	Fe II	152	− 0.80
3869.70	0.2	3869.56	Fe I	284	0.14
		3869.59	Fe I	284	0.11
3874.20	0.7	3873.76	Fe I	175	0.44
		3874.56	Cr II	143	− 0.36
3876.80	0.1				
3879.10	0.2	3878.02	Fe I	20	1.08
		3878.57	Fe I	4	0.53
		3878.72	V II	33	0.38
3880.30	0.7	3879.63	υ Sag		
3882.00	0.1	3881.92	Ni II	13	0.08

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
3882.00	0.1	3882.28	Ti II	34	− 0.28
3884.30	0.2	3884.85	V II	33	− 0.55
3886.70	1.9	3886.28	Fe I	4	0.42
		3887.05	Fe I	20	− 0.35
3889.50	0.1	3888.65	He I	2	0.85
3891.80	0.9				
3892.20	1.2	3892.14	Cr II		0.06
		3892.30	S II		− 0.10
3892.80	0.8	3893.39	Fe I	430	− 0.59
3894.10	0.4	3893.99	υ Sag		
		3895.00	Fe I	4	− 0.90
3899.30	0.3	3899.14	V II	33	0.16
		3899.71	Fe I	4	− 0.41
3900.70	0.3	3900.55	Ti II	34	0.15
		3900.68	Al II	1	0.02
3905.50	0.9	3905.53	Si I	3	− 0.03
		3905.64	Cr II	167	− 0.14
		3906.04	Fe II	173	− 0.54
		3906.48	Fe I	4	− 0.98
3909.80	0.1	3908.54	Fe II	29	1.26
		3909.84	Fe I	4	− 0.04
3910.80	0.2				
3911.40	0.2	3911.30	Cr II	129	0.10
3912.40	0.2	3913.46	Ti II	34	− 1.06
3917.10	0.2	3916.42	V II	10	0.68
3924.60	0.3	3924.91	υ Sag		
3925.40	0.1	3925.52	υ Sag		
		3925.95	Fe I	364	− 0.55
3930.80	0.1	3930.30	Fe I	4	0.50
		3930.31	Fe II	3	0.49
3933.40	1.3	3933.66	Ca II	1	− 0.26
3937.20	0.1	3936.95	Cr II	128	0.25
		3938.29	Fe II	3	− 1.09
3944.40	0.1	3944.01	Al I	1	0.39
		3945.11	Cr II	142	− 0.71
		3945.21	Fe II	3	− 0.81
3949.50	0.7	3949.95	Fe I	72	− 0.45
3950.60	1.0	3951.16	Fe I	661	− 0.56
3954.90	0.1	3954.30	Si II	7.07	0.60
		3954.51	Si II	7.07	0.39
3955.70	0.1	3956.05	υ Sag		
3957.00	0.1	3956.68	Fe I	278	0.32
3959.70	0.1	3959.04	α Cygni		
		3959.18	υ Sag		
3961.70	0.2	3960.90	Fe II	212	0.80
		3961.52	Al I	1	0.18

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
3963.70	0.2	3964.57	Fe II	29	− 0.87
		3964.73	He I	5	− 1.03
3969.40	0.1	3968.47	Ca II	1	0.93
3970.60	0.1	3970.19	v Sag		
3971.80	0.1	3972.42	v Sag		
3978.90	0.1	3979.51	Cr II	183	− 0.61
3981.30	0.1	3981.61	Fe II	3	− 0.31
		3982.00	Ti II	11	− 0.70
3984.70	0.1	3983.96	Fe I	277	0.74
3987.30	0.1	3987.63	Ti II	11	− 0.33
3989.40	0.1	3989.80	V II	32	− 0.40
3992.30	0.1	3991.77	Si II		0.53
		3992.06	α Cygni		
		3992.60	V II	10	− 0.30
3999.00	0.1	3998.98	Zr II	16	0.02
4001.90	0.2	4002.07	Fe II	29	− 0.17
4002.90	0.3	4002.55	Fe II	190	0.35
		4003.20	V II	9	− 0.30
		4003.33	Cr II	194	− 0.43
4009.90	0.2	4009.30	Ti II	11	0.60
4011.40	0.2	4012.37	Ti II	11	− 0.97
		4012.50	Cr II	183	− 1.10
4017.60	0.7	4017.16	Fe I	527	0.44
		4017.96	Cr II	166	− 0.36
4018.60	0.4				
4019.80	1.2	4019.72	v Sag		
4024.30	0.3	4023.39	V II	32	0.91
		4024.55	Fe II	127	− 0.25
4025.10	1.2	4025.14	Ti II	11	− 0.04
4026.30	0.8	4026.19	He I	18	0.11
		4026.36	He I	18	− 0.06
4029.00	0.1	4028.33	Ti II	87	0.67
		4029.68	Zr II	41	− 0.68
4030.40	0.1	4030.40	Mn I	2	0.00
		4031.46	Fe II	151	− 1.06
4032.40	0.1	4032.95	Fe II	126	− 0.55
		4033.07	Mn I	2	− 0.67
4037.60	0.1	4036.78	V II	9	0.82
4038.40	0.1	4038.03	Cr II	194	0.37
4041.00	0.6	4041.36	Mn I	5	− 0.36
		4041.64	Fe II	172	− 0.64
4043.40	0.1	4044.00	Fe II	127	− 0.60
		4044.01	Fe II	172	− 0.61
4046.40	0.2	4045.81	Fe I	43	0.58
		4046.81	Fe II	126	− 0.41
4047.80	0.4	4047.67	α Cygni		
		4048.83	Fe II	172	− 1.03
4050.60	0.1	4051.10	V II	32	− 0.50

