1991Ap&SS.183...67L

THE FAR UV SPECTRUM OF THE O4I(n)f STAR ζ PUPPIS

P. G. LASKARIDES, E. DANEZIS, and E. THEODOSSIOU

Section of Astrophysics, Astronomy and Theoretical Mechanics, Department of Physics, University of Athens, Greece

(Received 19 October, 1990)

Abstract. A detailed list of line identifications of the far UV spectrum of the O4I(n)f star ζ Puppis (HD 66811) in the wavelength range λλ1168–1984 Å recorded on 16 April, 1981 with the International Ultraviolet Explorer (IUE) is presented. The detailed analysis of the radial velocities measured in the same wavelength range is also presented.

1. Introduction

The hottest of the bright Of stars is ζ Pup, for which Walborn (1972) gave the spectral type O4I(n)f. Conti and Leep (1974) classified it as O4ef, while Lesh (1972) retained the historic type of O5f.

The visual spectrum was described by Baschek and Scholz (1971), Heap (1972), and Conti (1976); some features of the UV spectrum were described by Morton (1976), Holm and Cassinelli (1977), and Morton and Underhill (1977). The main parameters of the star were summarized by Lamers and Morton (1976). The determination of the effective temperature yields large problems. The value derived from the angular diameter and the UV flux distribution is $T_e = 32510 \pm 1930$ K according to Code *et al.* (1976) or 31900 ± 1800 K according to Brune *et al.* (1979). These values are similar to those of the later type stars ζ Oph (O9.5V) and τ Sco (B0V) and seem, therefore, much too low. A higher T_e value (50000 K) and $\log g = 4.0$ was found from a study of COPERNICUS observations of the helium spectrum by Snijders and Underhill (1975), who compared observations of He II lines with non-LTE predictions obtained for assumed non-LTE-plane-parallel model atmospheres by Auer and Mihalas (1972).

Morton (1976) and Lamers and Morton (1976) gave a detailed description of P Cygni profiles in ζ Pup using high-resolution spectral scans obtained with the COPERNICUS satellite. Rocket-UV spectra of ζ Pup have been described by Carruthers (1968), Morton *et al.* (1969), Stecher (1970), Smith (1970), and Burton *et al.* (1973, 1975). An absolutely calibrated rocket spectrum (12 to 15 Å resolution) was obtained by Brune *et al.* (1979). These investigations revealed strong P Cygni lines of C IV, N IV, N V, O IV, Si IV, S IV, and S VI in the far ultraviolet. Additionally, Snijders and Underhill (1975) have analyzed the He II observed with the COPERNICUS satellite along with those available from ground-based spectra. Finally, Franco *et al.* (1983) found line profile variability in ζ Pup and suggested that two different mechanisms could be producing the observed ionization stages.

In this paper we give a line-list as complete as possible of the far UV spectrum of the star ζ Pup in the spectral range 1168–1984 Å recorded on 16 April, 1981 (SWP 13726)

Astrophysics and Space Science **183**: 67–89, 1991.
© 1991 *Kluwer Academic Publishers. Printed in Belgium.*

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

with the IUE. The detailed analysis of the radial velocities measured in the same wavelength range is also given. Unfortunately, ζ Pup, like most other O-type stars, has relatively wide photospheric lines (Morton and Underhill, 1977), so that many of the features are blended. Nevertheless, it is important to have an example of such a hot star in this high-resolution survey from IUE.

2. Observational Data

The high-resolution far UV spectrum of ζ Pup (λλ1168–1984 Å) analysed in this paper has been obtained on 16 April, 1981 (SWP 13726) with the International Ultraviolet Explorer satellite. Figures 6 to 9 give the whole spectrum in reduction.

The line-identifications were performed on the basis of the multiplet tables of Moore (1962) and Kelly (1979). Two line lists are presented in this paper. Table I gives the list of absorption lines observed in the spectrum of ζ Puppis. We also give the corresponding ions, which may possibly produce these lines around these wavelengths. A great number of these lines is unclassified. The successive columns in Table I give:

(1) The measured wavelength in Å for the principal ions.

(2) The radial velocity (RV) of the line in km s^{-1}, measured at the line center.

(3) The identification of the principal ions contributing to the formation of the line for the classified lines or of the suggested ions for the unclassified lines.

(4) The multiplet number.

(5) The laboratory wavelength in Å.

(6) The intensity (from Kelly, 1979).

(7) Remarks.

The wavelengths of the lines are measured on the tracing of the spectrum on the basis of the wavelength markings on this tracing. The precision of the observed line position and of the radial velocity is limited by the IUE resolution (± 0.1 Å and more) which is translated into ± 15 to 25 km s^{-1} in velocity. Thus errors of this magnitude in velocity are to be expected. It is evident that the radial velocities listed, e.g., in Table I, are somewhat arbitrary and that the information from these data must be treated with caution and in a statistical sense only. In addition the credibility of these radial velocities is further reduced by the severe blending due to the crowding of the lines. The study of interstellar lines (Morton, 1976) indicates the absence of a line shift.

Table II gives the wavelength of the well-defined lines, which are present in the spectrum that we were not able to identify unambiguously.

3. Description of the Spectrum and Discussion

3.1. General description of the spectrum

The UV spectrum of ζ Pup presents a great variety of ionized species going from H I to the highly ionized species such as N V, N IV, C IV, and Si IV. Emission lines dominate the spectrum as N V[1] in the neighbourhood of λ1240 Å, the C IV[1] in the

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

TABLE I

Absorption lines in the spectrum of ζ Puppis

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
1168.60	+ 3	N IV	18.83	1168.59	150	
1169.00	+ 3	C IV	11.19	1168.99	200	i
	− 15	N IV	18.83	1169.06	100	B
1169.50	+ 5	N IV	18.83	1169.48	50	
1170.10	+ 5	N IV	–	1170.08	150	
1175.30	+ 10	C III	4	1175.26	700	
1175.70	0	C III	4	1175.70	1000	
1176.00	+ 3	C III	4	1175.99	700	
1176.40	+ 8	C III	4	1176.37	800	
1182.95	− 20	N III	20	1183.03	350	
1184.30	− 61	N III	20	1184.54	400	
1187.95	− 13	N IV	18.49	1188.00	300	
1190.30	+ 33	S III	1	1190.17	200	
1190.50	+ 23	Si II	5	1190.41	100	
1193.30	− 18	S III	1	1194.02	400	
1194.35	− 13	S III	1	1194.40	300	
1195.10	0	Ti IV	–	1195.25	100	
1203.50	− 22	P IV	–	1203.41	40	
1204.45	+ 37	P IV	–	1204.30	40	
1206.50	− 2	Si III	2	1206.51	600	in wing of Lα
	− 7	Si III	11	1206.53	600	
	− 5	P IV	–	1206.52	40	
1210.50	+ 12	Si III	21	1210.45	200	
1215.00	− 22	He II	13	1215.09	143	i
	− 42	He II	13	1215.17	260	
1215.30	− 10	D I	1	1215.34	1000	Lα
1215.70	+ 10	H I	1	1215.66	670	
	+ 7	H I	1	1215.67	330	B
1216.80	+ 5	Al IV	–	1216.78	50	?
1219.05	+ 10	Mg IV	–	1219.01	150	
	+ 5	Mg IV	–	1219.03	150	B
1222.40	− 24	Mn IV	–	1222.49	70	?
1222.60	− 5	Si II	8.02	1222.63	5	?
1224.30	+ 12	Si II	8.02	1224.25	20	?
1224.85	− 24	N IV	18.76	1224.96	50	
1225.10	− 22	N IV	18.76	1225.19	150	
1225.70	− 2	N IV	18.76	1225.71	200	
1229.50	− 2330	N V	1	1238.82	1000	S, ?
1230.40	− 27	C IV	11.14	1230.51	150	
1231.00	+ 7	Ca III	–	1230.97	400	
1233.36	− 2360	N V	1	1242.80	800	S, ?
1238.85	+ 7	N V	1	1238.82	1000	is N V [1]
1240.80	− 7	Al IV	–	1240.83	150	
1242.80	0	N V	1	1242.80	800	is
1244.00	− 36	Ni V	–	1244.15	300	
1246.60	+ 22	N IV	18.92	1246.51	100	
1247.40	+ 5	C III	9	1247.38	600	
1247.65	− 17	Mn IV	–	1247.72	850	
1248.75	+ 29	Mn IV	–	1248.63	300	

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

Table I (continued)

