THE QUASAR 0805 + 046 AS A HELIUM-RICH SHELL STAR

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Abstract. Within the framework of the plasma-laser star model of quasars it is proposed that the quasar 0805 + 046 is a helium-rich shell star. (a) The strong emission line at 4712 Å is identified with He I λ4713. (b) The discontinuity in the continuous energy distribution at λ3420 is identified with the helium discontinuity at λ3422. (c) In the absorption-line spectrum many lines have been identified. It is shown that the proposed model provides a consistent and satisfactory interpretation of the observed spectra.

1. Introduction

We have proposed a theory of quasars (Varshni, 1973, 1974a, 1975a, 1977a, b, 1978, 1979; Varshni and Lam, 1976), based on sound physical principles, which does not need the artificial assumption of redshifts and provides satisfactory explanations of the various phenomena associated with quasars. This theory is known as the plasma-laser star (PLS) model of quasars. Most of the observational evidence on quasars either supports our theory or else is consistent with it (Varshni, 1979, 1982). We have analysed the emission line spectrum, the absorption line spectrum and the continuous energy distribution of the quasar 0805 + 046 (also known as 4C 05.34) in the framework of the PLS theory and we propose the following model for this quasar: it is a helium-rich (Hunger, 1975) shell star. At this stage the observational evidence is not adequate to draw any conclusions concerning the degree of helium-abundance (Kaufmann and Theil, 1980).

2. Emission Lines

2.1. The Data

There are three other quasars which belong to the same spectral class (Varshni, 1976) as 0805 + 046. It is convenient to consider the four quasars together. It also helps in assessing the accuracy of the reported wavelengths. We summarize the data for the three important emission lines which have been observed in these quasars in Table I. For each quasar the first row shows the reported wavelengths. Below each wavelength, where known, are indicated the equivalent width and half-width (FWHM) of the line. A few other weak emission lines have been reported, but data on these are very uncertain and, hence, these lines are not included here.

0805 + 046. There are three sets of measurements available. (a) Lynds and Wills (1970) spectroscopic observations were made at Kitt Peak National observatory. (b) Osmer and Smith (1976) carried out absolute spectrophotometry using the SIT-

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vidicon spectrometer on the 1.5 m telescope at CTIO. (c) Jian-sheng *et al.* (1981) obtained the spectra of this quasar with the AAT at 2 Å resolution.

0138 – 381. Two sets of data are available. (a) It was first observed by Osmer and Smith (1976) who carried out absolute spectrophotometry. (b) Whelan *et al.* (1979) observed it using the AAT in the wavelength region 4550–6400 Å. As Table I shows, these authors found the equivalent widths of the three lines in Table I to be a factor two lower than those determined previously by Osmer and Smith (1976). Subsequent absolute spectrophotometry by Whelan *et al.* (1979) using the Boksenberg IPCS confirmed Osmer and Smith's original value for line No. 1 but yielded a value for the line No. 3 close to what they had found originally. From the available evidence it would appear that there was a large change in the relative intensities of line Nos. 1 and 3 between the times of observations of Osmer and Smith (1976) and those of Whelan *et al.* (1979). Such a change is readily understandable on the PLS model (Varshni, 1975a, 1979).

0316 – 203. The observations are due to White *et al.* (1980). Set (a) was obtained on 22 November, 1976 with a red sensitive image tube and set (b) on 27 October, 1978 with a blue sensitive image tube. There are large differences in the equivalent widths and FWHM's of the two sets. Line No. 1 is badly 'eaten' by absorption lines and the wavelength of its peak is poorly determined.

1124 + 571. The quoted values are from Walsh *et al.* (1984) whose observations were made in April 1981 using the Multiple Mirror Telescope intermediate-dispersion spectrograph with a 300 line mm^{-1} grating used in first order, and an image-intensified, photon-counting reticon detector. The wavelength and equivalent width of line No. 2 may have considerable uncertainty.

TABLE I

Emission line data for quasars. Below each wavelength are given, where available, the equivalent width (in Å) and the half-width (FWHM) of the line (in Å)

Quasar	Set	1 λ (Å)	2 λ (Å)	3 λ (Å)
0805 + 046	(a)	4714		6004
	(b)	4715	5424	5958
		205, 55		115, 125
	(c)	4712.1 ± 0.5		
0138 – 381	(a)	4703	5428	5996
		400, 75		185, 155
	(b)	4710	5415	5990
		267, –	31, –	77, –
0316 – 203	(a)	4750	5411	5957
		78, 280	12, 93	39, 128
	(b)	4755		5997
		60, 170		27, 58
1124 + 571		4731	(5364)	6023
		108, –	(26), –	60, –

2.2. Line identifications

Line No. 1. The most accurate measurement on this line is that of Jian-sheng *et al.* (1981) who give its wavelength as 4712.1 ± 0.5 Å. We identify this line in the context of the PLS model as the He I line $\lambda 4713.14\ 2^3P_0 - 4^3S$ (mult. 12). The line is undergoing laser action which gives rise to its great strength.

