The UV spectrum of the WC 11 star CPD $-$ 56°8032

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Abstract. UV observations of the WC 11 central star of the compact planetary nebula CPD $-$ 56°8032 show that the continuum flux is variable. This variability appears to be caused by a change in the circumstellar extinction properties. The UV energy distribution can be fitted with helium star models with $T_{\text{eff}} \sim 25000$ K, after correcting for two types of reddening: (1) $E_{B-V} \sim 0.4$ using Seaton's reddening curve applicable to diffuse interstellar medium; (2) $E_{B-V} \sim 0.25$ to 0.30 using the reddening curve defined by the laboratory extinction properties of amorphous carbon grains of Bussolletti et al. The stellar wind mass loss is estimated from the P-Cygni profile of C II $\lambda$ 1760.6 from the high resolution IUE spectrum. Similarities with other WC 11 stars are discussed.

Key words: stars: mass loss -- Wolf Rayet stars -- planetary nebulae -- CPD $-$ 56°8032

1. Introduction

Webster and Glass (1974) have identified a group of four cool Wolf-Rayet central stars of planetary nebulae which show large infrared excesses. These are CPD $-$ 56°8032, He 2-113, M 4-18 and V 348 Sgr, which form an extension of the carbon sequence in Wolf-Rayet stars to WC 11. One of these stars, V 348 Sgr, is classified as a hot RCrB type variable. Thus this group might form a link between the planetary nebulae and RCrB type stars. The brightest member of this group is CPD $-$ 56°8032. The optical spectrum of this star shows strong emission lines due to C II, C III, He I, O I etc., in addition to the nebular lines of [O I], [O II], [S II], [N II], [S III]. (Cowley and Hiltner, 1969; Thackeray, 1977; Rao, 1987). The star seems to be surrounded by an optical nebulosity of 1°-3 diameter (Roche et al., 1986). The nebular properties have recently been studied by Rao (1987). The central star is known to be hydrogen deficient and the H II emission lines seen in the optical spectrum are due to a nebulosity (Aitken et al., 1980; Rao and Houziaux, 1989). The star not only is a strong IRAS source but also shows an optically thin free-free spectrum between 2.7 and 14.7 GHz (Purton et al., 1981).

The study of the UV spectrum by Houziaux and Heck (1982) (hereafter HH) obtained with IUE brought out several interesting aspects regarding both the line spectrum and the nature of the circumstellar dust.

1.1. The UV line spectrum

The carbon abundance for the nebula estimated from C III]\ $\lambda$ 1908 and C IV]\ $\lambda$ 2326 is very high (log C $\sim$ 9.39), even higher than that for extreme carbon-enriched PN Hf 2-2 (Kaler, 1988). At the same time, HH report the presence of a feature at $\lambda$ 1751 of N III] in comparable strength to $\lambda$ 1908 of C III] which would also imply a high nitrogen abundance. Such a high nitrogen abundance is not supported by the analysis of the optical nebular lines (Rao, 1987). HH also identified the presence of the He II line in the UV spectrum which implies a very hot central star. However, even in the optical spectrum, $\lambda$ 4686 of He II is only a weak emission and He II $\lambda$ 1640 does not appear at all. Moreover, the wavelength of these lines correspond to the strong C II transitions.

1.2. UV reddening

Another feature which emerged out of the study of HH is the anomalous reddening properties of the circumstellar dust. The interstellar reddening in CPD $-$ 56°8032, as estimated by Aitken et al. (1980) from both Hα/Hβ measurements as well as the redshifted Hβ flux relationship, is $E_{B-V} = 0.6$ and $A_V = 1.83$. Aitken et al. (1980) also estimated the stellar temperature from the Hβ flux employing the Zanstra temperature method of Morton (1969), as 26000 K. The observed UV flux distribution of HH when corrected for interstellar reddening of $E_{B-V} = 0.6$ using the reddening law given by Seaton (1979), (applicable to diffuse ISM) showed a sudden hump at $\lambda$ 2180, quite unlike the energy distribution of hot stars.

Since a Zanstra temperature of 26000 K was already estimated by Aitken et al. (1980), HH tried to match the observed fluxes with the computed fluxes using the model atmospheres from Kurucz (1979). HH selected models with log $g = 4.5$, $T_{\text{eff}} = 20000$, 22500, and 30000 K and normal chemical composition (i.e. hydrogen rich) and calculated the emergent fluxes. Since the Seaton (1979) reddening law gave rise to a hump at $\lambda$ 2180 they modified the reddening law between 2800 A$-$1600 A such that the dereddened flux distribution of the star resembled the model atmospheric flux distribution. The corrected distribution looked very similar to the energy distribution of a normal B2 star in the wavelength range 3000 A to 1250 A and led to a stellar temperature estimate of 22000 K.

The above approach of comparing the energy distribution of CPD $-$ 56°8032 with model atmospheres of hydrogen rich stars seems to be inappropriate since CPD $-$ 56°8032 is known to be hydrogen-deficient. A comparison of the corrected energy distribution of HH with helium star models (Heber and

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Schönberner, 1980) indicate an effective temperature of \( \sim 18000 \) K which is too low compared to the Zanstra temperature (see Fig. 3). The application of a correction to the reddening law of Seaton seems to be arbitrary and it is not clear how much of reddening is due to the circumstellar material and how much is due to the interstellar medium. With a view to investigate both the emission line spectrum and the extinction properties in UV we obtained additional IUE observations of CPD – 56°8032.