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
4050.60	0.1	4051.21	Fe II	172	– 0.61
4052.60	0.1	4051.97	Cr II	19	0.63
		4052.63	v Sag		
4054.80	0.1	4053.81	Ti II	87	0.99
		4054.11	Cr II	19	0.69
		4054.82	v Sag		
4056.10	0.3	4055.54	Mn I	5	0.56
		4056.21	Ti II	11	– 0.11
4057.60	0.1	4057.46	Fe II	212	0.14
4060.80	0.1	4060.74	v Sag		
		4061.79	Fe II	189	– 0.99
4063.80	0.4	4063.60	Fe I	43	0.20
4064.40	0.1	4064.35	Ti II	106	0.05
		4065.07	V II	215	– 0.67
4073.40	0.1	4072.60	Cr II	26	0.80
4078.60	1.1	4077.71	Sr II	1	0.89
4080.40	0.3	4079.85	Fe I	359	0.55
		4080.44	v Sag		
4080.90	0.2				
4081.70	0.2	4081.42	Fe II	188	0.28
		4082.30	Cr II	165	– 0.60
4087.20	0.2	4087.27	Fe II	28	– 0.07
4088.70	0.1	4088.75	Fe II	39	– 0.05
		4088.90	Cr II	19	– 0.20
4091.70	0.1				
4093.90	0.1	4093.90	Mg II	29	0.00
4094.50	0.1				
4095.70	0.2				
4098.50	0.1	4098.44	Cr II	165	0.06
4100.70	0.1	4099.94	N I	10	0.76
4103.20	0.3				
4104.50	0.1	4104.18	Fe II	39	0.32
4108.00	0.2	4107.49	Fe I	354	0.51
4111.40	0.9	4111.01	Cr II	18	0.39
		4111.01	Cr II	26	0.39
4111.90	0.4	4111.90	Fe II	188	0.00
4112.40	0.4	4112.59	Cr II	18	0.19
4113.20	0.9	4113.24	Cr II	18	– 0.04
4113.90	0.6	4114.00	N I	10	– 0.10
4115.20	0.4	4115.36	v Sag		
4116.90	0.2	4116.66	Cr II	181	0.24
4117.70	0.2	4118.00	v Sag		
4118.20	0.7	4118.55	Fe I	801	– 0.35
4120.20	1.1	4119.53	Fe II	21	0.67
		4120.81	He I	16	– 0.61
4122.20	0.2	4122.64	Fe II	28	– 0.44
4123.70	0.2	4123.75	Fe I	217	– 0.05

Table II (continued)