Line No. 2. No accurate wavelength for this line is available. The measured values range from 5411 to 5428 Å (omitting the value of Walsh *et al.*, 1984). Possible candidates for its identification are O I λ5408 (mult. 53), O I λ5410 (mult. 51, 52) and S II λ5428 (mult. 6).

Line No. 3. Again no accurate value for the wavelength is available. Reported values range from 5957 to 6023 Å. Good candidates for its identification are Si II λ5979 (mult. 4), O I λλ5991–95 (mult. 44), S II λ5996 (mult. 13), N I λλ5999, 6008 (mult. 16), and Al II λλ6000, 6002, 6006 (mult. 93). Clearly, more accurate wavelengths for line Nos. 2 and 3 are required for their identification.

3. Continuous Energy Distribution

Oke (1970) carried out photoelectric spectrophotometry of 0805 + 046 and obtained the absolute spectral-energy distribution from λ3220 to λ9000. It was found that there was a drop of intensity by a factor of 2 at λ3420. We identify this drop with the helium discontinuity at λ3422 (the ionization limit from the 2^3P state of helium). This helium discontinuity was first observed by Popper (1947) in the helium-rich star HD 124448.

4. Absorption-Line Spectrum

We have discussed earlier (Varshni, 1977, 1978) the characteristics of the absorption-line spectrum of quasars that are predicted from our model. In short we expect the absorption-line spectrum of quasars to be quite similar to those of shell stars – except that a wider range of excitation is expected for quasars. It is well known that in the spectra of shell stars, absorption lines for which the lower level is metastable, are unusually strong and dominate the spectrum.

The correct identification of spectral lines from an astronomical source is extremely important. Because from it flows all our knowledge of the composition of and the conditions present in the region where absorption lines are formed. The correct identification of lines, in its turn, depends critically on the resolution, signal to noise ratio, accuracy, and completeness of the observational data.

There have been three investigations on the absorption line spectrum of 0805 + 046. Lynds (1971) obtained one spectrogram at 5 Å resolution and five spectrograms at 10 Å resolution. He lists a total of 93 lines – 90 of these are from the 5 Å resolution spectrogram, and the remaining 3 from the 10 Å resolution ones.

Coleman (1978) studied the absorption line spectrum of 0805 + 046 using the Steward Observatory 2.3 m telescope with the Cassegrain image-tube spectrograph, which was used in two different modes. Three plates were taken with the spectrograph in a conventional mode at a reciprocal dispersion of 47 Å mm^{-1}, while one was obtained using the cross-dispersed echelette configuration (Carswell *et al.*, 1975). In this system the reciprocal dispersion is roughly proportional to wavelength and is roughly 40 Å at 3900 Å mm^{-1}. Coleman (1978) reported a total of 135 lines in the spectral range $\lambda\lambda$3400–5000. The estimated resolution was $\sim$2 Å.

Jian-sheng *et al.* (1981) have obtained the spectra of 0805 + 046 with the Anglo–Australian telescope at 2 Å resolution from 3300 to 6100 Å with the image photon counting system. The observations were carried out on 17 February, 1977, 2, 3 May, 1978, and 12, 13 February, 1980. These authors list a total of 202 lines. Amongst the three investigations, the best results appear to be those of Jian-sheng *et al.* (1981). A comparison of the three sets of data is in order.

(a) Lynds (1971) and Coleman (1978)

Lynds (1971) reported 93 lines in the interval 3495–6010 Å. Of these, 79 are in the range 3495–5000 Å, which is common to the two sets. Coleman's observations confirm 64 of these as unresolved and 4 of them were resolved into two components. Eleven lines reported by Lynds were not found by Coleman.

(b) Lynds (1971) and Jian-sheng *et al.* (1981)

In the common interval 3495–6010 Å, Jian-sheng *et al.* (1981) found 189 lines as compared to 93 by Lynds (1971). Jian-sheng *et al.*'s observations divide Lynds's 93 lines as follows: 64 confirmed as singles, 10 split into two lines each, 3 split into three lines each, and 16 are not confirmed.

As regards the accuracy in this measurements, Lynds (1971) states "The r.m.s. error should be in the vicinity of 0.5 Å but it may be nearer to 1.0 Å because of the aforementioned uncertainties." This may be compared with the actual r.m.s. difference of 1.46 Å between Lynds and Jian-sheng *et al.*'s measurements for the 64 common lines. In Figure 1, we show the difference [λ(Lynds) $-$ λ(Jian-sheng *et al.*)] versus λ for these 64 lines. It will be noted that Lynds's values were systematically too low. The median of the point shown in Figure 1 is at -1.07 Å. The r.m.s. departure of Lynds's values from this line is 1.13 Å. Thus it would appear that Lynds's values had a systematic error of about 1 Å and a r.m.s. error of 1.13 Å.

To give an idea of the difficulty in identifying lines when the observations have such large errors, we note that in RMT (Moore, 1945) alone, at about 4000 Å, the number of possible identifications in an interval of $\pm$ 2 Å is about 30. And we should not forget that a lot of new data have accumulated since RMT was compiled.

