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PG 1323−086 and PG 1704+222 – two post-AGB stars at high galactic latitudes

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Abstract. Two high galactic latitude B-type stars, PG 1323−086 and PG 1704+222, are analysed from low and medium resolution optical spectra and Strömgren photometry. A differential abundance analysis for He, C, N, O, Mg, Al, and Si reveals that the He abundance is close to solar while metal underabundances relative to the solar value of typically 1.3 and 1.2 dex for PG 1323−086 and PG 1704+222, respectively, are found. For both stars, carbon is even more depleted. The atmospheric parameters are consistent with evolutionary tracks for stars evolving from the asymptotic giant branch (AGB) with a stellar mass of 0.55 $M_\odot$. The anomalous compositions are compatible with those of other high galactic latitude post-AGB stars. Hence, PG 1323−086 and PG 1704+222 are low mass post-AGB stars in an evolutionary stage between those of A- and F-type supergiants of low mass and central stars of planetary nebulae. From kinematic data and distances a population II membership is probable for both stars.

Key words: stars: abundances – stars: AGB and post-AGB – – stars: evolution – stars: individual: PG 1323-086; PG 1704+222

1. Introduction

In a long-term project we have followed-up spectroscopically on hot subdwarf candidates from the “Palomar-Green Catalogue of Ultraviolet Excess Stellar Objects” (Green et al., 1986). While most objects turned out to be hot subluminous stars (Moehler et al., 1990b, Theissen et al., 1993) or blue horizontal branch stars (Schmidt et al., 1992) a few candidates showed surface gravities too low for such stars and more typical for giant stars. In addition these objects exhibit normal helium line strengths, again in contrast to the usually helium weak-lined hot subdwarfs.

The normality of the H/He spectrum might indicate that these stars are normal, i.e. massive giants in a strange place, very far from the galactic disk. In this case they were either created in the disk and thrown out (cf. Leonard, 1991) or they were born in the halo (which could be explained by the model of the “galactic fountain”, Dyson & Hartquist, 1983). On the other hand, such stars could be post-AGB stars on their way from the asymptotic giant branch (AGB) to the white dwarf domain that spectroscopically mimic massive stars. Since this part of the evolution proceeds very fast (10^4 years, Schönberner, 1983), such objects should be rather rare. Indeed, not many have been found and analysed so far (Conlon et al., 1991, 1993a).

Since a metallicity analysis offers a good possibility to distinguish between young, massive OB stars and post-AGB stars we decided to get higher resolution (about 1 Å) spectra of some of these stars. Here we report the results for two objects, PG 1323−086 and PG 1704+222. Lower resolution spectra of PG 1704+222 have already been discussed by Conlon et al. (1993a). In addition to these stars we observed spectra of well known and analysed main-sequence and sub-giant OB stars to allow direct comparisons between the spectra. In Sect. 2 we describe the observations and the reduction of the data. Sects. 3 and 4 describe the determination of atmospheric parameters and abundances. Sect. 5 gives the kinematic data of the stars, while Sect. 6 gives a discussion of the results.

2. Observations and reduction

The observations and reduction of medium resolved spectra are described in Moehler et al. (1990a, PG 1323−086) and Conlon et al. (1993a, PG 1704+222). The higher resolved data were obtained with the Cassegrain Twin Spectrograph of the 3.5m telescope at the Calar Alto observatory, using a slit-width of 2.1″ and a mean dispersion of 18 Å/mm in the blue and of 36 Å/mm in the red channel. Both channels were equipped with Tektronix CCDs with 1024 × 1024 pixels of 24 μm size. Read-out-noise and gain were 9 e^- and 4.5 e^-/ADU in the blue and 8 e^- and 4.5 e^-/ADU in the red channel. With this setup we covered the wavelength range 3850 Å – 4710 Å in the blue channel with two exposures and in the red channel we used the wavelength range 5850 Å – 6720 Å. The mean FWHM of the calibration lines was about 0.9 Å and 1.8 Å for the blue and red channel, respectively, and represents the typical spectral resolution of the system.