λ_{obs}	W_λ	λ_{lab}	Ion	Mult.	δ
			Identification		
4123.70	0.2	4123.75	Fe I	422	− 0.05
4124.80	0.2	4124.79	Fe II	22	0.01
4125.70	0.1	4125.62	Fe I	1103	0.08
4129.50	0.3	4128.05	Si II	3	1.45
		4128.73	Fe II	27	0.77
4130.70	0.1	4130.88	Si II	3	− 0.18
5132.00	0.1	4132.06	Fe I	43	− 0.06
		4132.41	Cr II	26	− 0.41
4134.20	0.9	4134.34	Fe I	3	− 0.14
4135.00	0.3	4134.68	Fe I	357	0.32
4135.90	0.9	4136.30	v Sag		
4136.70	0.8	4136.50	Fe I	694	0.20
		4137.00	Fe I	726	− 0.30
4138.70	0.8	4138.21	Fe II	150	0.49
		4138.40	Fe II	39	0.30
4141.00	1.1	4141.25	v Sag		
4142.70	1.4	4142.29	S II	44	0.41
		4143.42	Fe I	523	− 0.72
4145.50	0.4	4145.10	S II	44	0.40
		4145.77	Cr II	162	− 0.27
4146.30	0.3				
4147.70	0.5	4147.26	Fe II	141	0.44
		4147.67	Fe I	42	0.03
4150.00	0.1	4149.22	Zr II	41	0.78
		4150.26	Fe I	695	− 0.26
		4151.00	Cr II	163	− 1.00
4152.10	0.1	4151.46	N I	6	0.64
		4152.19	Pleione		
		4152.98	Fe II	45	− 0.88
4155.30	0.1	4154.81	Fe I	694	0.49
4159.30	0.2	4158.45	Fe II	12	0.85
		4159.45	Al II	71	− 0.15
4160.80	0.1	4160.62	Fe II	39	0.18
		4161.05	Cr II	162	− 0.25
		4161.52	Ti II	21	− 0.72
4164.50	0.2	4163.64	Ti II	105	0.86
4165.60	0.3				
4169.00	0.2	4168.66	Fe II	22	0.34
4172.80	0.1	4171.90	Ti II	105	0.90
		4173.45	Fe II	27	− 0.65
4187.80	0.2	4187.04	Fe I	152	0.76
		4187.14	Si II	7.17	0.66
		4187.80	Fe I	152	0.00
4208.10	0.2	4207.35	Cr II	26	0.75
4209.30	0.2	4208.99	Zr II	41	0.31
		4209.02	Cr II	162	0.28
		4210.35	Fe I	152	− 1.05
4211.40	0.2	4211.88	Zr II	15	− 0.48

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
4211.40	0.2	4212.10	Fe II	21	− 0.70
4216.10	0.2	4215.52	Sr II	1	0.58
4217.40	0.1	4217.55	Fe I	693	− 0.15
4222.10	0.1	4222.22	Fe I	152	− 0.12
4224.10	0.1	4223.84	υ Sag		
4225.30	0.1	4224.85	Cr II	162	0.45
4228.10	0.1	4227.34	Ti II	33	0.76
		4227.43	Fe I	693	0.67
4232.10	0.2	4233.17	Fe II	27	− 1.07
4244.20	0.2	4244.80	Ni II	9	− 0.60
4247.10	0.1	4246.41	Cr II	31	0.69
		4246.83	Sc II	7	0.27
4248.60	0.2	4248.03	υ Sag		
		4248.23	Fe I	482	0.37
4250.60	0.1	4250.12	Fe I	152	0.48
		4250.79	Fe I	42	− 0.19
		4251.49	Fe II	12	− 0.89
4254.90	0.1	4254.35	Cr I	1	0.55
		4254.70	N I	4	0.20
4257.60	0.1	4258.15	Fe II	28	− 0.55
4261.60	0.2	4261.92	Cr II	31	− 0.32
4262.60	0.1	4263.20	α Cygni		
4269.70	0.2	4269.28	Cr II	31	0.42
4285.40	0.3	4285.41	Fe I	597	− 0.01
4286.70	0.2	4286.30	V II	23	0.40
		4286.31	Fe II		0.39
4288.10	0.3	4287.89	Ti II	20	0.21

For lines shortward of $\lambda3716$ or longward of $\lambda4290$, the available data are very poor, positions being accurate to only about 3 Å. Consequently, we have not attempted to identify these highly blended lines, but instead we predict the expected spectrum in the visible region outside of $\lambda\lambda3716 - 4290$ on the basis of our identifications of Table II.

He I. Many lines should be present.

Ti II, Cr II, Fe I, and Fe II. Many multiplets which arise from low-lying terms in these ions should be present, especially those shown on the Grotrian diagrams of Moore and Merrill (1968). This prediction is based on the assumption that there is no significant change in the spectrum in the region $\lambda\lambda3716 - 4290$. It is known that shell stars change with time. Should a significant change have occurred in the spectrum in the region $\lambda\lambda3716 - 4290$ when future observations are carried out, obviously a corresponding modification will have to be made in the prediction.

It would be most desirable to obtain the spectrum of 0237 − 233 over a wide wavelength interval (3200–5000 Å) at a high resolution $c/R \simeq 10$ km s^{-1}) with instrumentation which can detect weaker lines.

