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Spectroscopy of the central stars of three evolved planetary nebulae*

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Abstract. We present results of a spectroscopic project that aims at investigations of stars in the upper left part of the HRD. We observed the central stars of the three old planetary nebulae PN G011.4+17.9, PN G308.2+07.7, and PN G332.5−16.9. The spectra (echelle) were analysed by fitting the H and He II lines with theoretical profiles from a grid of non-LTE model atmospheres. The models are composed of H and He and disregard metal opacities. The three nuclei appear to be very hot ($T_{\rm eff}$ near 10^5 K) and comparison with post-AGB evolutionary tracks reveals that the masses range between 0.55 and 0.75 $M_\odot$; the central star of PN G332.5−16.9 shows an enrichment in He and probably also in C and N.

Key words: white dwarfs – planetary nebulae: individual: PN G011.4+17.9, PN G308.2+07.7, PN G332.5−16.9 – stars abundances – stars: fundamental parameters

1. Introduction

The knowledge of the planetary nebula central star (CSPN) - white dwarf (WD) transition region has dramatically increased during the most recent years and dozens of stars now populate this former gap in the HRD. The scientific strategy to explore the transition region essentially bases on an access from both sides of the gap, i.e., by searching for highly evolved PNe and investigating their central stars on the one hand and by searching for and studying very hot WDs on the other. A third way, namely an *a posteriori* search for hitherto undetected PNe around hot WDs was successful in very few cases only.

As a result of these efforts, an exciting and bewildering variety of pre-WDs has been discovered. Among them, the PG 1159 stars stand out as a particularly interesting class: they are hydrogen-deficient objects that have long defied a quantitative spectroscopic analysis due to their extremely high temperature and quite peculiar surface composition. Abundance analyses confirmed an evolutionary link between the early-type Wolf-Rayet (WC) central stars of PNe and the PG 1159 stars (Werner et al. 1996)

Generally, several of the hottest WDs are central stars of PNe. However, 10 PG 1159 and 16 DO white dwarfs not associated with a PN are known, whereas 17 PG 1159 stars and 2 O(He) stars are found among the CSPN. Also, 13 DAO stars not associated with a PN and 9 DAO-CSPN are known (Heber et al. 1996).

A detailed physical understanding of stars in the CSPN – WD transition region requires a precise determination of atmospheric parameters by modelling observed spectra. To achieve this goal with sufficient precision by use of telescopes of the 3 to 4 m class, the stars should not be fainter than V ≈ 17–18 mag. This constraint excludes the vast majority of the nuclei of the most evolved PNe and it appears that most of those CSPN have already been observed (Napiwotzki & Schönberner 1995). Each addition to this limited sample consequently is of value.– We have extracted three central stars of evolved PNe which have, to our knowledge, not been observed before.

2. Observations

Our central stars were selected from Dengel et al. (1979) (PN G011.4+17.9), Melmer & Weinberger (1990) (PN G308.2+07.7), and Hartl & Tritton (1985) (PN G332.5−16.9), where reproductions of the nebulae and their nuclei can be found. Approximate brightnesses (±0.5 mag) of these CSPN are 17.5, 17.3, and 15.2, respectively.

The spectroscopic observations were performed during a run with the ESO 3.6 m telescope under mostly moderate or poor weather conditions, on July 25 and 27, 1995. We used EFOSC 1 (echelle + blue cross-disperser), with a dispersion of 39-73 Å/mm within 3800-7300 Å. The slit width was chosen to be 1.″5. Feige 67 and Feige 110 were used as standard stars. Direct imaging was carried out in B and V, but due to the above-

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* Based on observations collected at the European Southern Observatory, La Silla, Chile

