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Spectral Analysis of Central Stars of PNe Interacting with the Interstellar Medium

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Abstract. Planetary Nebulae (PNe) are the result of heavy mass loss of the asymptotic giant branch (AGB) stars. They are understood in terms of Kwok's (1978) interacting-winds model as the product of the mass-loss history on the AGB and the central star (CS) evolution. Since the CS are close to the end of nuclear burning and at their hottest stage of evolution then, precise modeling of these pre-white dwarfs is a prerequisite in order to calculate reliable ionizing fluxes which are crucial input for the presently available 3D photoionization codes. In the framework of a systematic study of PNe which show evidence for an interaction with the ISM, we present a NLTE analysis of their CS.

1. Introduction

Recent developments in both, observational and deprojection techniques, spectral analysis, and numerical methods facilitate to closely examine and model PNe and their CS consistently. Spectral analysis of CSPN by means of modern NLTE model atmosphere techniques provides information about photospheric parameters. In comparison with evolutionary calculations, evolutionary status, distances, masses, and luminosities can be determined. The spectroscopic distances enable us to deal with precise linear diameters of the PNe. The stellar model fluxes are an important input as realistic ionizing spectra in nowadays available 3D photoionization codes (e.g. Ercolano et al. 2003) for analyses of the PNe. The consistent modeling of PN and CS allows to determine the yields of nuclear processed material which goes back to the ISM via PNe and thus, to investigate the chemical evolution of our Galaxy.

In the last decade, PNe which show evidence for an interaction with the ISM have been found. This process is an indicator for the evolution of their CS which are at their hottest stage of evolution close to the end of nuclear burning where gravitational effects become dominant (i.e. they display directly the formation of white dwarfs). The highly evolved CS are no longer dominating the processes in the PNe (Kerber & Rauch 2001); the nebulae display brightness asymmetries that reflect the degree of the interaction process. These complex objects are crucial tests for our models as well as for evolutionary theory.

Table 1. Exposure times of our programme stars

name	PN G	$m_{\rm v}$	exposure time [sec]
A 21	205.1+14.2	16	7200
A 52	050.4+05.2	18	3600
A 75	101.8+08.7	18	7200
DeHt 5	228.2−22.1	15	6000
EGB 1	124.0+10.4	17	6300
NGC 6781	041.8−02.9	17	2400
NGC 6842	065.9+00.5	16	2400
RX J2117.1+3412	080.3−10.4	13	1200
Sn 1	013.3+32.7	15	1200
WeSb 5	058.6−05.5	17	3600

Once regarded a curiosity, this complex PN – ISM interaction process appears to be a common phenomenon which allows to determine also properties of the ambient ISM. Recently, we have presented determinations of proper motions and Galactic orbits (Kerber et al. 2004a, 2004b). These unveil thin and thick disk populations and cast light on interaction with the ISM. First hydrodynamical test calculations (Müller et al. 2004) for these objects were performed with the aim of a more quantitative understanding of processes in PNe in decay. One of the pre-requisites for reliable modeling are spectral analyses of the CS. We present here preliminary results from a study which is based on line-blanketed models including H and He.

2. Observations

In July 1999, we performed medium-resolution spectroscopy of nine CS with the TWIN spectrograph attached to the 3.5m telescope at Calar Alto, Spain. The CS of A 21 was observed in January 1999 with EFOSC 1 at the 3.6m telescope of ESO, La Silla.

3. NLTE Model Atmospheres

For the classification and preliminary analysis of hot compact stars, we have set up a new grid of H+He models within $T_{\rm eff}$ = 50 - 190 kK in 10 kK steps, $\log g$ = 5 - 9 in 0.5 steps (cgs), H/He = 0 - 1 in 0.1 steps by mass. The plane-parallel, static models are calculated with TMAP, the Tübingen NLTE Model Atmosphere Package (Werner et al. 2003, Rauch & Deetjen 2003). The grid which we used for this analysis and some other grids of NLTE model atmosphere fluxes with different chemical composition will be available on the WWW (`http://astro.uni-tuebingen.de/~rauch`).