2. Observations
The UV observations were obtained with the IUE satellite on July 12, 1987 using LWP camera in the low resolution mode (covering wavelength range 2000 Å–3200 Å) and SWP camera in the high resolution mode to study the emission lines. The details are given in Table 1. These spectra have been reduced using the IUEDR package contained in STARLINK on the VAX-11/780 system at VBO, Kavalur. The flux calibration used for LWP camera was from Cassatella et al. (1988) and SWP high resolution calibration is as given in Cassatella et al. (1986). The visual magnitude \( m_v \) is estimated from the FES counts as 11.1 using the relations given by Imhoff and Wasatonic (1986). This value is the same as the magnitude estimated when HH observations were obtained on 8 May 1980 \( m_v \sim 11.15 \) indicating that the visual flux has not changed much in the meantime.

3. UV spectral features
The high resolution SWP spectrum has a low signal to noise, but the exposure is adequate to show several features. Particularly, there are two strong emission features at \( \lambda 1761 \) and \( \lambda 1908 \). There is no evidence for the presence of N III] features at \( \lambda 1748.1 \), \( \lambda 1749.7 \), \( \lambda 1752.2 \) and \( \lambda 1754.0 \). There is a strong emission feature at \( \lambda 1760 \), with a P-Cygni structure (see Fig. 5) corresponding to a strong C II transition. Also the radial velocity of the emission peak is \( -69 \) km s\(^{-1}\) quite consistent with the radial velocity observed in the optical spectrum.

The C III] lines at \( \lambda 1908 \) show the feature corresponding to \( \lambda 1908.72 \) but the \( \lambda 1906.68 \) feature is not detectable. The line width indicates that it is a stellar feature and not a nebular feature. The nebular line widths of H\( \beta \) from the Echelle spectrum (resolution \( \sim 35000 \)) obtained at ESO by one of us (NKR) indicates FWHM corresponding to about \( \sim 54 \) km s\(^{-1}\) whereas the FWHM of \( \lambda 1908 \) is \( 160 \) km s\(^{-1}\). Moreover, the radial velocity of C III] \( \lambda 1908.7 \) is \( -70 \) km s\(^{-1}\) which is also consistent with the radial velocity determination from the optical spectrum (Cowley and Hiltn, 1969). The only resonance lines which could be clearly discerned on the high resolution SWP spectrum is \( \lambda 1862.78 \) of Al III(1) in absorption which is shifted by about 260 km s\(^{-1}\) to the blue. The other resonance line of Al III (1) at \( \lambda 1854.7 \) falls at the edge of the order and it is also blue-shifted.

The conspicuous features of the LWP long wavelength low resolution spectrum are the strong emission features of C II at \( \lambda 2838, \lambda 2740 \), and \( \lambda 2997 \) of C III. There is no indication of lines of He II or \( \lambda 2470 \) of [O II] (Fig. 1). The He I line at \( \lambda 3187 \) is also not conspicuous, although He I lines in the optical spectrum show P-Cygni profiles.

The continuum from the 3000 Å to 2000 Å has varied between the observations obtained in July 1987 (Fig. 1). The continuum is lower by about 0.4 mag compared to the observation of HH which indicates that the UV continuum does not change although the FES magnitude is roughly the same.

Identification of the emission lines and their fluxes are given in Table 2 along with the fluxes estimated from HH observation as plotted in HH. The emission lines fluxes do seem to remain constant (within errors) even though the UV continuum varied by \( \sim 0.4 \) mag.

4. Analysis
4.1. The stellar temperature
The stellar temperature has been estimated by Aitken et al. (1980) using the dereddened H\( \beta \) flux and Morton’s method of estimating the Zanstra temperature, as 26000 K. However, this estimation is done using models of stars of normal hydrogen-rich composition. A hydrogen deficient star would have very little Lyman continuum absorption (see Heber, 1986). Hence, the above temperature could only be an upper limit. Unlike in the optical region, the IUE spectrum of CPD – 56°8032 is dominated by absorption lines. The low resolution short wavelength IUE spectra obtained by HH are compared in Fig. 2 with those of V 348 Sgr and other helium stars. The absorption features in CPD – 56°8032 are very similar to those in V 348 Sgr and BD –9°4395. The \( T_{\text{eff}} \) of V 348 Sgr is estimated to be between 20000 K to 23000 K (Schönberner and Heber, 1986; Rao and Nandy, 1984) and \( \log g \sim 2.5 \). For BD –9°4395 the estimated temperature is 23500 K and \( \log g = 2.5 \) (Drilling et al., 1984). Thus the \( T_{\text{eff}} \) of CPD – 56°8032 seems to have a similar value.

The reddening corrected \( (E_{B-V} \sim 0.60) \) \( B - V \), and \( m(2190) - m(2740) \) colors seem to be similar to an unreddened B2V star according to HH which indicates \( T_{\text{eff}} \sim 26000 \) K.

It is probably relevant to mention that Aitken et al. (1980) pointed out that the infrared luminosity required to explain the observed IR excess (as reradiated stellar flux) seems to be more than the available optical luminosity if \( T_{\text{eff}} = 26000 \) K. However, with the presence of variable extinction and the uncertainty in bolometric corrections it is possible to provide a just about

<table>
<thead>
<tr>
<th>Image no.</th>
<th>Date</th>
<th>Exposure time</th>
<th>Aperture</th>
<th>( m_v )(FES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWP 11203</td>
<td>July 12, 1987</td>
<td>30</td>
<td>large</td>
<td>11.1</td>
</tr>
<tr>
<td>SWP 31335</td>
<td>July 12, 1987</td>
<td>370</td>
<td>large</td>
<td>11.1</td>
</tr>
</tbody>
</table>

\( m_v \) is estimated from the relation of Imhoff and Wasatonic (1986).
adequate IR luminosity with $T_{\text{eff}} = 26000$ K. We, therefore assume that $T_{\text{eff}}$ is between 23500 to 26000 K.