4. The Discontinuity in the Ultraviolet

Bechtold *et al.* (1984) have measured the continuum energy distribution of 0237 − 233 with the *International Ultraviolet Explorer* and the Palomar 5 m multichannel spectro-photometer. A discontinuity was found in the ultraviolet and these authors state that it occurs at 2350 ± 10 Å. On the other hand, from the PLS model, for an atmosphere rich in HeI, we expect a discontinuity at $\lambda 2600$ (the ionization limit from the $1s2s\ ^3S$ state). To examine the problem carefully, we show in Figure 1, the observed data reported by Bechtold *et al.* (1984). The positions of $\lambda 2350$ and $\lambda 2600$ are indicated. There is an observed point at 2614 Å, but as shown in the figure, it has very large error bars. Allowing for this large uncertainty, the observed data are consistent with a discontinuity at $\lambda 2600$. We predict that more accurate observations will confirm the expected discontinuity at $\lambda 2600$.
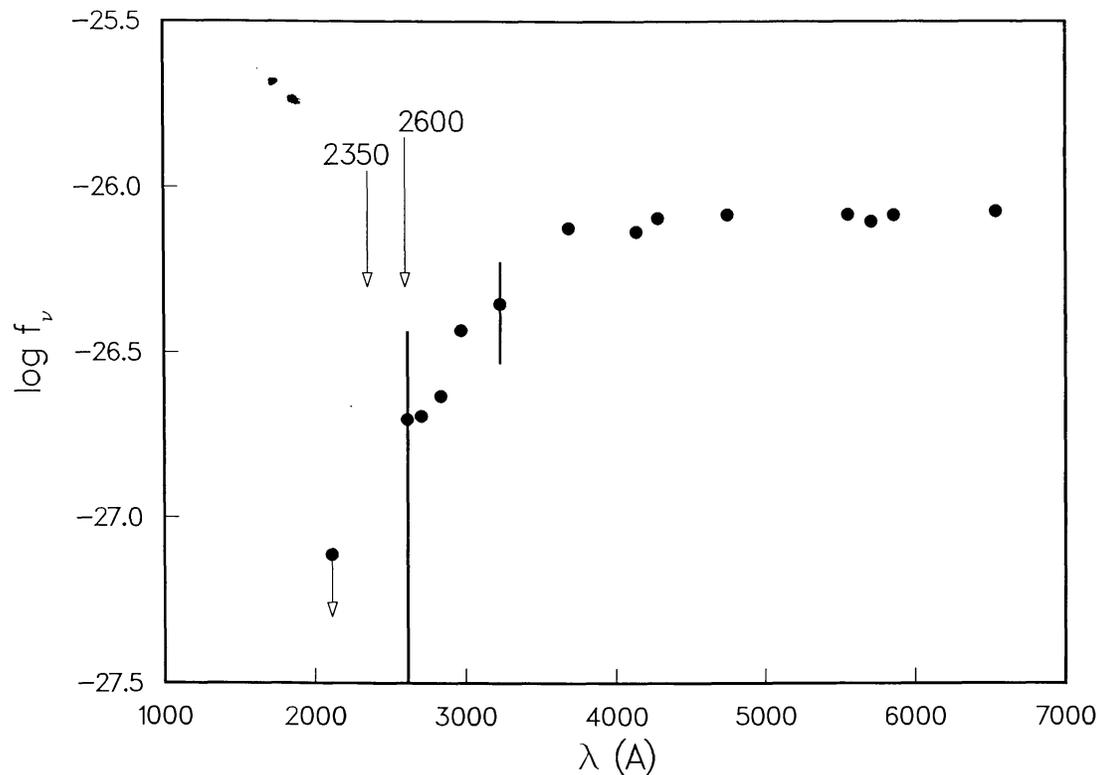
Fig. 1.   Continuum spectral energy distribution of 0237 − 233.

5. Similarities with Upsilon Sagittarii

A comparison of the absorption lines in the spectrum of 0237 − 233 in the interval $\lambda\lambda 3716 - 4290$ with the spectrum of the star υ Sgr shows that many of the identifications are common. Not only that, most of the unidentified lines in 0237 − 233 are common with unidentified lines in the spectrum of υ Sgr. Clearly a comparison between other spectral properties is of interest.

First we briefly summarize some of the important data about υ Sgr. The rich spectrum of υ Sagittarii (HD 181615; mag. 4.6; spect. B8–A2 Ia) has been investigated by a number of workers (Plaskett, 1928; Greenstein, 1940, 1943; Greenstein and Merrill, 1946; Greenstein and Adams, 1947). A strong helium spectrum is superposed on a complex metallic spectrum. Hydrogen lines are unusually weak. Emission lines are also present in the red and infra-red regions – Hα and those of Ca II and [Ca II], Fe II and possibly [Fe II]. It is believed there is an extended nebulous envelope around the star. Hack and Pasinetti (1963) found that the star is deficient in hydrogen and estimated $n(\text{H})/n(\text{He}) = 0.025$. A more recent analysis by Schoenberner and Drilling (1983) indicates a much lower hydrogen abundance, i.e., $n(\text{H})/n(\text{He}) < 0.0005$. The observed spectrum is that of a single star. This star is a member of a binary system (Wilson, 1914). In the visible region no spectroscopic evidence has been detected of the other member, but in the ultraviolet region, spectroscopic evidence has been obtained recently (Parthasarathy *et al.*, 1986).