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
1250.40	− 7	Si II	13.05	1250.43	150	
1255.50	− 43	Ne III	13	1255.68	500	
1257.40	+ 31	Mn IV	–	1257.27	950	
1257.50	− 119	Al IV	–	1258.00	150	?
1258.05	− 19	Mn IV	–	1258.13	750	
1259.60	+ 14	Fe IV	–	1259.54	–	
1261.00	+ 47	Si II	4	1260.80	–	
1262.70	+ 12	Ca III	–	1262.65	500	
1264.30	− 24	Mn IV	–	1264.41	900	
1264.80	+ 17	Si II	4	1264.73	1000	
1265.10	+ 24	Si II	4	1265.00	100	
1270.25	− 7	N IV	18.75	1270.28	250	
1270.40	+ 17	Ca III	–	1270.33	450	
1272.20	+ 9	N IV	18.75	1272.16	200	
1272.70	− 5	N IV	18.75	1272.72	100	
1273.50	+ 7	N IV	18.75	1273.47	150	
1273.70	− 2	N IV	18.75	1273.71	100	
1278.30	− 21	Ca III	–	1278.39	550	
1281.55	0	Ca III	–	1281.55	500	
1284.35	+ 30	N IV	18.87	1284.22	150	
1285.90	0	Ca III	–	1285.90	400	
1294.00	+ 16	Mn V	–	1293.93	150	
1294.60	+ 14	Si III	4	1294.54	340	
1296.35	+ 5	C III	12.07	1296.33	200	
1296.60	0	N IV	18.86	1296.60	250	
	− 2	S IV	–	1296.61	200	B
1296.75	+ 7	Si III	4	1296.72	280	
1298.10	+ 16	Ca III	–	1298.03	600	
1300.70	0	Si III	54	1300.70 P	–	
1301.30	+ 37	Si III	4	1301.14	280	
1303.40	+ 18	Si III	4	1303.32	320	
1306.55	− 11	Ni IV	–	1306.60	100	
1307.90	− 7	Mg IV	–	1307.93	100	
1309.60	+ 11	N IV	18.55	1309.55	200	
1314.55	+ 11	Mg III	–	1314.50	–	
1317.60	− 20	Ca III	–	1317.69	550	
1318.00	− 16	Mg III	–	1318.07	12	
1320.85	0	Cr IV	–	1320.85	40	
1324.00	+ 5	N IV	18.81	1323.98	100	
1331.60	− 7	Mg IV	–	1331.63	30	?
1332.00	+ 22	Cr IV	–	1331.91	50	
1332.45	+ 2	Cr IV	–	1332.44	250	
1334.60	+ 4	C II	1	1334.53	800	
1335.75	+ 11	C II	1	1335.70	1000	
	+ 9	P III	–	1337.71	150	
1338.15	+ 20	Mn IV	–	1338.06	350	
1338.50	− 22	O IV	–	1338.60	200	
1339.00	− 16	Ni IV	–	1339.07	740	
1344.30	− 9	P III	1	1344.34	1000	
1345.05	+ 33	P III	1	1344.90	650	

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

Table I (continued)

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
1345.80	+35	Mg IV	–	1345.67	10	
1345.90	+20	N III	25.02	1345.81	200	
1346.35	−49	Mg IV	–	1346.57	800	
1350.00	−47	Ni IV	–	1350.21	650	
1352.00	−9	Mg IV	–	1352.04	600	
1353.80	+16	Al IV	–	1353.73	10	?
1356.85	−46	Ni IV	–	1357.06	760	
1358.45	−31	Mn IV	–	1358.59	450	
1361.45	+7	Fe V	–	1361.42	500	
1361.50	−22	Si III	46	1361.60	160	
1362.55	−4	Si III	17.72	1362.57	100	
1363.00	0	Fe V	–	1363.00	400	
1363.35	+12	Ni IV	–	1363.25	560	
1363.55	+22	Si III	38	1363.45	140	
1365.25	0	Si III	38	1365.25	160	
1365.60	+13	Si IV	19	1365.54 P	–	
1371.00	0	Fe V	–	1371.00	400	
1371.20	+28	Mg IV	–	1371.07	150	
1371.35	+13	O V	7	1371.29	800	
1371.75	+17	Ni IV	–	1371.67	580	
1372.15	+31	P III	–	1372.01	100	
1373.65	+20	Fe V	–	1373.56	600	
1376.30	−33	Fe V	–	1376.45	600	
1379.90	+7	P III	7	1379.87	500	
1380.40	−13	P III	7	1380.46	1000	
1381.10	−2	P III	7	1381.11	1000	
1384.20	−2050	Si IV	1	1393.76	1000	S, ?
1385.30	−4	Fe V	–	1385.32	200	
1385.90	+28	Mg IV	–	1385.77	500	?
1386.55	+30	Fe V	–	1386.43	50	?
1387.50	−4	Mg IV	–	1387.52	800	
1390.20	+43	Fe V	–	1389.97	50	?
1392.40	−290	Si IV	1	1393.76	1000	S, ?
1393.20	−2050	Si IV	1	1393.76	1000	S, ? + Si IV [1] ?
1393.75	−2	Si IV	1	1393.76	1000	is Si IV [1]
1397.55	−38	Ca III	–	1397.68	500	
1397.90	−49	S IV	–	1398.13	–	?
	+50	Fe V	–	1398.15	300	?
1398.90	+11	Mg IV	–	1398.85	30	
1400.10	+21	Fe V	–	1400.00	400	
1401.10	−11	O V	–	1401.15	60	?
1401.50	−260	Si IV	1	1402.77	800	S, ?
1402.30	−100	Si IV	1	1402.77	800	S, ?
1402.75	−4	Si IV	1	1402.77	800	is
1406.80	+4	Fe V	–	1406.78	700	
1407.30	−19	O IV	–	1407.39	25	?
1408.20	+2	Fe V	–	1408.19	100	
1409.20	+2	Fe V	–	1409.19	600	
1409.30	−45	Fe V	–	1409.51	700	
	−13	Mg IV	–	1409.36	1000	

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

Table I (continued)

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
1409.95	+ 23	N IV	–	1409.84	640	?
1410.25	+ 6	Si II	13.02	1410.22	20	?
1412.20	– 8	Al IV	–	1412.24	10	?
1417.15	– 17	Si III	9	1417.23	260	
1417.50	– 32	O V	–	1417.65	40	?
1417.85	– 11	O V	–	1417.90	80	
1418.10	– 42	O V	–	1417.90	80	?
1418.85	– 32	O V	–	1419.01	80	?
1420.20	– 40	Fe V	–	1420.39	300	
	– 40	O V	–	1420.39	120	
1424.45	– 36	Cr IV	–	1424.62	100	
	– 67	Si III	62	1424.77	40	
1424.95	– 11	Al IV	–	1425.00	10	?
1427.40	– 11	Ni IV	–	1427.45	400	
1430.10	– 17	Ni IV	–	1430.18	430	
1430.30	– 27	P III	–	1430.41	200	
1430.50	+ 15	Ni IV	–	1430.43	540	
	+ 19	P III	–	1430.41	200	
1432.80	+ 2	Mg IV	–	1432.79	50	
1433.50	– 40	Si III	66	1433.69	120	?
1434.90	+ 2	Mg IV	–	1434.89	150	?
1435.80	+ 2	Ni IV	–	1435.79	100	?
1437.75	+ 46	Mg IV	–	1437.53	500	
1438.50	+ 35	N IV	18.96	1438.37	150	?
1439.10	– 60	Si III	66	1439.39	40	
1441.70	– 6	Si III	3.05	1441.73	100	
1442.70	– 21	Mn IV	–	1442.80	80	
1444.15	+ 17	Mn IV	–	1444.07	100	
1444.45	+ 6	Ni IV	–	1444.42	440	
1445.85	– 52	N IV	18.85	1446.11	250	?
1451.60	– 31	Ti IV	3	1451.75	600	
1453.15	0	Ca III	–	1453.15	650	
1455.10	+ 29	Mn IV	–	1454.96	60	
1455.30	– 60	Fe V	–	1455.59	500	
1457.65	+ 19	Mn IV	–	1457.56	80	
1459.45	– 18	Mg IV	–	1459.54	300	
1459.90	+ 10	Fe V	–	1459.85	500	
1460.55	– 74	Fe V	–	1460.86	200	
1461.00	+ 29	Fe V	–	1460.86	200	?
1462.80	+ 27	Fe V	–	1462.67	300	
1464.85	+ 25	Fe V	–	1464.73	600	
1465.50	+ 27	Fe V	–	1465.37	300	
1466.45	+ 12	Fe III	–	1466.39	250	?
1467.30	– 10	Ti IV	3	1467.35	600	
1468.95	– 6	Fe III	–	1468.98	150	i
1469.10	– 22	Ti IV	3	1469.21	300	
1476.15	+ 26	Mn V	–	1476.02	30	
1479.30	+ 2	Fe V	–	1479.29	400	
1484.40	– 22	P IV	–	1484.51	240	?
1485.45	+ 2	Mg IV	–	1485.44	80	

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

1991Ap&SS.183...67L

Table I (continued)