(c) Coleman (1978) and Jian-sheng *et al.* (1981)

The region 3410 to 5000 Å is common to the observations of Coleman (1978) and Jian-sheng *et al.* (1981). In this region, Coleman found 135 lines, while Jian-sheng *et al.*, 186. A comparison of the two sets shows that Jian-sheng *et al.*'s results divide Coleman's lines as follows: 6 lines resolved in two, one resolved in three. There was blending of two lines at two places. Sixteen Coleman lines were not confirmed; most of these were weak lines. Sixty-one new lines were found, not all of them are weak: 3 have $W_\lambda > 3$, 3 have $3 \le W_\lambda \le 2$, and 28 have $2 \le W_\lambda \le 1$ (all in Å). While the claimed resolution is approximately the same in two cases, it appears that there were some important shortcomings in the techniques used by Coleman (1978) which led to the non-detection of so many lines.

From the above discussion it is obvious that the resolution alone is not an adequate indicator of the quality of the reported spectrum. It is desirable that the signal-to-noise ratio also be given in observational papers.

A comparison of the common lines between Coleman and Jian-sheng *et al.* shows that the ratio W_λ(Jian-sheng *et al.*)/W_λ(Coleman) varies between 1 and 7. One, of course, has to remember that the equivalent widths depend on how the continuum is drawn. We wish to emphasize the large discrepancies in the equivalent widths given by different observers to indicate that for the purpose of identification of lines the recorded equivalent widths can only be taken as a qualitative guide and no more.

The progressive increase in the number of observed lines – 93 (Lynds), 135 (Coleman), and 203 (Jian-sheng *et al.*) – with the improvement in observational technique clearly indicates that even the list of Jian-sheng *et al.* is not complete and this factor has to borne in mind while considering the number of lines of any element which are identified as against the expected number of lines. This also applies to the question of completeness of multiplets in the identifications. In addition, one has to remember that in the spectra of stars it is known that 'mutilated multiplets' do occur.

The tolerance (or wavelength discrepancy) that one can permit in the identifications depends on the resolution, uncertainty in the wavelength calibration and the width of

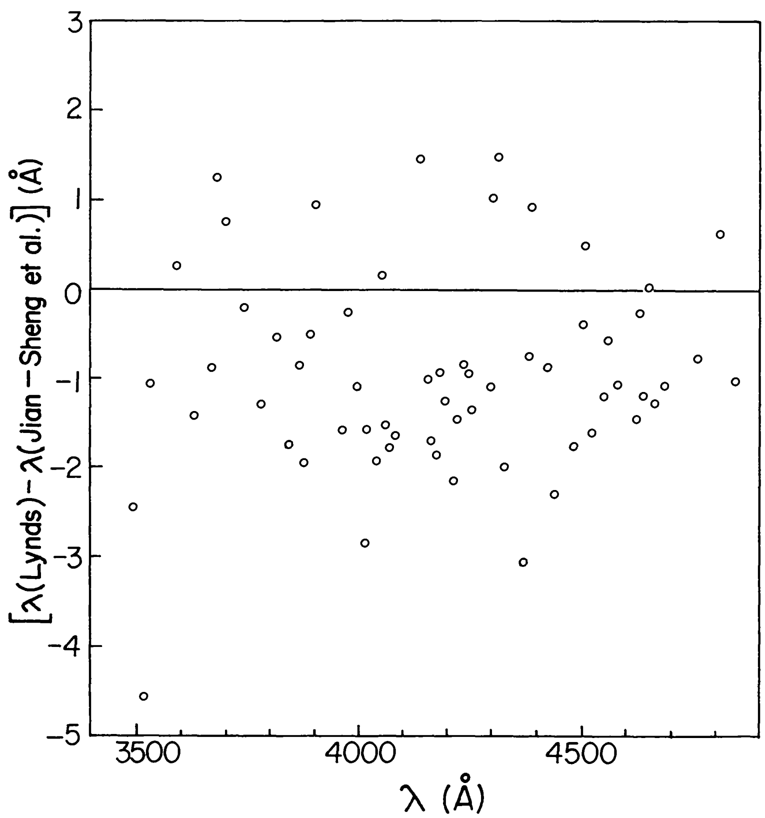

Fig. 1. The difference [λ(Lynds) – λ(Jiang-sheng *et al.*)] as a function of λ.

the line. The claimed resolution in the work of Jian-cheng *et al.* (1981) is 2 Å which would suggest a tolerance of $\simeq 1$ Å, provided the two adjacent lines are of equal intensity, which would not be the case in general. The wavelength calibration of Jian-sheng *et al.* was quite good, residuals being 0.1 Å for 3700 Å but up to 0.2 Å at shorter wavelengths. The widths of the lines arising from the limitations of the instrumentation and/or blending poses a more serious problem. An examination of an enlargement of the spectrum shown in Figure 1 of Jian-sheng *et al.* (1981) shows that there are a good many lines having a width greater than 2 Å. Sometimes a blend is several Ångstroms wide. Clearly in such cases a tolerance commensurate with the width has to be allowed. In the light of the above discussion we have taken 1.5 Å as a guiding value for the tolerance but larger values have been allowed in appropriate situations.

