1992A&A...264..159P

Astron. Astrophys. 264, 159–168 (1992)

ASTRONOMY
AND
ASTROPHYSICS

The chemical composition of the high velocity post AGB star HD 56126 (F 5I)*

M. Parthasarathy[1], **P. Garcia Lario**[2], **and S.R. Pottasch**[3]

[1] Indian Institute of Astrophysics, Bangalore 560034, India
[2] Laboratorio de Astrofisica Espacial Y Fisica Fundamental, Estacion de Villafranca del Castillo,
Apartado de Correos 50727, E-28080 Madrid, Spain
[3] Kapteyn Astronomical Institute, Postbus 800, NL-9700 AV Groningen, The Netherlands

Received November 12, 1991; accepted April 7, 1992

Abstract. HD 56126 (F 5I) is an IRAS source with detached cold dust shell with characteristics similar to the dust shells around planetary nebuale. From an analysis of high resolution, high signal-to-noise ratio spectra using model atmospheres, metal and CNO abundances have been determined. It is found that in HD 56126 $[C/H] \simeq -0.01$, $[N/H] \simeq +0.17$, $[O/H] = -0.02$, $[S/H] \simeq +0.01$ and $[Fe/H] \leq -1.0$. The C/N/O abundance ratios and CNO abundances relative to Fe suggest that HD 56126 and related stars are evolved and in some of these stars the material processed by triple α, CN and ON cycles has reached the surface.

From the high resolution spectra we derive the radial velocity of HD 56126 to be $+105.0 \pm 1.0$ km s^{-1} which suggests that HD 56126 is a high velocity star belonging to the old disk.

The abundance ratios [C/Fe], [N/Fe], [O/Fe] and [S/Fe] in HD 56126 and related post AGB stars are large and cannot be easily explained by nucleosynthesis and/or mixing. The large ratios of [C/Fe], [N/Fe], [O/Fe] and [S/Fe] are due to depletion of Fe but not of C, N, O and S elements. The depletion of refractory elements and the lack of depletions in CNO and S in the atmosphere of these post AGB stars is similar to that observed in the interstellar medium. Since most of these stars have circumstellar dust shells the depleted refractory elements appear to be locked up in dust grains. The results suggest that in the recent past (possibly during the OH IR stars stage) the outer atmospheres of these stars expanded and cooled to the limit of the condensation temperature of refractory elements. Formation of cores of dust grains very close to the stars and the resulting dust-driven mass loss may be able to explain the observed abundances peculiarities in these post AGB stars.

Key words: stars: abundances – atmospheres of – evolution of – supergiants – circumstellar matter – mass loss – stars: individual: HD 56126

1. Introduction

The F-type supergiant HD 56126 (=SAO 96709) is an IRAS source (IRAS 07134+1005, $l=207°$, $b=+10°$) for which the IRAS 12 μm (24.6 Jy), 25 μm (116.7 Jy), 60 μm (49.8 Jy) and 100 μm (18.2 Jy) fluxes reveal the presence of a detached cold circumstellar dust shell (Parthasarathy 1989). The characteristics of the dust shell around HD 56126 are very similar to the dust shell characteristics found around the high galactic latitude F supergiant HD 161796 (Parthasarathy & Pottasch 1986) and related protoplanetary nebulae (Parthasarathy 1989; Hrivnak et al. 1989). Zuckerman et al. (1986) detected CO $J=1 \rightarrow 0$ emission from HD 56126. The detached cold circumstellar dust shell and the circumstellar molecular envelope show properties similar to those found in evolved stars suggesting that HD 56126 has experienced significant mass loss in the recent past during the asymptotic giant branch (AGB) stage of evolution and it is likely that it is now in the post AGB stage of evolution. Only recently it is becoming possible through IRAS data to recognize stars which may be in the post AGB stage of evolution (Parthasarathy & Pottasch 1986; Lamers et al. 1986; Hrivnak et al. 1988). The optical counterparts of these IRAS sources were found to show A, F, G, K supergiant type spectra (Pottasch & Parthasarathy 1988). With the advent of the IRAS satellite this new class of stars or hitherto unseen phase of stellar evolution came to light. Some of these stars are at high galactic latitudes and show significant metal deficiencies indicating that they have evolved from old low mass stars. Clearly detailed chemical composition analysis of all these stars is important to further understand their evolutionary stage, nucleosynthesis, mixing, and mass loss processes experienced by these stars. In this paper we report and discuss the chemical composition of HD 56126 derived from an analysis of high resolution spectra.

2. Observations

High resolution and high signal to noise ratio spectra of HD 56126 were obtained with the European Southern Observatory (ESO) Coudé Auxiliary Telescope (CAT) equipped with

---

Send offprint requests to: M. Parthasarathy
* Based on observations collected at the European Southern Observatory (ESO), La Silla, Chile

the Coudé Echelle Spectrograph (CES) and CCD detector. Spectra of HD 56126 were obtained centered around the following wavelength regions: 6158 Å (O I), 6300 Å ([O I]), 6363 Å ([O I]), 6563 Å, 7115 Å (C I), 7450 Å (N I), 8335 Å (C I) and 8710 Å (N I). Each exposure covers about 50–60 Å centered around the above mentioned wavelengths. The spectra were linearized and flat field corrected. The wavelength calibration is made with PANDORA. This is a standard software package which includes the program SCRUNCH which rebins the whole pixel maps to equal increments in lambda by fitting a polynomial which relates pixel with wavelength. The result is a wavelength calibrated spectrum with a linear scale. The spectral resolution ranged from 0.165 Å at 6150 Å to 0.210 Å at 8700 Å. The Hα region spectrum has a resolution of 0.121 Å.

3. Analysis

3.1. *Atmospheric parameters*

The atmospheric parameters ($T_{\rm eff}$, $\log g$) of HD 56126 were obtained from spectral type and luminosity class. Nassau et al. (1965) classified the spectrum of HD 56126 as F 5I. The recent low dispersion spectra also yield the spectral type to be F 5I (Hrivnak et al. 1989; Parthasarathy 1989). Pel (1976) and van Genderen et al. (1986) observed HD 56126 in the Walraven intermediate band *VBLUW* system. van Genderen et al. (1986) give $(B-V)=0.9$. The *JHKLM* observations of HD 56126 by Hrivnak et al. (1989), Manchado et al. (1989) and IRAS LRS spectrum suggests for the presence of near infrared excess due to warm dust around the star. The flux distribution of HD 56126 including the IRAS data is shown in Fig. 1. The higher flux around 21 μm in the LRS spectrum is due to an emission feature which may be due to the bending mode of a transient carbon-bearing molecule (Kwok et al. 1989).

The $T_{\rm eff}$ can be estimated from the spectral type, $B-V$ and $T_{\rm eff}$ calibrations given by Böhm-Vitense (1972), Flower (1977) and Schmidt-Kaler (1982). Böhm-Vitense (1972) calibration of spectral-type – $T_{\rm eff}$ relation of F and G supergiants yields $T_{\rm eff}=6500$ K for a F 5 supergiant. For HD 56126 van Genderen et al. derive $(B-V)_0=0.49$. Using the $T_{\rm eff}$-$(B-V)_0$ calibration derived by Böhm-Vitense (1972) for F and G supergiants we find the $T_{\rm eff}$ of HD 56126 to be 6000 K, and the $T_{\rm eff}$ calibration of Flower (1977) yields 6200 K. The spectral-type – $T_{\rm eff}$ calibration of Schmidt-Kaler (1982) gives $T_{\rm eff}=6900$ K, and the $(B-V)_0-T_{\rm eff}$ relation (Schmidt-Kaler 1982) gives $T_{\rm eff}=6350$ K. From an analysis of high resolution spectra of several F and G supergiants Luck & Bond (1989) derived their $T_{\rm eff}$ and $\log g$ values. Their results also suggest $T_{\rm eff}=6500$ K for F 5 supergiants and $T_{\rm eff}=6000$ K for F 8 supergiants, and their $\log g$ values are in the range 0.5–1.0. However the spectral type, $(B-V)_0$ and $T_{\rm eff}$ relations mentioned above and the $T_{\rm eff}$ and $\log g$ values derived from an analysis of high resolution spectra (Luck & Bond 1989) are for normal F-G supergiants of solar metallicity. Inspection of high resolution spectra of HD 56126 suggests that it is metal poor. For very metal poor stars the spectral types assigned are generally too early. Therefore the $T_{\rm eff}$ estimated from the spectral type will be higher. However for moderately low metallicities ($[{\rm Fe/H}]\geq-1.0$) the above-mentioned calibrations may still be used. Recently Spite et al. (1989) and Russell & Bessell (1989) used for SMC F-supergiants ($[{\rm Fe/H}]=-0.7$) the $T_{\rm eff}$ – colour calibrations of Schmidt-Kaler (1982) and found agreement with the $T_{\rm eff}$ and $\log g$ values derived from an analysis of their high resolution spectra.