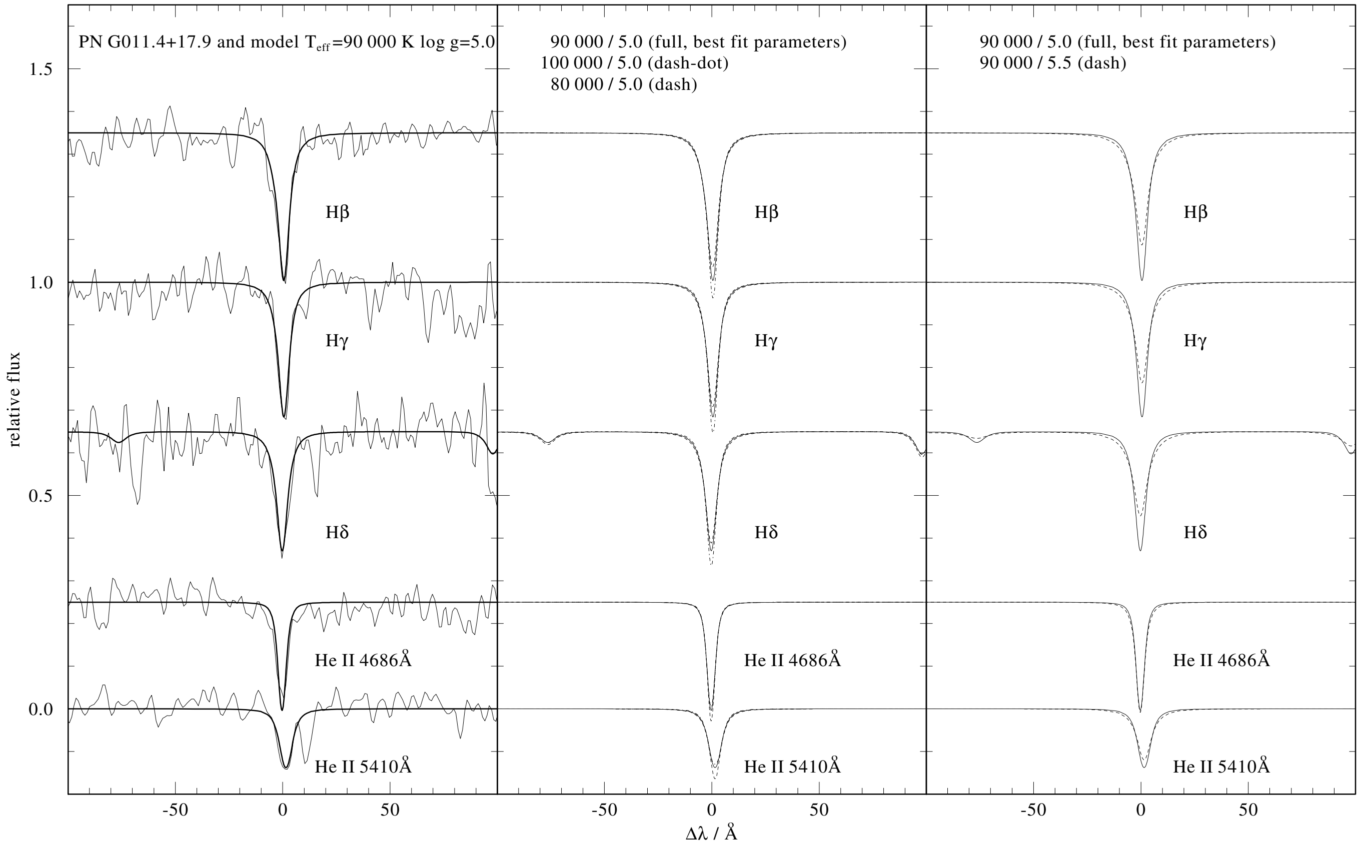

Fig. 1. Synthetic spectra calculated with T_{eff} = 80 000, 90 000, 100 000 K, log g = 5.0, 5.5 compared to the normalized observed spectrum of PN G011.4+17.9 for five lines.

