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UV (IUE) spectra of the central stars of high latitude planetary nebulae Hb7 and Sp3*

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Abstract. We present an analysis of the UV (IUE) spectra of the central stars of Hb7 and Sp3. Comparison with the IUE spectrum of the standard star HD 93205 leads to a spectral classification of O3V for these stars, with an effective temperature of 50 000 K. From the P-Cygni profiles of CIV (1550 Å), we derive stellar wind velocities and mass loss rates of -1317 km s^{-1} $\pm$ 300 km s^{-1} and 2.9×10^{-8} $M_{\odot}$ yr^{-1} and -1603 km s^{-1} $\pm$ 400 km s^{-1} and 7×10^{-9} $M_{\odot}$ yr^{-1} for Hb7 and Sp3 respectively. From all the available data, we reconstruct the spectral energy distribution of Hb7 and Sp3.

Key words. planetary Nebulae: individual: Hb7, Sp3 – stars: AGB and Post-AGB – stars: evolution – stars: mass-loss – stars: winds – ultraviolet: stars

1. Introduction

The central stars of planetary nebulae (CSPNe) are in general very hot objects and their continuum flux is more easily detectable in the UV than in the optical. The detection of fast winds in CSPNe from UV observations may be considered one of the important discoveries of the IUE satellite (Heap 1986; Patriarchi & Perinotto 1991). NV (1240 Å) and CIV (1550 Å) resonance line doublets are the most dominant lines formed in the winds of hot stars. A study of the stellar wind profiles of these lines is important to determine the terminal wind velocities and hence the post-AGB mass-loss rate.

We have carried out a program to study the wind profiles of several high galactic latitude planetary nebulae (PN). A monitoring of the NV and CIV wind profiles in Hen 1357 (=SAO 244567) showed wind variability in this young PN (Parthasarathy et al. 1993, 1995) which may be a signature of episodic mass loss in post-AGB stars. In this paper we present an analysis of the UV (IUE) low resolution spectra of the high galactic latitude PNe Hb7(PN G003.9$-$14.9 = IRAS 18523$-$3219; l = 3.97, b = -14.9) and Sp3 (PN G342.5$-$14.3 = IRAS 18033$-$5101; l = 342.51, b = -14.32). The photometric colours and optical spectra of these two PNe had indicated that they contain hot central stars (Acker et al. 1992; Aller 1976). We also present the JHK photometry of Hb7 from the 2MASS Point Source Catalog.

2. Observations

Low resolution UV spectra of Hb7 and Sp3 were obtained on September 29, 1994 with the SWP camera onboard the IUE satellite. The SWP52257LL image of Hb7 (80 min exposure) and the SWP52256LL image of Sp3 (30 min exposure) were obtained by centering the central stars in the $10'' \times 23''$ aperture. The spectra have been re-extracted from the IUE Final Archive at VILSPA which were reprocessed using the IUE NEWSIPS pipeline which applies the SWET extraction method as well as the latest flux calibration and close-out camera sensitivity corrections. Line-by-line images have been inspected for spurious features.

3. Analysis

The spectra of Hb7 and Sp3 from 1150 Å to 1950 Å in absolute flux units are shown in Figs. 1a and b. The spectra were dereddened by using $E(B-V)$ = 0.19 for Hb7 (from c(Hβ) = 0.28, Tylenda et al. 1989), and $E(B-V)$ = 0.159 for Sp3 (from HST data, Ciardullo et al. 1999). The dereddened spectra of Hb7 and Sp3 were

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* Based on the observations obtained with the International Ultraviolet Explorer (IUE), retrieved from the IUE Final Archive at VILSPA, Madrid, Spain.

compared with the dereddened IUE spectra of standard stars (Heck et al. 1984). For comparison, the three spectra were normalised to λ 1601.53 Å. Savage et al. (1985) quote a value of $E(B-V)=0.37$ for the standard O3 V star, HD93205. Using the 2200Å feature in the UV, we found $E(B-V)=0.34$ for this star. Hb7 and Sp3 show good agreement with the UV continuum and spectral features of HD93205 (see Fig. 1). Therefore, we adopt the same effective temperature of 50 000 K for the nuclei of Hb7 and Sp3.