Next we compare 0237 − 233 with υ Sgr.

(1) The absorption line spectra of the two objects are rather similar. Both objects are strongly deficient in hydrogen.
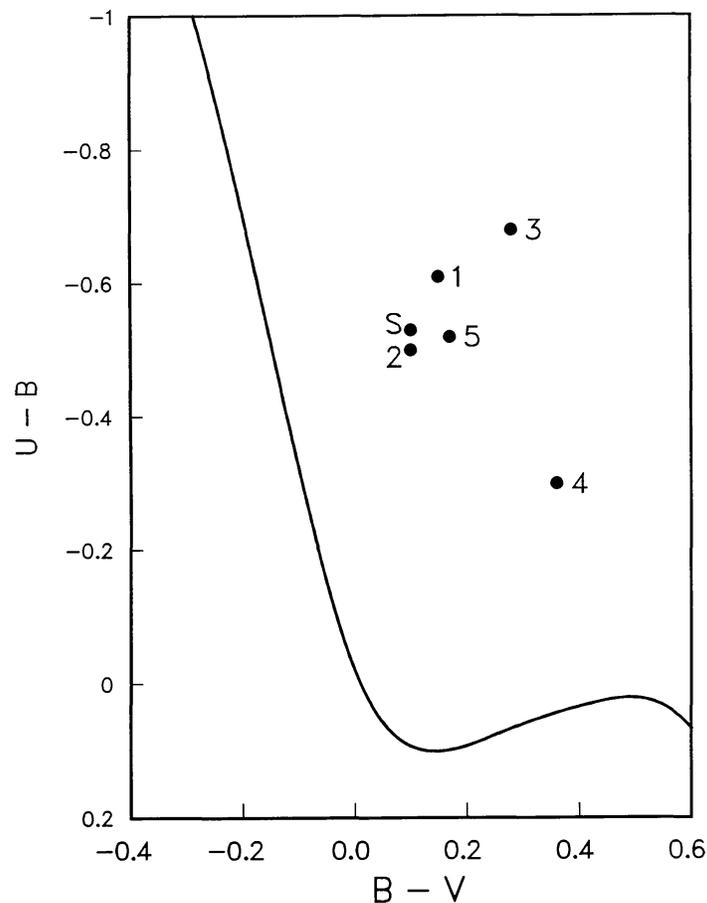
Fig. 2. (U–B) versus (B–V) plot. Key to points 1: 0237 − 233, 2: 0851 + 197, 3: 1225 + 317, 4: 1246 − 057, 5: 1448 − 232, S: υ Sgr.

(2) Both objects show emission lines in their spectra, but the nature of the emission lines in the two is different. The emission lines in 0237 – 233 are broad, while those in v Sgr are relatively sharp. v Sgr shows several emission lines in the red region (Greenstein and Merrill, 1946). It would be of interest to investigate if there is any emission at those wavelengths in 0237 – 233.

(3) In Figure 2 we show the positions of 0237 – 233 and v Sgr on the two-colour $(U–B)$ versus $(B–V)$ plot. The positions of a few other quasars in Table I for which data are available and also shown. 0237 – 233 and v Sgr are seen to be very close on this plot.

