HST and FUSE Spectroscopy of Hot Hydrogen-Rich Central Stars of Planetary Nebulae

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Abstract. High-resolution UV spectra, obtained with HST and FUSE, enable us to analyse hot hydrogen-rich central stars in detail. Up to now, optical hydrogen and helium lines have been used to derive temperature and surface gravity. Those lines, however, are rather insensitive; in particular, neutral helium lines have completely vanished in the hottest central stars. Therefore, we have concentrated on ionization balances of metals, which have a rich line spectrum in the UV, to establish a new temperature scale for our sample. Furthermore, we have determined abundances of light metals, which had been poorly known before. They show considerable variation from star to star. We present results of quantitative spectral analyses performed with non-LTE model atmospheres.

1. Introduction

Central stars of planetary nebulae (CSPN) with effective temperatures of more than 70000 K are in the hottest phase of post-AGB evolution and give information about late evolutionary stages of sun-like stars, representing the connective link between Red Giants and White Dwarfs. Caused by the so called Balmer-line problem and the lack of neutral helium lines in the spectra of the hottest stars, the results of recent spectroscopic studies on these objects are sometimes quite uncertain. For these reasons, we have focused on ionization balances of metals, which show a vast number of lines in the UV, to derive the photospheric parameters such as \( T_{\text{eff}} \), \( \log g \), and light metal abundances of a sample of seven hot hydrogen-rich CSPN.

2. Observation and Models

With HST and FUSE, we have obtained high-resolution UV and far-UV spectra of seven hot hydrogen-rich CSPN. Besides, optical spectra of four of the objects are available (obtained at Siding Spring Observatory, Australia; Hobby-Eberly Telescope, Texas, USA; Calar Alto Observatory, Spain).
Figure 1. Sections of the HST spectrum of NGC 7293 compared with three models with different effective temperatures. The O\textsc{iv}/O\textsc{v}/O\textsc{vi} ionization balance allows a precise temperature determination. At $T_\text{eff} = 115 000$ K (dashed), the computed line cores of the O\textsc{iv} triplet at 1338 / 1343 Å are too deep, whereas the $T_\text{eff} = 125 000$ K model (dash-dotted) does not fit the O\textsc{v} lines. The best fit is achieved at $T_\text{eff} = 120 000$ K (full line).

Figure 2. Location of the analysed stars in the $\log g - \log T_\text{eff}$ plane. For each object we show the “old” location from previous analyses and the “new” location from the present work. Evolutionary tracks are from Schönberner (1983) and Blöcker & Schönberner (1990).
Spectral analyses are performed with plane-parallel, line-blanketed non-LTE model atmospheres in hydrostatic and radiative equilibrium, calculated by NGRT and other programs of the Tübingen NLTE Model Atmosphere Package (Werner & Dreizler 1999). Due to deficiencies in line-broadening theory and in the knowledge of levels and transitions of highly ionized elements in the UV, atomic data particularly of O\textsuperscript{vi} is uncertain. In comparison with the high-resolution spectra, we have been able to revise and adjust the predicted wavelengths of several O\textsuperscript{vi} lines.

### 3. Results

Ionization balances of light metals, in particular those of O\textsuperscript{iv}/O\textsuperscript{v}/O\textsuperscript{vi} (Fig. 1), enabled us to determine the photospheric parameters of our sample rather precisely and to establish a new temperature scale. Besides the surface gravity, we derived element abundances of helium, carbon, nitrogen, oxygen, and silicon. A wide spread of abundances from 0.05 solar up to 20 times solar shows the variety in chemical compositions of hot hydrogen-rich CSPN.

Most of the objects show considerably higher effective temperatures than previously thought (Fig. 2). We determined temperatures from 90 000 K up

#### Table 1. Photospheric parameters of the analysed objects. Due to prominent stellar wind features, we suspect that the derived surface gravity of LSS 1362 is quite uncertain. Accuracy of temperature determination is 5\%, of log $g$ 0.2\,dex, and of element abundances better than a factor of 2.

| Star  | $T_{\text{eff}}$ [K] | log $g$ [cgs] | $n_{\text{He}}/n_H$ | $n_{\text{C}}/n_H$ | $n_{\text{N}}/n_H$ | $n_{\text{O}}/n_H$ | $n_{\text{Si}}/n_H$ |
|-------|---------------------|---------------|----------------------|------------------|-------------------|-------------------|-------------------|
| LS V +4621 | 93 000 | 6.90 | 0.0100 | 0.00004 | 0.000001 | 0.0001 | 0.00002 |
| NGC 1360 | 97 000 | 5.30 | 0.2500 | 0.0002 | 0.0005 | 0.0002 | 0.0004 |
| Abell 36 | 113 000 | 5.60 | 0.2000 | 0.0002 | 0.0001 | 0.0005 | 0.00005 |
| LSS 1362 | 114 000 | 5.70 | 0.1000 | 0.0002 | 0.0001 | 0.0002 | < 0.0004 |
| NGC 7293 | 120 000 | 6.30 | 0.0300 | 0.00003 | 0.00005 | 0.00035 | 0.000004 |
| NGC 6853 | 126 000 | 6.50 | 0.1000 | 0.0008 | 0.00002 | 0.0004 | 0.000004 |
| NGC 4361 | 126 000 | 6.00 | 0.1000 | 0.0080 | 0.0006 | 0.0005 | 0.000002 |
| solar | | | 0.1000 | 0.0004 | 0.0001 | 0.0008 | 0.00004 |

#### Table 2. Additional parameters of the CSPN sample.

| Star  | $v_{\text{rad}}$ [km/s] | $N_H$ [cm$^{-2}$] | $M/M_\odot$ | $R/R_\odot$ | $\log(L/L_\odot)$ | $d$ [kpc] | $M_V$ [mag] |
|-------|------------------------|------------------|-----------------|--------------|-----------------|--------|--------|
| LS V +4621 | +22.4 | $8.6 \cdot 10^{19}$ | 0.55 | 0.04 | 2.10 | 0.24 | 5.9 |
| NGC 1360 | +48.1 | $5.1 \cdot 10^{19}$ | 0.65 | 0.30 | 3.64 | 0.93 | 1.8 |
| Abell 36 | +36.5 | $4.9 \cdot 10^{20}$ | 0.65 | 0.21 | 3.70 | 0.77 | 2.5 |
| LSS 1362 | −2.7 | $4.2 \cdot 10^{20}$ | 0.60 | 0.18 | 3.70 | 1.03 | 2.6 |
| NGC 7293 | −5.5 | $1.1 \cdot 10^{20}$ | 0.56 | 0.09 | 3.13 | 0.78 | 4.3 |
| NGC 6853 | −23.1 | $1.3 \cdot 10^{20}$ | 0.58 | 0.07 | 3.20 | 0.94 | 4.5 |
| NGC 4361 | +16.4 | $1.2 \cdot 10^{20}$ | 0.59 | 0.13 | 3.65 | 1.08 | 3.2 |
NGC 4361 has the highest temperature in our sample. It appears to be a metal-poor halo object with a remarkable overabundance in carbon.

To almost 130 000 K. Surface gravity covers the range between log $g = 5$ and log $g = 7$ [cgs]. In comparison with evolutionary theory, we have furthermore derived stellar parameters such as mass, radius, and luminosity. The results are shown in Tables 1 and 2.

Details about these analyses can be found in Traulsen (2004). We are also modeling the spectral lines from iron group elements. From these we will determine heavy metal abundances and we can further improve the temperature scale of the CSPN sample (Hoffmann et al., these proceedings).

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