Two early-type post-AGB stars at high galactic latitudes

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SUMMARY
Two high galactic latitude B-type stars, PHL 1580 and PHL 174, originally identified as distant early-type objects from low-resolution spectroscopy and photometry are re-analysed using high-resolution spectra. The results of LTE and non-LTE model atmosphere analyses reveal general metal underabundances relative to solar values of typically 0.6 and 1.0 dex for PHL 1580 and PHL 174, respectively. For both stars carbon is significantly more underabundant. The anomalous compositions are compatible with those of other high galactic latitude post-AGB objects, while the derived atmospheric parameters are coincident with post-AGB evolutionary tracks. Thus it appears that PHL 1580 and PHL 174 are low-mass post-AGB objects at an evolutionary stage intermediate between those of the A-, F- and G-type objects and planetary nebulae previously identified. The severe carbon deficiency may be evidence that both objects left the AGB before the products of the CNO bi-cycle were mixed to the stellar surface.

1 INTRODUCTION
This paper is one of a series devoted to spectroscopic investigations of hot stars at high galactic latitudes. Model atmosphere analyses of high-resolution spectra have identified many of these objects as normal young Population I stars (see Keenan, Brown & Lennon 1986; Conlon et al. 1988) with kinematics that are generally compatible with simulations of the ejection of stars from young clusters (Conlon et al. 1990). However, a small number cannot be explained in this way and their existence at large distances from the galactic plane (for example, z = 18 kpc in the case of PG0832 + 676; Brown et al. 1989) challenges the idea that star formation is confined to spiral arms.

It is thus important that the true nature of these halo stars be reliably established. This is particularly the case as some post-AGB objects have recently been observed with only slight metal underabundances compared to solar values (Ebbets & Savage 1982; Parthasarathy, Pottasch & Wamsteker 1988). According to the post-AGB evolutionary tracks of Schönberner (1983) and Gingold (1976), these evolved objects can pass through a region of the surface gravity–effective temperature diagram corresponding to the atmospheric parameters of Population I stars that have just evolved off the hydrogen-burning main sequence. In this paper, we present abundance analyses of two halo objects, PHL 1580 and 174, originally classified as B1 II–III and B2 from low-resolution spectroscopy and uvby photometry, respectively (Kilkenny & Lydon 1986; Kilkenny 1984), but which we believe are evolved low-mass post-AGB stars. We argue that careful model-atmosphere analyses of high-quality spectroscopic data are necessary to reveal relatively small composition differences between normal young Population I and evolved stars.

2 OBSERVATIONS AND DATA REDUCTION
The visible spectra of PHL 1580 and 174 were obtained during observing runs on the 3.9-m Anglo–Australian Telescope (AAT) in 1987 August and 1988 August, respectively, using an Image Photon Counting System (IPCS) as the detector. An ultraviolet (UV) spectrum for PHL 1580 was also obtained using the IUE satellite. Details of the observations are given in the relevant section below.

2.1 RGO spectrograph observations
PHL 1580 was observed with the RGO spectrograph, the 1200R grating and 25-cm camera resulting in a linear dispersion of approximately 17 Å mm$^{-1}$ over two wavelength regions, namely 3830–4320 and 4200–4700 Å. Continuum counts were greater than 3800–4320 and 4200–4700 Å. Continuum counts were greater than 4000 resulting in minimum signal-to-noise ratios of 60.

Reduction of the original two-dimensional images was performed using the interactive STARLINK reduction package FIGARO (Shortridge 1986) and methods discussed by Conlon et al. (1988). Briefly, this involved sky subtraction and flat-fielding followed by wavelength calibration using Cu–Ar arc exposures interleaved between the stellar observations. Spectral resolutions estimated from the emission lines were normally less than 0.5 Å (FWHM).
2.2 Échelle spectrograph observations

Spectra of PHL 174 were obtained using the University College London Échelle Spectrograph (UCLES) with the 79-grooves mm\(^{-1}\) grating and the 70-cm camera giving a linear dispersion of 2 Å mm\(^{-1}\). In order that complete wavelength coverage could be obtained in the range 3910–4645 Å, two overlapping wavelength regions were observed, with spectra being collected in orders 57–49 inclusive. The continuum counts recorded in the spectra of PHL 174 were typically 1500.