4.2. UV energy distribution and circumstellar extinction

The IS reddening estimate essentially comes from the nebular lines and radio continuum. As pointed out earlier, the corrected energy distribution with this reddening $E_{B-V} = 0.6$ and the HH reddening law gives a value of $T_{\text{eff}}$ which is too low when compared with helium star model atmospheres. Applying either Seaton’s as well as modified reddening law of HH with $E_{B-V} = 0.6$ to the present LWP observations, not only we get a much lower temperature, but a depression appears in the energy distribution around $\lambda 2500$ which suggests the existence of an additional agent causing the extinction. It is known that amorphous carbon dust has a peak in its extinction properties around 2400 Å and the peak wavelength depends on the particle size.

Furthermore, the change in the UV energy distribution observed between the two epochs does not appear to be due to the change in the stellar temperature because the emission line fluxes

Table 2. Observed emission line strengths

<table>
<thead>
<tr>
<th>Observed wavelength</th>
<th>Laboratory wavelength</th>
<th>Identification</th>
<th>Line fluxes LWP 11203 erg/s cm$^{-2}$Å</th>
<th>Line fluxes HH erg/s cm$^{-2}$Å</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda$</td>
<td>$\hat{\lambda}$</td>
<td></td>
<td>$\times 10^{-13}$</td>
<td>$\times 10^{-13}$</td>
</tr>
<tr>
<td>3208</td>
<td>3165.46</td>
<td>C II (9)</td>
<td>2.1 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>3166</td>
<td>3165.97</td>
<td>C II (9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3088: 3042</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2993</td>
<td>2992.6</td>
<td>C II (8)</td>
<td>3.0 ± 0.25</td>
<td>3.09</td>
</tr>
<tr>
<td>2997: 2905.71</td>
<td>2908.90</td>
<td>C II UV (41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2837</td>
<td>2836.71</td>
<td>C II UV (13)</td>
<td>b</td>
<td>17</td>
</tr>
<tr>
<td>2747</td>
<td>2747.28</td>
<td>C II UV (15)</td>
<td>6.6 ± 0.30</td>
<td>6.48</td>
</tr>
<tr>
<td>2730: 2729.71</td>
<td>2729.21</td>
<td>C II UV (31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2610</td>
<td>2604.86</td>
<td>C II UV (33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2574: 2574.83</td>
<td>2574.93</td>
<td>C II UV (24)</td>
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</tr>
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<td>2509.11</td>
<td>C II UV (14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2511.71</td>
<td>2512.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2470</td>
<td>2470.01</td>
<td>[O II]</td>
<td>&lt;0.08</td>
<td>5.6</td>
</tr>
<tr>
<td>2327</td>
<td>2327.01</td>
<td>C II UV (0.01)</td>
<td>9.6 ± 1.0</td>
<td>5.6</td>
</tr>
<tr>
<td>2297</td>
<td>2296.87</td>
<td>C III UV (8)</td>
<td>2.6 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>2218</td>
<td></td>
<td></td>
<td>0.13 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>1908</td>
<td>1908.73</td>
<td>C III UV (0.01)</td>
<td>4.5 ± 0.4</td>
<td>4.3</td>
</tr>
<tr>
<td>1760</td>
<td>1760.53</td>
<td>C II UV (10)</td>
<td>(1.1 ± 0.3)$^{a}$</td>
<td>5.5</td>
</tr>
</tbody>
</table>

$^a$ Line flux estimated from the corrected fluxes given by HH

$^b$ Saturated

$^{P}$ P-Cygni profile, on the emission flux is given here
upto only $T_{\text{eff}} = 20000$ K. We have used the dereddened observed energy distribution of the hot helium star HD 160641 as representative of a star of $T_{\text{eff}} = 31900$ K as given by Drilling et al. (1984). We used UV observations of HD 160641 obtained by the ANS satellite. The absolute calibration and reddening law as given by Wesselius et al. (1980) have been used. Since the fluxes for the model energy distributions of Heber and Schönberner (1980) were normalized to $\log F_{\lambda V} = -12.43$ the corrected fluxes of CPD $-56^\circ 8032$ as well as HD 160641 have been normalized to the same value and are shown in Fig. 3. It is to be noted that the contribution attributed to the ISM (i.e. following Seaton’s reddening curve) is also kept constant. We have used the extinction coefficients for various type of submicron amorphous carbon grains determined from the laboratory as given by Bussoletti et al. (1987). The resulting reddening curve upto $\sim 3000$ Å is essentially the same for both for Seaton’s as well as for amorphous carbon grains. The extinction properties differ only in the UV range, $< 3000$ Å.

Out of the several combinations used, we could fit the energy distribution of HH reasonably well (after dereddening it) with a combination of $E_{\beta} = 0.40$ and $0.25$ for Seaton’s and amorphous carbon grains of the type AC(2) as given by Bussoletti et al. (1987) respectively (Fig. 3). Similarly, the present observations would need a combination of $E_{\beta} = 0.40$ and 0.30 of Seaton’s and amorphous carbon grains of the type AC(2) to agree with the dereddened energy distribution of HH. The AC(2) of Bussoletti et

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**Fig. 2.** The short wavelength IUE spectrum of CPD $-56^\circ 8032$ (third from top) as obtained by Houziaux and Heck (1982) along with V 348 Sgr, the helium star HD 124448 and normal B Supergiants. (Heber et al., 1984). Note the similarity of C IV, line and Fe II lines in CPD $-56^\circ 8032$ and V 348 Sgr.

