UV Spectroscopy of the Central Star of the Planetary Nebula A 43

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Abstract. About 25% of all post-AGB stars are hydrogen-deficient, e.g. the PG 1159 stars with a typical abundance pattern He:C:O = 33:50:17 (by mass). Only four out of about 40 known PG 1159 stars exhibit H in their spectra. The exciting star of the planetary nebula A 43 is one of these so-called hybrid PG 1159 stars. We present preliminary results of an on-going spectral analysis by means of NLTE model-atmosphere techniques based on UV spectra obtained with FUSE, HST/GHRS, and IUE as well as on optical observations.

Keywords. ISM: planetary nebulae: individual: A 43 – Stars: abundances – Stars: atmospheres – Stars: evolution – Stars: individual: WD 1721+106 – Stars: AGB and post-AGB

1. Introduction

PG 1159 stars are hydrogen-deficient post-AGB stars. They have temperatures between 75 000 K and 200 000 K and their surface gravities log g range between 5.5 and 8.0. They experienced a Final Thermal Pulse (FTP), that mixed the envelope and the inter-shell (Fig. 1), and became a born-again star (Werner & Herwig 2006). Depending on the occurrence of this FTP a maximum remaining hydrogen content of about 20% (by mass) is possible. This maximum value is predicted for the AGB Final Thermal Pulse (AFTP) scenario, where the FTP happens at the end of the AGB phase and the masses of the mixing shells are nearly the same. When the FTP happens later, it is called Late Thermal Pulse (LTP) and the hydrogen content of the star is about 1% due to the smaller envelope mass at the time the FTP happens. An even later FTP (a Very Late Thermal Pulse occurs on the white dwarf cooling sequence) causes a complete burning of the hydrogen. Most PG 1159 stars experienced a LTP or VLTP. Only four stars show hydrogen lines in their spectra which is a hint for an AFTP. Three of these so-called hybrid PG 1159 stars (namely the central stars of Sh 2–68, A 43, and NGC 7094) are surrounded by a planetary nebula. One of these hybrid PG 1159 stars, A 43, is used as an example to introduce the spectral analysis technique in Sect. 3. Then our preliminary results are discussed in Sect. 4. The opportunity to access TMAP or already calculated TMAP spectra via the VO service TheoSSA is described in Sect. 5.
2. Observational data

To perform a precise analysis, observed spectra with a high S/N ratio and resolution are required. Moreover, these spectra should cover a wide wavelength range. Because of the high temperature of PG 1159 stars, their maximum flux is located in the UV. A lot of strategic lines is located in this wavelength range, and thus, these spectra are very important for our analysis. To determine the surface gravity, optical spectra are advantageous. For our analysis, we retrieved FUSE, GHRS, and IUE spectra from MAST (standard pipeline reduction, Table 1). The spectra for the optical wavelength range were obtained with the 3.5 m telescope equipped with the TWIN spectrograph of the German-Spanish Astronomical Center on Calar Alto on April 13-14, 2001. They were reduced with the Image Reduction and Analysis Facility (IRAF, http://iraf.noao.edu/).

To determine the interstellar extinction we used the UV spectra as well as brightnesses in the optical and infrared wavelength range and considered the Fitzpatrick law (1999). The resulting reddening is $E_{B-V} = 0.265 \pm 0.035$.

Table 1. Log of our UV observations.

| Instrument | Obs ID     | Obs Start Time (UT) | Aperture | Exp. Time (sec) |
|------------|------------|---------------------|----------|-----------------|
| FUSE       | B0520201000| 2001-07-29 20:41:47  | LWRS     | 11438           |
| FUSE       | B0520202000| 2001-08-03 22:18:20  | LWRS     | 9528            |
| GHRS       | Z3GW0304T  | 1996-09-08 07:00:34  | 2.0      | 4243            |
| IUE        | LWR08735   | 1980-09-06 21:45:21  | LARGE    | 3600            |
| IUE        | SWP10245   | 1980-09-28 21:50:02  | LARGE    | 5100            |

3. Spectral analysis

The spectral analysis was performed with the Tübingen NLTE Model-Atmosphere Package (TMAP) which was developed over the last 25 years. It uses an Accelerated Lambda Iteration (ALI, see e.g. Werner & Dreizler 1999; Werner et al. 2003; Rauch & Deetjen 2003). Hydrostatic and radiative equilibrium and plane-parallel geometry are assumed. About 1000 atomic levels can be considered as NLTE levels and thousands of individual lines can be calculated.
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In the UV range numerous interstellar lines overlay the photospheric lines. The program OWENS was used to calculate the interstellar line-absorption spectrum. With OWENS various interstellar clouds, that consider different temperatures, radial and turbulent velocities, chemical compositions, and column densities can be modeled.