The data were reduced to a two-dimensional nine order échellogram using the échelle reduction package in figaro. The observations were sky-subtracted and wavelength calibrated using Cu–Ar arc exposures taken between stellar observations. Central and extreme orders were analysed interactively, enabling the remaining intermediate orders to be fitted automatically. Mean wavelength residuals for the Cu–Ar exposures were less than 0.02 Å, while the spectral resolution was approximately 0.2 Å (FWHM).

2.3 IUE observations of PHL 1580

We obtained a high-resolution UV spectrum in the SWP wavelength region using two consecutive shifts with the IUE satellite (Boggess et al. 1978) in 1987 December (image number SWP 34252). An exposure time of 13 hr and 40 min yielded a high-resolution SWP image relatively well exposed for most of the wavelength region, but saturated and under-exposed for wavelengths of greater than 1800 Å and less than 1250 Å, respectively.

The image was reduced using the STARLINK package, iudec (Giddings & Rees 1989). Because of the long exposure time, care had to be taken to flag cosmic-ray events. Rather than extracting all the orders using a single choice of slit height and background position, these parameters were optimized for each order which contained important stellar features.

3 RADIAL VELOCITY AND EQUIVALENT WIDTH MEASUREMENT

After reduction, all the one-dimensional spectra were analysed using the STARLINK program dipso (Howarth & Murray 1988). Radial velocities were estimated from the Doppler shifts of the single strong metal, helium and hydrogen lines in the visible spectra. Continuum distributions were estimated by fitting low-order (< 5) least-squares polynomials in the regions of spectra free from absorption features. For the échelle data some orders contained strong and broad hydrogen lines which were difficult to normalize; in these cases the continuum fits for adjoining orders were interpolated. Equivalent widths were measured by fitting Gaussian profiles to metal and non-diffuse helium lines in the normalized spectra (see Brown et al. 1986a,b, for details of the procedures used). These data are extensive and hence are not reproduced here, but are available from the authors on request.

4 METHOD OF ANALYSIS

The method of analysis was to compare the observed spectral features with those generated using the line blanketed LTE models of Kurucz (1979). These methods have been described in, for example, Conlon et al. (1988) and will only be briefly discussed here. Non-LTE effects may be important particularly for the lower gravity star PHL 174 and these are considered in Section 4.3.

4.1 LTE atmospheric parameters

Effective temperatures were determined from the reddening-free Strömgren colour indices \([c_i] = (c_i - 0.2(b-y))\) and \([u-b] = (c_u + 2.0(m_i))\) taken from Kilkenny & Lydon (1986) and Kilkenny (1984) for PHL 1580 and 174, respectively. The calibrations of Lester, Gray & Kurucz (1986) were used and led to estimates that agreed to within ±1000 K for both stars. For PHL 1580 a third estimate of the effective temperature was derived from the ionization equilibrium condition for the Si iii/Si iv lines and is in good agreement with those deduced from the Strömgren photometry. The broadening theory of Vidal, Cooper & Smith (1973) was used to generate profiles for H\(_\alpha\), H\(_\delta\) and H\(_\gamma\) (see Fitzsimmons et al. 1990 for details) and these were compared to the observed profiles to determine surface gravities. Observational uncertainties in the line profiles imply an error estimate for the surface gravity of typically ±0.2 dex. The adopted atmospheric parameters are listed in Table 1; within the combined uncertainties of the two analyses, the derived atmospheric parameters of PHL 1580 are consistent with the results of Kilkenny & Lydon (1986).