**Fig. 3.** The dereddened continuum of CPD $-56^\circ 8032$ as observed by Houziaux and Heck (1982) compared with the energy distribution of a helium star model (Heber and Schönberner, 1980) normalised at $V$. The meaning of the various symbols is the following: □ squares: energy distribution of HD 160641 from ANS observations corrected for reddening to represent the energy distribution of a helium star of $T_{\text{eff}} = 31900$ K, $\log g = 2.5$; ○ circles: energy distribution of CPD $-56^\circ 8032$ corrected for reddening of $E_{\beta} = 0.6$, using a modified Seaton’s reddening law as given by HH; ● dots: energy distribution of HH corrected for a reddening of $E_{\beta} = 0.40 + 0.25$ using the reddening curves of Seaton and the curve for laboratory amorphous carbon particles respectively; × crosses: energy distribution of CPD $-56^\circ 8032$ LWP 11203 corrected for $E_{\beta} = 0.40 + 0.30$ using the reddening curves of Seaton and laboratory amorphous carbon particles respectively.

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al. (1987) refers to spheroidal particles of mean diameter of 80 Å produced in an arc between two amorphous carbon electrodes in a controlled Ar atmosphere. The above exercise shows that the amount of small circumstellar grains might change with time.

In addition to the variability of the continuum in the UV, there might be variability of the continuum in the optical region also. From the spectrophotometry obtained in 1979 with AAT, Aitken et al. (1980) estimate \( V \sim 11.4 \text{mag} \) using the emission free continuum. The emission-free continuum value at \( \lambda 5480 \) obtained by Houziaux (1986) from the IDS spectrophotometry in 1982 July with 1.5 meter ESO telescope gives a value of \( V \sim 11.7 \text{mag} \). The continuum flux at \( \lambda 4267 \) obtained in 1982 July by Houziaux (1986) is \( 7.6 \times 10^{-14} \text{ergs}^{-1} \text{cm}^{-2} \text{A}^{-1} \) whereas 1987 July CCD observations by us give a value of \( 10 \times 10^{-14} \text{ergs}^{-1} \text{cm}^{-2} \text{A}^{-1} \) (Rao and Houziaux, 1989) although the C II \( \lambda 4267 \) emission line flux is the same on both occasions \( \sim 2.6 \times 10^{-13} \text{ergs}^{-1} \text{cm}^{-2} \).

4.3. Emission line spectrum

As mentioned earlier the emission line flux does not appear to be variable. Particularly, the strong C II emission lines and even the C II \( \lambda 1908 \), lines also seem to have roughly the same flux on both occasions. This fact is also true in the optical region, e.g. the C II \( \lambda 4267 \) flux remained constant between the two observations obtained in 1987 July and 1982 July.

The flux of the nebular lines as characterised by the HÎ² flux also seems to be unchangeable. The HÎ² flux obtained in 1979 by Aitken et al. (1980) is \( F_{\lambda 3969} \sim 11.95 \) whereas the observations of Houziaux (1986) in 1982 show \( F_{\lambda 3969} \sim 11.99 \) (\( F_{\lambda 3969} \) in ergs cm\(^{-2}\) s\(^{-1}\)).

The undetectability of \( \lambda 1906 \) emission in the CIII feature in the high resolution spectrum relative to the one at \( \lambda 1908.7 \), sets a lower limit to the electron density as \( 10^6 \text{cm}^{-3} \) in the line forming region. Following the calculation of Altamore et al. (1981) another independent estimate of the electron density could be obtained from the ratio N II \( \lambda 1754.9 \) to C II \( \lambda 1908.7 \) provided there are no abundance anomalies. These two ions are expected to form and survive in the same stellar region because of similar ionization energies and the C II \( \lambda 1754.9 \)/N II \( \lambda 1754.9 \) depends little on \( T_e \). Again the absence of N II \( \lambda 1754.9 \) lines in our spectra probably puts the limit on \( n_e \sim 10^8 \text{to} 10^9 \text{cm}^{-3} \).

Recently Kaler (1986) has obtained a relation between electron temperature and the flux ratio of C II \( \lambda 1909 \) to CII \( \lambda 4267 \) in planetary nebulae. As we have mentioned earlier, both these lines occur in CPD \( \sim 56^\circ 8032 \) in the Wolf-Rayet emission line region around the star but not in the nebula. However, the same nebular relationship might apply in the WR emission region also (since the relations are independent of electron density). Taking the values of the C II \( \lambda 4267 \) flux mentioned earlier from observations obtained in July 1987 (Rao and Houziaux, 1989) and the flux of CIII \( \lambda 1908 \) measured by us (given in Table 2) and after correcting for the reddening of \( E_{B-V} \sim 0.4 \pm 0.3 \) (Seaton + AC(2)), we get the observed line ratio \( R_C (\lambda 1908/\lambda 4267) \) as 3.08 and \( \log R_C \sim 0.4 \pm 0.3 \). This value is similar to \( \log R_C = 0.64 \pm 0.3 \) given by Kaler (1986) for the other WC 11 object M 4-18. Even in the case of M 4-18, it is likely that these two lines are formed in the emission line region surrounding the star but not the nebula. It should be remarked that the value of \( E_{B-V} \) estimated by Goodrich and Dahari (1985) is too high. Use of the measured radio flux at 10 GHz (15 ± 6 mJy Purton et al., 1981) and the HÎ² flux (Goodrich and Dahari, 1985) lead to an estimate of \( E_{B-V} \) between 0.56 to 0.41 which indicates the values of \( \log R_C \sim 0.3 \) if Seaton's reddening law is used.