The star HD 56126 is a peculiar F supergiant similar to the high galactic latitude F supergiants, some of which are metal poor. It is appropriate to compare the spectra of HD 56126 with the spectra of high galactic latitude F supergiants for which $T_{\rm eff}$ and $\log g$ values are estimated from an analysis of high resolution spectra (Luck et al. 1990). We have compared the low dispersion blue region spectrum of HD 56126 with the low dispersion spectra of several high galactic latitude F supergiants (Parthasarathy 1992) for which Luck et al. (1990) derived $T_{\rm eff}$ and $\log g$ values. For HD 56126 we adopt $T_{\rm eff}=6500$ K and $\log g=0.5$. The uncertainties in $T_{\rm eff}$ and $\log g$ values are of the order ±500 K, and ±0.5 respectively.

Hrivnak et al. (1989) estimate $T_{\rm eff}=6600$ K from the flux distribution of the star in the optical region. We adopt $T_{\rm eff}$ of HD 56126 to be 6500 K. However in addition to the 6500 K model atmosphere of Kurucz (1979) we have also used 7000 K, 6000 K and 5500 K model atmospheres of Kurucz (1979) in deriving abundances. The luminosity class I or $\rm I_a$ of HD 56126 (Parthasarathy 1989) suggests a surface gravity $\log g$ in the range 0.5–1.0, similar to that of high galactic latitude A and F supergiants with dust shells (Parthasarathy & Pottasch 1986; Luck et al. 1990). All these objects show supergiant-like spectra and are most likely low mass low gravity stars (Parthasarathy & Pottasch 1986; Luck et al. 1990; also see the discussion section). In our present analysis we have used Kurucz model atmospheres with above mentioned temperatures, and surface gravities $\log g=0.5$ and 1.0. Very low surface gravity is also indicated by the presence of large Balmer discontinuity. Another characteristic feature of all these stars is that most of them show Hα in emission. The Hα profile (Fig. 2) shows emission in the wings and a narrow absorption core which indicates an extended atmosphere and mass loss. The emission strength in the violet and red wings of Hα line are found to be variable (Parthasarathy 1989). The Brackett series lines were found to be inverted P Cygni and shell-like profiles (Kwok et al. 1990).

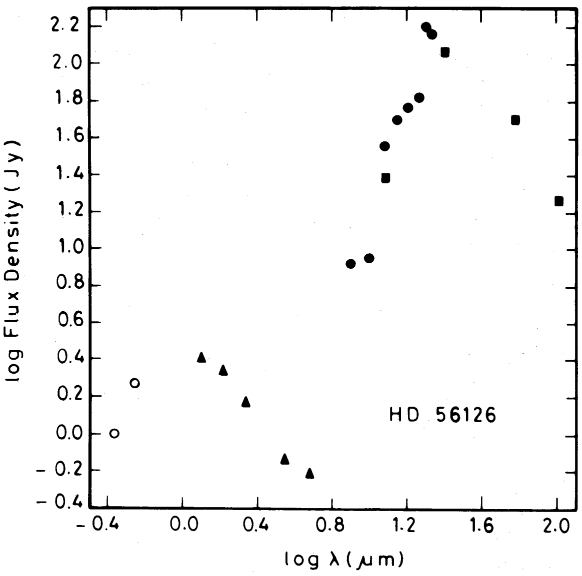

Fig. 1. Flux distribution of HD 56126

In the $V-B/B-U$ diagram for normal galactic supergiants (corrected for reddening) and LMC supergiants, HD 56126 is located below $\log g=0.5$ grid and in the $T_{\rm eff}$ interval 6000–6500 K (van Genderen et al. 1986). van Genderen et al. (1986) note that HD 56126 is still very red in $B-U$ and $U-W$ and suggest that it should be shifted in the $V-B/B-L$ diagram up to $V-B\sim0.1$, $B-L\sim0.2$ and $B-U\sim0.6$ to bring the colours in agreement with the spectral type of F 5I. With this shift also the star is located in the region close to $\log g=0.5$ line and $T_{\rm eff}$ interval 6500–7000 K. The reddening independent indices $[B-L]$ and $[L-U]$ (Pel et al. 1981) also suggest low gravity and low metallicity for HD 56126.

Accurate values of $T_{\rm eff}$ and $\log g$ can be obtained from an analysis of several Fe I lines by demanding that the [Fe/H] abundance as derived from individual Fe I lines shows no systematic trend with the excitation potential of the lines. Similarly the surface gravity $\log g$ can be estimated by forcing the Fe I and Fe II lines to yield the same abundance. In this paper we are not able to carry out such an analysis as we have found very few Fe I and Fe II lines in the spectral regions of HD 56126 that we have used in the present analysis. We plan to obtain high resolution spectra of HD 56126 in the blue region where one can find several Fe I and Fe II lines which may permit us to derive accurate $T_{\rm eff}$ and $\log g$ values using the above mentioned method.

In addition to $T_{\rm eff}$ and $\log g$ values two parameters needed for spectrum synthesis are microturbulent velocity ($\zeta_{\rm T}$) and macroturbulent velocity ($V_{\rm M}$). We have adopted $\zeta_{\rm T}=4$ km s^{-1}. Recently Luck et al. (1990) derived microturbulent velocity of 4 km s^{-1} from an analysis of the spectra of high galactic latitude F supergiants HD 161796 and 89 Her which are very similar to HD 56126. The microturbulent velocity of 4 km s^{-1} is in agreement with the low surface gravity of these stars. The abundance versus equivalent width relation also supports a value of 4 km s^{-1} (Luck et al. 1990). The macroturbulent velocity was derived during the spectrum synthesis by comparing spectra computed for different velocities with the observed spectra.

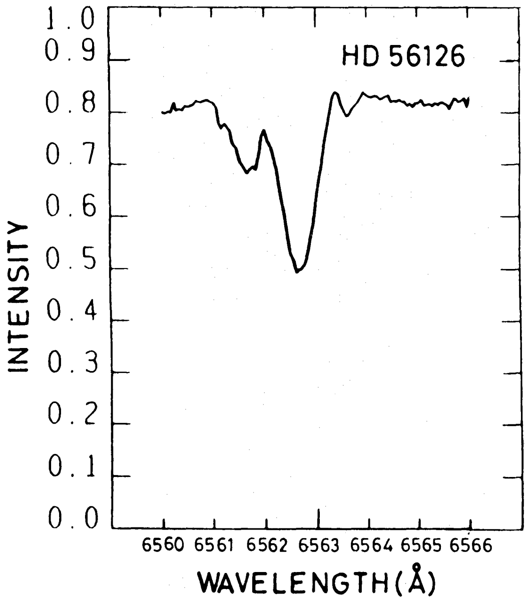

Fig. 2. High resolution Hα profile HD 56126

3.2. *CNO lines data*

The spectral lines of CNO and their equivalent widths in the observed spectra of HD 56126 are given in Table 1. The observed spectra are shown in Figs. 3–5. We have used the oscillator strengths (log *gf*) of CNO lines (Table 1) listed in Lambert et al. (1982). We have also used the S I lines at 8693.15 15 Å and 8694.64 Å in the abundance analysis. The oscillator strengths of S I lines (Table 1) listed by Luck & Lambert (1985) were adopted. For other atomic lines we have adopted the oscillator strengths listed by Luck & Lambert (1985). In the spectrum synthesis calculations we have included all the lines including the weak lines present in the spectral regions under investigation. Line lists and oscillator strengths were obtained from the compliation of Kurucz.