<table>
<thead>
<tr>
<th>Star</th>
<th>PHL 1580</th>
<th>PHL 174</th>
<th>Normal B star value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric parameters</td>
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</tr>
<tr>
<td>(\log g)</td>
<td>3.6</td>
<td>3.5</td>
<td>2.7</td>
</tr>
<tr>
<td>(V_T)</td>
<td>8.0</td>
<td>10.0</td>
<td>-</td>
</tr>
<tr>
<td>(V_{hel})</td>
<td>11.00±0.1 (8)</td>
<td>10.80±0.2 (8)</td>
<td>10.90</td>
</tr>
<tr>
<td>C</td>
<td>6.40±0.2 (2) &lt; 6.10 (1)</td>
<td>8.20</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>7.50±0.3 (8)</td>
<td>6.80±0.1 (8)</td>
<td>8.00</td>
</tr>
<tr>
<td>O</td>
<td>8.20±0.3 (43)</td>
<td>7.90±0.3 (5)</td>
<td>8.80</td>
</tr>
<tr>
<td>Mg</td>
<td>6.70 (1)</td>
<td>6.20 (1)</td>
<td>7.40</td>
</tr>
<tr>
<td>Al</td>
<td>6.00±0.2 (1) &lt; 5.70 (1)</td>
<td>6.20</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>7.00±0.3 (7)</td>
<td>6.50±0.1 (3)</td>
<td>7.50</td>
</tr>
<tr>
<td>S</td>
<td>6.70 (4) &lt; 6.50 (1)</td>
<td>7.20</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>&lt;6.20 (2)</td>
<td>-</td>
<td>7.50</td>
</tr>
</tbody>
</table>

4.2 LTE abundances

The helium and metal line strengths measured from the optical spectra were used to derive abundances in PHL 174 and 1580. The microturbulent velocity \(V_T\) for PHL 1580 was estimated using the abundances determined from the numerous O ii lines, the microturbulent velocity being selected to minimize the standard error in the abundance. This method was also employed for PHL 174 but because of its lower effective temperature the O ii lines are weak and the Si iii lines were used. The adopted microturbulence was 8±5 km s\(^{-1}\) for PHL 1580 and 10±5 km s\(^{-1}\) for PHL 174.

Abundances were also derived from equivalent widths of Cu/C iii/C iv lines at 1323, 1247 and 1233 Å deduced from a high-resolution IUE spectrum of PHL 1580. The value of
The abundance estimate from the optical spectra (6.4 ± 0.4 dex) is compatible with that obtained using the optical spectra. Although iron lines were clearly visible in the IUE spectrum of PHL1580, these were severely blended and the atomic data required for a full analysis were not available. Upper limits for the equivalent widths of the Fe m lines at 4164 and 4303 Å of approximately 25 mÅ were measured and used to set limits to the iron abundance. Table 1 lists the derived mean LTE logarithmic abundances on the scale log[H] = 12 together with the current estimates of normal B-type values (He: Wolff & Heasley 1985; C, O: Kane, McKeith & Dufton 1980; N: Dufton, Kane & McKeith 1981; Mg: Snijders & Lamers 1975; Al: Sadakane, Takada & Jugato 1983; Si: Kamp 1982; S: Peters 1976; Fe: Kodaira & Scholz 1970); note that the values are based on non-LTE analyses when available but are otherwise taken from LTE analyses. The numbers in brackets in Table 1 indicate the number of lines used to determine the abundance value and the error bars refer to the sample standard deviation obtained whenever more than one line was employed (note that if the errors are randomly distributed the standard deviation should be larger than the uncertainty on these mean abundance values).

Table 1. Measured equivalent widths and derived LTE logarithmic abundances of PHL174 and oCMa.