The observations and data reduction were performed as described by Moehler et al. (1995) except that we did not use any

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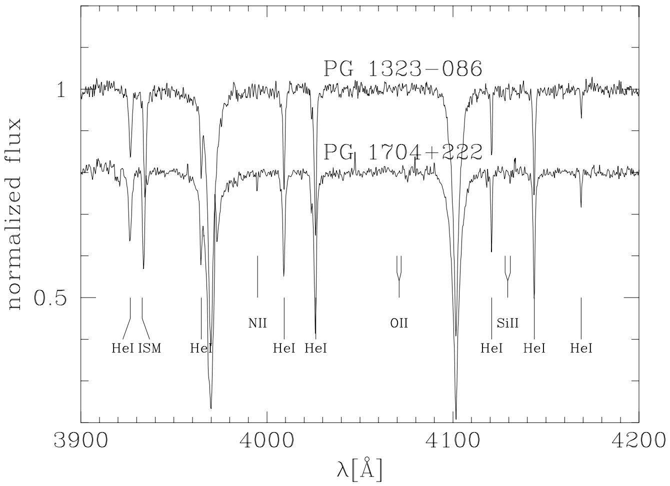

Fig. 1. Part of the blue spectra of PG 1323−086 and PG 1704+222. Those spectral lines that could be identified are marked.

optimal extraction algorithm, as the spectra were tilted on the CCD. Instead we summed up the rows of each spectrum after sky-subtraction and tried to get rid of cosmic events by comparing several spectra of the same object. Finally the spectra were corrected for the Doppler shifts and coadded. The resulting mean radial velocities are listed in Table 5. To give an idea of the quality of our spectra we show part of them in Fig. 1.

3. Physical parameters

For both stars Strömgren photometry is available from the literature (Wesemael et al. 1992), which can be used in combination with the observed Balmer line profiles to derive effective temperatures and surface gravities for these objects.

$T_{\rm eff}$ and $\log g$ were derived from the reddening-free indices [c_1] and [u−b]. Since post-AGB stars tend to show sub-solar metallicities (see McCausland et al., 1992) we used theoretical colours for metallicity −1 (Napiwotzki & Lemke, priv. comm., a recent extension of the Napiwotzki et al., 1993, calibration to lower metallicities). We also fitted theoretical ATLAS9 Balmer line profiles for metallicity −1 and solar helium abundance to the H_δ to H_β lines (keeping $T_{\rm eff}$ fixed), which yielded another set of $T_{\rm eff}$, $\log g$ values. The intersection of the curves shown in Fig. 2 resulted in the parameters listed in Table 1. The He I lines are fitted very well by these models, suggesting a close to solar helium abundance.

As a cross check we also derived the physical parameters from the line profiles only, using the routines of Bergeron et al. (1992) and Saffer et al. (1994), which employ a χ^2 test. We computed model atmospheres using ATLAS9 (Kurucz 1991, priv. comm.) and used the LINFOR program (developed originally by Holweger, Steffen, and Steenbock at Kiel university) to compute a grid of theoretical spectra, which include the Balmer lines H_α to H_{22} and He I lines. We fitted H_ϵ to H_β and the He I lines λλ 4026, 4121, 4388, 4437, 4471 simultaneously. As can be seen from Table 1 the values are very similar for both procedures.

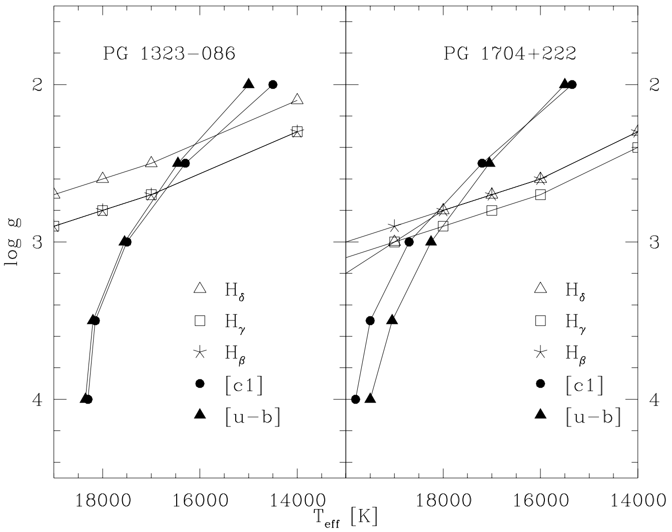

Fig. 2. The range of physical parameters resulting from Strömgren photometry (Wesemael et al., 1992) and from fits to the Balmer lines.

Table 1. The physical parameters for the programme stars and the calibration star.