The empirical fit to the observed value of electron temperature as a function of \( \log R_C \) (Fig. 1 of Kaler, 1986) gives a value of electron temperature of 7000 K for the line emitting region for CPD \( \sim 56^\circ 8032 \) (similar to that for M 4-18). The error in this estimate is hard to assess. Moreover the applicability of this relation from planetary nebulae to Wolf-Rayet envelopes is not beyond doubt (as it probably depends on the assumption that \( \lambda 4267 \) line is due to recombinations alone). Dahari and Osterbrock (1984) estimate \( T_e \sim 1.05 \times 10^4 \) K for the emission region in V 348 Sgr from a LTE analysis of C II emission lines.

5. Stellar wind and mass loss rate

It was pointed out by Cowley and Hiltner (1969) that in the optical region the lines of He I and O II show P-Cygni profiles indicative of mass loss, although the lines of the dominant ion C II do not show the P-Cygni characteristics. The strongest emission lines in the spectrum are C II \( \lambda 7236 \) and \( \lambda 4267 \) and neither have a P-Cygni nature. However, Thackeray (1977) mentioned a P-Cygni profile for \( \lambda 6578 \) of C II with the absorption dip shifted from the emission peak by \( -173 \text{ km s}^{-1} \). The spectrum obtained by Herbig (1986) with CTIO 4-meter telescope also shows a P-Cygni profile for \( \lambda 6578 \) with the absorption shifted by \( -160 \text{ km s}^{-1} \) from the emission peak. In the UV region P-Cygni type line profiles are not seen in the low resolution (\( \sim 6 \text{ Å} \)) IUE spectra but our high resolution SWP spectrum shows the C II line at \( \lambda 1760.6 \) having a P-Cygni profile with a radial velocity difference between emission and absorption of \( -240 \text{ km s}^{-1} \). The edge velocity is \( -350 \text{ km s}^{-1} \) relative to the emission peak (Fig. 4). Thus the only C II lines which show P-Cygni profiles are those transitions whose lower levels are the upper levels to the resonance lines, e.g. \( \lambda 1760 \) with \( \lambda 1335 \) and \( \lambda 6578 \) with \( \lambda 1037 \).

The only resonance line which could be discerned with some confidence in our spectrum is \( \lambda 1862 \) of Al III (1) which shows a blue shifted absorption dip with a blue edge occurring at \( -380 \text{ km s}^{-1} \) from the emission. Although the spectrum is weak, the C II resonance lines at \( \lambda 1335 \) seem to be present and the blue edge velocity seems to agree with Al III value and indicates that the terminal velocity (Fig. 5) probably is close to this edge value. But the optical He I lines which show P-Cygni profiles show a much smaller edge velocity.

The profile of C II \( \lambda 1760 \) is shown in Fig. 5 converted in terms of the continuum flux and \( W = V - V_0/V_\infty \) where \( V_\infty \) is taken as the edge velocity of Al III lines.

Olson (1981) has proposed a method to estimate the mass loss rate and stellar wind properties from the P-Cygni line profiles of the subordinate lines arising from the excited levels that are upper levels for the strong resonance lines. We applied this method to C II \( \lambda 1760.5 \) line profile to estimate the mass loss rate. We compared the theoretically computed profiles of Olson (1981) for various velocity laws with observed profiles till a reasonable match was obtained. The basic variable is the radial optical depth which is expressed in terms of the atomic constants. The stellar parameters are put into one constant \( T \) and the remaining factors of the profile function depend on the velocity law used. Line profiles were computed theoretically for a range of \( T \) values and three velocity laws. We proceeded by matching the theoretical
The high resolution IUE spectrum in the region of \( \lambda \) 1862 Al III and \( \lambda \) 1335 C II resonance lines, which show blue-shifted absorptions. The blue edge of Al III \( \lambda \) 1862.7 is assumed to represent the terminal velocity of the stellar wind.

\[
T = 2.12 \times 10^{-1} f \frac{W_{\lambda}}{W_{\lambda_0}} \lambda_0 \lambda F_{\lambda_0} A_k \frac{R_0}{R_\star} \left( \frac{1000}{V_\infty} \right)^2 \frac{g_1}{\mu} 1.35
\]