We used the parameters determined by Ziegler (priv. comm.) for the so-called spectroscopic twin of A 43, namely NGC 7094, as start values for our analysis ($T_{\text{eff}} = 105 \text{ kK}, \log g = 5.4$). First, we checked these values with H+He models. Then we calculated more detailed model atmospheres for the newly determined values and included the elements H-Ni. After fitting the effective temperature and surface gravity, the elemental abundances are fine-tuned. In the UV range this is done in an iterative process with TMAP and OWENS until the interstellar as well as the photospheric lines reproduce the observed lines (Fig. 2).

4. Preliminary results and discussion

The analysis yields slightly different values $T_{\text{eff}} = 105 \text{ kK} \pm 10 \text{ kK}, \log g = 5.6 \pm 0.3$, and different abundances (Table 2). Within the error limits these parameters agree with those of the CSPN of NGC 7094. A mass of 0.53 $M_\odot$ (evolutionary tracks, Miller Bertolami & Althaus 2006, 2007) and a distance of 2.2 kpc were determined.

Table 2. Abundances of the CSPN of A 43, X is given in mass fractions, [X] denotes log abundance relative to solar abundance. The typical error range is $\approx 0.3$ dex.

|  | H   | He  | C   | N   | O   | F   | Si  | P   | S   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| X | 0.24 | 0.56 | 0.19 | 2.4E-4 | 1.8E-3 | 2.8E-6 | 1.8E-3 | 1.3E-6 | 1.2E-3 |
| [X]| -0.483 | -0.350 | 1.909 | -0.491 | -0.516 | 0.694 | -0.560 | -0.593 | -0.378 |
4.1. The German Astrophysical Virtual Observatory

The German Astrophysical Virtual Observatory (GAVO) aims to make astronomical data accessible. It is funded by the Federal Ministry for Education and Research (BMBF) and operates within the International Virtual Observatory Alliance (IVOA). In the framework of a GAVO project the model-atmosphere code TMAP was made accessible in different ways via TheoSSA (Theoretical Simple Spectra Access). It provides:

- SEDs (TheoSSA, http://vo.ari.uni-tuebingen.de/ssatr-0.01/TrSpectra.jsp?)
- Simulation Software (TMAW, http://astro.uni-tuebingen.de/~TMAW/TMAW.shtml)
- Atomic Data (TMAD, http://astro.uni-tuebingen.de/~TMAD/TMAD.html)

It is controlled via a web interface where the fundamental parameters like $T_{\text{eff}}$ or $\log g$ are entered. As a result a table of already available spectral energy distributions (SEDs) within a parameter range is given which can be downloaded directly. If a requested SED is not available, it can be calculated via TMAW, the web interface of TMAP. The database is growing in time because newly calculated SEDs are automatically ingested. In this way, the TMAP code can easily be used for spectral analysis by everybody. This simplifies getting reliable fluxes of central stars that are e.g. necessary to model planetary nebulae properly.

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References

Fitzpatrick, E. L. 1999, PASP, 111, 63
Miller Bertolami, M., & Althaus, L. 2006, A&A, 454, 845
Miller Bertolami, M., & Althaus, L. 2007, A&A, 470, 675
Rauch, T., & Deetjen, J. L. 2003, in Stellar Atmosphere Modeling, edited by I. Hubeny, D. Mihalas, & K. Werner, vol. 288 of ASPCS, 103
Werner, K., Deetjen, J. L., Dreizler, S., Nagel, T., Rauch, T., & Schuh, S. L. 2003, in Stellar Atmosphere Modeling, edited by I. Hubeny, D. Mihalas, & K. Werner, vol. 288 of ASPCS, 31
Werner, K., & Dreizler, S. 1999, Journal of Computational and Applied Mathematics, 109, 65
Werner, K., & Herwig, F. 2006, PASP, 118, 183