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
	− 12	Si II	15.04	1485.51	100	
1486.20	− 12	Fe III	85	1486.26	450	?
1489.10	0	P IV	–	1489.10	160	?
1489.90	+ 30	Cr V	–	1489.75	500	
1490.40	− 10	Mg IV	–	1490.45	350	
1493.60	− 8	Fe III	85	1493.64	600	?
1496.10	+ 22	Mg IV	–	1495.99	60	?
1498.05	+ 6	Cr V	–	1498.02	700	
1499.85	− 54	Ni IV	–	1500.12	300	
1501.10	− 10	Si III	36	1501.15	–	
	− 18	Si III	36	1501.19	200	B
1501.50	− 10	P III	6	1501.55	700	i
1501.75	− 6	Si III	36	1501.78 P	–	
1503.50	+ 4	Ni IV	–	1503.48	310	?
1525.30	− 2	Ni IV	–	1525.31	710	
1525.85	+ 10	Fe III	–	1525.80	400	?
1526.80	+ 20	Si II	2	1526.70	500	
1528.00	− 26	Mn V	–	1528.13	120	
1531.15	− 27	Fe III	84	1531.29	400	
1531.50	− 27	Fe III	84	1531.64	550	
1532.75	− 10	Fe V	–	1532.80	400	
1533.30	− 25	Si II	2	1533.30	1000	
1538.45	− 35	Fe III	84	1538.63	650	
1538.60	− 1920	C IV	1	1548.18	1000	S ?
1539.10	− 6	Fe III	84	1539.13	550	
1541.30	− 1882	C IV	1	1550.77	950	S ?
1546.10	− 4	Fe III	84	1546.12	550	
1548.20	+ 4	C IV	1	1548.18	1000	is C IV [1]
1550.00	− 37	Fe III	84	1550.19	800	
1550.75	− 4	C IV	1	1550.77	950	
	+ 8	Fe III	84	1550.86	550	B
1551.35	+ 35	Fe III	84	1551.17	250	
1552.20	+ 27	Fe III	84	1552.06	550	
1557.20	− 8	Al IV	–	1557.24	250	?
1557.55	− 2	Fe III	–	1557.56	150	
1559.40	− 11	Fe III	–	1559.46	150	?
1569.25	− 4	Ni IV	–	1569.27	30	?
1572.60	− 21	Mg III	–	1572.71	400	
1577.70	− 42	Fe III	–	1577.92	150	?
1584.10	− 26	Fe III	–	1583.97	20	?
1589.00	− 4	P IV	–	1589.02	–	?
1592.40	+ 8	Mg III	–	1592.36	60	
	− 24	Mn IV	–	1592.53	300	B
1595.30	+ 21	Ca III	–	1595.19	450	
1597.65	+ 4	Fe III	–	1597.63	70	i
1602.90	+ 19	Cr IV	–	1602.80	–	?
1606.10	+ 17	Fe III	119	1606.01	200	?
		Mn IV	–	1606.11	150	
1611.20	− 4	Mg IV	–	1611.22	200	?
1620.00	− 13	C III	11.72	1620.07	300	

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

Table I (continued)

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
	− 61	C III	11.72	1620.33	200	B
1636.90	− 16	Si III	47	1636.99	20	?
1640.05	+ 4	Fe IV	–	1640.03	–	?
1651.55	− 24	Mn IV	–	1651.68	350	
1655.60	+ 9	Cr V	–	1655.55	250	
	+ 51	N V	49	1655.88	40	?
1672.40	+ 40	Fe IV	–	1672.18	–	?
1688.20	+ 16	N IV	20	1688.11	150	?
1695.25	+ 39	Fe III	–	1695.03	150	?
1698.25	− 78	Mn IV	–	1698.69	750	
1699.90	+ 4	N III	–	1699.88	200	
1703.40	+ 32	N V	45	1703.22	60	?
1710.40	+ 5	Fe III	–	1710.37	200	
1718.65	+ 17	N IV	7	1718.55	1000	N IV [7]
1720.40	− 21	Mn IV	–	1720.52	750	
1727.30	− 12	Si IV	10	1727.37	300	
1731.05	− 31	Cr IV	14	1731.22	100	
1731.65	− 5	Mn IV	–	1731.68	200	
1734.55	− 22	Cr IV	–	1734.68	60	
1738.90	+ 12	Mg III	–	1738.83	600	
	− 22	S IV	–	1739.03	50	
1745.90	+ 46	Fe III	–	1745.63	250	?
1747.70	− 27	N III	19	1747.86	450	
1748.90	− 5	Mg III	–	1748.93	500	
1751.15	− 15	N III	19	1751.24	300	
1751.60	− 8	N III	19	1751.65	500	
1760.00	− 20	O III	–	1760.12	700	
1760.60	+ 51	C II	10	1760.39	450	i
	+ 22	C II	10	1760.47	100	B
1761.10	+ 48	C II	10	1760.82	300	
1762.75	+ 24	Cr IV	13	1762.61	250	i
1764.35	− 22	O III	–	1764.48	700	
1767.80	+ 3	O III	–	1767.78	1000	
1768.15	− 15	O III	–	1768.24	900	
1769.30	− 3	O III	–	1769.32	400	
1773.75	− 17	O III	–	1773.85	500	
1780.90	− 22	O III	–	1781.03	600	
1783.20	− 8	Mg III	–	1783.25	550	
1795.70	+ 8	Mn IV	–	1795.65	800	
1795.90	+ 28	Mn IV	–	1795.78	800	
1800.20	+ 3	Mg IV	–	1800.18	200	?
1801.40	− 60	Fe III	–	1801.76	200	?
1805.50	0	N III	22	1805.50	350	
1808.15	+ 23	Si II	1	1808.01	150	
1821.90	+ 6	Fe III	–	1821.86	20	?
1826.20	+ 6	C IV	12	1826.16	150	
1830.70	+ 13	Fe III	117	1830.62	200	?
1835.55	+ 7	N III	–	1835.51	150	
1838.35	+ 8	Fe III	117	1838.30	450	?
1841.45	+ 26	Fe III	97	1841.39	200	?

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

Table I (continued)

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
1843.05	+21	Fe III	97	1842.92	300	?
1844.95	+2	Fe III	97	1844.94	200	
1845.70	+10	N III	–	1845.64	250	
	+11	O V	–	1845.63	40	B
1848.20	−10	O III	–	1848.26	500	
1849.85	−18	Fe III	53	1849.96	300	?
1854.35	−5	Fe III	97	1854.38	200	?
1854.90	+13	Fe III	63	1854.82	600	i
1855.50	−2	Fe III	–	1855.51	200	?
1858.50	−6	Fe III	63	1858.54	300	B
1868.70	−10	Si II	9.02	1868.76	1	?
1869.70	−19	Fe III	52	1869.82	650	
1870.75	−5	Si II	9.02	1870.78	3	?
1871.40	+14	Fe III	–	1871.31	150	i
1872.30	+14	Fe III	–	1872.21	400	?
1872.80	+3	O III	–	1872.78	800	
	−11	O III	–	1872.87	800	B
1873.35	−80	Cr IV	11	1873.86	125	
1875.05	+18	O III	–	1874.94	800	
1884.85	−33	N III	24	1885.06	–	
	−63	N III	24	1885.25	500	B
1886.50	−40	Fe III	52	1886.75	800	?
1887.10	−8	Mn IV	–	1887.15	350	i
1888.60	−8	P IV	5	1888.65	400	
1889.40	−8	Fe III	53	1889.45	300	?
1891.35	−25	Fe III	–	1891.19	200	i, ?
1894.50	0	Fe III	–	1894.50	200	?
1895.05	+11	Fe III	96	1894.98	250	?
1895.75	−47	Fe III	34	1895.45	1000	
1896.70	−16	Fe III	83	1896.80	600	?
1898.00	+24	Cl III	8	1897.85	300	
1899.25	−11	Fe III	96	1899.32	300	?
1900.90	−32	Fe III	95	1901.10	600	?
1901.80	+30	Cl III	8	1901.61	500	
1902.30	−16	Fe III	–	1902.40	400	?
1903.10	−24	Fe III	–	1903.25	200	?
1906.70	−17	Fe III	–	1906.81	400	?
1907.40	−27	Fe III	83	1907.57	650	?
1910.25	0	Mn IV	–	1910.25	750	
1910.50	+16	Fe III	57	1910.40	400	?
1914.14	+14	Fe III	34	1914.05	1000	
1915.65	−16	Fe III	57	1915.75	150	?
1916.70	+30	Fe III	95	1916.51	300	?
1917.50	+23	Fe III	95	1917.35	550	B
1919.20	+36	Fe III	–	1918.97	200	?
1920.95	+14	N III	29	1920.86	400	
1923.15	+23	Fe III	95	1923.00	450	?
	−2	C III	12.02	1923.16	200	B
1924.15	+6	Fe III	–	1924.11	250	?
1925.90	−17	Fe III	57	1926.01	500	?

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

1991Ap&SS.183...67L

Table I (continued)

λ_{mes}	RV	Ion	Mult.	λ_{lab}	Int.	Remarks
1927.30	− 20	Fe III	–	1927.43	300	?
1927.85	+ 28	Fe III	–	1927.67	150	?
1928.90	− 8	Mn IV	–	1928.95	200	
1929.45	+ 6	Fe III	–	1929.41	250	?
1930.45	+ 11	Fe III	51	1930.38	1000	?
1943.40	− 12	Fe III	51	1943.48	950	?
1945.35	+ 2	Fe III	61	1945.34	800	?
1950.30	− 5	Fe III	116	1950.33	650	i
1951.10	+ 15	Fe III	68	1951.00	800	?
1951.35	+ 6	Fe III	68	1951.31	200	i
1953.05	− 41	Fe III	68.82	1953.32	900	?
1953.70	+ 32	Fe III	68	1953.49	650	i
1954.00	+ 6	Si III	69	1953.97	–	?
1954.75	− 2	Fe III	–	1954.76	250	?
1955.00	+ 5	Fe III	116	1954.97	550	?
1957.30	+ 26	Fe III	–	1957.13	200	?
1964.75	− 3	Fe III	82	1964.77	550	?
1968.40	− 33	Fe III	–	1968.62	150	?
1972.10	− 21	Fe III	–	1972.24	150	?
1976.15	+ 5	Fe III	54	1976.12	550	?
1978.35	− 9	Fe III	54	1978.41	250	?
1980.45	+ 9	Fe III	–	1980.39	150	?
1982.90	+ 15	Fe III	56	1982.80	550	?
1983.65	+ 6	Cl III	–	1983.61	500	
	− 5	Fe III	81	1983.68	150	?, B

B = blended with the previous line, i = probable blends, ? = the proposed identification remains doubtful, S = satellite line, is = interstellar line.

neighbourhood of λ1550 Å, the N IV[7] in λ1718.55 Å and the Si IV[1] line in the neighbourhood of λ1400 Å.