Identifications for most of the absorption lines in the region shortward of 5000 Å reported by Jian-sheng *et al.* (1981) are presented in Table II. Beyond 5000 Å the available data are very unsatisfactory. Only two sets are available, those of Lynds (1971) and Jian-sheng *et al.* (1981), and there are serious disagreements between the two sets. Also for identification purposes the requirements on accuracy become more demanding in this region – the reason being that most of the lines in this region arise from excited states and are generally weak as compared to those at shorter wavelengths. Because of this, we have not even attempted to propose any identifications for lines in this region.

For judging the relative intensities of lines for identification purposes, we have taken as our guide the relative intensities of those lines in the spectra of shell stars (Struve and Roach, 1939; Struve and Swings, 1941, 1943; Baldwin, 1941a, b, 1943; Struve, 1943; Broyles, 1943; Hiltner, 1944; Merrill and Sanford, 1944; Weaver, 1952; Merrill and Lowen, 1953; Ballereau, 1980), rather than the laboratory intensities listed in Moore (1945). The reported equivalent widths of lines in 0805 + 046 appear to indicate that in some cases, besides the proposed identifications, there is blending due to unknown components. The r.m.s. value of ($\lambda_{\text{obs}} - \lambda_{\text{iden.}}$) for all the identifications is 1.24 Å which is quite satisfactory.

Next we shall consider some of the identified ions.

He I. A great many lines are present. The only important line missing is λ4026.

Mg I. $\lambda\lambda$3829, 3838 are present but λ3832 is absent. This is, however, not surprising. The lower level of λ3832 is not strictly metastable (Struve, 1939; Baldwin, 1941) and this line is sometimes absent in the spectra of shell stars (Baldwin, 1941).

Mg II. The well-known line λ4481 is present.

Si II. Multiplets 1 and 3 are present.

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

Sc II. Scandium is a rare element, but λ4247 attains considerable strength in a few shell stars. λ4247 is present here. In addition, most members of multiplets 2 and 3 are present.

Fe II. Many members of multiplets 27, 28, 37, and 38 are present.

The observed line at λ4225 deserves special mention. The tracing given by Jian-sheng *et al.* (1981) shows it to be a strong, wide, and slightly asymmetrical line. The width at half intensity is about 7 Å. Ca I λ4226 has been included in the identification of this line

TABLE II

Identification of lines in the spectrum of 0805 + 046.
$\delta = \lambda_{obs} - \lambda_{lab}$. λ_{obs}, W_λ, λ_{lab}, and δ all are in Å.

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
3414.59	2.14	3414.14	Fe II	91	0.45
		3415.78	Co II	2	− 1.19
3420.09	4.16	3421.20	Cr II	3	− 1.11
3423.36	3.97	3422.74	Cr II	3	0.62
		3423.85	Co II	2	− 0.49
3432.42	3.36	3433.30	Cr II	3	− 0.88
3439.55	3.05	3440.61	Fe I	6	− 1.06
		3440.99	Fe I	6	− 1.44
3446.73	2.39	3444.31	Ti II	6	2.42
		3446.40	Co II	2	0.33
		3447.59	He I	7	− 0.86
3453.38	1.34	3454.98	Cr II	136	− 1.60
3457.32	3.64	3456.39	Ti II	99	0.93
		3456.93	Fe II	76	0.39
		3457.15	V II	147	0.17
		3457.62	Cr II	135	− 0.30
		3459.29	Cr II	136	− 1.97
3467.30	2.04	3465.86	Fe I	6	1.44
		3468.68	Fe II	114	− 1.38
3473.20	1.84	3471.80	He I	44	1.40
		3472.07	Cr II	135	1.13
		3475.13	Cr II	2	− 1.93
		3475.45	Fe I	6	− 2.25
3481.85	3.61	3484.15	Cr II	2	− 2.30
3489.83	3.91	3487.72	He I	42	2.11
		3490.58	Fe I	6	− 0.75
		3490.62	He I	41	− 0.79
3494.74	1.04	3493.47	Fe II	114	1.27
		3495.37	Cr II	2	− 0.63
3500.27	2.88	3497.84	Fe I	6	2.43
		3498.64	He I	40	1.63
		3501.73	Co II	2	− 1.46
		3502.38	He I	39	− 2.11
3504.70	1.48	3504.89	Ti II	88	− 0.19
3519.38	4.06	3517.33	He I	37	2.05
		3520.25	Ti II	98	− 0.87
3529.87	0.74	3530.49	He I	36	− 0.62
		3530.77	V II	5	− 0.90
3532.24	1.15	3532.65	Fe II	132	− 0.41
3537.06	2.00	3535.41	Ti II	98	1.65
		3536.82	He I	35	0.24
3541.13	2.52		V II	145	− 0.21
3547.92	1.14		Pleione		
3550.23	1.91				
3553.52	1.56	3554.39	He I	34	− 0.87
		3554.52	He I	34	− 1.00