where \( f \) is the oscillator strength of the transition, \( \lambda_0 \) is the wavelength of the transition in \( \text{Å} \) and \( \lambda_1 \), \( \gamma \), are the wavelength and frequency of the line that photoexcites the level 1. \( F_{\lambda_0} \) is the monochromatic stellar flux, \( w_1 \) and \( w_2 \) are the statistical weights of the level and the ground level. \( V_\infty \) is the terminal velocity in \( \text{km s}^{-1} \), \( g_1 \) is the fractional abundance of the ion = \( n(\text{ion})/n \) (element); \( A_k \) is \( n/\text{n_{tot}} \), \( \mu \) is the mean molecular weight. When applying this method to C II \( \lambda \) 1760, the various parameters are estimated as follows. The \( \lambda_0 \) is 1760.53 \( \text{Å} \) and \( \lambda_1 \), the resonance transition which populates the lower level of the transition is \( \lambda \) 1335.38. \( w_1 \) and \( w_2 \) are statistical weights of the term, and have the values of 10 and 6 respectively. The oscillator strength \( f = 0.01216 \) is given by Nussbaumer and Storey (1981). The material is assumed to have the composition of helium star as estimated for BD \( -9^\circ 4395 \) (Heber, 1986) which gives \( A_k = 6.55 \times 10^{-3} \); and the terminal velocity \( V_\infty = -380 \text{ km s}^{-1} \). The value of \( R_\star \), the stellar radius for CPD \( -56^\circ 8032 \) is estimated as follows. From the spectral similarity with BD \( -9^\circ 4395 \) the log \( g \) value is assumed as 2.6 and the mass as 0.55 \( M_\odot \) corresponding to mass of central stars of planetary nebulae which leads to \( R_\star \sim 6 R_\odot \). From the infrared excess observed, Aitken et al. (1980) estimated that the minimum stellar luminosity required to produce the IR flux is \( 2.25 \times 10^3 D_2 L_\odot \) (\( D \) in kpc). By adopting the size of the nebula of \( 1.3 \) (Roche et al., 1986) and using the IRAS dust temperature (mainly based on 60\( \mu \), 100\( \mu \) flux) and linear nebular radius relation of Pottasch et al. (1984) for planetary nebulae, the distance estimated is 2.36 kpc, which would make the luminosity as \( 1.25 \times 10^3 L_\odot \) with an assumed \( T_{\text{eff}} \sim 25000 \text{K} \). \( R_\star \) is estimated as \( 6.2 R_\odot \).

The stellar flux \( F_{\lambda_1} \) is estimated from the model atmosphere of helium stars. For \( T_{\text{eff}} = 20000 \text{K} \) and \( \log g = 2.5 \), \( F_{\lambda_1} = 1.04 \times 10^{-3} \text{ erg cm}^{-2} \text{ cm}^{-2} \text{ Hz}^{-1} \) (Heber, 1986). For HD 160641, the \( F_{\lambda_1} \) estimated by Drilling et al. (1984) with \( T_{\text{eff}} = 31900 \) and \( \log g = 2.5 \) as \( 5.1 \times 10^{-3} \text{ erg cm}^{-2} \text{ cm}^{-2} \text{ Hz}^{-1} \). We adopt a value of \( 2 \times 10^{-3} \text{ erg cm}^{-2} \text{ cm}^{-2} \text{ Hz}^{-1} \) for CPD \( -56^\circ 8032 \) and the composition is assumed to be mostly He I thus the value of \( \mu \) is 4.

The fits of the theoretical profile to the observed profile show that \( T \sim 100 \) and \( \beta \sim 1 \) seem to be appropriate, although \( T \sim 100 \) and \( \beta \sim 2 \) would not give too bad a fit. Thus the mass loss rate is obtained as \( M = 1.09 \times 10^{-7} \text{ g yr}^{-1} \) with \( R_\star = 6 R_\odot \).

If most of the carbon is assumed to be in the form of C II and C III, and if they are in the ratio 0.7 to 0.3 then the mass loss rate is \( 1.56 \times 10^{-7} \text{ m}_\odot \text{ yr}^{-1} \). An estimation of the uncertainty in this mass loss rate is not easy to assess but could be within a factor \( \sim 5 \). The terminal velocity of the wind estimated here seems to be lower compared to other WC central stars of planetary nebula, (Kalirai et al., 1989) but higher resolution and better signal to noise IUE spectra are needed to reduce the uncertainty, however the value estimated above is not likely to change very much. As a comparison, He 2-99 which is a PN with a central star classified as WC9 and has \( T_{\text{eff}} \sim 26000 \text{K} \) estimated by Kalder et al. (1989) shows a half-width at zero intensity for \( \lambda 4267 \) of \( \sim 740 \text{ km s}^{-1} \) whereas CPD \( -56^\circ 8032 \) shows a \( \lambda 4267 \) half-width of \( \sim 227 \text{ km s}^{-1} \) (Rao and Houziaux, 1989) which is a factor of three lower. The terminal velocity of He 2-99 is estimated as \( \sim 1200 \text{ km s}^{-1} \). If this factor of three reduction is applied, the terminal velocity of CPD \( -56^\circ 8032 \) is expected to be \( \sim 400 \text{ km s}^{-1} \) which is quite consistent with the value used.

Sw St 1 a WC10 star with a compact PN around it has a terminal velocity of 1950 km s\(^{-1}\). In the case of CPD \( -56^\circ 8032 \) although the terminal velocity is lower, the mass loss estimated above is comparable to that of other WC9 and WC10 stars e.g.
1990A&A...234..410K

Fig. 5. The observed P-Cygni line profile of λ 1760.53 C II (continuous line) superposed on the theoretical profile with T = 100 and β = 1 as given by Olson (1981) (dashed curve).

for Sw St 1 it is \(6 \times 10^{-8} m_\odot \text{yr}^{-1}\) (de Freitas Pacheco and Veliz, 1987).