Broad and asymmetrical absorption profiles are observed for the resonance lines of N IV, N V, C IV, and Si IV with blue edge velocities from 2000 to 3300 km s^{-1} ($\pm$ 50 km s^{-1}).

The Si IV λλ1393.75, 1402.75 Å, the C IV λλ1548.20, 1550.77 Å, the N V λλ1238.85, 1242.8 Å resonance lines and the N IV λ1718.55 Å line present a strong P Cygni profile.

The Si IV doublet is a complex feature (Figure 1). In this and the following three figures the wavelength λ is in Å, open dots are contamination by reseaux marks and 'f' symbolize echelle order superpositions. Morton and Underhill (1977) recognized in the COPERNICUS spectra one sharp and one broad component for each one of the two lines and a possible narrow component slightly displaced for the λ1402.77 line. The IUE feature agrees completely with the COPERNICUS except for the broad component at λ1387, which is deeper in the COPERNICUS spectrum. However, this is exactly the wavelength where Franco *et al.* (1983) detected variation of the profile of ζ Puppis and this should not worry us. A more complete picture of the whole doublet should recognize five absorption components and one emission for each line (Figure 1).

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

TABLE II

Unidentified lines in the spectrum of ζ Puppis
(λ in Å)

1170.40	1276.00	1413.60	1708.40
1170.50	1277.90	1415.50	1709.40
1170.65	1281.70	1415.90	1713.25
1184.85	1282.20	1416.15	1713.90
1186.00	1283.85	1422.05	1715.10
1188.40	1284.60	1422.60	1717.75
1189.25	1285.70	1429.65	1723.50
1191.70	1287.45	1429.80	1723.65
1198.90	1290.65	1437.20	1724.00
1202.90	1293.00	1442.80	1727.95
1203.05	1295.35	1445.20	1728.80
1208.75	1297.00	1446.35	1729.35
1214.70	1297.60	1453.30	1735.95
1216.50	1300.15	1453.60	1736.25
1216.95	1302.65	1453.90	1737.10
1217.40	1305.15	1458.15	1774.55
1217.80	1306.20	1462.35	1777.35
1219.50	1311.10	1463.55	1777.90
1221.40	1313.75	1464.25	1794.30
1221.55	1314.15	1472.45	1798.45
1231.70	1324.65	1474.90	1798.70
1232.50	1325.20	1475.50	1804.80
1232.70	1326.15	1476.35	1815.40
1236.75	1326.80	1478.80	1816.00
1239.15	1328.20	1485.10	1816.65
1239.50	1328.40	1488.80	1823.40
1239.70	1331.00	1489.40	1824.50
1241.50	1332.15	1489.60	1851.50
1243.60	1339.40	1496.30	1860.80
1248.10	1340.90	1497.60	1868.20
1249.55	1346.45	1500.75	1869.00
1252.35	1348.20	1522.75	1871.85
1253.10	1352.35	1530.60	1873.75
1253.15	1353.40	1554.80	1874.00
1255.30	1368.30	1563.65	1885.45
1257.85	1378.20	1565.80	1934.80
1258.30	1378.20	1606.30	1938.20
1262.85	1379.10	1616.80	1941.00
1265.50	1380.75	1631.70	1942.15
1265.95	1383.60	1636.60	1945.60
1266.15	1391.90	1644.30	1968.20
1269.90	1395.55	1676.55	1970.00
1272.45	1402.30	1680.95	1972.50
1272.90	1407.70	1681.20	1973.20
1273.20	1410.45	1685.25	1976.55
1274.10	1412.30	1704.80	1982.40

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

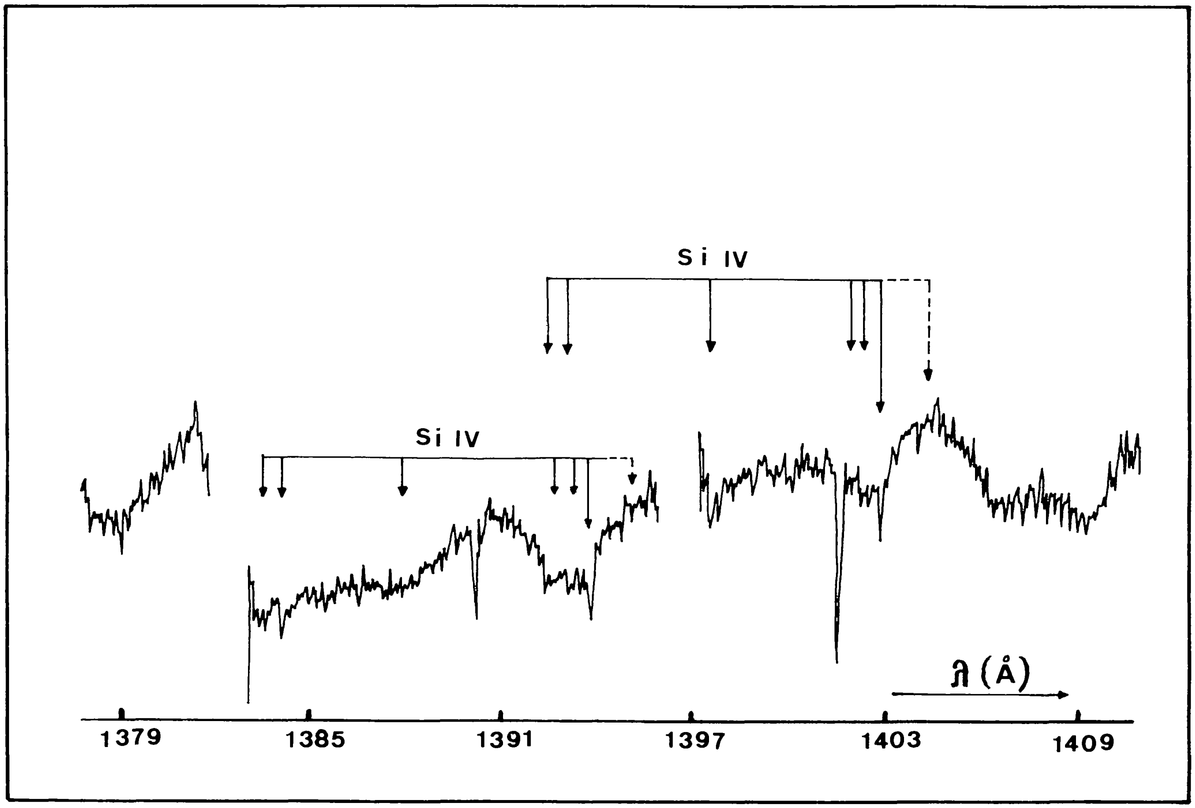

Fig. 1. The structure of the Si IV [1] doublet. 'f' symbolizes echelle order superpositions. Open dots are contamination by reseaux marks. The longer arrows give the unshifted components of the two lines. Shorter arrows give the positions of the identified absorption and emission components of the two lines. Dashed line shows the assumed position of the emission component of the first line.

If the above picture is correct it should be also present in the other resonance lines of ζ Puppis. Figure 2 gives the structure of the N V [1] doublet. As in Figure 1 the longest arrows point to the laboratory positions of the two resonance lines (λ1238.82 and 1242.80) and the other shorter arrows to the assumed positions of the absorption and emission components possibly recognized in Figure 1. The emission of the first line is given by the dashed arrow since it is not possible to be recognized. All other positions seem plausible given the heavy blending. The position of the emission component of the second line is properly found and only the position of the broad absorption component of the first line with the smaller wavelength seems somewhat overestimated by 2 Å.

Figure 3 gives the profile of the C IV doublet. As previously the longer arrows indicate the laboratory positions of the λ1548 and λ1551 lines, while all other arrows indicate again the spacing of the absorption and emission components assumed in Figure 1 for Si IV. The positions of the emission line as well as of the sharp interstellar absorption components are the proper ones while those of the other components seem plausible. The position of the broad absorption component of the line with the smaller wavelength seems this time underestimated by 1.53 Å.