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
3557.30	0.79	3556.80	V II	5	0.50
		3558.54	Sc II	3	– 1.24
3563.61	2.78	3562.95	He I	33	0.66
3566.21	2.16	3567.70	Sc II	3	– 1.49
3569.37	2.67	3570.10	Fe I	24	– 0.73
3571.96	1.81	3572.52	Sc II	3	– 0.56
3574.89	0.53	3576.34	Sc II	3	– 1.45
3581.86	3.22	3580.93	Sc II	3	0.93
		3581.20	Fe I	23	0.66
3585.66	4.40	3585.31	Cr II	13	0.35
		3585.54	Cr II	13	0.12
		3587.25	He I	31	– 1.59
		3587.40	He I	31	– 1.74
3591.90	1.77	3589.64	Sc II	3	2.26
		3590.48	Sc II	3	1.43
3594.86	1.49	3593.49	Cr I	4	1.37
3601.71	2.60	3599.30	He I	30	2.41
		3599.44	He I	30	2.27
		3603.61	Cr II	13	– 1.90
		3603.80	Cr II	13	– 2.09
		3603.86	Cr II	13	– 2.15
3607.14	5.30	3605.33	Cr I	4	1.81
		3608.86	Fe I	23	– 1.72
3613.90	1.27	3613.21	Cr II	13	0.69
		3613.64	He I	6	0.26
		3613.84	Sc II	2	0.06
3619.01	1.31	3618.77	Fe I	23	0.24
		3621.22	Co II	1	– 2.21
		3621.27	Fe II	144	– 2.26
3625.54	1.86	3624.83	Ti II	52	0.71
		3624.89	Fe II	144	0.65
3631.68	1.79	3630.74	Sc II	2	0.94
		3631.46	Fe I	23	0.22
		3631.49	Cr II	12	0.19
		3631.72	Cr II	12	– 0.04
3641.82	3.31	3641.33	Ti II	52	0.49
		3642.79	Sc II	2	– 0.96
3644.77	2.51	3645.31	Sc II	2	– 0.54
3647.77	1.17	3647.84	Fe I	23	– 0.07
3655.94	0.53		17 Lep		
3658.91	1.29	3658.19	Cr II	146	0.72
		3659.77	Ti II	75	– 0.86
3663.08	2.16	3662.24	Ti II	75	0.84
		3664.95	Cr II	156	– 1.87
3669.27	4.65	3669.41	V II	116	– 0.14
3682.29	2.66	3679.92	Fe I	5	2.38
		3684.25	Cr II	145	– 1.96
3687.02	2.08	3685.19	Ti II	14	1.83

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
3687.02	2.08	3686.67	Cr II	118	0.35
		3687.46	Fe I	21	− 0.44
3694.05	2.09				
3698.92	1.41	3698.00	Cr II	118	0.92
3703.18	1.06		υ Sgr		
3705.33	1.30	3705.00	He I	25	0.33
		3705.14	He I	25	0.19
		3705.57	Fe I	5	− 0.24
3709.67	2.23	3709.25	Fe I	21	0.42
		3709.25	Fe I	21	0.42
3724.23	1.45	3722.56	Fe I	5	1.67
3729.93	3.14	3727.62	Fe I	21	2.31
3735.95	0.98	3734.87	Fe I	21	1.08
		3737.13	Fe I	5	− 1.18
		3738.38	Cr II	20	− 2.43
3744.94	3.26	3745.56	Fe I	5	− 0.62
		3745.81	V II	15	− 0.87
		3745.90	Fe I	5	− 0.96
3766.95	2.59	3767.19	Fe I	21	− 0.24
3769.76	2.14	3769.46	Ni II	4	0.31
		3770.97	V II	21	− 1.21
3780.72	4.01	3781.51	Fe II	130	− 0.79
3791.06	1.40		48 Lib		
3797.98	1.99	3798.51	Fe I	21	− 0.53
		3799.55	Fe I	21	− 1.57
3803.20	1.70				
3812.55	2.61	3812.96	Fe I	22	− 0.41
		3814.12	Fe II	153	− 1.57
3816.64	1.31	3815.84	Fe I	45	0.80
3819.26	1.07	3819.61	He I	22	− 0.35
		3819.76	He I	22	− 0.50
		3820.43	Fe I	20	− 1.17
3823.49	1.61	3824.44	Fe I	4	− 0.95
		3824.91	Fe II	29	− 1.42
3828.21	1.21	3825.88	Fe I	20	2.33
		3827.08	Fe II	153	1.13
		3827.83	Fe I	45	0.38
		3829.35	Mg I	3	− 1.14
3839.92	0.40	3838.29	Mg I	3	1.63
		3838.29	Mg I	3	1.63
		3840.44	Fe I	20	− 0.52
		3841.05	Fe I	45	− 1.13
3845.68	1.61	3847.32	V II	156	− 1.64
3855.60	1.03	3853.66	Si II	1	1.94
		3856.02	Si II	1	− 0.42
		3856.37	Fe I	4	− 0.77
3862.17	0.52	3859.91	Fe I	4	2.26
		3862.59	Si II	1	− 0.42

Table II (continued)