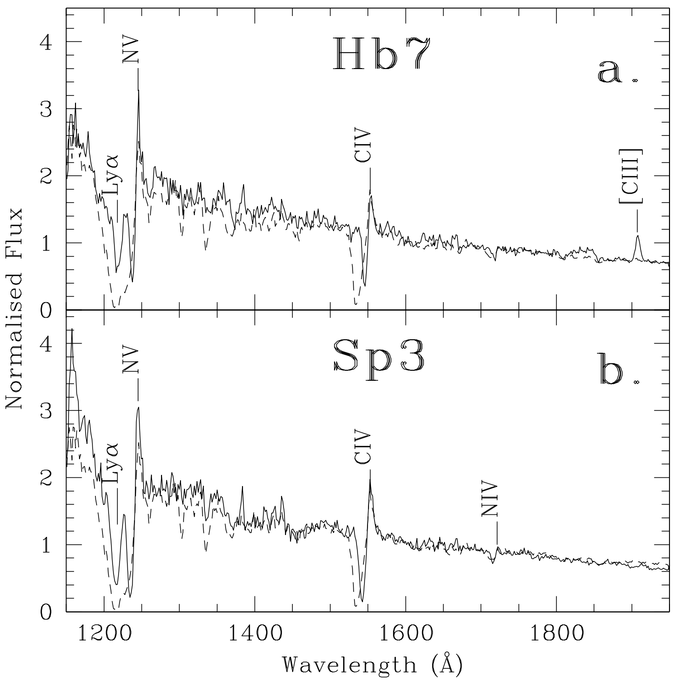

Fig. 1. The dereddened spectra of Hb7 **a)**, $E(B-V)=0.19$ and Sp3 **b)**, $E(B-V)=0.159$ are plotted along with the dereddened SWP spectra of a standard O3-dwarf star (HD 93205, $E(B-V)=0.34$) from the standard star atlas by Heck et al. (1984). The standard star spectrum is represented by a dotted line.

3.1. Terminal wind velocity

Using the violet absorption edge in the high resolution UV spectra of HD 93205, Prinja et al. (1990) calculated a terminal wind velocity (v_∞) of -3370 km s^{-1} for this star. They estimated a measurement error of less than 100 km s^{-1} in the determination of this Doppler velocity.

The determination of terminal wind velocity from Doppler shifts in low-dispersion spectra is complicated by the fact that the absorption troughs of strong (saturated) stellar wind lines do not exhibit extended regions of zero residual intensity. In the low resolution spectra of Hb7 and Sp3, the violet edge of NV is contaminated by Lyman α absorption. By measuring differential shifts of the CIV absorption profiles of the two stars with respect to HD 93205, we found Doppler velocities of -1435 km s^{-1} for Hb7 and -1628 km s^{-1} for Sp3. These values may be compared with velocities calculated following the analysis of Prinja (1994).

The empirical relation provided by Prinja (1994) uses the difference between the position of the emission peak and the absorption minimum for the CIV line i.e. $v_\infty = a_1 + a_2(\Delta\lambda) + a_3(\Delta\lambda)^2$ where, $a_1 = -883 \pm 48$, $a_2 = 259 \pm 9$, $a_3 = -3 \pm 2$ and $\Delta\lambda = \lambda^{\rm Emis}_{\rm peak} - \lambda^{\rm Abs}_{\rm min}$, ($\lambda$ in Å and v_∞ in km s^{-1}). Using this relation, we found $v_\infty = -1317$ km s^{-1} $\pm$ 316 km s^{-1} for Hb7 and $v_\infty = -1603$ km s^{-1} $\pm$ 389 km s^{-1} for Sp3. Finally, we adopt a terminal velocity of -1317 km s^{-1} $\pm$ 300 km s^{-1} for Hb7 and of -1603 km s^{-1} $\pm$ 400 km s^{-1} for Sp3.