3.3. *Method of analysis*

Abundances were derived using the LTE model atmospheres from the model atmosphere grid computed by Kurucz (1979). For computing the spectrum and equivalent widths we used the SYNTHE and WIDTH8 codes of Kurucz (Kurucz & Avrett 1981) kindly made available by Dr. F. Castelli (Castelli & Hack 1990).

3.4. *Abundances*

The Kurucz model atmosphere with $T_{\rm eff}=6500$ K, $\log g=0.5$, $[{\rm Fe/H}]=-1.0$ and microturbulent velocity $\zeta_{\rm T}=4$ km s^{-1} may be a reasonably good approximation to the atmospheric parameters of HD 56126. Abundances derived using the above model are adopted here and these are given in Table 2. However we have also derived abundances using Kurucz models with $T_{\rm eff}$

Table 1. Spectral lines of CNO and their equivalent widths in the spectrum of HD 56126

λ	Element	EW (mÅ)	LEP	log *gf*
7108.92	C I	40	8.64	−1.68
7111.475	C I	75	8.64	−1.33
7113.180	C I	122	8.64	−0.96
7115.186	C I	119	8.64	−0.93
7116.990	C I	143	8.64	−1.10
7119.671	C I	93	8.64	−1.31
7423.64	N I	62	10.32	−0.61
7442.29	N I	70	10.33	−0.31
7468.31	N I	89	10.33	−0.13
8680.28	N I	134	10.33	+0.236
8683.4	N I	255	10.33	+0.14
8686.15	N I	193	10.33	−0.27
8703.248	N I	196	10.33	−0.27
8711.703	N I	238	10.33	−0.16
8718.837	N I	140	10.34	−0.23
6155.976	O I	38	10.74	−0.66
6156.766	O I	103	10.74	−0.44
6158.184	O I	56	10.74	−0.29
8694.64	S I	158	7.87	+0.061

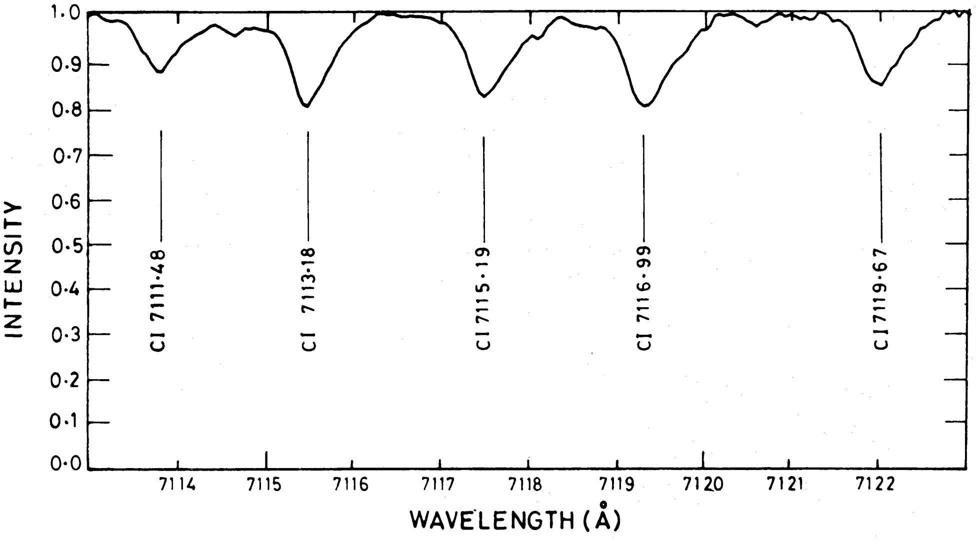

Fig. 3. C I lines around 7110 Å in the spectrum of HD 56126

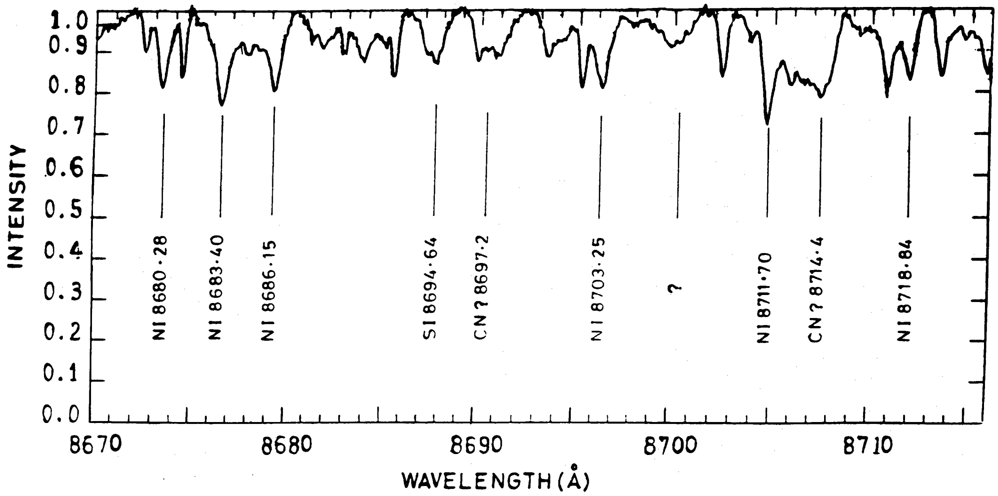

Fig. 4. N I lines around 8690 Å in the spectrum of HD 56126

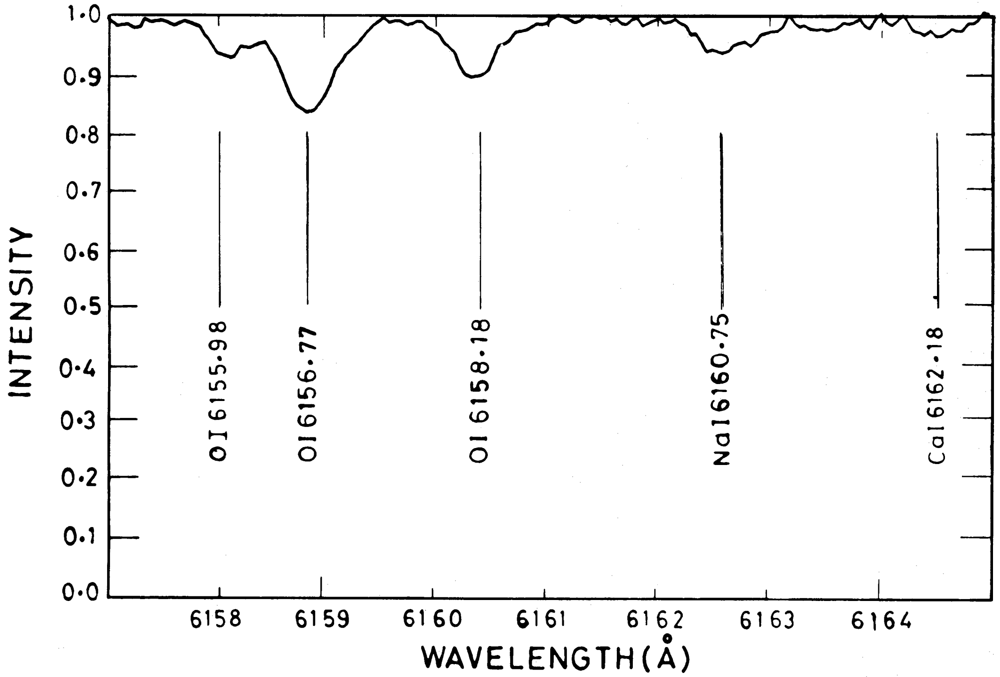

Fig. 5. O I lines around 6157 Å in the spectrum of HD 56126

$=7000$ K, $\log g=0.5$; $T_{\rm eff}=6000$ K, $\log g=0.5$; $T_{\rm eff}=6000$ K, $\log g=1.0$ and $T_{\rm eff}=5500$ K, $\log g=0.5$ The results obtained using these models also support the conclusion that HD 56126 is metal poor and CNO and S elements are overabundant relative to Fe. The abundances derived using the $T_{\rm eff}=6000$ K, $\log g=0.5$ and 1.0 and $\zeta=4$ km s^{-1} are also listed in Table 2. From the use of above model atmosphere we found the iron abundance of HD 56126 to be in the range [Fe/H] $=-1.18$ to -1.38 (Table 2). Analysis of blue region high resolution spectra of HD 56126 is needed which will enable us to derive accurate iron abundance using several Fe I and Fe II lines.