(4) Both objects show large infrared excesses. Infrared photometry of v Sgr has been carried out by Lee and Nariai (1967), Woolf (1973), and by Treffers *et al.* (1976), and that of 0237 – 233 by Hyland and Allen (1982). In Figure 3 we compare the colours of 0237 – 233 with those of v Sgr. It will be noted that both objects are very red at long wavelengths and the spectral energy distributions of the two are very similar. Two hypotheses have been advanced to explain the infra-red excess in v Sgr. A late-type secondary or the circumstellar envelope. Parthasarathy *et al.* (1986) have found that the companion is a hot star (late O or early B-type). Thus the second possibility seems most likely (see also Treffers *et al.*, 1976). In the case of 0237 – 233, it is a natural consequence of our theory that the ejected material from the star will form a circumstellar envelope and in due course some of it will condense to form dust, which will lead to infrared
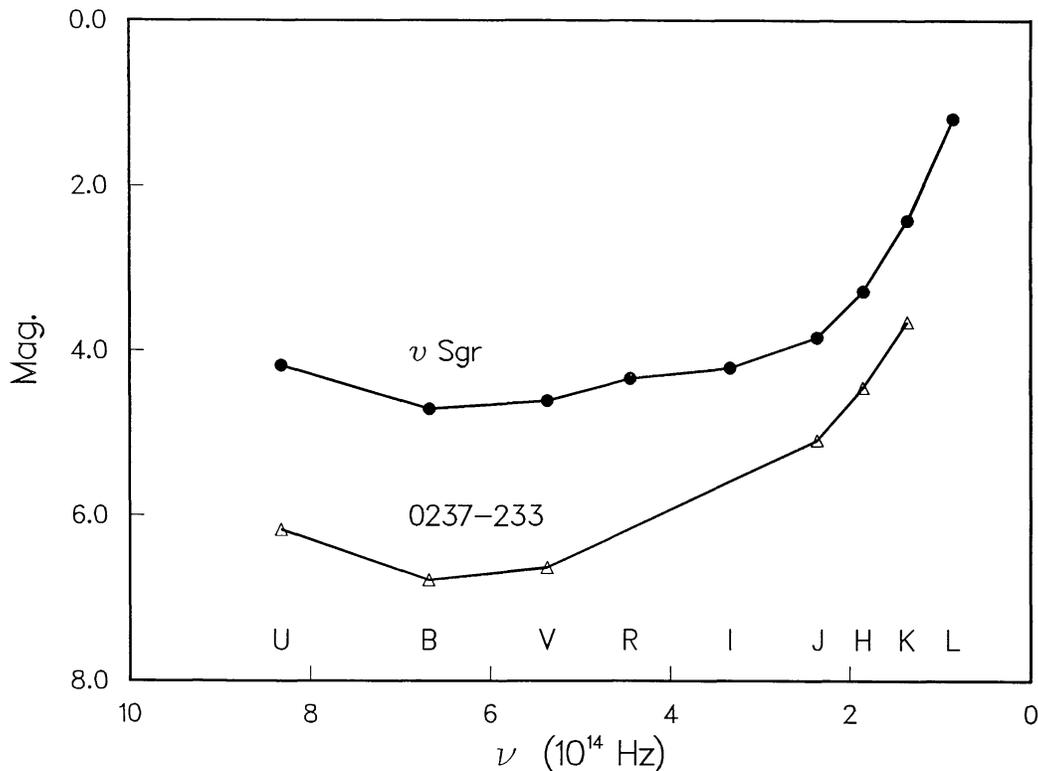

Fig. 3.   The colours of v Sgr and 0237 – 233. The data points for v Sgr are from Lee and Nariai (1967) and those for 0237 – 233, from Hewitt and Burbidge (1987) and Hyland and Allen (1983). To accomodate the two objects on the same plot, the magnitudes for 0237 – 233 have been increased by 10.

excess. v Sgr shows a 10 μ emission feature (Treffers *et al.*, 1976), which is similar to the 10 μ emission feature found around oxygen-rich stars and interpreted as being due to silicates. Irrespective of its interpretation it would be of interest to investigate if 0237 – 233 also shows the 10 μ emission feature.

(5) The positions of 0237 – 233 and v Sgr on the $(J-H)$ versus $(H-K)$ plot are shown in Figure 4. Two other quasars in Table I, for which data are available, are also shown. In judging the proximity of the points, it should be kept in mind that we have shown here only a small portion of the usual $(J-H)$ versus $(H-K)$ diagram for quasars in which both axes run from 0 to 1.5 (Hyland and Allen, 1982). Again, here also, as in Figure 2, 0237 – 233 and v Sgr are seen to be in close proximity.
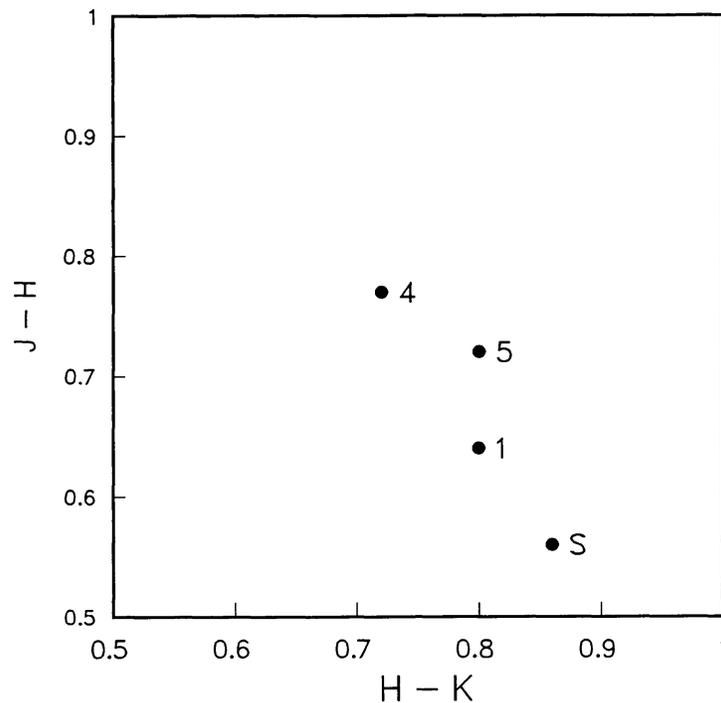
Fig. 4.   The $(J-H)$ versus $(H-K)$ diagram for 3 quasars and v Sgr. Symbols have the same meaning as in Figure 2.