Figure 4 gives the profile of the N IV [7] λ1718.55 resonance line with the spacing of

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

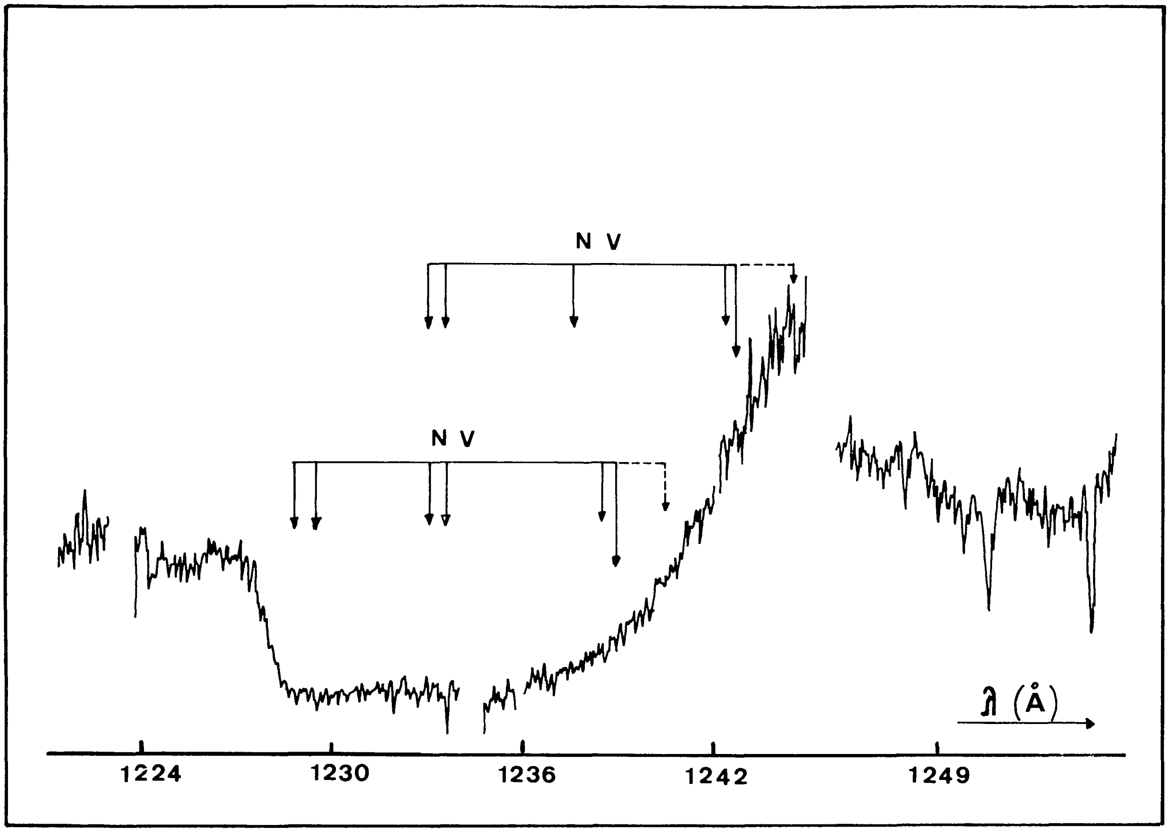

Fig. 2. The structure of N V [1] doublet. The markings are similar to those in Figure 1. The spacing of the absorption and emission components is that assumed for the Si IV lines in Figure 1.

the absorption and emission components deduced in Figure 1. In this case, however, the emission component is displaced to higher wavelengths by about 2.15 Å.

These four figures could fit into the model with the radial sequence of atmospheric regions of Doazan and Thomas (1982) with the more specific regions discussed by Franco *et al.* (1983).

A list of the lines of high ionization with a P Cygni profile is given in Table III, where the successive columns give:

(1) The laboratory wavelength in Å.
(2) The identification of the principal ion contributing to the line.
(3) The low ionization potential in eV.
(4) The measured velocity in km s^{-1} of the emission peak.
(5) The measured velocity in km s^{-1} of the absorption core, and
(6) The blue edge velocity of the shortward absorption component in km s^{-1}.

In the second part of Table III the blue edge velocities of two lines of low ionization potential are given to help us plot Figure 5, which gives the blue edge velocities of these two lines as well as the same velocities for the lines with a P Cygni profile versus the ionization potential in eV.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

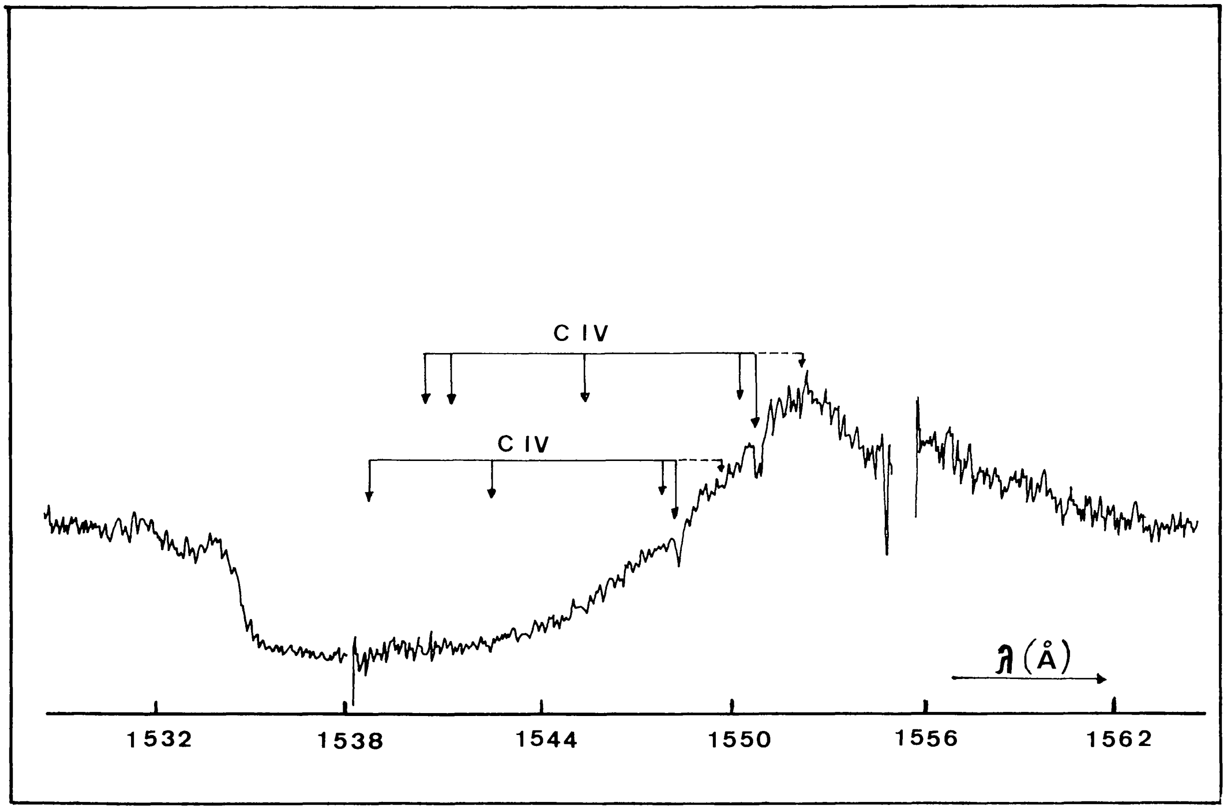

Fig. 3. The structure of C IV [1] doublet. The markings are similar to those in Figure 1. The spacing of the absorption and emission components is that assumed for the Si IV lines in Figure 1.

3.2. The observed spectrum

The spectrum is dominated by shell absorption lines. Most of them present narrow absorption cores blended with the corresponding interstellar lines. Table IV gives the average radial velocities of all the lines with reasonable identificaiton in this spectrum of ζ Puppis. In this table the first column gives the ion, the second the low ionization potential in eV, the third the average radial velocity in km s^{-1} and the fourth the standard error S.E. also in km s^{-1}. The next three columns give the total number of lines of this particular ion identified in this spectrum (Tt), the number of classified lines among them (Cl) and the number of lines finally included in the average (In) since some of the identified lines presented radial velocities exceeding the value of 1.6σ (σ is the standard error S.E.).

Below we present a summary of the relevant atomic species and some comments on their presence or absence are given.

– Hydrogen

H I: This ion is probably present as a part of a blend with Lα.

– Helium

He II: Lines of this element are present.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

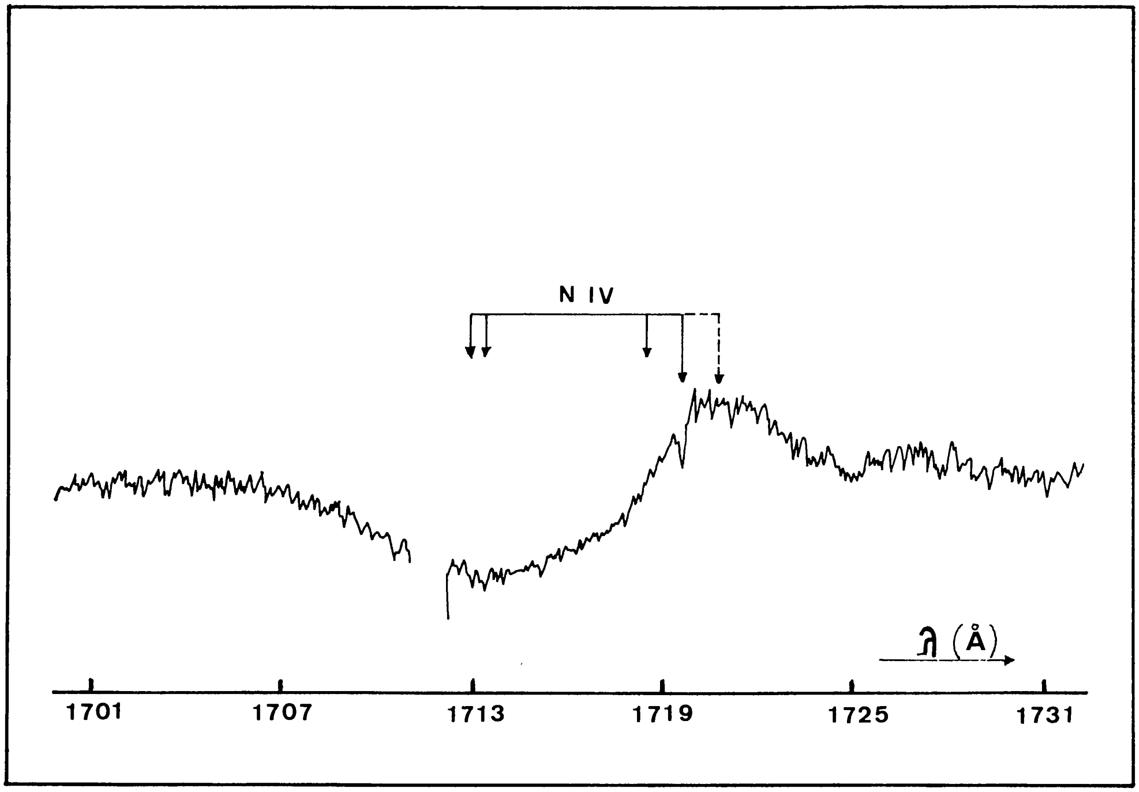

Fig. 4. The structure of N IV [7] resonance line. The markings are similar to those in Figure 1. The spacing of the absorption and emission components is that assumed for the Si IV lines in Figure 1.