<table>
<thead>
<tr>
<th>Species</th>
<th>PHL 174</th>
<th>oCMa</th>
</tr>
</thead>
<tbody>
<tr>
<td>He I</td>
<td>4120.81/99 145</td>
<td>10.38</td>
</tr>
<tr>
<td>N II</td>
<td>3955.00 47</td>
<td>6.71</td>
</tr>
<tr>
<td>O II</td>
<td>4072.16 11</td>
<td>7.47</td>
</tr>
<tr>
<td>Mg II</td>
<td>4525.62 20</td>
<td>6.50</td>
</tr>
<tr>
<td>Si III</td>
<td>4575.76 29</td>
<td>6.52</td>
</tr>
</tbody>
</table>

The results discussed above are based on the assumption of LTE and here we consider briefly the validity of this approximation using silicon as an example. Non-LTE calculations of the silicon spectrum have been performed by Kamp (1978), Lennon et al. (1986) and Becker & Butler (1990), with in some cases significant differences from the LTE results being found. In Figs 1 and 2, the observed Si m and Si iv lines in PHL 1580 at 1300 and 1400 Å are compared with profiles taken from Lennon et al. for an effective temperature of 20 000 K and logarithmic surface gravity of 2.5 dex are similar to that of PHL 174, in particular as the inclusion of metal line-blanketing would reduce the effective temperature estimate of van Helden by approximately 1000 K (Erhorn, Groote & Kaufmann 1984). Using the equivalent widths of lines common to both stars, relative abundances were obtained using Kurucz's (1979) LTE models after adjusting the oCMa effective temperature to 19 000 K to take account of the effect of line-blanketing. The results of this differential analysis are summarized in Table 2, with the derived metal abundances of PHL 174 being typically 0.8 dex below that found in oCMa, except for silicon. However, the adoption of a lower microturbulence value of 15 ± 5 km s⁻¹ for oCMa, determined in the same manner as described for PHL 174, would lead to a silicon abundance difference of 0.7 dex. Thus it would appear that in comparison with the normal B-type supergiant oCMa, PHL 174 is underabundant in metals by approximately 0.8 dex (which is comparable to the typical underabundance of 1.0 dex relative to normal B-type values listed in Table 1).

4.3 Validity of LTE

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Figure 1. Observed lines of Si m around 1300 Å in the IUE spectrum of PHL 1580. The theoretical non-LTE profiles of Lennon et al. (1986) corresponding to a logarithmic abundance of 7.2 dex imply a lower silicon abundance for PHL 1580. Note the presence of an interstellar Si m line at 1305 Å.

Figure 2. Observed Si iv resonance lines at 1400 Å for PHL 1580 together with the non-LTE theoretical profiles as in Fig. 1. Given that the observed profiles are likely to be contaminated by interstellar absorption lines, 7.2 dex should be an upper limit to the silicon abundance of PHL 1580. Note there is no evidence of P Cygni features in these lines.
25 000 K, logarithmic gravity of 3.5, microturbulence of zero and a silicon abundance of 7.2 dex (the lowest value they considered). Note that for the Si iv features the observed spectrum may be affected by the presence of interstellar lines which can have a strength of up to 200 mÅ (Pettini & West 1982). The adopted atmospheric parameters correspond to the nearest grid point to our LTE values and inspection of the non-LTE results at adjacent grid points indicates that this choice should not be a significant source of error. For both the Si iii and Si iv lines, the theoretical profiles are too strong despite the relatively low silicon abundance. This discrepancy could not be removed by increasing the microturbulence as this would also increase the strength of the theoretical lines. Hence we conclude that the non-LTE results imply a silicon abundance of less than 7.2 dex from the UV lines in PHL 1580. Additionally for the optical lines the results of Lennon et al. and Becker & Butler imply that for the atmospheric parameters appropriate to PHL 1580, non-LTE effects could be as large as 0.5 dex. However, abundances derived from non-LTE calculations are in good agreement with the LTE results summarized in Table 1 (mean abundance values of 7.2 ± 0.2 dex and 7.3 ± 0.2 dex, respectively, are obtained). Hence we conclude that at least for silicon, the underabundance deduced from the LTE analysis should be secure.