λ_{obs}	W_{λ}	Identification			δ
		λ_{lab}	Ion	Mult.	
3867.91	2.80	3865.59	Cr II	167	2.32
		3867.48	He I	20	0.43
		3867.63	He I	20	0.28
3876.76	1.56	3878.02	Fe I	20	− 1.26
		3878.58	Fe I	4	− 1.81
		3878.72	V II	33	− 1.95
3887.56	1.99	3886.28	Fe I	4	1.28
		3888.65	He I	2	− 1.09
3895.33	2.64	3895.66	Fe I	4	− 0.33
3903.12	1.39	3903.27	V II	11	− 0.15
3907.34	2.98	3905.53	Si I	3	1.81
		3905.64	Cr II	167	1.70
		3906.04	Fe II	173	1.30
3911.53	0.97		Pleione, υ Sgr		
3914.35	0.40	3913.46	Ti II	34	0.89
		3914.33	V II	33	0.02
		3916.42	V II	10	− 2.07
3924.65	1.80	3922.91	Fe I	4	1.74
3933.44	0.50	3933.66	Ca II	1	− 0.22
3938.93	0.60	3938.97	Fe II	190	− 0.04
3950.65	0.48	3951.97	V II	10	− 1.32
3955.50	2.27	3954.60	O I	30	0.90
		3954.69	O I	30	0.81
3966.99	2.31	3964.73	He I	5	2.26
		3968.47	Ca II	1	− 1.48
3974.59	1.45	3974.16	Fe II	29	0.43
3977.72	1.00	3977.73	V II	10	− 0.01
3980.37	0.49	3979.51	Cr II	183	0.86
3986.18	2.77		Pleione		
3989.63	2.16		υ Sgr		
3998.17	6.77	3997.13	V II	9	1.04
4004.16	1.77	4002.07	Fe II	29	2.09
		4003.33	Cr II	194	0.83
		4005.71	V II	32	− 1.55
4013.33	1.34	4012.50	Cr II	183	0.83
4021.23	5.14	4023.39	V II	32	− 2.16
4038.05	1.78	4035.63	V II	32	2.42
		4038.03	Cr II	194	0.02
4044.14	3.26	4045.82	Fe I	43	− 1.68
4052.89	3.39	4051.97	Cr II	19	0.92
4057.20	1.56				
4063.01	1.65	4063.60	Fe I	43	− 0.59
4065.99	1.13	4067.05	Ni II	11	− 1.06
4070.97	4.46	4070.90	Cr II	193	0.07
		4071.74	Fe I	43	− 0.77
4078.09	1.25	4077.71	Sr II	1	0.38
4086.05	3.05	4086.14	Cr II	26	− 0.09
4092.14	0.44				
4095.38	0.65				

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
4098.37	1.09	4098.44	Cr II	165	−0.07
4114.41	2.19	4113.24	Cr II	18	1.17
4119.26	1.44	4120.81	He I	16	−1.55
		4120.99	He I	16	−1.73
4128.97	0.70	4128.05	Si II	3	0.92
		4128.74	Fe II	27	0.23
		4130.88	Si II	3	−1.91
4136.04	1.61				
4140.87	1.28				
4147.11	1.82	4145.77	Cr II	162	1.34
4155.95	2.78				
4164.85	4.73	4163.64	Ti II	105	1.21
4173.22	2.48	4171.90	Ti II	105	1.32
		4173.45	Fe II	27	−0.23
4186.41	5.54	4187.04	Fe I	152	−0.63
4193.12	2.08	4192.07	Ni II	10	1.05
4198.65	3.25	4198.31	Fe I	152	0.34
4213.06	2.23		υ Sgr		
4217.58	2.52	4215.52	Sr II	1	2.06
4225.06	6.60	4224.85	Cr II	162	0.21
		4226.73	Ca I	2	−1.67
4234.59	1.20	4233.17	Fe II	27	1.42
4247.94	3.04	4246.83	Sc II	7	1.11
4257.98	2.09	4258.16	Fe II	28	−0.18
4297.59	2.97	4296.57	Fe II	28	1.02
		4300.05	Ti II	41	−2.46
4303.61	2.01	4303.17	Fe II	27	0.44
4315.73	1.43	4314.08	Sc II	15	1.65
		4314.29	Fe II	32	1.44
		4314.98	Ti II	41	0.75
4324.25	2.44	4325.01	Sc II	15	−0.76
4331.80	2.95		Pleione		
4345.16	1.20		48 Lib		
4351.73	1.51	4351.76	Fe II	27	−0.03
4364.97	2.01				
4369.55	4.49	4369.40	Fe II	28	0.15
4381.19	3.16				
4390.18	2.32	4390.58	Mg II	10	−0.40
4394.93	2.25	4395.03	Ti II	19	−0.10
4417.73	1.41	4416.82	Fe II	27	0.91
4423.72	5.65				
4432.50	0.72	4433.99	Mg II	9	−1.49
4439.04	5.60				
4464.61	4.03				
4468.33	2.23	4468.49	Ti II	31	−0.16
4471.41	1.19	4471.48	He I	14	−0.07
		4471.69	He I	14	−0.28
		4472.92	Fe II	37	−1.51
4481.38	4.02	4481.13	Mg II	4	0.25

Table II (continued)