We aim to arrive at a maximum error in our preliminary spectral analysis of about 1 dex in $T_{\rm eff}$, 0.3 dex in $\log g$, and 0.3 dex in the H/He abundance ratio. We employed a χ^2 fit procedure in order to judge our fit-by-eye procedure. In

Table 2. Parameters of our programme stars. Detailed analyses of the CSPN of DeHt 5 and EGB 1 have been presented by Barstow et al. (2003, $T_{\rm eff} = 58\,582$ K and $\log g = 7.05$) and Napiwotzki (1999, $T_{\rm eff} = 147$ kK and $\log g = 7.34$), respectively. The CSPN of A 21 and RX J2117.1+3412 have been analyzed by Rauch & Werner (1995) and Rauch & Werner (1997), respectively. Stanghellini et al. (2002) presented Zanstra temperatures for the CSPN of NGC 6842 (97 kK), A 75 ($<$ 290 kK), and NGC 6781 (105 kK).

name	$T_{\rm eff}$ [kK]	$\log g$ [cgs]	H/He [mass]
DeHt 5	70	7.5	>100
EGB 1	120	7.5	>100
NGC 6842	70	5.0	2
A 75	80	6.0	1.7
NGC 6781	70	6.5	1.5
WeSb 5	100	6.5	$<$ 10
Sn 1	100	5.0	0.4
A 52	110	6.0	0.25
A 21	140	7.5	He:C:O=35:51:14
RX J2117.1+3412	180	6.1	He:C:O=38:56:6

those cases where we have almost pure H or He atmospheres, the deviations were smaller than 10 kK in $T_{\rm eff}$ and 0.3 dex in $\log g$. However, since the S/N of our spectra was not very high and we have partly relics from nebular emission which even survived a careful data reduction, we present here our fit-by-eye results. These are summarized in Table 2 and Fig. 1.

4. Results

Within our sample of ten CS of PNe which show interaction with the ISM, our spectral analysis includes two hydrogen-rich DA (pre-) white dwarfs (DeHt 5, EGB 1), two hydrogen-deficient PG 1159 stars (A 21 and RX J2117.1+3412), and six CS with intermediate H/He ratios (from 0.25 to 10 by mass).

Fine tuning of the parameters with models which consider metal opacities in the next part of this analysis will enable us to determine e.g. their spectroscopic distances reliably. These are necessary to calculate the linear dimensions of the PNe for hydrodynamical modeling.

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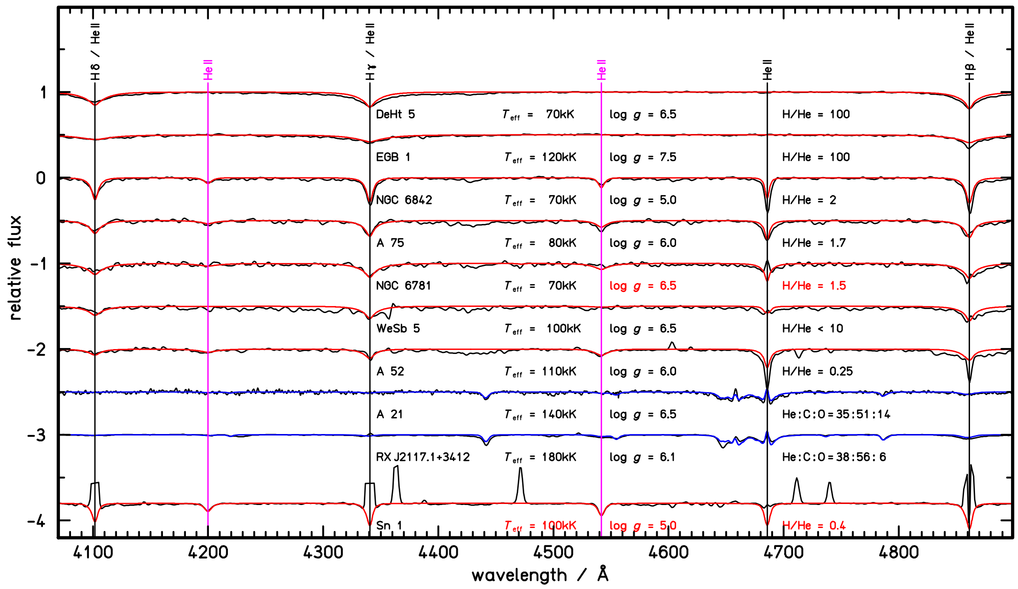

Figure 1. Comparison of synthetic spectra with the observation.

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