– Carbon

C I: This ion is absent.

C II: This ion is not present. The two resonance lines of C II at λλ1334.60 and 1335.75 Å are not present as photospheric lines.

C III: This ion is probably present. Lines of the multiplet 4 are clearly seen at λλ1175.30, 1175.70, 1176.00, and 1176.40 Å.

The intercombination line at 1908.734 Å is not present in absorption or emission.

C IV: This ion is present in the shell and in the photosphere. The C IV doublet at 1550 Å presents the complex structure described earlier. All possible lines in our spectral range that are not masked by strong features have been detected.

– Nitrogen

N III: This ion is present in the photospheric spectrum.

N IV: This ion is present in the photosphere, all of the strongest lines being found. The N IV line at 1718 Å presents the complex structure described earlier. The resonance lines do not fall in the accessible spectral range, but the resonance line of multiplet 7 at 1718.65 Å, which arises from a metastable level at 16.20 eV, is shortward displaced and comes from the expanding atmosphere. The intercombination line at λ1486.496 Å is not present in absorption or emission.

N V: The N V resonance lines are present as strong shortward-displaced absorption

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

TABLE III

Lines of high ionization with a P Cygni profile

λ_{lab} Å	Ion	i.p. (eV)	Emission peak (km s^{-1})	Absorption core (km s^{-1})	R.V. (km s^{-1})	b.e.v. (km s^{-1})
1393.75	Si IV			1393.20	−118	
				1392.70	−333	
				1388.40	−1156	−273 ± 15
		33.94		1384.20	−2070	
				1383.60	−2201	
1402.77	Si IV		+363 ± 60	1402.30	−100	
				1401.85	−196	
				1397.55	−1125	−165 ± 20
				1393.20	−2050	
				1392.40	−2222	
1718.55	N IV	47.45	+377 ± 100	1713.30	−919	
				1712.90	−989	−2365 ± 290
1548.185	C IV			1547.90	−55	
				1542.35	−1143	−3040 ± 290
		47.89				
				1538.65	−1857	
1550.77	C IV		+484 ± 120	1550.30	−77	
				1545.30	−1048	
				1541.20	−1863	
				1540.30	−2039	
1238.82	N V			1238.55	−66	
				1233.55	−1282	−3260 ± 200
				1229.50	−2152	
				1228.90	−2432	
		77.47				
1242.80	N V		+484 ± 120	1242.55	−60	
				1237.55	−1273	
				1233.55	−2250	
				1233.00	−2384	
Some blue edge velocities (b.e.v. in km s^{-1}) for lines with low ionization potentials						
1335.70	C II	11.26				−91 ± 20
1206.53	Si III	15.34				−231 ± 50

lines with longward-displaced emission components. The N V doublet at 1240 Å presents the multiple structure described earlier.

– Oxygen

O III: This ion is present. Eleven of the 27 strong lines between 1760 and 2000 Å are present.

O IV: This ion is possibly present. Only 1 line of O IV at λ1338.60 Å is present, which shows a small displacement and additional absorption in the short wavelength wings.

The line of O IV at λ1343.46 Å is not recorded.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

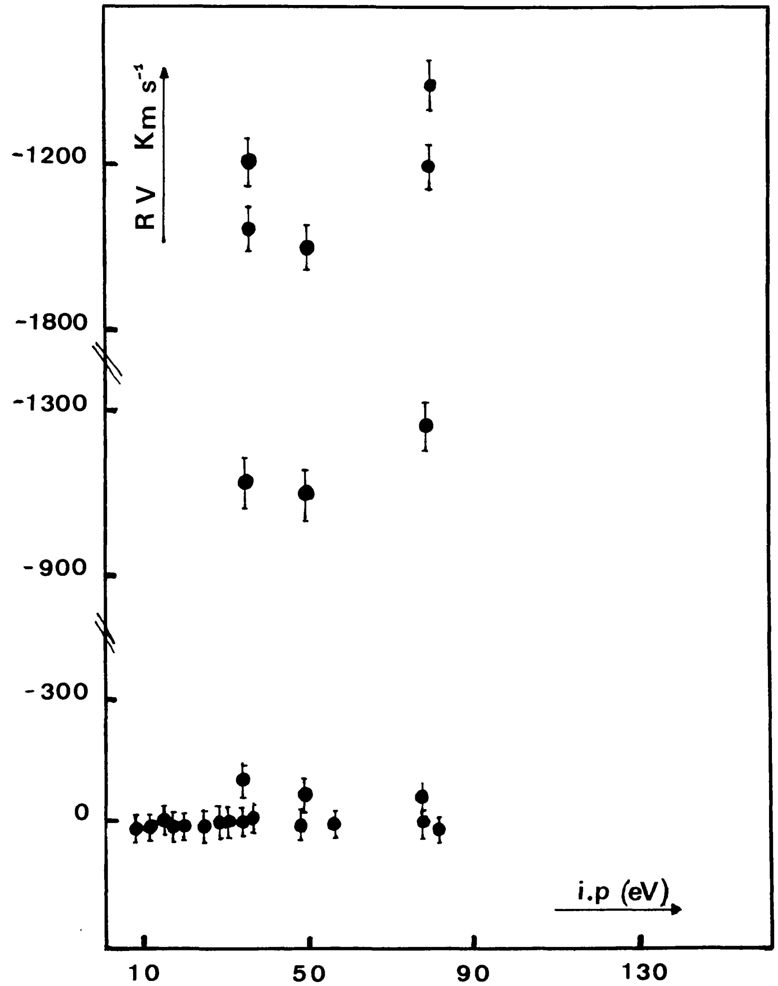

Fig. 5. The relation between the mean blue edge velocity (b.e.v.) in km s^{-1} of each component of the lines in Table III versus the ionization potential (i.p.) in eV.

O V: This ion is probably present.

The strong line of O V at λ1371.35 Å of multiplet 7, which has a lower E.P. of 19.69 V, may be present as a part of a blend with Mg IV and Fe V. It appears that this line has an extended short-wavelength wing due to the expanding envelope. Four lines of O V of a multiplet in the neighbourhood of λ1418 Å are also detected.

The intercombination line from the ground state at λ1218.406 Å is not present in absorption or emission.

– Neon

Ne III: This ion is possibly absent. Only 1 line at λ1255.68 Å of the three listed near λ1256 Å is found. (However, one of them is not recorded in our spectrum because of a gap in the vicinity.)

– Magnesium

Mg III: This ion is probably present. The 5 stronger lines of intensity ≥ 350 listed by Kelly and Palumbo (1973) have been identified.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

TABLE IV

Average velocities of lines of ζ Pup

Ion	i.p. (eV)	RV S.E. (km s^{-1})	No. of lines Tt	Cl	In
Si II	8.15	+7 ± 13.6	14	14	12
Ca III	11.87	+3 ± 13.8	11	0	10
Mg III	15.04	−3 ± 12.3	7	0	7
Fe III	16.18	−1 ± 16.1	82	51	69
Si III	16.35	−3 ± 14.8	22	22	19
P III	19.73	+4 ± 14.5	10	6	8
C III	24.38	+2 ± 6.7	9	9	8
Al IV	28.45	−2 ± 9.6	7	0	6
N III	29.60	−4 ± 16.7	13	10	11
P IV	30.18	−4 ± 18.7	7	1	7
Cr IV	30.96	−3 ± 22.7	9	3	8
Mn IV	33.66	−1 ± 21.0	23	0	22
O III	35.12	−11 ± 9.1	11	0	10
Ni IV	35.17	0 ± 11.2	15	0	12
N IV	47.45	+3 ± 14.0	23	21	21
Fe V	54.80	−6 ± 22.7	24	0	21
O V	77.41	−15 ± 20.0	7	0	7
Mg IV	80.14	+2 ± 13.0	21	0	18

i.p. = low ionization potential, RV = radial velocity, Cl = classified, In = lines included in the average velocity, Tt = total number of lines examined.

Mg IV: This ion is probably absent. Only 8 lines, 5 of which are blends with other ions, have been found. Absorption lines from Mg IV would be week owing to the high lower E.P. of most lines.

– Aluminium

Al IV: This ion is not present. Kelly and Palumbo (1973) list 49 lines between 1118 and 1881 Å, but only one (at λ1240.80 Å) coincides.

– Silicon

Si II: This ion is absent. Most of the major lines are not found. Evidence is found for lines of only 4 multiplets. Coincidences are listed in Table I for the following lines: 1 line at λ1250.40 Å of multiplet 13.05, 3 lines at λλ1261, 1264.80, and 1265.10 Å of multiplet 4, 1 line at λ1485.45 Å of multiplet 15.04 and 1 line at λ1533.30 Å of multiplet 2 in the wing of C IV.