(6) The polarization in the optical region in both cases is small – $\sim 0.25\%$ for 0237 – 233 (Moore and Stockman, 1984) and $\leq 1\%$ for v Sgr (Coyne and Gehrels, 1967).

It is not implied or suggested that the absolute magnitudes of 0237 – 233 and v Sgr (Rao and Venugopal, 1985) might be similar. Rather we think that 0237 – 233 is an intrinsically fainter object (Varshni, 1977a) than v Sgr. The spectral similarities between the two are reminiscent of the spectral similarities between classical Wolf–Rayet stars and some planetary nuclei. We suspect that 0237 – 233 has some relation with hydrogen-deficient planetary nuclei (Mendez *et al.*, 1986).

v Sgr is known to be a binary. Thus naturally the question arises if 0237 – 233 might also be a binary. The historical light curve of 0237 – 233 has been summarized by

Angione (1973). The available data are rather patchy but are suggestive of an eclipsing binary nature.

6. Predictions

We summarize our predictions.

(1) In the optical region outside of $\lambda\lambda 3716 - 4290$, many lines due to He I, Ti II, Cr II, Fe I, and Fe II should be observable, especially those arising from low-lying terms in the case of Ti II, Cr II, Fe I, and Fe II.

(2) Narrow-band spectrophotometry would show that the discontinuity in the ultraviolet is close to $\lambda 2600$. Further if any discontinuity is observed in the ultraviolet in any of the other quasars listed in Table I, it is expected to occur either at $\lambda 2600$ or at $\lambda 3122$ (the ionization limit from the $1s2s\,^1S$ state of He I).

The crying need in quasar spectral studies is for better resolution, greater accuracy and the ability to detect weaker lines.

References

Angione, R. J.: 1973, *Astron. J.* **78**, 353.

Arp, H. C., Bolton, J. G., and Kinman, T.: 1967, *Astrophys. J.* **147**, 841.

Bahcall, J. N., Greenstein, J. L., and Sargent, W. L. W.: 1968, *Astrophys. J.* **153**, 689.

Bechtold, J., Green, R. F., Weymann, R. J., Schmidt, M., Estabrook, F. B., Sherman, R. D., Wahlguist, H. D., and Heckman, T. M.: 1984, *Astrophys. J.* **281**, 76.

Boksenberg, A. and Sargent, W. L. W.: 1975, *Astrophys. J.* **198**, 31.

Boroson, T., Sargent, W. L. W., Boksenberg, A., and Carswell, R. F.: 1978, *Astrophys. J.* **220**, 772.

Burbidge, E. M.: 1967, *Astrophys. J.* **147**, 845.

Burbidge, E. M., Lynds, C. R., and Stockton, A. N.: 1968, *Astrophys. J.* **152**, 1077.

Chaffee, F. H., Weymann, R. J., Latham, D. W., and Strittmatter, P. A.: 1983, *Astrophys. J.* **267**, 12.

Chen, J.-S., Morton, D. C., Peterson, B. A., Wright, A. E., and Jauncey, D. L.: 1983, *Kexue Tongbao* **28**, 1075.

Chen, J.-S., Morton, D. C., Peterson, B. A., Wright, A. E., and Jauncey, D. L.: 1984, *Proc. Astron. Soc. Australia* **5**, 355.

Coyne, G. V. and Gehrels, T.: 1967, *Astron. J.* **72**, 887.

Greenstein, J. L.: 1940, *Astrophys. J.* **91**, 438.

Greenstein, J. L.: 1943, *Astrophys. J.* **97**, 252.

Greenstein, J. L.: 1984, *Ann. Rev. Astron. Astrophys.* **22**, 1.

Greenstein, J. L. and Adams, W. S.: 1947, *Astrophys. J.* **106**, 339.

Greenstein, J. L. and Merrill, P. W.: 1946, *Astrophys. J.* **104**, 177.

Greenstein, J. L. and Schmidt, M.: 1967, *Astrophys. J.* **148**, L13.

Grueff, G.: 1969, *Astrophys. Letters* **4**, 141.

Hack, M. and Pasinetti, L.: 1963, *Contr. Oss. Astr. Milano- Merate*, No. 215.

Hewitt, A. and Burbidge, G.: 1987, *Astrophys. J. Suppl.* **63**, 1.

Hyland, A. R. and Allen, D. A.: 1982, *Monthly Notices Roy. Astron. Soc.* **199**, 943.