The carbon abundance is based on the analysis of 6 carbon C I lines in the region of 7108–7120 Å (Fig. 3, Table 1). The 8335 Å region C I is not included in estimating the C I abundance. It is strong and is likely to be influenced by non-LTE effects. The nitrogen abundance is based on the analysis of nitrogen lines in the region 7420–7470 Å (multiplet 3) (Table 1) and 8680–8720 Å (multiplet 1) (Fig. 4, Table 1). The N I lines of multiplet 1 around 8710 Å are relatively strong and yield higher abundance relative to the 7440 Å region N I lines (multiplet 3). The N I abundance is based on three lines in the 7440 Å region and two lines in the 8700 Å region (8680.3 and 8718.8 Å). The 8680.3 and 8718.8 Å N I lines are relatively weak and yielded reliable abundance similar to the 7440 Å region lines. The remaining lines in the 8700 Å region are strong and yield 0.7 dex higher abundance compared to the 7440 Å regions lines. It is likely that the N I 8683.4, 8686.2, 8703.2 and 8711.7 Å lines in the spectrum of HD 56126 are influenced by non-LTE effects. A similar effect was found in Canopus, i Car and α Lep by Luck & Lambert (1985). They stated that an LTE analysis yielded high nitrogen abundance for Canopus, i Car, and α Lep with the stronger lines of RMT 1 of N I (around 8700 Å) requiring an abundance about 0.6 dex larger than the value provided by the weakest lines. Luck et al. (1990) also found similar result from an analysis of 7440 Å region and 8700 Å region N I lines in the spectra of high galactic latitude F supergiants. The 8700 Å region spectrum of HD 56126 shows two relatively strong absorption features centered around 8697.3 and 8714.4 Å (Fig. 4). These absorption features are not present in the spectrum of high galactic latitude supergiant HD 161796 (F 3I) and normal F supergiant α Per (F 5I) [compare with Fig. 4 in Luck et al. (1990) and Fig. 6 in Luck & Lambert (1985)]. These two absorption features centered around 8697.3 and 8714.4 Å may be due to CN. The near IR CN features are normally very weak or absent in the near infrared spectra of F 5I stars with CNO abundances similar to that found in HD 56126. Observation of Red CN system at 8000 Å is needed to settle this question.

The oxygen abundance is based on the O I triplet lines at 6157 Å (Fig. 5). The [O I] 6300 and 6363 Å lines were found to be very weak or absent in the spectrum of HD 56126. We have also computed synthetic spectra in these regions. However our O I abundance adopted here is based only on three lines in the region of 6157 Å. We find HD 56126 is metal poor and we estimate the Fe abundance relative to the Sun to be [Fe/H] $=-1.0$. However the carbon, oxygen and sulphur abundances are nearly solar [C] $=-0.01$, [O I] $=-0.02$, [S] $=+0.01$ and nitrogen is slightly overabundant [N] $=0.17$ (Table 3). The CNO and S abundances in HD 56126 are not similar to the CNO abundances in population I supergiants. In population I supergiants the CNO abundances are found to be $\langle$[C/Fe]$\rangle=-0.56$, $\langle$[N/Fe]$\rangle=+0.46$, and $\langle$[O/Fe]$\rangle=-0.35$ (Luck & Lambert 1985), whereas the CNO and S elements in HD 56126 are found to be overabundant: [C/Fe] $=+0.99$, [N/Fe] $=+1.17$, [O/Fe] $=+0.98$, and [S/Fe] $=+1.01$. In addition to S, Na, Mg and Si are also slightly overabundant.

The Fe abundance is based on three Fe I lines and one Fe II line. The abundances of Na and Ca are based on one line each and the Si abundance is based on two Si II lines. The uncertainty in the [Fe/H] abundance is of the order ±0.3. The standard deviations in the C, N, O abundances are 0.06, 0.086 and 0.177 respectively. The blue spectral region contains several Fe I and Fe II lines; therefore an analysis of blue region spectra may yield accurate $T_{\rm eff}$ and $\log g$ and [Fe/H] values. An analysis of the blue region spectra and the abundances derived from individual lines including the C, N, O lines (used in the present analysis) will be published separately. The uncertainties in $T_{\rm eff}$ and $\log g$ values of these stars may still be of the order of 500 K and 0.5, or larger even after detailed analysis of high resolution spectra. For example for 4912 HR Luck et al. (1983) derived $T_{\rm eff}=6000$ K and $\log g=0.4$–0.8 and Böhm-Vitense & Proffitt (1984) derive $T_{\rm eff}=5500$ K and $\log g=-0.3$. Another example is the very metal poor post AGB star HR 4049 for which $T_{\rm eff}$ and [Fe/H] values are uncertain (Lambert et al. 1988; Waelkens et al. 1990; Takada-Hidai 1990).

Table 2. Abundances in HD 56126

$T_{\rm eff}$ (K)	5500	6000	6000	6500	7000
$\log g$	0.5	0.5	1.0	0.5	0.5
ζ (km s^{-1})	4	4	4	4	4
[C/H]	+0.33	+0.05	+0.17	−0.01	+0.15
[N/H]	+1.02	+0.57	+0.73	+0.17	+0.03
[O/H]	+0.81	+0.34	+0.49	−0.02	−0.16
[Na/H]	−0.08	+0.06	+0.02	+0.42	+0.81
[Si/H]	−0.30	−0.64	−0.48	−0.85	−1.15
[S/H]	+0.23	−0.04	+0.14	+0.01	+0.25
[Ca/H]	−2.98	−2.74	−2.79	−2.24	−1.70
[Fe/H]	−1.38	−1.47	−1.32	−1.35	−1.18

Table 3. Abundances in HD 56126 and in the high velocity F supergiant HD 46703

	HD 56126	HD 46703
	$T_{\rm eff}=6500$ K	$T_{\rm eff}=6000$ K
	$\log g=0.5$	$\log g=0.4$
	$\zeta=4$ km s^{-1}	$\zeta=3.5$ km s^{-1}
	Ref: This paper	Bond & Luck (1987)
[Fe/H]	≤ -1.00	−1.6
[C/Fe]	0.99	1.0
[N/Fe]	1.17	1.8
[O/Fe]	0.98	1.1
[$\alpha_{\rm el}$/Fe]	0.15	−0.1
[S/Fe]	1.01	1.2

($\alpha_{\rm el}\Rightarrow$Mg, Si)

3.5. *Spectral peculiarities*

The Ni I at 6176.816 Å is relatively strong and yields large overabundance. This line appears to be blended with Cr II. It is likely that the 6176.816 Å Ni I (Cr II) feature may be affected by the circumstellar shell. The 6380.748 Å Fe I line also shows similar behaviour and yields significant overabundance of Fe. The profile of 6380.748 Å Fe I line is very similar to the Hα profile (Fig. 2). The strength and profile shape suggests this line in also affected by the circumstellar shell. The Ba II line at 6141.73 Å also shows evidence for the presence of the shell component (Fig. 6). The Ba II line profile shown in Fig. 6 clearly shows the presence of an asymmetry and an absorption (shell) component in the red wing. The shift from the line center is $\sim +10$ km s^{-1}. A weak shell component may be present in the red wings of Si II lines at 6347.1 and 6371.3 Å. The spectral line asymmetry is clearly noticeable in the C I lines at 7110 Å (Fig. 3). Such line asymmetry may be the result of velocity gradients in the expanding atmosphere of HD 56126. The line broadening when matched with synthetic spectrum calculations yields a macroturbulent velocity of 13 km s^{-1}. Luck et al. (1990) found a similar value for macroturbulent velocity in the high galactic latitude A and F supergiants.