For the silicon spectrum in PHL 174, the results of Kamp (1978) were employed as its atmospheric parameters lie outside the range covered by Lennon et al. and Becker & Butler. For the four closest parameter sets (namely: $T_{\text{eff}} = 17 500$ K, $\log g = 2.5$ dex and $v_t = 15$ km s$^{-1}$; $17 500$ K, $3.0$ dex and $5$ km s$^{-1}$; $20 000$ K, $2.5$ dex and $15$ km s$^{-1}$; and $20 000$ K, $3.0$ dex and $5$ km s$^{-1}$), the difference in predicted LTE and non-LTE abundances range from 0.2 to 1.0 dex, with the non-LTE abundances being the larger. Thus non-LTE effects, both for silicon and possibly other metal species, may be substantial for PHL 174; given its low surface gravity this is not surprising. However, such effects should be decreased if not completely eliminated by the differential analysis for this star considered in Section 4.2 above. Hence again we believe that the systematic heavy element underabundances found for this star are probably secure.

5 DISCUSSION
Although the atmospheric parameters of PHL 1580 and 174 (see Section 3) imply that they are young Population I objects, the anomalous compositions listed in Tables 1 and 2 are not compatible with this idea. PHL 1580 reveals a general metal deficiency of approximately 0.6 dex with the exception of iron which is more than 1.3 dex below solar and carbon which is underabundant by 2.2 dex (or by approximately 1.6 dex in comparison with the typical B-type stellar value of 8.2 dex deduced from similar LTE methods – see

Figure 3. Logarithmic surface gravity versus effective temperature diagram adapted from Groth et al. (1985) showing the locations of PHL 1580 and 174 in relation to (a) the post-HB tracks of Schönberner (1983) and Gingold (1976) and (b) previously identified post-AGB objects.
Kane et al. 1980). Similarly, PHL 174 is metal deficient but typically by 1.0 dex and the upper limit to the carbon abundance of 6.1 dex indicates a severe carbon depletion of greater than 2.0 dex.

Fig. 3 reproduces a gravity versus effective temperature diagram taken from Groth, Kudritzki & Heber (1985) and shows the theoretical core-helium-burning horizontal branch and various post-HB evolutionary tracks. The dotted line represents the zero-age hydrogen-burning main sequence for a range of masses between 2 and 20 $M_\odot$ (Claret & Giménez 1989). The positions of evolved subdwarfs (sB and sDo), and central stars of planetary nebulae are indicated. In addition, a number of objects that have been classified as being in a post-AGB evolutionary stage are plotted. From their positions in this diagram, PHL 1580 and 174 lie in an intermediate region between the cooler post-AGB stars and the more evolved subdwarfs or planetary nebulae.

Six cooler objects, HD 161796, HD 46703, HR 4912, HR 4049, BD + 39°4926 and 89 Her are plotted; some of these objects were originally thought to be high latitude A- and F-type supergiants from low-resolution optical spectra (Bond, Carney & Grauer 1984; Sasselov 1983), but all have subsequently been identified as being post-AGB stars (Parthasarathy & Pottasch 1986; Lamers et al. 1986; Bond & Luck 1987; Waelkens et al. 1987; Trams et al. 1989). The two hotter objects, DDDM-1 and RWT 152, are believed to be in a more evolved post-AGB stage. RWT 152 was originally classified as an O5 main-sequence halo object with a normal Population I composition, at a z-distance of 6 kpc from the UV profile in the UV and found it to be a subluminous low-mass object. No quantitative information is available on its surface composition. DDDM-1 is one of the four halo planetary nebulae so far identified and Clegg, Peimbert & Torres-Peimbert (1987) have determined its nebular abundances.

The atmospheric parameters of PHL 1580 and 174 are compatible with a previously unobserved post-AGB phase intermediate between those discussed above. In order to establish that they are indeed post-AGB stars, we compare their chemical composition relative to the Sun in Table 3 with those of previously identified post-AGB objects. Note that due to non-LTE effects the B-type stellar carbon abundance is typically 0.4 dex below the solar value (Eber & Butler 1988). There appears to be a number of stars with nitrogen enhancements strongly indicating mixing of CNO-cycled material to the stellar surface (Renzini & Fusi Pecci 1988), while the remaining objects, which include the programme stars, are all severely underabundant in carbon. It can be seen that the compositions of PHL 174 and 1580 are similar to those of HR 4912 and DDDM-1. Given the errors in the analyses, the wide variety of derived abundances would appear to reflect the stellar evolutionary history (in particular the duration of the AGB stage) and a variety of initial compositions.