Name	$T_{\rm eff}$ [K]	log g	$\log \frac{N_{He}}{N_H}$
PG 1323−086	16000[1]	2.50[1]	−1.00[4]
	15700[2]	2.35[2]	−0.83[2]
	17500[3]	2.65[3]	−1.00[4]
PG 1704+222	18000[1]	2.80[1]	−1.00[4]
	17200[2]	2.65[2]	−0.94[2]
HR 6588[5]	17700[1]	3.90[1]	−1.23

[1] from Strömgren photometry and Balmer lines
[2] from Balmer and He I lines only
[3] $T_{\rm eff}$ from Si II/Si III, $\log g$ from the Balmer lines
[4] He abundance kept fixed
[5] Hambly et al. (1997)

A third approach to derive $T_{\rm eff}$ is to use the Si II/Si III ionization equilibrium, which is applicable only to PG 1323−086 and results in $T_{\rm eff}$=17500 K, somewhat higher than the other values. This is a well known phenomenon discussed e.g. by Hambly et al. (1997), who derive 21000 K for HR 6588 from the Si II/Si III ionization equilibrium as opposed to 17700 K from Strömgren photometry.

For the further analysis we use the values derived from Strömgren photometry and Balmer lines, as the temperature information is more reliably described by Strömgren photometry at the low gravities involved, and keep the helium abundance fixed at $\log \frac{N_{He}}{N_H} = -1.00$.

In Fig. 3 the physical parameters are compared to post-AGB tracks from Schönberner (1983) and Blöcker & Schönberner (1990). Also shown are post-AGB stars analysed elsewhere (McCausland et al., 1992, Conlon et al., 1993b, and references therein). It can be clearly seen that PG 1323−086 and PG 1704+222 are well described by post-AGB tracks with masses between 0.546 $M_\odot$ and 0.565 $M_\odot$.

Table 2. The measured equivalent widths and derived abundances for the programme stars and the reference star HR 6588 (ϵ denotes the particle numbers of the respective element with $\log \epsilon = \log(X/H)+12.00$). For HR 6588 we used the same microturbulent velocity as Hambly et al. (1997, 5 km/s).

Name	Ion	λ [Å]	$\log gf$	W_λ [mÅ]	$\log \epsilon$
PG 1323−086	C II	4267.02	0.559		
		4267.27	0.734	<17	<5.99
	N II	3995.00	0.225	20	6.77
	O II	4069.62	0.157		
		4069.89	0.365	15	7.89
		4072.16	0.546	13	7.86
		4349.43	0.085	6	7.32
	Mg II	4481.13	0.568		
		4481.33	0.732	51	5.79
	Al III	4528.91	−0.294		
		4529.20	0.660	20	5.57
	Si II	4128.07	0.369	27	5.97
		4130.89	0.545	31	5.87
	Si III	4552.62	0.283	35	6.36
		4567.82	0.061	24	6.33
PG 1704+222	C II	4267.02	0.559		
		4267.27	0.734	60	6.52
		6578.03	−0.040	60	6.77
		6582.85	−0.340	59	7.04
	N II	3995.00	0.225	33	6.86
	O II	4069.62	0.157		
		4069.89	0.365	15	7.89
		4349.43	0.085	9	7.59
		4414.90	0.211	14	7.77
	Mg II	4481.13	0.568		
		4481.33	0.732	68	6.13
	Al III	4528.91	−0.294		
		4529.20	0.660	<20	<5.38
	Si II	4128.07	0.369	26	6.17
		4130.89	0.545	38	6.17
HR 6588	C II	4267.02	0.559		
		4267.27	0.734	195	8.09
		4411.20	0.517		
		4411.52	0.672	21	8.27
		6578.03	-0.040	69	7.92
		6582.85	-0.340	67	8.08
	N II	3995.00	0.225	39	7.71
		4447.03	0.238	18	7.82
		4601.48	-0.385	21	8.04
		4607.16	-0.483	13	7.80
		4613.87	-0.607	10	7.79
	O II	4069.89	0.157		
		4069.89	0.365	29	8.69
		4072.16	0.546	21	8.68
		4414.90	0.211	28	8.75
		4416.97	-0.041	24	8.84
		4590.97	0.346	11	8.64
		4595.96	-1.037		
		4596.18	0.196	14	8.91
		4649.14	0.343	37	8.76
		4650.84	-0.331	17	8.81
	Mg II	4481.13	0.568		
		4481.33	0.732	213	7.15
	Al III	4512.54	0.405	20	6.31
		4528.91	-0.294		
		4529.20	0.660	38	6.38
	Si II	4128.07	0.369	63	6.61
		4130.89	0.545	74	6.57
	Si III	4552.62	0.283	74	7.68
		4567.82	0.061	56	7.63
		4574.76	-0.416	33	7.60