λ_{obs}	W_λ	Identification			δ
		λ_{lab}	Ion	Mult.	
4481.38	4.02	4481.33	Mg II	4	0.05
4486.38	0.72				
4495.44	0.74	4494.57	Fe I	68	0.87
4502.84	1.55	4501.27	Ti II	31	1.57
4507.48	3.08	4508.28	Fe II	38	−0.80
4511.96	1.05		υ Sgr		
4519.90	1.74	4520.22	Fe II	37	−0.32
4525.91	1.73	4625.91	Fe II	186	−0.19
4531.53	4.78	4533.97	Ti II	50	−2.44
4550.29	2.55	4549.21	Fe II	186	1.08
		4549.47	Fe II	38	0.82
		4549.62	Ti II	82	0.67
4557.87	2.82	4555.89	Fe II	37	1.98
		4558.66	Cr II	44	−0.79
4564.48	1.02	4563.76	Ti II	50	0.72
4584.02	5.13	4582.83	Fe II	37	1.19
		4583.83	Fe II	38	0.19
4592.06	0.93	4592.09	Cr II	44	−0.03
4615.63	1.94	4616.64	Cr II	44	−1.01
4625.72	2.07				
4631.31	4.35	4629.34	Fe II	37	1.97
4636.29	2.13	4634.11	Cr II	44	2.18
		4635.33	Fe II	186	0.96
4640.30	1.90				
4653.93	1.20				
4658.00	0.89	4656.97	Fe II	43	1.03
4666.89	1.43	4666.75	Fe II	37	0.14
4685.37	0.66				
4689.09	1.75				
4699.10	0.50				
4703.01	0.65				
4709.94	2.83				
4713.19	1.76	4713.14	He I	12	0.05
		4713.37	He I	12	−0.18
4718.95	0.37				
4722.93	0.36		υ Sgr		
4753.20	1.11				
4760.33	1.22				
4772.50	0.73				
4797.80	0.45				
4800.00	0.91		υ Sgr		
4803.50	0.93				
4807.40	0.49				
4813.70	0.53	4812.35	Cr II	30	1.35
4816.32	0.88				
4843.31	1.22		υ Sgr		
4875.53	1.00	4876.41	Cr II	30	−0.88
4884.21	0.88				

because of its strong intensity. It could, of course, be argued that at the level of excitation indicated by other ions, Ca I is unlikely to be present. However, there may be stratification in the shell. The problem can be resolved by higher resolution observations.

Attempts have been made by some workers to explain the absorption-line spectrum of 0805 + 046 on the redshifts hypothesis by assuming multiple redshifts. We have, however, shown (Varshni, 1974b, c; 1975b) that the number and properties of these proposed absorption redshift systems are insignificantly different from those that would be expected from chance coincidences. It may be of some interest to note that in the region shortward of 5000 Å, the redshift hypothesis identifies 50 lines (Jian-sheng *et al.*, 1981) while we have identified 140 lines.

In earlier papers (Varshni, 1978, 1979) we have emphasized the need of obtaining the absorption-line spectra of quasars with high resolution and accuracy (~ 0.1 Å). Recently a number of papers have appeared in which high-resolution studies of quasars have been reported (Chaffee *et al.*, 1983, 12 km s^{-1}; Carswell *et al.*, 1984, 0.25 Å; York *et al.*, 1984, 10 km s^{-1}), though these investigations cover only a narrow region of the spectrum. Clearly, the techniques are now available. It would be most desirable to obtain the spectrum of 0805 + 046 over a wide wavelength interval (3200–5000 Å) at a high resolution and with a high signal-to-noise ratio.

Absorption lines have been noted in the low-resolution spectra of 0138 – 381 and 0316 – 203. It would be of considerable interest to obtain high resolution absorption-line spectra of these two quasars. An intercomparison of the absorption lines in 0805 + 046 can provide clues to the evolution of the shell in a quasar. It would also be of interest to look for the helium discontinuity at λ3422 in 0138 – 381, 0316 – 203, and 1124 + 571.

During the last twelve years since the PLS model was first proposed, progress has been made in theoretical studies and in experimental observations of population inversion in an expanding plasma. We note here one point which is of direct relevance to the present paper. Zhinzhikov *et al.* (1978) have observed population inversion in helium in supersonic plasma expansion. The experimental data confirm the operation of a recombination mechanism for the population of the He I levels under the experimental conditions. Population inversion has also been observed in some helium-like ions (Apruzese *et al.*, 1978; Bhagavatula and Yaakobi, 1978; Zhizhan and Guangyu, 1983).

Finally, we may also note here that He I λ4713 emission is known to occur in the spectra of certain novae and nova-like stars.

Note added in proof: The quasars 2343 + 008 (Gaston, 1983; emission line at 4715 Å) and 0420 + 003 (Margon *et al.*, 1985) also appear to belong to the same spectral class 0805 + 046, but the available data are very scanty.

References

Apruzese, J. P., Davis, J., and Whitney, K. G.: 1978, *J. Phys.* **B11**, L643.
Baldwin, R. B.: 1941a, *Astrophys. J.* **93**, 333.
Baldwin, R. B.: 1941b, *Astrophys. J.* **93**, 420.
Baldwin, R. B.: 1943, *Astrophys. J.* **97**, 388.