3.6. *Radial velocity*

The radial velocity of HD 56126 derived from 6563, 7115, 6158, and 6363 Å spectral region is found to be $+105.0 \pm 1$ km s^{-1}. All the spectral lines yield almost the same radial velocity. The velocity with respect to local standard of rest $V_{\rm LSR} = 52.3$ km s^{-1}. The radial velocity of HD 56126 clearly suggests that it is a high velocity star. The population I, A and F supergiants do not have such high radial velocity. The radial velocity of $+105$ km s^{-1}, low metal abundance $[\mathrm{Fe/H}] \leq -1.0$ and detached circumstellar cold dust shell suggests that HD 56126 is an evolved low mass star of the old disk population. The F supergiant HD 56126 appears to be similar to the post AGB F supergiant HD 46703 for which Luck & Bond (1984) find the radial velocity to be -105 km s^{-1} suggesting halo kinematics.

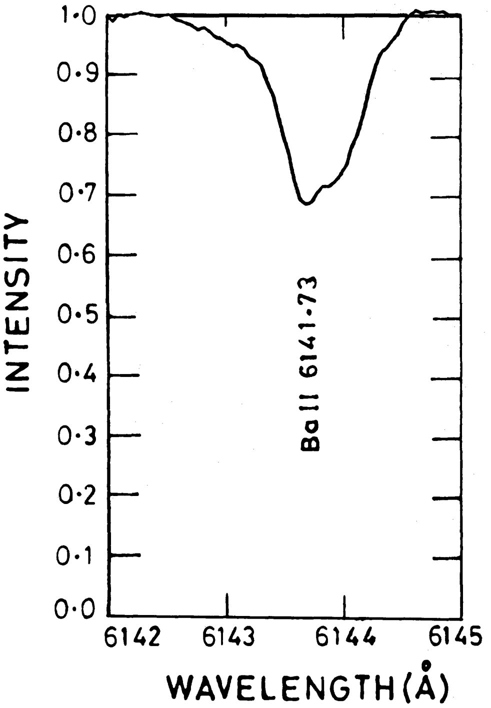

Fig. 6. Ba II line in the spectrum of HD 56126. Notice the shell absorption component in the red wing (at $+10$ km s^{-1} from the line center)

4. Discussion

The [Fe/H], [C/Fe], [O/Fe] and [S/Fe] abundances in HD 56126 are similar to the abundances in the high velocity metal poor F supergiant HD 46703 (Table 3). The [C/Fe], [N/Fe], [O/Fe] and [S/Fe] values are very much larger than those expected in metal poor stars. Similar values were found by Luck et al. (1990) and Waelkens et al. (1990) from an analysis of several post AGB stars. All these stars show A and F supergiant type spectra and have warm and/or cold dust shells. Some of them are at high galactic latitudes. The CNO and S abundances trends in these stars as a function of [Fe/H] are shown in Fig. 7. In metal poor dwarfs the $[\mathrm{C/Fe}] = 0.0$ and at $[\mathrm{Fe/H}] = -2.5$, $[\mathrm{C/Fe}] \simeq +0.2$; $[\mathrm{N/Fe}] \simeq -0.2$ for $[\mathrm{Fe/H}] = -2.5$ to -1.0, and $[\mathrm{N/Fe}] = 0.0$ for $[\mathrm{Fe/H}] = 0.0$; and $[\mathrm{O/Fe}] = +0.4$ for [Fe/H] in the range -1.0 to -3.0 (see Wheeler et al. 1989). The [C/Fe], [N/Fe] and [O/Fe] ratios observed in post AGB stars (Fig. 7) are much larger than expected in extreme metal poor stars. The relation between [Fe/H] and [C/Fe] shown in Fig. 7 and similar relations between [N/Fe] and [O/Fe] and [S/Fe] cannot be explained

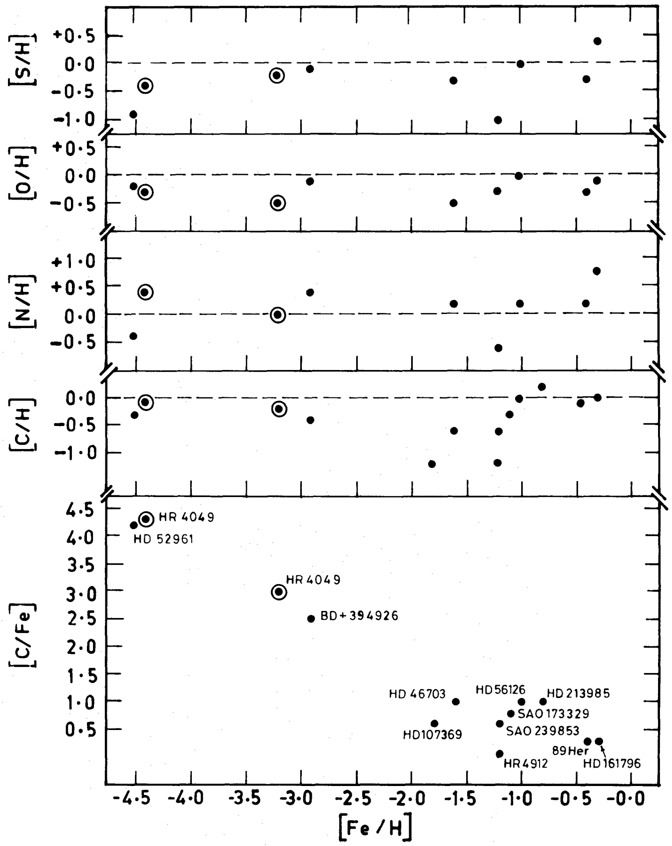

Fig. 7. [C/Fe] and C, N, O and S abundances relative to solar in post AGB stars

easily in terms of nucleosynthesis or galactic chemical evolution. From Fig. 7 it is clear that CNO and S abundances in these post AGB stars are nearly solar or slightly different from solar values. The abundance results shown for extremely metal poor post AGB stars are from Lambert et al. (1988) (HR 4049), Waelkens et al. (1990) (HR 4049 and HD 52961), Takada-Hidai (1990) (HR 4049) and Kodaira (1973) (BD+39°4926). In most of the post AGB stars shown in Fig. 7 the carbon abundance [C/H] is in the range 0.0 to −0.5, [N/H] = 0.0 to +0.5, [O/H] = 0.0 to −0.5 and [S/H] = 0.0 to −0.5. For HR 4912 Luck et al. (1984) give [Fe/H] = −1.2 and [C/H] = −1.1 A redetermination of C abundance in HR 4912 using several C lines is needed.

Table 4. The C/N/O abundance ratios in post AGB stars

	[Fe/H]	C/N	C/O	O/N
HD 161796	−0.3	0.76	0.44	1.66
89 Her	−0.4	2.40	0.89	2.63
HD 213985	−0.8	4.79	1.77	2.70
HD 56126	−1.0	3.16	0.57	5.37
HD 46703	−1.6	0.76	0.44	1.66
BD+394926	−2.9	0.76	0.28	2.63
HR 4049	−4.4	1.51	0.88	1.66
HD 52961	−4.5	6.03	0.89	6.80
Sun	0.0	4.79	0.56	8.32
GKM giants	0.0	1.45	0.34	4.26
Pop I Supergiants	0.0	0.46	0.35	1.25
PN Type I		1.32	1.15	1.15
PN Types II–III		5.62	1.45	3.89

The C/N/O abundance ratios which are more meaningful in understanding the evolutionary aspects are given in Table 4. The CNO abundances and C/N/O ratios (Figs. 7 and 8 and Table 4) in these stars suggest that they are evolved and nitrogen is overabundant. Figure 8 shows the position in the C/N–O/N plane of various types of evolved stars (for details see Nussbaumer et al. 1988) and the post AGB stars. The points clearly form two regions: the Sun, all the G, K, M giants and supergiants and symbiotic stars lie to the left of the C/O = 1 line. Separated by a gap we see the carbon stars on a small strip to the right of the C/O = 1 line. In descending order of C/N, O/N ratios we first find G and K giants, then M, MS, S giants and symbiotic stars, and in the lowest the supergiants. In this order they increasingly exhibit the products of CNO-cycling (enhancement of N at the expense of C and O). The carbon stars are clearly separated from the other giants and supergiants. By definition they lie to the right of the C/O = 1 line. The carbon stars do not peter out to the right of the C/O = 1 line but lie in a narrow strip close to the C/O = 1 line. All carbon stars have O/N $\geq$ 3. Their location in Fig. 8 indicates that the helium burning products have been brought to the stellar