The level of ionization of Si II is low for appearance in the spectrum of ζ Puppis.

Si III: This ion is possibly present. A few strong lines seem to appear but many are missing. All possible coincidences with Si III lines are entered in Table I.

The intercombination line from the ground state at λ1892.233 Å is not present in absorption or emission.

Si IV: This ion is present. The 2 resonance lines of Si IV at λλ1393.85 and 1402.80 Å are present in a complex structure described earlier in the text.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

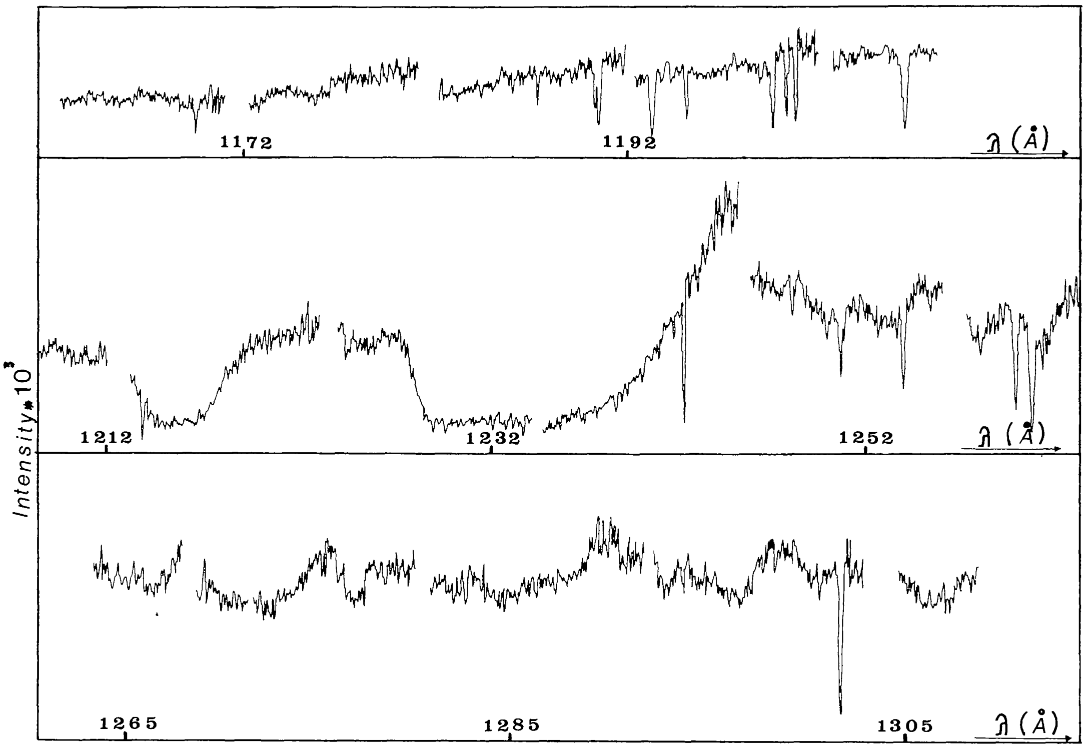

Fig. 6. The observed spectrum from 1150 to 1310 Å.

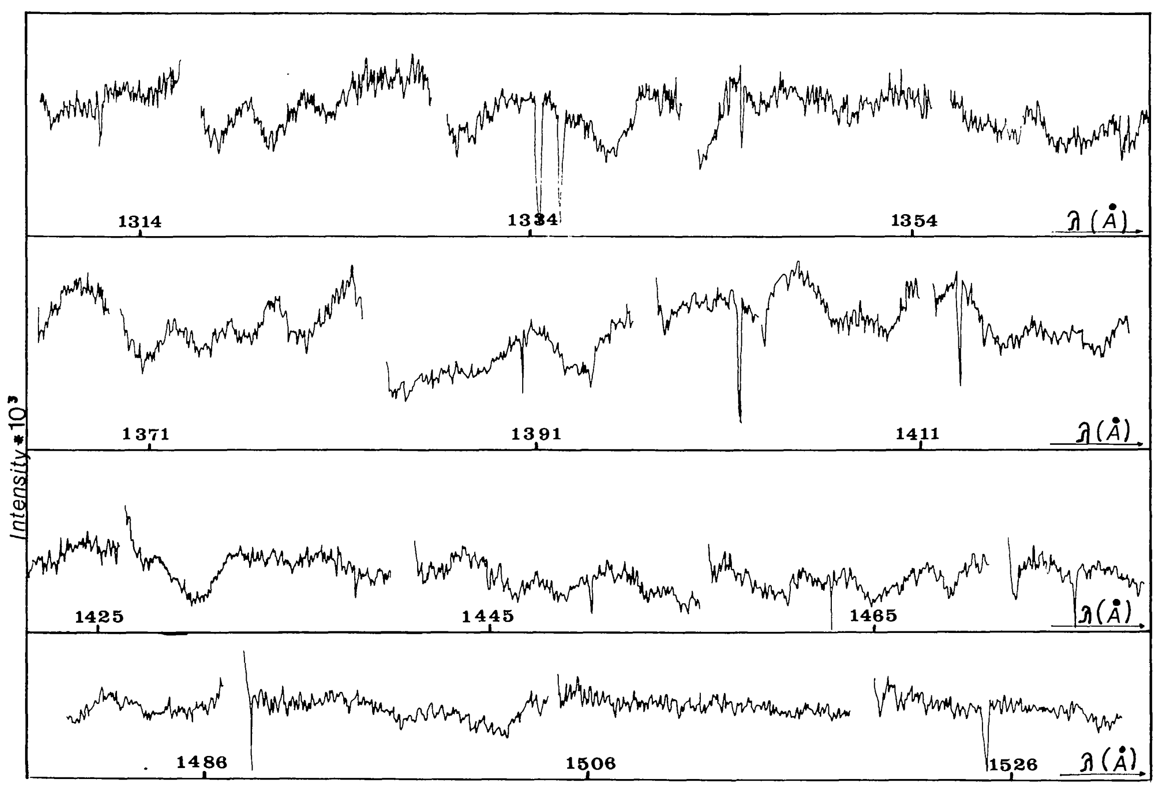

Fig. 7. The observed spectrum from 1310 to 1530 Å.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

– Phosphorus

P III: This ion is possibly present. Coincidences are found with 3 weak lines out of 5 of intensity 1000 in the 1344–1700 Å spectral region. No lines are listed longward of 1700 Å.

P IV: This ion is probably present. Coincidences with 4 lines are found and given in Table I.

– Sulphur

S III: This ion is possible present. Coincidences with 3 out of 6 lines listed of multiplet 1 are recorded in Table I.

S IV: This ion is possible present.

S V: No lines are known in the observed wavelength range.

– Chlorine

Cl III: This ion is probably absent. Only 3 lines are found and recorded in Table I.

– Argon

Argon is absent.

– Calcium

Ca III: This ion is not present. Many strong lines are listed in the observed region and only 5 coincidences with lines of intensity ≥ 500 are recorded.

– Titanium

Ti IV: This ion is possibly present. Kelly and Palumbo (1973) list 5 lines in the range 1183–1470 Å and 4 of them are probably identified in ζ Pup.

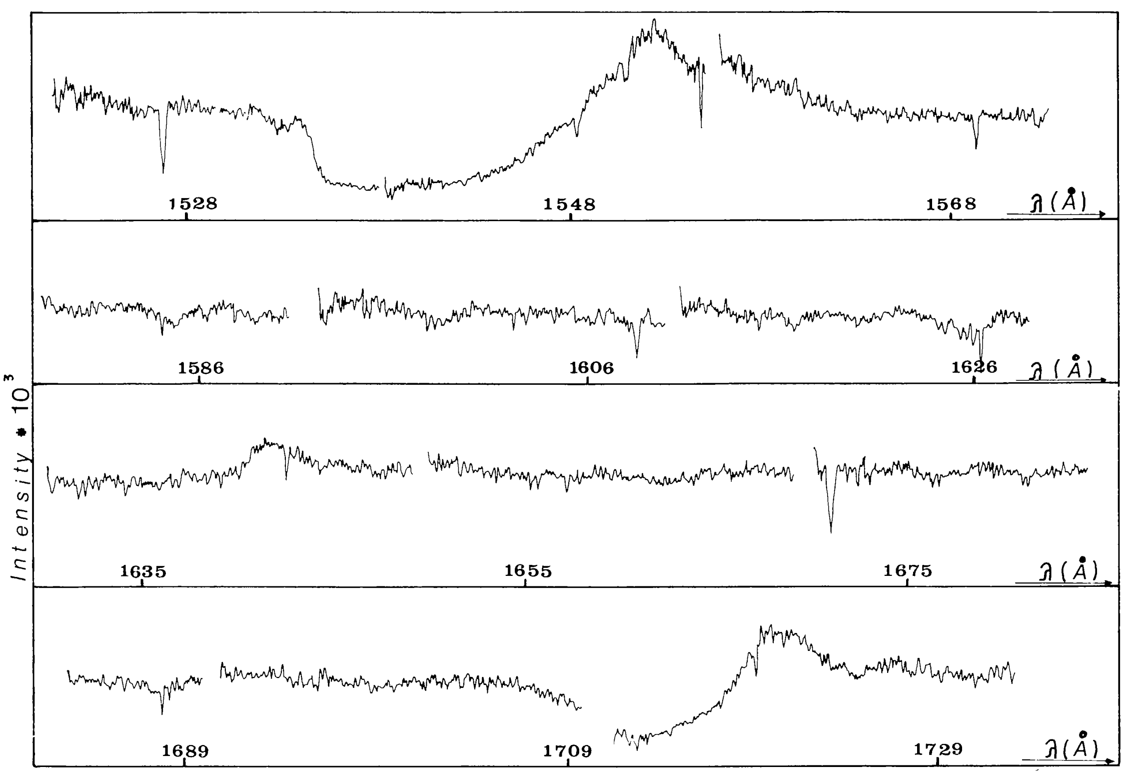

Fig. 8. The observed spectrum from 1530 to 1735 Å.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