Table 1. Relevant parameters of the fitting procedure and of comparisons with evolutionary tracks

Name	R.A., DEC (1950)		He/H	$T_{\rm eff}$	$\log g$	$M_\odot$
PN G011.4+17.9 (DHW 1-2)	17 04 10	−09 43 08	0.1	90 000	5.0	0.75
PN G308.2+07.7 (MeWe 1-3)	13 24 57	−54 26 25	0.1	100 000	5.5	0.59
PN G332.5−16.9 (HaTr 7)	17 49 36	−60 49 22	0.2	100 000	6.0	0.56

mentioned weather conditions we abstained from deriving the stars' brightnesses.

The spectra were flat-fielded, wavelength calibrated, then the emission of the nebulae was subtracted, and finally normalized, using standard procedures of the IRAF package. The subtraction of the sky and nebula emissions was done by using CCD columns located as close as possible to the stellar spectra. The quality of this reduction can be checked by means of the [OIII] line at 5007 Å. This very strong line has disappeared in the reduced spectra, i.e. it cannot be separated from the noise of the data.

3. Results and discussion

The spectra were analysed by fitting the H and He II lines with theoretical profiles from non-LTE model atmospheres. The models are composed of hydrogen and helium and disregard metal opacities which, however, yields reliable results. The influence of CNO, as well as light metals and iron group elements on Balmer lines (high series members) and He II lines is almost negligible (Werner 1996a, Dreizler & Werner 1993). Errors in the parameter determination are estimated to 10 000 K in $T_{\rm eff}$, 0.3 dex in log g and He/H number ratio.

NLTE models and line profiles were computed with the PRO 1 and LINE 1 codes which were mainly developed at the Kiel institute. Basic model assumptions are plane-parallel geometry, hydrostatic and radiative equilibrium. Details on the model atoms are described in Werner (1996b)

Fig. 1 shows an illustrative example of the quality of the line fitting. All results of the fitting procedure are displayed in Fig. 2. Relevant data are listed in Table 1.

The position of the three analysed central stars in the $T_{\rm eff}$–log$g$ diagram is shown in Fig. 3. Also shown are the locations of other hydrogen-rich post-AGB objects taken from earlier anal-