6. Comparison with other WC11 stars

The UV spectra of the two other WC11 stars M 4-18 and V 348 Sgr obtained by Goodrich and Dahari (1985) and Heck et al. (1983) respectively are shown in Fig. 6 along with that of CPD -56°032. They show a remarkable similarity; particularly the spectra of M4-18 and CPD -56°032 closely resemble each other. The photospheric features like C IV also seem to be very similar (Fig. 2). In the case of V 348 Sgr the circumstellar absorption lines are more enhanced and the emission lines are weak (Fig. 6). They also show a gradual change in the excitation and in the emission line to the continuum ratio from CPD -56°032 to V 348 Sgr. In CPD -56°032 the C II emissions are much stronger relative to the continuum when compared to M 4-18. In addition, the C III \(\lambda 2297\) feature is present whereas in V 348 Sgr the C II emission is weak or absent. The circumstellar absorptions due to Fe II, Mg II are present in all three stars but are much stronger in V 348 Sgr. The stellar temperature for M 4-18 was estimated by Goodrich and Dahari (1985) from the energy-balance method as \(T_{\text{eff}} = 22000 \text{ K} \pm 2000 \text{ K}\).

The UV energy distribution of V 348 Sgr has been fitted by Schönberner and Heber (1986) with a helium star model of \(T_{\text{eff}} = 20000 \text{ K} \) and \(\log g = 3\) after correcting for the reddening of \(E_{B-V} = 0.45 \pm 0.15\) with a combination of 0.4 Seaton's and 0.15 caused by amorphous carbon grains. A similar approach is applied here for CPD -56°032. In both stars the amorphous carbon grains are probable constituents of the circumstellar dust.

In the long wavelength IUE spectrum (Fig. 6) there appears to be obvious differences in the strengths of forbidden lines (presumably from the nebula). In CPD -56°032 the \(\lambda 2326 \text{ C II}\) feature is quite strong which is absent in M 4-18 and V 348 Sgr. The sharp emission feature occurring at \(\lambda 2326\) in LWR 8401 of M 4-18 is an ion hit or defect (Goodrich and Dahari, 1985; Stickland, 1988 personal communications). This feature is suppressed in Fig. 6. However the comparison of the spectra of these stars (Fig. 6) shows that there is an emission feature V 348 Sgr corresponding to \(\lambda 2470\) of [O II] which is weak or absent in M 4-18 and CPD -56°032. Although HH mention that [O II] \(\lambda 2470\) is present in their IUE spectrum of CPD -56°032, it is not obvious in our spectrum. If C II \(\lambda 2326\) also comes from the nebula then the ratio of \(\lambda 2326\) to \(\lambda 2470\) emissions would be a good indicator of \(\text{C}^+ / \text{O}^+\) ratio in the nebulae independent of reddening. An estimate of the \(\text{C}^+ / \text{O}^+\) ratio in V 348 Sgr from the \(\lambda 2470\) emission mentioned above is 0.06 assuming \(T_{\ast} \sim 1.25 \times 10^4 \text{ K} \) and \(N_e \sim 10^3\) (Dahari and Osterbrock, 1984).
to the analysis of Goodrich and Dahari (1985), M 4-18 is sup-
posed to have a high O abundance, but still the λ 2470 feature is not
conspicuous in the UV spectrum of M 4-18. The expected line
flux estimated using $E_{B-V} = 0.4$ and reddening law of Seaton and
the observed flux of [O II] $\lambda\lambda$ 7319, 30 from Goodrich and Dahari
(1985) is $\sim 3 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$ (which is about half the flux of
C II $\lambda 2747$). The sharp feature in Fig. 6 at $\lambda 2470$ could corre-
stitute to this. A better estimate of carbon abundance in the CPD
$-56^\circ$032 nebula needs high resolution observation of $\lambda 2326$
feature to discern the nebular C II lines.

Cohen and Jones (1987) added another member IRAS 21282+
5050 to this class of WC11 CPNs. This source however differs from
other WC11 stars in having 5.8 mag visual extinction and a large
and an extensive molecular envelopes with strong CO (1–0) and
(2–1) emissions (Likkèl et al., 1988). It also shows strong dust emis-

sion features at 7.7, 8.7, 11.3 $\mu$m which are attributed to
calycigenic aromatic hydrocarbon (PAH) molecules. All the WC11
stars show these features except V 348 Sgr, which shows a very
weak 3.3 $\mu$m feature. The central star for IRAS 21282+5050 is
classified to be WC11, showing $\lambda 4686$ He II, C IV, O IV features
which makes this star hotter than CPD $-56^\circ$032. Another major
difference is the extensive molecular envelope around
IRAS 21282+5050 for which the estimated size is $10^\prime$ and the CO
mass rate is $M \sim 1.5 \times 10^{-5} m_{o} \gamma$yr$^{-1}$ ($D$ in kpc) with an ex-
pansion velocity $V_{e}$ of $\sim 16.5$ km s$^{-1}$.

Knapp et al. (1989) detected CO (2–1), and Nyman (1989) CO
(1–0) in CPD $-56^\circ$032. Although the expansion velocity $V_{e}$ is
roughly the same for CPD $-56^\circ$032 (i.e. $\sim 17$ km s$^{-1}$) and
IRAS 21282+5050, the mass loss rate and the ratio $T_{mb}$ (CO)/F
(FIR) of the brightness temperature to the far infrared flux is more
than an order of magnitude smaller in both CPD $-56^\circ$032 and
He 2-113 (Likkèl et al., 1988). It is likely that IRAS 21282 is in an
earlier evolutionary stage than CPD $-56^\circ$032. The mass-loss rate
estimated by Knapp et al. (1989) is $1.6 \times 10^{-6} m_{o} \gamma$yr$^{-1}$
assuming a distance of 630 pc. This estimate is supposed to re-

flect the mass-loss rate in the AGB phase, which appears to be too low.
In the plot of $M$(CO) versus log $S_{2}$/$S_{12}$ (Fig. 1 of Knapp et al.,
1989), CPD $-56^\circ$032 occurs in a position too far down reflect-
ing too low an $M$ relative to other PNS. If the distance 2.3 kpc is
used (as estimated in Sect. 5), then the $M$ ($\sim 2.13 \times 10^{-6} m_{o}$)
is more consistent with the other PNS.