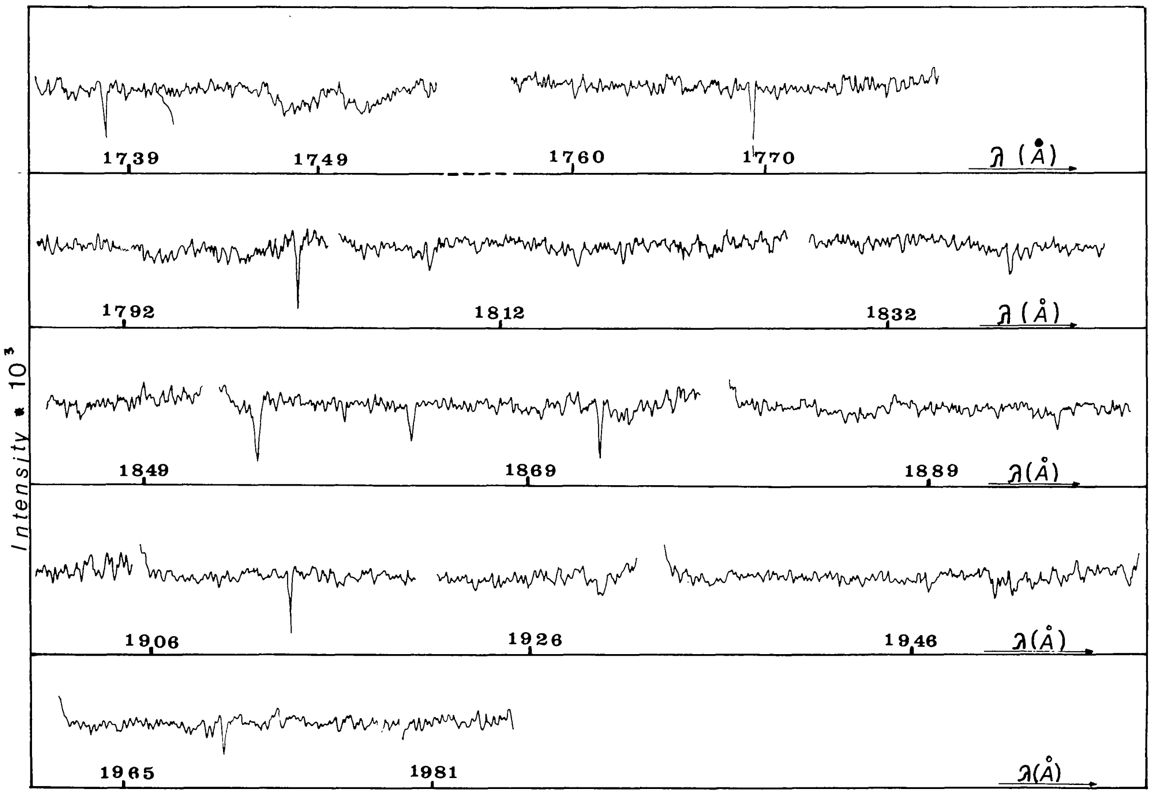

Fig. 9. The observed spectrum from 1735 to 2000 Å.

– Vanadium

Vanadium is not present.

– Chromium

Cr III: This ion is not present.

Cr IV: This ion is probably not present. Laboratory spectra reveal strong lines in the observed region. Coincidences with 8 lines are entered in Table I.

Cr V: This ion is possibly not present. Coincidences with only 3 lines are entered in Table I.

– Manganese

Mn IV: This ion is possibly present. Many strong lines are known in the studied region and coincidences are recorded with 22 of these.

Mn V: This ion is not present. Eight strong lines are known in the region 1431–2000 Å and only 2 of these (λλ1476.15 and 1528.00 Å) are found.

– Iron

Fe III: This ion is possibly present. The 9 weak lines of multiples 34 and 84 are found.

Fe IV: This ion is probably not present. Kelly and Palumbo (1973) list no lines in the range 923–2000 Å, while Striganov and Sventitskii (1968) list 67 lines between λλ1254 and 1826 Å. Coincidences occur with only two of these at λλ1640.05 and 1672.40 Å, but most are possible blends with lines of other ions.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

Fe V: This ion is present. Kelly and Palumbo list 45 strong lines between λλ1302 and 1554 Å. Most of them are present or masked by strong absorption lines of other ions.

– Nickel

Ni IV: This ion is possibly present. Twelve coincidences occur out of the 32 stornger lines listed between λλ1306 and 1829 Å.

Ni IV: This ion is possibly not present. Ten lines are known between λλ1123 and 1520 Å. Coincidence occur with only the strongest one at 11244.0 Å, which is also masked by the N V shortward-displaced absorption.

There is no evidence of elements heavier than nickel.

We could summarize our conclusions about the atomic and ionic spectra visible in the ultraviolet spectrum of ζ Pup as:

(1) H I, He II, C III, C IV, N III, N IV, N V, O III, Mg III, Si IV, P IV, and Fe V are present or probably present in the photospheric spectrum.

(2) O V, Si III, P III, S III, S IV, Ti IV, Mn IV, Fe III (?), and Ni IV are possibly present in the photosphere.

(3) C II, Ne III, Mg IV, Al IV, Si II, S V, Cl III, Ar, Ca III, V, Cr III, Cr IV, Cr V, Mn V, Fe IV, and Ni V are probably absent.

Acknowledgements

The authors would like to express their gratitude to Dr R. Stalio for suggesting the subject and providing the IUE tapes for them. They also thank Mrs Julia Nicolaou for making the intensity tracings from these tapes in the Observatory of Trieste.

References

Auer, L. H. and Mihalas, D.: 1972, *Astrophys. J. Suppl.* **24**, 193.
Baschek, B. and Scholz, M.: 1971, *Astron. Astrophys.* **15**, 285.
Brune, W. H., Mount, G. H., and Feldman, P. D.: 1979, *Astrophys. J.* **227**, 884.
Burton, W. M., Evans, R. G., Griffin, W. G., Lewis, G., Paxton, H. J. B., Sheaton, D. B., Macchetto, F., Boksenberg, A., and Wilson, R.: 1973, *Nature (Phys. Sci.)* **246**, 37.
Burton, W. M., Evans, R. G., and Griffin, W. G.: 1975, *Phil. Trans. Roy. Soc. London* **279**, 355.
Carruthers, G. R.: 1968, *Astrophys. J.* **151**, 543.
Code, A. B., Davis, J., Bles, R. C., and Hanbury Brown, R.: 1976, *Astrophys. J.* **203**, 417.
Conti, P. S.: 1976, *Mem. Soc. Sci. Liège* **IX**, 6e série, 193.
Conti, P. S. and Leep, E. M.: 1974, *Astrophys. J.* **193**, 113.
Doazan, V. and Thomas, R. N.: 1982, *B-Stars with and without Emission Lines*, NASA-CNRS Monograph Series.
Franco, M. L., Kontizas, E., Kontizas, M., and Stalio, R.: 1983, *Astron. Astrophys.* **122**, 9.
Heap, S.: 1972, *Astrophys. Letters* **10**, 49.
Holm, A. V. and Cassinelli, J. P.: 1977, *Astrophys. J.* **211**, 432.
Kelly, R. L.: 1979, *Atomic Emission Lines in the Near Ultraviolet,* NASA, TM 80268.
Kelly, R. L. and Palumbo, L. J.: 1973, *Atomic and Ionic Emission Lines below 2000 Å*, N.R.L. Report 7599, Washington.
Lamers, H. J. G. L. M. and Morton, D. C.: 1976, *Astrophys. J. Suppl.* **32**, 715.
Lesh, J. R.: 1972, *Astron. Astrophys. Suppl. Ser.* **5**, 129.
Moore, C. E.: 1962, *NBS Circ.* **488**, 1–4.
Morton, D. C.: 1976, *Astrophys. J.* **203**, 386.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System

1991Ap&SS.183...67L

Morton, D. C. and Underhill, A. B.: 1977, *Astrophys. J. Suppl.* **33**, 83.
Morton, D. C., Jenkins, E. B., and Brooks, N. H.: 1969, *Astrophys. J.* **155**, 875.
Smith, A. M.: 1970, *Astrophys. J.* **160**, 595.
Snijders, M. A. J. and Underhill, A. B.: 1975, *Astrophys. J.* **200**, 634.
Stecher, T. P.: 1970, *Astrophys. J.* **159**, 543.
Striganov, A. R. and Sventitskii, N. S.: 1968, *Tables of Spectral Lines of Neutral and Ionized Atoms,* IFI/Plenum Data Corporation, New York.
Walborn, N. R.: 1972, *Astron. J.* **77**, 312.

© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System