Further evidence to support the idea that PHL 1580 and 174 are post-AGB stars comes from the fact that, in common with the objects discussed above, their atmospheric parameters coincide with the post-horizontal branch evolutionary tracks of both Schönberner (1983) and Gingold (1976); these are indicated in Fig. 3 as the solid lines labelled S1 (0.546 $M_\odot$) and G2 (0.519 $M_\odot$), respectively. The Schönberner models are calculated for AGB stars with sufficient hydrogen-burning material to survive mass loss on the AGB and evolve to the top by which stage a circumstellar gas and dust shell has formed. When the envelope mass is reduced to a certain value, the star will begin to evolve towards higher effective temperatures while the circumstellar shell expands (Schönberner 1983). Eventually the central star is hot enough (30 000 K) to ionize the surrounding shell and the characteristic features of a planetary nebula can then be observed. According to the Schönberner models, this post-AGB and pre-PN stage is short ($\sim 10^4$ yr); thus it is not surprising that observations of this type of object have been relatively rare. In the case of the Gingold (G2) model, there is insufficient mass for the star to evolve very far up the AGB. The subsequent bluewards evolution towards the hot sdOs, passes through a high-luminosity region in the gravity-effective temperature diagram, again coincident with the observed positions of PHL 1580 and 174.

All the A-, F- and G-type post-AGB objects have revealed an infrared (IR) excess indicating the absorption and re-radiation of optical and/or UV stellar photons in the circumstellar shell. This is consistent with the idea that these stars have only recently evolved from the AGB. A search of the IRAS Point Source Catalogue revealed no evidence of a far-infrared excess near PHL 1580 of 174 with, for example, the nearest IR source being 14 arcmin away from PHL 1580 (corresponding to a separation of approximately 12 pc at a distance of 3 kpc from the plane). Given the higher stellar temperature of the two programme stars, a near-IR excess

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Table 3. Comparison of compositions of PHL 1580 and 174 and six previously identified post-AGB objects relative to solar values.

<table>
<thead>
<tr>
<th>Star</th>
<th>He</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>S</th>
<th>Fe</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHL1580</td>
<td>+0.01</td>
<td>-2.2</td>
<td>-0.6</td>
<td>-0.7</td>
<td>-0.9</td>
<td>-0.5</td>
<td>-0.6</td>
<td>-0.3</td>
<td>&gt;1.3</td>
<td>1</td>
</tr>
<tr>
<td>PHL174</td>
<td>-0.19</td>
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<td>-1.0</td>
<td>-1.4</td>
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<td>-0.5</td>
<td>&gt;1.3</td>
<td>-1.1</td>
<td>1</td>
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<tr>
<td>HR4912</td>
<td>-1.1</td>
<td>-0.6</td>
<td>-0.3</td>
<td>-0.9</td>
<td>-0.7</td>
<td>-1.0</td>
<td>-1.2</td>
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<tr>
<td>DDDM-1</td>
<td>+0.01</td>
<td>&gt;1.5</td>
<td>-0.7</td>
<td>-0.8</td>
<td>-1.6</td>
<td>-1.3</td>
<td>-1.0</td>
<td>-1.4</td>
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<td>3</td>
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<tr>
<td>89 Her</td>
<td>-</td>
<td>-0.3</td>
<td>+0.5</td>
<td>+0.0</td>
<td>-</td>
<td>-</td>
<td>-0.3</td>
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<tr>
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<td>-1.7</td>
<td>+0.1</td>
<td>-2.9</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1 - this paper; 2 - Luck, Lambert & Bond (1983); 3 - Clegg et al. (1987); 4 - Luck, Lambert & Bond (1987); 5 - Luck & Bond (1984); 6 - Bond & Luck (1987); 7 - Kodaira, Greenstein & Oke (1970).
could also be expected and indeed the post-AGB object, HR 4049 (B9.5I) has been observed with a near-IR excess (Waters et al. 1989). However, even in this case, a cooler dust component is detected which is thought to be a remnant of the earlier AGB wind. In contrast to the accompanying UV deficiency observed for HR 4049, the IUE flux distribution of PHL 1580 (deduced from the observations as discussed in Section 2) shows no significant UV deficiency. Mass loss is also observed in a number of cooler post-AGB objects (Trams et al. 1989); however, the inability to detect P Cygni profiles in the C IV and Si IV lines in the ultraviolet spectrum of PHL 1580 suggests that any mass loss in this star is relatively small. Indeed, an upper limit to the terminal velocity estimated from the blue wings of the C IV resonance lines of approximately 300 km s\(^{-1}\) is less than the escape velocity of approximately 340 km s\(^{-1}\) expected for a low-mass (approximately 0.5 \(M_\odot\)) evolved star.