4. Abundances

By comparing the spectra of the two objects to spectra of the well known main-sequence B star HR 6588 (that were obtained with the same equipment) we identified lines of O II, N II, C II (only PG 1704+222), Si II, Si III (only PG 1323−086), Mg II, and Al III (only PG 1323−086). We measured equivalent widths (resp. upper limits) for those lines in the object spectra and in the spectrum of HR 6588.

A differential abundance analysis is performed using HR 6588 as a reference star. This obviously is not an ideal choice, since HR 6588 is a main sequence star. Although its $T_{\rm eff}$ is similar to those of our programme stars, its gravity is considerably higher.

From model atmospheres for the appropriate values of effective temperature and surface gravity (see Table 1) we calculated curves of growth for the elements mentioned above, from which we then derived abundances. The number of spectral lines of any ion is insufficient to derive microturbulent velocities for the programme stars. Therefore we adopted a value of 15 km/sec, which is in good agreement with microturbulent velocities derived for other post-AGB stars (McCausland et al., 1992, see also Table 4). A change of 5 km/sec in the microturbulent velocity results typically in a change of 0.05 dex or less in abundance. Even if we decrease the microturbulent velocity to 5 km/sec the abundances increase by 0.08 to 0.2 dex only. A change in $T_{\rm eff}$ by 1000 K results in abundance changes of less than 0.1 dex (except for O II: 0.2 dex). Table 2 lists the abundances derived from individual lines for each star.

Using the abundances derived from the same lines in the spectrum of HR 6588 we determined abundances relative to HR 6588 on a line by line basis. Most notably the abundances derived from Si II and Si III lines in PG 1323−086 and HR 6588 disagree by 0.43 dex and 1.05 dex, respectively, underlining the need for a differential abundance analysis.

Among the many abundance analyses of HR 6588 in the literature we choose the recent work by Hambly et al. (1997) to convert the relative abundances (averaged if possible) into absolute ones, since the authors used the same calibration of Strömgren colours to derive $T_{\rm eff}$ as we did. The results are listed in Table 3 and plotted in Fig. 4. The silicon abundance

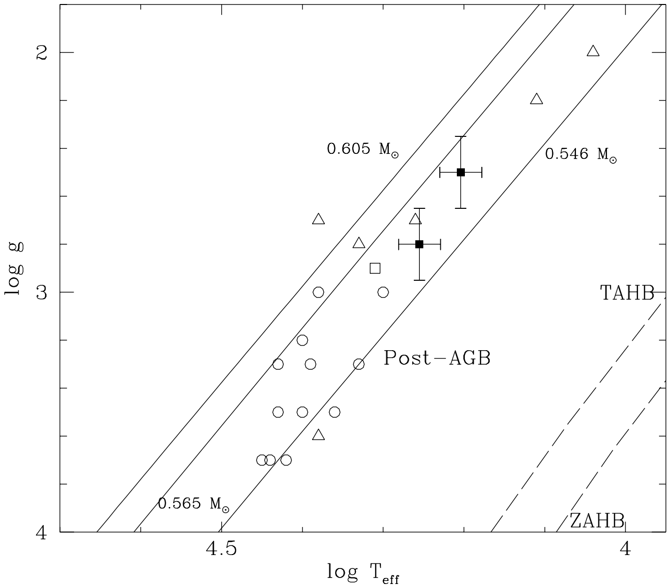

Fig. 3. The physical parameters of the programme stars compared to post-AGB tracks (solid lines) by Schönberner (1983; 0.546 M⊙, 0.565 M⊙) and Blöcker & Schönberner (1990, 0.605 M⊙). The dashed lines show horizontal branch models by Dorman et al. (1993). Also marked are the positions of possible post-AGB stars analysed by other groups: Conlon et al. (1993b, circles, no abundance analyses); Napiwotzki et al. (1994, square); McCausland et al. (1992, triangles).