3.2. Stellar temperature and core-mass

Samland et al. (1992) estimated the temperature of the central star of Hb7 from photoionization model to be 56 000 K. For the central star of Sp3, Preite-Martinez et al. (1991) estimated the energy-balance temperature to be 39 400 K. For an O3 star, the effective temperature ($T_{\rm eff}$) is estimated to be 50 000 K (Lang 1992). We adopt the same value of 50 000 K ($\log T_{\rm eff} = 4.7$) for the two stars. Pauldrach et al. (1988) analysed the relation between the effective temperature, mass of the nuclei, the terminal velocity and mass-loss rate (see their Figs. 10 and 6a). From these relations, we can deduce a core-mass of 0.644 and 0.565 $M_\odot$ and a mass-loss rate of 2.9×10^{-8} $M_\odot$ yr^{-1} and 7×10^{-9} $M_\odot$ yr^{-1} for Hb7 and Sp3 respectively.

3.3. Spectral energy distribution (SED)

The IUE spectra of Hb7 and Sp3 were combined with the available BVI photometry, JHK photometry (Hb7) from the 2MASS Point Source Catalog and IRAS photometry at 12, 25, 60 and 100 μm to reconstruct the overall spectral energy distribution (Figs. 2a and b). The UV data of both stars shows good agreement with a blackbody distribution at 50 000 K. The IRAS fluxes do not seem to obey a single black body temperature. By fitting mean blackbody curves to the IRAS fluxes for Hb7 and Sp3, we estimated cold dust temperatures of 130 K and 100 K respectively.

The JHK flux distribution, for Hb7, shows no indication of the presence of warm dust around the central star. Warm dust is generally attributed to emission from dust grains formed in the outflow close to the central star as a result of on-going post-AGB mass loss. The absence of warm dust may be attributed to photodissociation and diffusion of the dust grains formed close to the hot central star.

Ciardullo et al. (1999) imaged Sp3 with the Wide Field Planetary Camera 2 onboard HST. They found the central star to be a binary with a separation of 0.3″. They found $V = 13.20$, $V - I = -0.19$, and $E(B-V) = 0.159$ for the central star and $V = 16.86$ and $V - I = 0.83$ for the companion. They considered it as a probable physical pair. The binary nature of the nuclei of Sp3 may explain the too bright value of the magnitude calculated by

Table 1. Photometric data of Hb7 and Sp3.

	B	V	I	J	H	K
Hb7	13.76($\Delta m < 0.10$) (Tylenda et al. 1989)	13.97($\Delta m < 0.10$) (Tylenda et al. 1989)	-	12.768 ± 0.040 (2MASS	12.866 ± 0.047 Point Source	12.251 ± 0.034 Catalog)
Sp3	12.45(0.10< $\Delta m < 0.25$) (Tylenda et al. 1991)	13.2($\Delta m < 0.05$) (Ciardullo et al. 1999)	13.39($\Delta m < 0.05$)	-	-	-

Tylenda et al. (1991; $B = 12.45$, $V = 12.51$). The $V - I$ colour of the companion is similar to that of an F star. The B magnitude by Tylenda et al. (1991) has been corrected for the contribution from a main sequence F type star and plotted in Fig. 2b. In the IUE SWP spectrum of Sp3 we do not find any evidence for the companion star spectrum. Since the F-type companion is several magnitudes fainter, its effect on the continuum flux of the central star in the SWP spectrum appears to be insignificant.

Assuming a temperature of 50 000 K for the central stars, the integrated flux in the UV (1150 Å to 1950 Å) is 1.34×10^{-9} erg s^{-1} cm^{-2} for Hb7 and 2.49×10^{-9} erg s^{-1} cm^{-2} for Sp3. The integrated far infrared fluxes (12 μ to 100 μ) for Hb7 and Sp3 with blackbody temperatures of 130 K and 100 K respectively are 0.59×10^{-9} erg s^{-1} cm^{-2} 0.45×10^{-9} erg s^{-1} cm^{-2}. Thus, almost as much energy is radiated in the infrared as is seen coming from the central star(s).