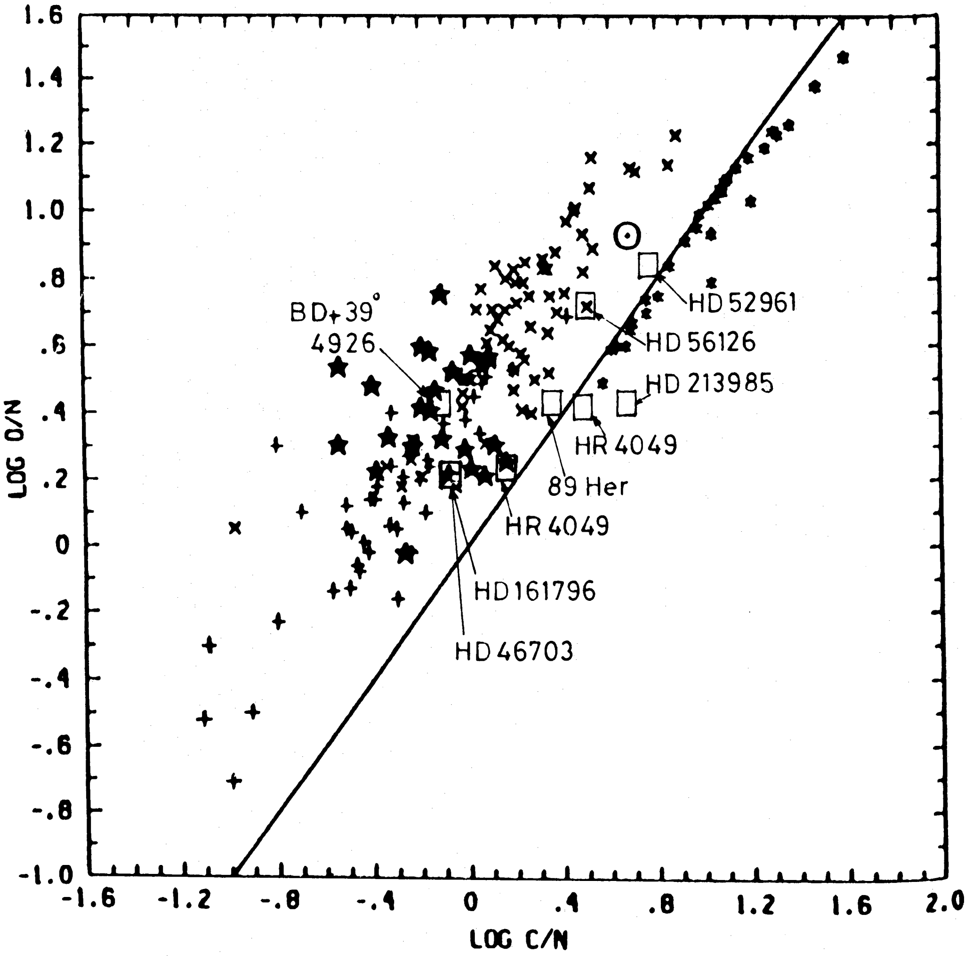

Fig. 8. Relative abundance O/N against C/N for post AGB stars (□), G, K, M, MS and S giants (×), carbon stars (∗) and intermediate supergiants (+), symbiotic stars (⋆). The symbol (⊙) shows the Sun. The data on symbiotic stars G, K, M, MS and S giants, carbon stars, and intermediate supergiants are from Nussbaumer et al. (1988)

surface. The location of post AGB stars HD 52961, HD 213985, HR 4049, and 89 Her in Fig. 8 is the same as that of carbon stars and suggests that these stars also have helium burning products on their surfaces and may be related to carbon stars. In the log O/N against log C/N diagram (Fig. 8) HD 161796, HD 46703, BD + 39°4926 and HD 56126 are in the region occupied by G, K, M giants.

In the log O/N against C/N diagram (Fig. 8) none of the post AGB stars given in Table 4 is in the region defined by intermediate mass supergiants indicating that progenitors of the post AGB stars (Fig. 8, Table 4) originated from low mass stars. The C/N/O ratios (Table 4) and location in the O/N against C/N diagram (Fig. 8) suggest that they have products of CNO-cycling on their surface and also that some of them may have helium burning products on their surfaces. HD 213985 (C/N = 4.79), HD 52961 (C/N = 6.03) and HD 56126 (C/N = 3.16) have relatively high C/N ratios. However these are high galactic latitude supergiants and HD 56126 is a high velocity star (see Sect. 3.5) belonging to the old disk. Cottrell & Sneden (1986) found solar C/N ratios and enhanced O/Fe ratios in evolved high velocity giant stars (metal poor members of the disk population).

Planetary nebulae lie on both sides of C/O = 1 line (Nussbaumer et al. 1988). However a majority of them lie on the side of the carbon stars. Some of them seem to display only CNO processed material and coincide with F-M giants whereas others clearly show He burning products and are located near the carbon stars. Post AGB stars also show both these aspects. Recently Perinotto (1991) evaluated average chemical abundances for planetary nebulae (PN) of type I and types II-III of Peimbert. He used the chemical abundances of 209 well studied planetary nebulae. For type I PN he found C/H = 8.72, N/H = 8.60 and O/H = 8.66 and for types II-III PN, C/H = 8.82, N/H = 8.07 and O/H = 8.66. The C/H abundances clearly show that the carbon abundance in type I and types II-III PN is nearly solar or within 0.1 dex of solar carbon abundance. Type I PN show 0.6 dex overabundance of nitrogen. The oxygen is 0.25 dex underabundant in type I and type II-III. The abundances in PN are consistent with the possibility that the enrichment of nitrogen in type I PN is due mostly to the ON cycle, while that in PN of types II-III is due mostly to the CN cycle. The C/N/O abundance ratios in PN are given in Table 4. The C/H, N/H and OH abundances in post AGB stars (Fig. 7) are not very different from the average C/H, N/H and O/H abundances of PN derived by Perinotto (1991). The C/O ratio of PN is in the range 1.15–1.45 (Table 4). Some of the post AGB stars also show C/O ratio close to 1. Type I PN are helium and nitrogen rich and may have progeniters with initial mass $\geq 2.4 M_{\odot}$. Type II PN may have progenitors with initial masses 1.2–$2.4 M_{\odot}$, and type III 1–$1.2 M_{\odot}$. The O/N ratio of several post AGB stars given in Table 4 are comparable to the O/N ratio of type II-III PN. However some of the post AGB stars appear to be nitrogen rich and some have C/N ratio comparable to that of type II-III PN. We have no idea of the helium abundances in the atmospheres of these stars. There are several uncertainties such as the initial main sequence masses, path of evolution and mixing and mass loss stages of these stars. However in addition to the CNO abundances, high galactic latitude position and high velocities of some of these stars suggest that they have evolved from low mass stars.

The C/N/O ratios (Table 4, Fig. 8) suggest that the [C/Fe], [N/Fe], [O/Fe] and [S/Fe] ratios (Fig. 7) are much larger than expected from metal poor stars. In metal poor dwarfs sulfur is found to be slightly overabundant [S/Fe] = + 0.4 (Wheeler et al. 1989). However in the post AGB stars the [S/Fe] ranges up to + 3.6 (Fig. 7; Luck et al. 1990; Bond 1991). Such large [S/Fe] values cannot be accounted in terms of nucleosynthesis (Luck et al. 1990; Bond & Luck 1987).