Table 3. The mean abundances of the programme stars

name	ion	mean abundance		
		absolute	solar	relative to solar
PG 1323−086	C II	<6.16	8.58	< −2.42
	N II	6.93	8.05	−1.12
	O II	7.98	8.93	−0.95
	Mg II	5.87	7.58	−1.71
	Al III	5.42	6.47	−1.05
	Si II	6.17	7.55	−1.38
	Si III	6.20	7.55	−1.35
PG 1704+222	C II	7.01	8.58	−1.57
	N II	7.02	8.05	−1.03
	O II	7.90	8.93	−1.03
	Mg II	6.21	7.58	−1.37
	Al III	<5.23	6.47	< −1.24
	Si II	6.42	7.55	−1.13

of PG 1323−086 as derived from Si II now agrees with that derived from the Si III lines. We adopt ±0.3 dex as a typical error for all abundances.

All measured metals are heavily depleted with respect to solar abundances, carbon showing the largest depletion in both stars, nitrogen and oxygen the lowest depletions. The abundance patterns resemble very closely that of BD +33°2642 (Napiwotzki et al., 1994), a central star of a halo planetary nebula (halo CSPN), as well as those of PHL 1580 and PHL 147, two post-AGB stars analysed by Conlon et al. (1991) (see Fig. 4). Note, however, that other B type PAGB stars show a much larger scatter in abundance patterns (see Table 4).

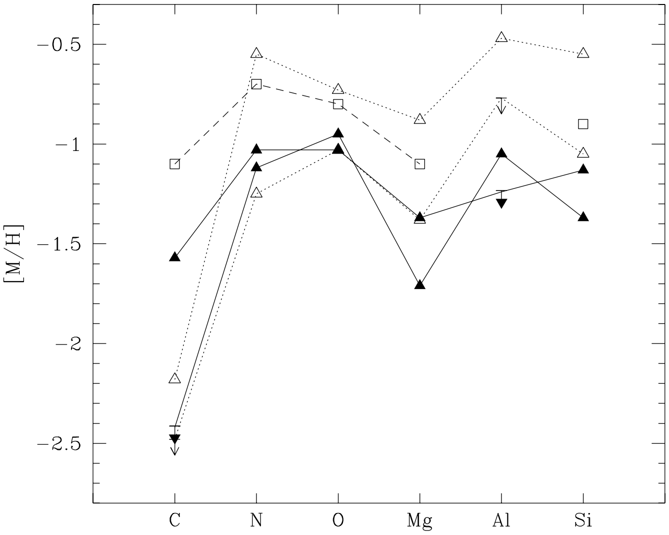

Fig. 4. The abundances determined in this paper (filled symbols) compared to abundances of PAGB stars with similar abundance patterns (open triangles: PHL 174, PHL 1580, Conlon et al., 1991; open square: BD +33°2642, Napiwotzki et al., 1994). The C abundances relying only on the C II 4267 Å line might be underestimated due to NLTE effects (Eber & Butler, 1988).

5. Kinematics

Using the derived physical parameters and the photometric data by Wesemael et al. (1992) together with theoretical fluxes and colours from Kurucz (1992) and an assumed mass of 0.55 M⊙ we can estimate the distances of the two stars. The results are listed in Table 5. The error of 23% in distance is dominated by the error in log g (Moehler et al., 1990b), which we estimate to be 0.15 dex. Thejll et al. (1997) also measured proper motions for both stars, which we use to derive galactocentric velocities according to Johnson & Soderblom (1987). We used 8 kpc for the galactocentric distance of the Sun, (10, 15, 8) [km/s] for ($U_{\odot}$, $V_{\odot}$, $W_{\odot}$) and 225 km/s for the galactic rotation velocity at the place of the Sun. We also derived the velocities of PG 1704+222 along the axis pointing from the galactic center to its current position (within the galactic plane, Π) and along the galactic rotation at its place (Θ). From the value of Θ we note that PG 1704+222 does not participate in the galactic rotation. The error of the proper motion of PG 1323−086 is so large that the resulting space velocity is inconclusive and therefore not listed in Table 5.