In Table 1 we have listed the BVI, JHK magnitudes of Hb7 and Sp3 adopted in this paper. The JHK magnitudes for Hb7 were obtained from the 2MASS Point Source Catalog within a search radius of 6″. The K band image of Hb7 from the 2MASS Catalog is shown in Fig. 3. The NICMOS arrays mounted on the 2MASS telescopes provide a resolution of 2″ per pixel. Hb7 is not resolved at this resolution and does not appear as an extended source in the 2MASS JHK images.

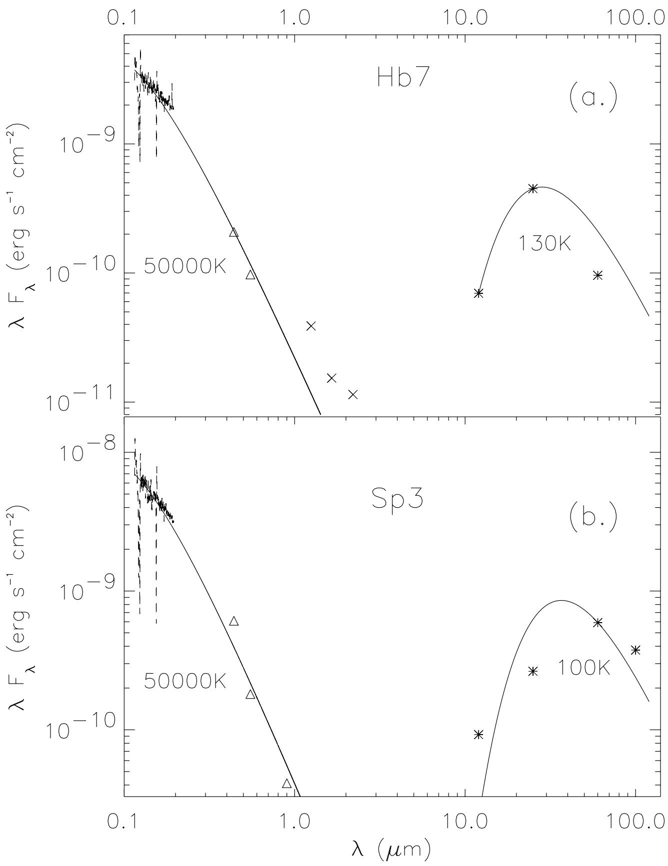

Fig. 2. Energy distribution of Hb7 **a)** and Sp3 **b)** from the UV to the far infrared is shown. The data is corrected for interstellar reddening using $E(B - V) = 0.19$ for Hb7 and $E(B - V) = 0.159$ for Sp3. IUE data (dashed line) is plotted along with BVI (open triangles), JHK (crosses) and IRAS photometry (asterix marks).

3.4. Dynamical age of the nebula

For Hb7, all distance estimates in the literature have been obtained assuming a nebular diameter of 4″ (Vorontsov-Velyaminov 1962). However, Vorontsov-Velyaminov's estimate of the nebular diameter was based on low resolution photographic plates and may be wrong. Recently, based on CCD images, Gorny et al. (1999) estimated an angular size of 13″× 12″ in H_α. We found this to be consistent with the nebular diameter estimated from the 2MASS images. Since distance estimates for Hb7 based on the wrong angular diameter of 4″ cannot be used, we have used the relation between core-mass and quiescent luminosity maximum (L_Q) for AGB stars (Wood & Zarro 1981) to derive the distance. Using L_Q for the luminosity of the star (8828 $L_\odot$ for Hb7) and M_{bol}(Sun)(= 4.75) we found M_{bol}(Hb7) to be −5.1. Applying the bolometric correction and using the formula for the distance modulus we obtained a distance of 5.5 kpc.