Jauncey, D. L., Batty, M. J., Wright, A. E., Peterson, B. A., and Savage, A.: 1984, *Astrophys. J.* **286**, 498.

Lee, T. A. and Nariai, K.: 1967, *Astrophys. J.* **149**, L93.

MacAlpine, G. M. and Lewis, D. W.: 1978, *Astrophys. J. Suppl.* **36**, 587.

Mendez, R. H., Miguel, C. H., Heber, U., and Kudritzki, R. P.: 1986, in K. Hunger, D. Schonberner, and N. K. Rao (eds.), *Hydrogen Deficient Stars and Related Objects*, D. Reidel Publ. Co., Dordrecht, Holland, p. 323.

Moore, C. E. and Merrill, P. W.: 1968, *Partial Grotrian Diagrams of Astrophysical Interest*, NSRDS-NBS 23, U.S. Government Printing Office, Washington, D.C.

Moore, R. L. and Stockman, H. S.: 1984, *Astrophys. J.* **279**, 465.

Osmer, P. S. and Smith, M. G.: 1977, *Astrophys. J.* **213**, 607.

Parthasarathy, M., Cornachin, M., and Hack, M.: 1986, *Astron. Astrophys.* **166**, 237.

Plaskett, J. S.: 1928, *Publ. Dominion Astrophys. Obs.* **4**, 103.

Rao, N. K. and Venugopal, V. R.: 1985, *J. Astrophys. Astron.* **6**, 101.

Savage, A., Browne, I. W. A., and Bolton, J. G.: 1976, *Monthly Notices Roy. Astron. Soc.* **177**, 77P.

Savage, A., Clowes, R. G., Cannon, R. D., Cheung, K., Smith, M. G., Boksenberg, A., and Wall, J. V.: 1985, *Monthly Notices Roy. Astron. Soc.* **213**, 485.

Savage, A. and Wright, A. E.: 1981, *Monthly Notices Roy. Astron. Soc.* **196**, 927.

Schmidt, M.: 1974, *Astrophys. J.* **193**, 509.

Schoenberner, D. and Drilling, J. S.: 1983, *Astrophys. J.* **268**, 225.

Shaver, P. A., Boksenberg, A., and Robertson, J. G.: 1982, *Astrophys. J.* **261**, L7.

Treffers, R., Woolf, N. J., Fink, U., and Larson, H. P.: 1976, *Astrophys. J.* **207**, 680.

Ulrich, M.-H.: 1976, *Astrophys. J.* **207**, L73.

Varshalovich, D. A. and Levshakov, S. A.: 1981, *Soviet Astron. Letters* **7**, 113.

Varshni, Y. P.: 1973, *Bull. Am. Phys. Soc.* **18**, 1384.

Varshni, Y. P.: 1974, *Bull. Am. Astron. Soc.* **6**, 213, 308.

Varshni, Y. P.: 1975, *Astrophys. Space Sci.* **37**, L1.

Varshni, Y. P.: 1976, *Astrophys. Space Sci.* **43**, 3.

Varshni, Y. P.: 1977a, *Astrophys. Space Sci.* **46**, 443.

Varshni, Y. P.: 1977b, *J. Roy. Astron. Soc. Canada* **71**, 403.

Varshni, Y. P.: 1978, in S. Fujita (ed.), *The Ta-You Wu Festschrift: Science of Matter*, Gordon and Breach, New York, p. 285.

Varshni, Y. P.: 1979, *Phys. Canada* **35**, 11.

Varshni, Y. P.: 1981, *Astrophys. Space Sci.* **74**, 3.

Varshni, Y. P.: 1982, *Spec. Sci. Tech.* **5**, 521.

Varshni, Y. P.: 1983, *Soviet Astron. Letters* **9**, 368.

Varshni, Y. P.: 1985, *Astrophys. Space Sci.* **117**, 337.

Varshni, Y. P.: 1988a, *Bull. Am. Astron. Soc.* **20**, 733.

Varshni, Y. P.: 1988b, *Bull. Am. Phys. Soc.* **33**, 1184.

Varshni, Y. P. and Lam, C. S.: 1976, *Astrophys. Space Sci.* **45**, 87.

Varshni, Y. P. and Nasser, R. M.: 1986, *Astrophys. Space Sci.* **125**, 341.

Walsh, D., Wills, B. J., and Wills, D.: 1979, *Monthly Notices Roy. Astron. Soc.* **189**, 667.

Wilson, R. E.: 1914, *Lick Obs. Bull.* **8**, 134.

Woolf, N. J.: 1973, *Astrophys. J.* **185**, 229.

York, D. G., Green, R. F., Bechtold, J., and Chaffee, F. H., Jr.: 1984, *Astrophys. J.* **280**, L1.