The deficiency of refractory elements such as Mg, Al, Si, Ca, Ti and Fe and the lack of such deficiency in CNO and S is similar to that observed in the abundances of interstellar medium. The abundances in the interstellar medium (lower column density, diffuse clouds) and in BD + 39°4926 (Kodaira 1973) are compared in Fig. 9. The abundance trends in BD + 39°4926 (Kodaira 1973), HD 46703 (Luck & Bond 1984; Bond & Luck 1987), HR 4049 and HD 52961 (Waelkens et al. 1990) and the present star HD 56126 are similar to that observed in the interstellar medium (Fig. 9). The fact that most of the post AGB stars discussed here show evidence for the presence of warm and/or cold circumstellar dust shells lends strong support to the idea that the depleted elements are locked up in the dust grains. Hoyle & Wickramasinghe (1962) (see also Kamijo 1963) were the first to suggest that the dust grains tend to be formed in the atmospheres of cool red giants and supergiants at temperatures less than 2700 K. They suggested that the dust grains that have formed in the atmospheres of these cool stars have significant effect on the photospheric opacity causing the photospheric density to decrease very

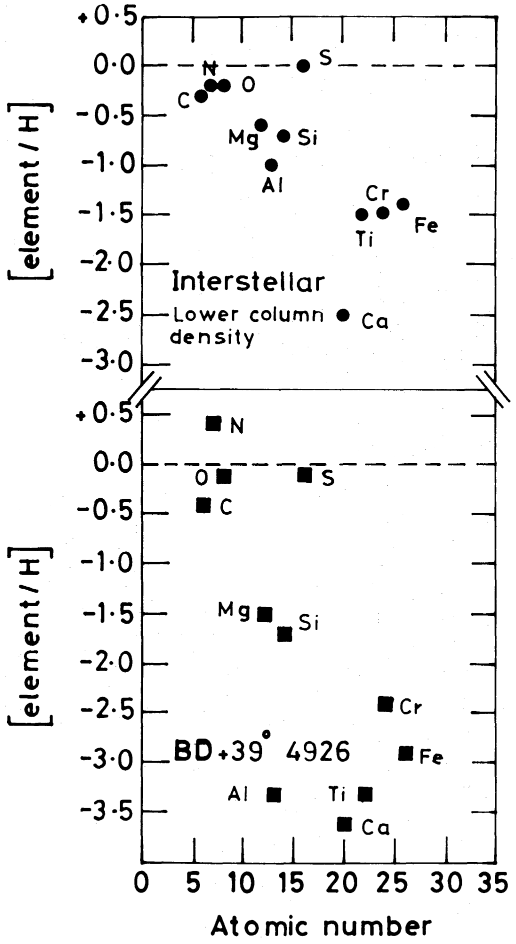

Fig. 9. Comparison of abundances in the post AGB star BD + 39°4926 (Kodaira 1973) and in the diffuse interstellar medium (lower column density)

markedly as the temperature falls towards 2000 K. They further suggested that it is this fall of density that allows the grains to be repelled outwards by radiation pressure and to leave the star altogether in spite of the frictional resistance of the photospheric gases and these dust grains do not evaporate as they leave the atmosphere of the star.

The formation of brand new dust grains out of free atoms, ions and molecules via nucleation requires a very special environment. The density needs to be of the order of 10^9 cm^{-3} or higher and the temperatures around 1000–2000 K. These conditions exist primarily in outflows from evolved cool red giants and supergiants where cores of dust grains have formed (Salpeter 1977; Field 1974). The presence of dust shells, molecular envelopes, and photospheres showing depletions of refractory elements suggests that these post AGB stars (that are being discussed here, Table 4) once were very cool and had extended cold outer atmospheres reaching $T < 2000$ K. The depletion of Ti, Al, Ca, Si, Fe, etc. in the photospheres of these post AGB stars suggests that the condensation (formation of clusters and cores of dust grains with refractory elements) has taken place when the present post AGB stars had envelopes with T in the range 1000–1600 K. The refractory elements such as Ti, Al, Ca (1400–1600 K) condensed and locked up in the cores of dust grains when the temperature of the extended atmosphere was close to the condensation temperature of these elements (Field 1974) [Ti, Al, Ca (1400–1600 K); Si, Mg (1270–1320 K); Fe, Ni (1280 K)]. Therefore we see the depletions of these elements in these post AGB stars. Volatile elements (C, N, O, Zn) with low T_c (condensation temperature < 700 K) do not show significant depletions in the atmosphere of these stars indicating temperatures above 1000 K before the ejection of the dust shell or dust driven mass loss. Recently Cardelli (1984) found observational evidence for the formation of dust grains close to the star and also found depletion of refractory elements in the atmosphere. Cardelli (1984) analysed IUE spectra of α Sco. The hot component of α Sco shines through the circumstellar envelope of the M 1.5 I ab companion. Cardelli's analysis of absorption lines that arise in the circumstellar shell around M 1.5 ab (α Sco A) shows clear evidence for depletions of refractory elements similar to that found in the interstellar medium. These depletions are due to the formation of dust (nucleation of grain cores by equilibrium condensation) in the circumstellar envelope very close to the star.

Observations and theory suggest that dust forms very close to the star (around 2 stellar radii); however the dust formation region may extend from two stellar radii to ten stellar radii (Dyck et al. 1984; Zuckerman 1980; Lafon & Berruyer 1991). In the post AGB stars the dust seems to have formed close to the star during the expansion and cooling of the outer atmospheres of these stars. Tielens (1983) model of dust driven mass loss suggests that grains may attain large drift velocity with respect to gas and also that the velocities of expansion and flow (dust driving) during rapid mass loss phase are not very high (< 30 km s^{-1}). High velocity flows and shock waves destroy the dust grains and can also stop nucleation of dust grains. The conditions of temperatures, velocities in the outer expanding regions of the progenitors of present post AGB stars discussed here may be different from that of other stars with circumstellar dust shells. Some of the post AGB stars such as BD +39°4926, HR 4049 and HD 52961 are extremely deficient in Fe and most likely in other refractory elements. However their C, N, O and S abundance do not share this extreme deficiency. Why some of these objects show extreme deficiency of refractory elements while others do not suggest that some of them had very dense cool envelopes where dust formation was very efficient which has depleted large fraction of refractory elements, or that these stars have gone through several cycles of envelope expansion, cooling to the limit of condensation temperature, dust formation close to the star.

The depletion of Fe, Mg, Si, Al but not of C, N, O was also noticed in planetary nebulae (Shields 1978; Pwa et al. 1984; Harrington & Marionni 1981). In NGC 7027 Shields found the gas phase iron abundance to be low ([Fe/H] = −1.4), whereas oxygen has the solar abundance and suggested that the iron depletion results from grain formation. Shields found similar iron depletions in the gas phase abundances in several other planetary nebulae. He found the gas-phase Fe abundance range $-2.0 \leq [\mathrm{Fe/O}] \leq -0.4$. In all these PN the oxygen abundances are essentially solar and show no correlation with [Fe/H]. In the planetary nebula NGC 6543 Pwa et al. (1984) found for carbon and silicon lower than solar values by factors 2 and 4, but iron was found to be depleted by at least a factor of 70, and aluminium by a factor of 300. Harrington et al. (1982) found similar depletions in the gas phase abundances of Mg, Fe, and Si in the planetary nebula NGC 7662. The absence of the Mg II 2800 Å feature in several planetary nebulae implies that depletion of Mg is widespread (Harrington & Marionni 1981; Flower & Penn 1981). IRAS data of all these planetary nebulae show evidence for the presence of dust shells. These results indicate efficient condensation of iron and other refractory elements into dust grains in PN and post AGB stars.

We have mentioned earlier that the C/N and O/N ratios (Fig. 8) suggest that these stars are evolved and the presence of warm and/or cold detached circumstellar dust shells, the CO-molecular envelopes around them, the high galactic latitude location of some of these stars and high radial velocities of some of these stars, all indicate that they are low mass stars and are now in the AGB or post AGB stage of evolution. If these stars have gone through or are still on the AGB we expect them to show characteristics similar to the carbon stars i.e. large overabundance of carbon and s-process elements. Luck et al. (1990) found no enhancements of s-process elements in these stars. The J-type carbon stars ($12_C/13_C \sim 4$–15, 13_C rich) and early R stars (warm carbon stars) do not show overabundance of s-process elements. The J-type carbon stars, early R stars and the post AGB stars that are being discussed here may be the result of helium core flash which results in overabundance of carbon but not of s-process elements. Recently Lattanzio's (1989) AGB models produced carbon stars without enhancement of s-process elements. However the observed circumstellar dust shell around these post AGB stars suggests that they have lost a significant amount of mass before becoming carbon stars. It has been shown that in models with smaller envelope mass when carbon dredge-up begins the reduced envelope mass means a smaller dilution of the add carbon, and fewer shell flashes (thermal pulses) and therefore no overabundances of s-process elements.