Gussie & Taylor (1994) found two components in the expansion velocity distribution of a large sample of PNe. Nebulae with the low-velocity component (12.5 km s^{-1}) were found to be smaller in linear extent than high-expansion velocity nebulae (27.5 km s^{-1}). Assuming an expansion velocity of 12.5 km s^{-1}, angular diameter of 13″ and distance of 5.5 kpc, we obtained a dynamical age of 13 418 years for Hb7.

Using Daub's (1982) formalism and an angular radius of 17.8″ (Acker et al. 1992), Cahn et al. (1992) obtained a distance of 1.9 ± 0.3 kpc for Sp3. The angular diameter and expansion velocity of Sp3 is 35.5″ and 22 km s^{-1} respectively (Acker et al. 1992). At a distance of 1.9 kpc, we found the age of the nebula to be 7278 years.

The theoretical evolutionary tracks of Blöcker & Schönberner (1990) predict an age of 3000 years for PNe with $\log(T_{eff}/K)$ of 4.7 and core mass of 0.605 $M_\odot$, along

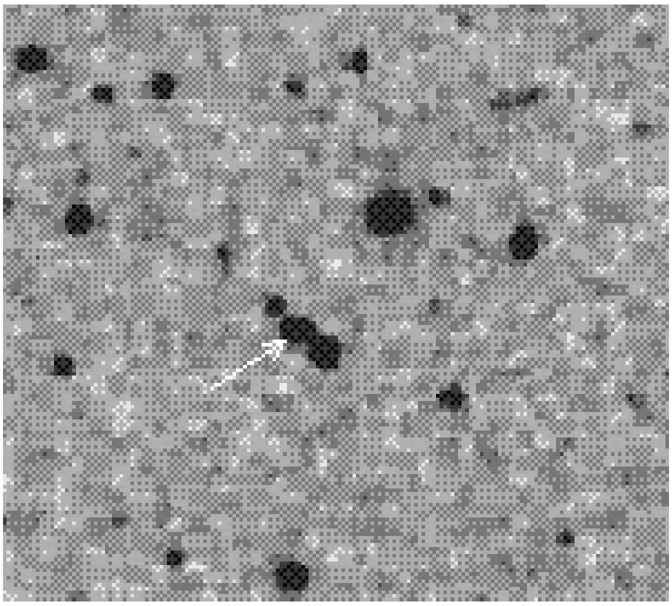

Fig. 3. 2MASS image of Hb7 in K band.

the horizontal part of the evolutionary track on the HR-diagram.

4. Discussion and conclusions

Our analysis of the UV (IUE) spectra reveals that the central stars of Hb7 and Sp3 are O3 -dwarfs with effective temperatures of 50 000 K, core-mass of 0.644 $M_\odot$ and 0.565 $M_\odot$ and mass loss rates of 2.9×10^{-8} $M_\odot$ yr^{-1} and 7×10^{-9} $M_\odot$ yr^{-1} respectively. The IRAS fluxes of these objects revealed a cold dust component at 130 K for Hb7 and 100 K for Sp3. The cold dust component may be interpreted as thermal emission from the dust present in the circumstellar envelope of these stars, a remnant of the previous strong mass loss AGB phase. We estimated dynamical ages of 13.4×10^3 yrs and 7.3×10^3 yrs for Hb7 and Sp3 respectively.

Cerruti-Sola & Perinotto (1985) investigated the frequency of occurence of stellar winds in CSPNe. They found that it depends on the stellar gravity in the sense that CSPNe with a gravity smaller than $\log g = 5.2$ (cgs) almost always have a wind while at higher gravities the presence of wind becomes less and less frequent. The presence of wind in the CSPNe Hb7 and Sp3 indicates that their surface gravities $\log g < 5.2$. Pauldrach et al. (1988) have shown that the presence of a fast wind in a CSPN depends not only on the stellar gravity but also on the luminosity. That is, the more a CSPN departs from the Eddington luminosity, the less frequent is the occurence of the wind.

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