7. Discussion
The UV observations of CPD $-56^\circ$032 show that the con-
tinuum of the star does vary though the emission line fluxes do
not. This is also true in the optical region. The fact that the FES
magnitudes are roughly constant, even though the UV fluxes have
changed by $\sim 0.4$ mag. is probably due to the domination of
emission lines in the broad wavelength band of the FES where the
continuum is much weaker than the emission lines.

These variations could be interpreted as due to a change in
the amount of circumstellar dust and may be to some extent even to
the particle size. Thus, it shows a great similarity with V 348 Sgr
which shows a much larger RCrB type variability. In addition, both
objects require (and also RCrB) extinction due to amorphous
carbon grains to explain the energy distribution. To explain the
variation of the continuum without changing the emission line
flux might need a special kind of geometry for the distribution of
dust.

One of the problems regarding the IR emission in CPD
$-56^\circ$032 is that the IR luminosity required seems to be higher
than the stellar luminosity (Aitken et al., 1980). The observed IR
luminosity is $2.25 \times 10^{5} D^{2} L_{o}$ ($D$ in kpc). The dereddened magni-

tudes and $T_{eff} = 25000$ K could produce, with proper bolometric

correction and small variability in $V$ magnitude, just about
adequate stellar luminosity to match the IR, which implies almost
100% conversion of stellar luminosity to infrared. One possibility
out of this dilemma is to increase th $T_{eff}$ of the star to $\sim 33000$ K
but this seems to be inconsistent for several reasons. The other
possible alternative is to invoke neutral extinction caused by
bigger particles mainly effecting the star (but not the nebula since
the Hβ-radio flux relation seems to be consistent with reddening).

The presence of such big particles has been invoked in the so
called proto planeraries like HD 161796, HR 4049 to explain large
infrared excesses (Lamers et al., 1986). In particular, the presence
of 11.3 $\mu$m emission feature in HR 4049, which is also prominently
present in CPD $-56^\circ$032 supports this similarity. Most of the IR
luminosity in CPD $-56^\circ$032 comes from hotter dust which is
presumably closer to the star.

Pottasch et al. (1986) have plotted the 6 cm radio flux versus
infrared flux for planetary nebulae including the proto and
compact planeraries, which shows positive correlation between
the free-free flux and the IR flux. In this figure, CPD $-56^\circ$032
occupies a place quite far from the mean corresponding to the
6 cm flux density (26 mJy – Purton et al., 1981), showing that it has
too much IR luminosity for the amount of ionized gas. This trend
is also seen in other hydrogen deficient nebulae like A 30 and A 58
(Pottasch et al., 1986; Rao et al., 1987). The CO rotation lines
seem to imply that the cool gas to dust ratio is an order of
magnitude smaller than in the other compact PNS like
IRAS 21282. It appears that somehow CPD $-56^\circ$032 has very
efficiently produced (or is producing) circumstellar dust (or has
retained it) whereas the gas is depleted.

The preliminary estimate of the nebular expansion/velocity
from the Hβ line (half the FWHM) corresponds to 26 km s$^{-1}$
(Rao and Houziaux, 1989) which is higher than the CO
gas expansion velocity of $\sim 17$ km s$^{-1}$ (Knapp et al., 1989). Since
the nebular expansion velocity is believed to increase with age in
PNS, this probably implies that CPD $-56^\circ$032 is more evolved in
particular. When compared with other compact PNS like Sw
St 1 which has a nebular expansion velocity of 9 km s$^{-1}$.

The observed terminal velocity $V_{e}$ of the winds from the
central stars of planerary nebulae increase with $T_{eff}$ (Kudritzki
and Mendez, 1989). This is attributed to the radiation-driven
winds being present in the outer layers of CSPN, since in this case
the terminal velocity increases with the surface escape velocity
and thus with $T_{eff}$ (Kudritzki and Mendez, 1989). The low value of the
terminal velocity $\sim 380$ km s$^{-1}$ obtained for CPD
$-56^\circ$032 also indicates a low $T_{eff}$. The terminal velocity seems
to undergo a dramatic change within about one spectral subclass,
going from 1200 km s$^{-1}$ for He 2-99, and 1950 km s$^{-1}$ for Sw
St 1 (WC 9) to $380$ km s$^{-1}$ for CPD $-56^\circ$032 which is a
WC10/WC11 star (Heap, 1982). The estimate of $V_{e}$/V_{esc} gives
a value $\sim 2$ rather than $\sim 3.5$ expected from Kudritzki and
Mendez’s calculations (their Fig. 20). It is not clear whether the
stellar wind is driven by radiation at this low $T_{eff}$.

The sequence of WC11 stars shows a decrease in the degree
of excitation of the emission line spectrum between CPD $-56^\circ$032
to M 4-18 to V 348 Sgr indicative of a change in stellar tempera-
ture from 25000 K to 20000 K. The inspection of Fig. 6 also
shows a strengthening of circumstellar absorption features of Fe II (multiplets 78, 63, 62 etc.) apart from the resonance lines of Fe II, Mg II which might have a contribution from interstellar medium. A list of circumstellar features for V 348 Sgr has already been given by Heck et al. (1982). Further optical and UV observations (higher resolution) are needed before a physical model can be developed.

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