6. Conclusions

PG 1323−086 and PG 1704+222 are giant stars with normal helium abundances. Both stars share a characteristic abundance pattern with BD +33°2642, the central star of a halo planetary nebula, and with two high galactic latitude B-giants discussed by Conlon et al. (1991), most notably the strong carbon deficiency. Depletions of N, O, Mg, Al, and Si by 1 dex or more in PG 1323−086 and PG 1704+222 point towards a low metallicity and, hence, membership of an old stellar population, while they

Table 4. The abundances of PG 1323−086 and PG 1704+222 compared to those of other PAGB stars of spectral type B.

name	T_{eff} [K]	log g	[C/H]	[N/H]	[O/H]	[Mg/H]	[Al/H]	[Si/H]	ξ_{micro} [km/sec]
PG 1323−086	16000	2.5	< -2.42	-1.12	-0.95	-1.71	-1.05	-1.37	15^1
PG 1704+222	18000	2.8	-1.57	-1.03	-1.03	-1.37	< -1.24	-1.13	15^1
LS IV-4.01[3]	11000	2.0	< -1.38	–	–	-1.98	–	-2.05	18
LB 3193[3]	12900	2.2	< -2.08	–	–	-2.08	–	-2.15	15^1
PHL 174[2]	18200	2.7	< -2.48	-1.25	-1.03	-1.38	< -0.77	-1.05	10
BD +33°2642[4]	20200	2.9	-1.1	-0.7	-0.8	-1.1		-0.9	15^1
LB 3219[3]	21400	2.8	-1.88	-0.45	-1.33	-0.58	< -1.27	-0.95	16
LS IV-12.111[3]	24000	2.7	-1.88	-0.25	-0.13	-0.28	< -1.07	+0.05	15^1
PHL 1580[2]	24000	3.6	-2.18	-0.55	-0.73	-0.88	-0.47	-0.55	8

[1] set to this value for the abundance analysis (not determined)
[2] Conlon et al. (1991)
[3] McCausland et al. (1992)
[4] Napiwotzki et al. (1994)

Table 5. Kinematic data for the two programme stars. U points from the sun to the galactic center, V towards l = 90°, b = 0°, W towards the galactic north pole. Π and Θ are defined to point from the galactic center to the star (within the galactic plane) and along the galactic rotation at the place of the star, respectively.

Name	l [°]	b [°]	d [kpc]	z [kpc]	$v_{r,hel.}$ [km/s]	μ_α [mas/yr]	μ_δ [mas/yr]	U_{GSR} [km/s]	V_{GSR} [km/s]	W_{GSR} [km/s]	Π [km/s]	Θ [km/s]
PG 1323−086	317.1	+53.1	15.8	12.6	-46	-3.9	+0.8	–	–	–	–	–
			±3.7	±3.0	±15	± 4.0	± 4.9	–	–	–	–	–
PG 1704+222	42.9	+32.4	6.9	3.6	-38	-8.4	0	-53	+57	+209	+78	+1
			±1.6	±0.9	±15	±3.1	–	±19	±72	±98	±54	±51

are not compatible with the values found for young B stars. The positions of both stars in the (T_{eff}, log g) diagram are consistent with evolutionary tracks starting from the AGB for masses of about 0.55 $M_\odot$. We therefore conclude that both stars are in the post-AGB stage of their evolution.

The similarity of the abundance patterns to that of BD +33°2642 suggests that the successors of the B-type PAGB stars can be found amongst the halo CSPNe as already suggested by McCausland et al. (1992). Potential progenitors could be found among the optically bright post-AGB stars discussed by van Winckel (1997). However, van Winckel finds only one star, HD 107369, for which the abundance pattern comes close to that of B-type PAGB stars. The CNO abundances of this star are consistent with being the product of CN cycling. In the B-type PAGB stars, however, the C/N ratio can be explained by CN cycling, but not the N/O ratio.

Conlon et al. (1991), McCausland el. (1992) and Napiwotzki et al. (1994) discussed various scenarios to explain the abundance pattern of B-type PAGB stars in terms of nuclear processing and subsequent dredge-up, but no conclusion could be reached. The high [O/Fe] ratio (+1.2±0.5) observed in BD +33°2642 prompted Napiwotzki et al. (1994) to suggest that its abundance pattern could be affected by gas-dust separation invoked by Bond (1991) to explain the extreme [O/Fe] $>$ 4 ratio found in two peculiar PAGB stars of spectral type F (Lambert et al., 1988 and Waelkens et al., 1992). Therefore, the determination of the iron abundance in the B-type PAGB stars is a prerequisite for an interpretation of their abundance patterns.

According to the kinematic behaviour of PG 1704+222 and the large distance from the galactic plane for PG 1323−086 both stars are probably Population II objects.

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