5. Conclusions

From an analysis of high resolution spectra of IRAS source HD 56126 (F 5I) we find that its photospheric abundances of C, O, S are nearly solar and N is overabundant by ~0.2 dex. However the abundance of Fe and related elements suggest that HD 56126 is metal poor ([Fe/H] ≤ −1.0). The atmospheric parameters of

HD 56126 are found to be $T_{\rm eff} = 6500$ K, $\log g = 0.5$, $[{\rm Fe/H}] = -1.0$ and $\zeta = 4$ km s^{-1}. The radial velocity measurements yield $V_{\rm r} = +105$ km s^{-1} and $V_{\rm LSR} = +52.3$ km s^{-1}, and show that HD 56126 is a high velocity star belonging to the old disk population.

The chemical composition of HD 56126 appears to be similar to the high velocity post AGB star HD 46703 analysed by Bond & Luck (1987). However the abundance ratios of [C/Fe], [N/Fe], [O/Fe] and [S/Fe] in HD 56126 and related post AGB stars are too large and cannot be explained by nucleosynthesis, mixing and galactic chemical evolution. The large abundance ratios of CNO and S elements with respect to Fe are due to depletions of Fe and related elements but not of CNO and S elements. Since most of these post AGB stars have circumstellar dust shells the depletion of Fe and other related refractory elements in the photospheres of these stars suggests that the depleted refractory elements are locked up in the cores of circumstellar dust grains. The results suggest that in the recent past during the AGB stage of evolution of these stars they had extended cool denser outer envelopes in which the temperature reached to the limit of condensation temperature of refractory elements resulting in the formation of dust grains close to the star.

Acknowledgements. MP is very grateful to Prof. Margherita Hack for her kind encouragement and support. MP is also grateful to Prof. F. Castelli for her kind encouragement and for providing SYNTHE, WIDTH8 and other computer routines for the analysis of spectra. We thank Prof. F. Castelli, and Prof. A Peraiah for useful conversations.

References

Böhm-Vitense E., 1972, A&A 17, 335
Böhm-Vitense E., Proffitt C., 1984, PASP 96, 897
Bond H.E., 1991, in: Proc. IAU Symp. 145, p. 341
Bond H.E., Luck R.E., 1987, ApJ 312, 203
Cardelli J.A., 1984, ApJ 89, 1825
Castelli F., Hack M., 1990, Mem. Soc. Astron. Ital. 61, 595
Cottrell P.L., Sneden C., 1986, A&A 161, 314
Dyck H.M., Zuckerman B., Leinert C.H., Beckwith S., 1984, ApJ 287, 801
Field J.B., 1974, ApJ 187, 453
Flower P.J., 1977, A&A 54, 31
Flower D.R., Penn C.J., 1981, MNRAS 194, 13p
Harrington J.P., Marionni P.A., 1981, in: Chapman R.D. (ed.) The Universe at Ultraviolet Wavelengths NASA Conference Pub. 2171. NASA, GSFC, Maryland, p. 623
Harrington J.P., Seaton M.J., Adams S., Lutz J.H., 1982, MNRAS 199, 517
Hoyle F., Wickramasinghe N.C., 1962, MNRAS 124, 417
Hrivnak B.J., Kwok S., Volk K.M., 1988, ApJ 331, 832
Hrivnak B.J., Kwok S., Volk K.M., 1989, ApJ 346, 265
Jenkins E.B., 1987, in: Hollenbach D.J., Thronson H.A., Reidel D. Jr. (eds.) Interstellar Processes. Reidel, Dordrecht, p. 533
Jenkins E.B., 1989, in: Allamandola L.J., Tielens A.G.G.M. (eds.) Interstellar Dust, IAU Symp. 135. Kluwer, Dordrecht , p. 23
Kamijo F., 1963, PASJ 15, 440
Kodaira K., 1973, A&A 22, 273
Kurucz R.L., 1979, ApJS 40, 1
Kurucz R.L., Avrett E.H., 1981, SAO Special Rep. 391
Kwok S., Volk K.M., Hrivnak B.J., 1989, ApJ 354, L51
Kwok S., Hrivnak B.J., Geballe T.R., 1990, ApJ 360, L23
Lafon J.-P.J., Berruyer N., 1991, A&AR 2, 249
Lambert D.L., Roby S., Bell R.A., 1982, ApJ 254, 663
Lambert D.L., Hinkle K.M., Luck R.E., 1988, ApJ 333, 917
Lamers H.J.G.L.M., Waters L.B.F.M., Garmany C.D., Perez M.R., Waelkens C., 1986, A&A 154, L20
Lattanzio J.C., 1989, in: Johnson H.R., Zuckerman B. (eds.) The Evolution of Peculiar Red Giant Stars. Cambridge University Press, Cambridge, p. 161
Luck R.E., Bond H.E., 1984, ApJ 279, 729
Luck R.E., Bond H.E., 1989, ApJS 71, 559
Luck R.E., Lambert D.L., 1985, ApJ 298, 782
Luck R.E., Lambert D.L., Bond H.E., 1983, PASP 95, 413
Luck R.E., Bond H.E., Lambert D.L., 1990, ApJ 357, 188
Manchado A., Pottasch S.R., Garcia-Lario P., Esteban C., Mampaso A., 1989, A&A 214, 139
Nassau J.J., Stephenson C.B., MacGonnell D.J., 1965, Luminous Stars in the Northern Milky Way VI, Warner and Swasey Observatory, Ohio
Nussbaumer H., Schild H., Schmid H.M., Vogel M., 1988, A&A 179, 186
Parthasarathy M., 1989, in: Johnson H.R., Zuckerman B. (eds.) The Evolution of Peculiar Red Giant Stars. Cambridge University Press, Cambridge, p. 384
Parthasarathy M., 1990, in: Michaud G., Tutukov A., Bergevin M. (eds.), Contributed Papers. University of Montreal, Quebec, Canada, p. 119
Parthasarathy M., 1992 (in preparation)
Parthasarathy M., Pottasch S.R., 1986, A&A 154, L16
Pel J.W., 1976, A&AS 24, 413
Pel J.W., van Genderen A.M., Lub J., 1981, A&A 99, L1
Perinotto M., 1991, ApJS 76, 687
Pottasch S.R., Parthasarathy M., 1988, A&A 192, 182
Pwa T.H., Mo J.E., Pottasch S.R., 1984, A&A 139, L1
Russell S.C., Bessell M.S., 1989, ApJS 70, 865
Salpeter E.E., AR 1977, ARA&A 15, 267
Schmidt-Kaler Th., 1982, in: Schaifers K., Voigt M.H. (eds.) Landolt Börnstein, A&A VI, 2b. Springer, Berlin, p. 451
Shields G.A., 1978, ApJ 219, 559
Spite F., Spite M., Francois P., 1989, A&A 210, 25
Takada-Hidai M., 1990, PASP 102, 139
Tielens A.G.G.M., 1983, ApJ 271, 702
van Genderen A.M., Nan Driel W., Greidanus H., 1986, A&A 155, 72
Waelkens C., Van Winckel H., Bogaert E., 1990, in: Confrontation between Stellar Pulsation and Evolution, ASP Conference Series II, p. 125
Waelkens C., Van Winckel H., Trams N.R., 1991 in: Michaud G. (ed.) IAU Symp 145, Contributed Papers. University of Montreal, Quebec, Canada, p. 121
Wheeler J.C., Sneden C., Truran J.W., 1989, ARA&A 27, 279
Zuckerman B., 1980, ARA&A 18, 263
Zuckerman B., Dyck H.M., Claussen M.J., 1986, ApJ 304, 401