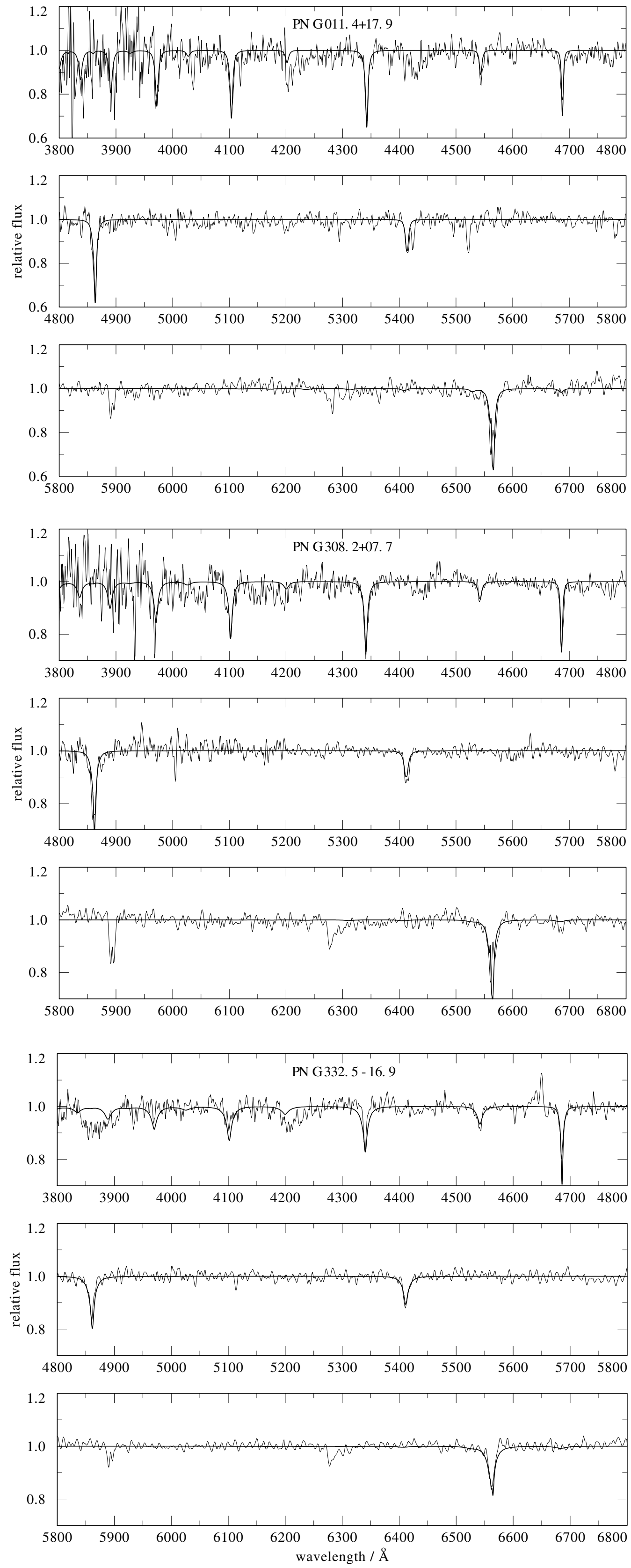

Fig. 2. The results of the fitting procedure for the three central stars in the wavelength range 3800–6800 Å; the relevant parameters are listed in Table 1

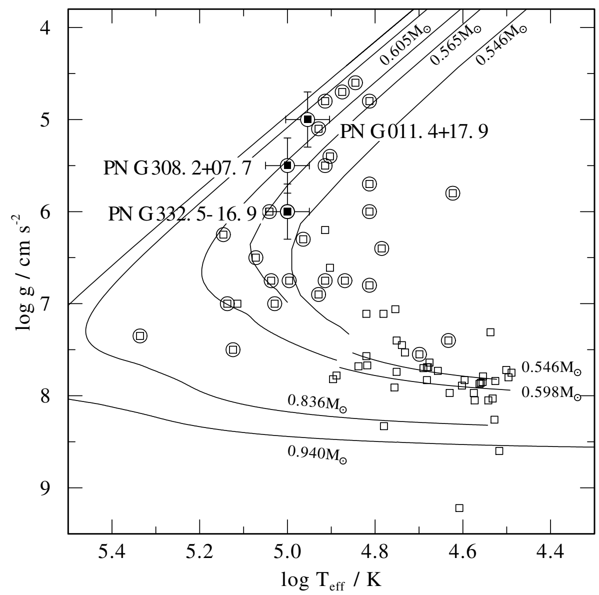

Fig. 3. The three central stars in the $\log g - \log T_{\rm eff}$ diagram. Encircled symbols denote stars with an associated PN, the others are mostly hot DA white dwarfs. The lines represent calculated evolutionary tracks for post-AGB stars of different remnant masses

yses (Napiwotzki 1995; Mendez et al. 1981, 1985, 1988; Bergeron et al. 1992, 1994). Encircled symbols denote stars with an associated PN, the others are mostly hot DA white dwarfs. Comparison with post-AGB evolutionary tracks (Schönberner 1983; Koester & Schönberner 1986; Blöcker & Schönberner 1990) reveals that the masses of the three central stars range between 0.55 and 0.75 $M_\odot$.

Hence, the stars appear to be quite hot, but chemically rather normal stars. PN G332.5−16.9 is an exception, because the helium content in the atmosphere is enriched. In addition, carbon and nitrogen are probably enriched too, because a C IV emission line near 4650 Å is detectable, as well as the N V doublet at 4604/4620 Å. A more detailed analysis is required to confirm this chemical peculiarity.

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