Ballereau, D.: 1980, *Astron. Astrophys. Suppl.* **41**, 305.
Bhagavatula, V. A. and Yaakobi, B.: 1978, *Opt. Comm.* **24**, 331.
Boiko, V. A., Bryunetkin, B. A., Duvanov, B. N., Dyakin, V. M., Pikuz, S. A., Skobelev, I. Yu., Faenov, A. Ya., Fedosimov, A. I., and Shilov, K. A.: *Pis'ma Zh. Tekh. Fiz.* **7**, 665 (*Soviet Tech. Phys. Letters* **7**, 285).
Broyles, A. A.: 1943, *Astrophys. J.* **97**, 234.
Carswell, R. F., Hilliard, R. L., Strittmatter, P. A., Taylor, D. J., and Weymann, R. J.: 1975, *Astrophys. J.* **196**, 351.
Carswell, R. F., Morton, D. C., Smith, M. G., Stockton, A. N., Turnshek, D. A., and Weymann, R. J.: 1984, *Astrophys. J.* **278**, 486.
Chaffee, F. H., Weymann, R. J., Latham, D. W., and Strittmatter, P. A.: 1983, *Astrophys. J.* **267**, 12.
Coleman, G. D.: 1978, 'The Absorption Line Spectra of High Redshift QSOs', Ph.D. Thesis, University of Arizona.
Gaston, B.: 1983, *Astrophys. J.* **272**, 411.
Hiltner, W. A.: 1944, *Astrophys. J.* **99**, 103.
Hunger, K.: 1975, in B. Baschek, W. H. Kegel, and G. Traving (eds.), *Problems in Stellar Atmospheres and Envelopes*, Springer-Verlag, New York.
Jian-sheng, C., Morton, D. C., Peterson, B. A., Wright, A. E., and Jauncey, D. L.: 1981, *Monthly Notices Roy. Astron. Soc.* **196**, 715.
Kaufmann, J. P. and Theil, U.: 1980, *Astron. Astrophys. Suppl.* **41**, 271.
Lynds, R.: 1971, *Astrophys. J.* **164**, L73.
Lynds, R. and Wills, D.: 1970, *Nature* **226**, 532.
Margon, B., Downes, R. A., and Chanan, G. A.: 1985, *Astrophys. J. Suppl.* **59**, 23.
Merrill, P. W. and Lowen, A. L.: 1953, *Astrophys. J.* **118**, 18.
Merrill, P. W. and Sanford, R. F.: 1944, *Astrophys. J.* **100**, 14.
Moore, C. E.: 1945, *A Multiplet Table of Astrophysical Interest*, NSRDS-NBS 40, U.S. Government Printing Office, Washington D.C.
Oke, J. B.: 1970, *Astrophys. J.* **161**, L17.
Osmer, P. S. and Smith, M. G.: 1976, *Astrophys. J.* **210**, 267.
Popper, D. M.: 1947, *Publ. Astron. Soc. Pacific* **59**, 320.
Struve, O.: 1939, *Proc. Am. Phil. Soc.* **81**, 237.
Struve, O.: 1943, *Astrophys. J.* **98**, 98.
Struve, O. and Roach, F. E.: 1939, *Astrophys. J.* **90**, 727.
Struve, O. and Swings, P.: 1941, *Astrophys. J.* **93**, 446.
Struve, O. and Swings, P.: 1943, *Astrophys. J.* **97**, 426.
Varshni, Y. P.: 1973, *Bull. Am. Phys. Soc.* **18**, 1384.
Varshni, Y. P.: 1974a, *Bull. Am. Astron. Soc.* **6**, 213, 308.
Varshni, Y. P.: 1974b, *Astrophys. J.* **193**, L5.
Varshni, Y. P.: 1974c, *Bull. Am. Astron. Soc.* **6**, 449.
Varshni, Y. P.: 1975a, *Astrophys. Space Sci.* **37**, L1.
Varshni, Y. P.: 1975b, *Astrophys. J.* **201**, 547.
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.: 1982, *Spec. Sci. Tech.* **5**, 521.
Varshni, Y. P. and Lam, C. S.: 1976, *Astrophys. Space Sci.* **45**, 87.
Walsh, D., Bechers, J. M., Carswell, R. F., and Weymann, R. J.: 1984, *Monthly Notices Roy. Astron. Soc.* **211**, 105.
Weaver, H. F.: 1952, *Astrophys. J.* **116**, 541.
Whelan, J. A. J., Smith, N. G., and Carswell, R. F.: 1979, *Monthly Notices Roy. Astron. Soc.* **189**, 363.
White, G. L., Murdoch, H. S., and Hunstead, R. W.: 1980, *Monthly Notices Roy. Astron. Soc.* **192**, 545.
York, D. G., Green, R. F., Bechtold, J., and Chaffee, F. H., Jr.: 1984, *Astrophys. J.* **280**, L1.
Zhinzhikov, G. M., Luk'yanov, G. A., Nazarov, V. V., and Pavlova, N. O.: 1978, *Zh. Tekh. Fiz.* **48**, 949 (*Soviet Phys. Tech. Phys.* **23**, 554).
Zhizhan, Xu and Guangyu, Y.: 1983, *Sci. Sinica* **26**, 657.