The apparent lack of an expanding dust shell around PHL 1580 and 174 does not, however, rule out the possibility that they have been surrounded by a dust shell in the recent past. According to Schönberner (1983), the transition time from the AGB to \(T_{\text{eff}} = 4.4\) for the S1 track is \(\sim 10^5\) yr, exceeding the dynamical lifetime of the expanding circumstellar shell. We note that the evolved low-mass star, RWT 152, whose atmospheric parameters also correspond to the low-mass (0.546 \(M_\odot\)) Schönberner track, also shows no evidence of a circumstellar dust shell (Ebbets & Savage 1982).

Alternatively, the proximity of the programme stars to the Gingold track in Fig. 3 implies that PHL 1580 and 174 may have left the AGB before a circumstellar shell formed. Further evidence to support this comes from the striking deficiency of carbon in these two objects as carbon is believed to be convected to the stellar surface during the third dredge-up near the top of the AGB (Renzini & Fusi Pecci 1988). Indeed, many AGB and post-AGB objects are carbon-rich, for example both HR 4049 and HD 187885 and three of the four halo planetary nebulae (Waters et al. 1989; Parthasarathy et al. 1988; Clegg et al. 1987), presumably as the result of such mixing.

In addition, the kinematics of the programme stars are compatible with those of post-AGB evolved objects. Adopting masses of approximately 0.5 \(M_\odot\) and \(E(B-V)\) estimates of 0.05 and 0.00 implies distances of 3 and 15 kpc to PHL 1580 and 174, respectively. The previously identified post-AGB stars discussed in this paper are located at distances of up to 4 kpc, while distance estimates for the halo planetary nebulae are in the range 10–20 kpc. We note the present results for PHL 1580 and 174 lend support to the findings of Sandage & Fouts (1987) and Carney & Latham (1987) who identified an intermediate-metallicity stellar population (Fe/H \(-0.7\) dex) out to a few kpc and a more metal-poor halo population at larger distances.

In summary, it would appear that PHL 1580 and 174, originally misidentified from low-resolution spectroscopy and photometry as distant early-type stars evolving off the hydrogen-burning main sequence, are in fact evolved low-mass post-AGB objects. The lack of evidence of a circumstellar dust shell (and, in the case of PHL 1580, significant mass loss) around these two objects sets them apart from most of the post-AGB objects observed to date. Hence they could be either proto-planetary nebulae that have lost their nebulae (similar to the previously observed object, RWT 152), or they did not reach the top of the AGB and hence did not produce a circumstellar shell. The very low carbon abundances found in both stars supports the latter hypothesis.

The results of this abundance analysis highlights the possibility of misclassification from photometry or low-resolution spectroscopy, and emphasizes a need for high-resolution spectral analysis to identify abundance anomalies. In addition, the optical spectra of apparently hot subgiant or supergiant stars should be complemented with IR and UV observations to enable their evolutionary status to be established more reliably.

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