O(He) Stars

T. Rauch¹, E. Reiff¹, K. Werner¹, J. W. Kruk²

¹Institute for Astronomy and Astrophysics, Kepler Center for Astro and Particle Physics, Eberhard Karls University, Tübingen, Germany
²Department of Physics and Astronomy, Johns Hopkins University, Baltimore, U.S.A.

Abstract. Spectral analyses of H-deficient post-AGB stars have shown that a small group of four extremely hot objects exists which have almost pure He absorption-line spectra in the optical. These are classified as O(He) stars. For their evolution there are two scenarios: They could be the long-sought hot successors of RCrB stars, which have not been identified up to now. If this turns out to be true, then a third post-AGB evolutionary sequence is revealed, which is probably the result of a double-degenerate merging process. An alternative explanation might be that O(He) stars are post early-AGB stars. These depart from the AGB just before they experience their first thermal pulse (TP) which will then occur as a late thermal pulse (LTP). This would be a link to the low-mass He-enriched sdO stars and low-mass, particularly He-rich PG 1159 stars.

1. Introduction

95% of all stars end their lives as white dwarfs. About 20% of the hot post-AGB stars are H deficient. Most of these are the result of a (very) late He-shell flash, but the evolutionary status of a fraction of about 10 − 20% of the hottest H-deficient stars, namely the O(He) stars (Méndez 1991), is as yet unexplained. O(He) stars form a small group of four extremely hot post-AGB stars which exhibit absorption-line spectra dominated by He II. For a detailed introduction see Rauch et al. (1998) and Rauch et al. (2006).

(V)LTP evolutionary models can explain the observed He/C/O abundances in Wolf-Rayet and PG1159 stars (see, e.g., Herwig et al. 1999), but they have never reproduced He-dominated surface abundances. Recently, Miller Bertolami & Althaus (2006) presented a “numerical test” where they increased the mass-loss rate of a LTP star artificially in order to “blow away” the H from the stellar surface. However, this is in contradiction with radiation-driven wind theory (Pauldrach et al. 1988) and, if at all, valid for low-mass O(He) stars only (see below).

As an alternative, a third post-AGB evolutionary sequence might exist and the O(He) stars could be the successors of the RCrB stars which are relatively cool ($T_{\text{eff}}$ around 10,000 K) stars with He-dominated atmospheres, too. If this is true, we can expect similar metal abundances. In order to investigate on these in O(He) stars, we have performed FUV observations of all four objects with the Far Ultraviolet Spectroscopic Explorer (FUSE).
2. Observations and Analysis

Previous spectral analyses of O(He) stars were based on optical, UV (International Ultraviolet Explorer, IUE), and X-ray (ROSAT) observations (Rauch et al. 1994, 1996, 1998). The photospheric parameters are summarized in Table 1.

Table 1. Parameters of the four known O(He) stars, determined by our analyses of optical spectra (Rauch et al. 1998). Typical uncertainties are: \( T_{\text{eff}} \pm 10\% \), \( \log g \pm 0.5 \) dex, abundance ratios \( \pm 0.3 \) dex. For comparison, the last two lines give the mean element abundances of the majority RCrB stars and the peculiar RCrB star V854 Cen, respectively (Rao & Lambert 1996).

| Star      | \( T_{\text{eff}} \) (kK) | \( \log g \) | H/He | C/He | N/He | O/He | Element     |
|-----------|-----------------|--------------|------|------|------|------|-------------|
| LoTr 4    | 120             | 5.5          | 0.5  | < 0.004 | 0.001 | < 0.008 | V854 Cen   |
| HS 1522+6615 | 140            | 5.5          | 0.1  | 0.003                          |
| HS 2209+8229 | 100            | 6.0          | < 0.2 | < 0.005 | 0.005 |
| K 1-27    | 105             | 6.5          | < 0.2 | < 0.005 | 0.005 |
| majority RCrB | < 0.0001       | 0.010        | 0.004 | 0.003 | 0.003 |
| V854 Cen  | 0.5             | 0.030        | 0.0003 | 0.003 |

Since high-resolution and high-S/N UV spectra are a prerequisite for a reliable determination of metal abundances in hot stars, we have applied for observations with the Hubble Space Telescope (HST) and the Space Telescope Imaging Spectrograph (STIS). We were awarded observational time in Cycle 13. Unfortunately, STIS encountered a failure during that Cycle on Aug 4, 2004 while our first observations were scheduled on Aug 9.

A FUSE campaign in 2002 (Cycle 3, program C178, exposure time about 40 ksec) was more successful. For the analysis of the obtained FUV spectra we used TMAP, the Tübingen NLTE Model-Atmosphere Package (Werner et al. 2003), and calculated fully-line blanketed models in order to identify weak photospheric lines. In the course of this analysis, it turned out that the spectra are strongly contaminated by interstellar absorption and the S/N was not sufficient for our purpose. The mass-loss rates could be determined from the O\( \text{vi} \) \( \lambda \lambda 1031.9, 1037.6 \) Å resonance doublet (Rauch et al. 2006) and appear in agreement with radiation-driven wind theory.

One O(He) star (HS 1522+6615) was included in a re-observation campaign (Cycle 7, program U103, exposure time about 4 ksec) and our own re-observation proposal (Cycle 8, program H024, 204 ksec in order to improve the S/N) was accepted. These observations were scheduled for summer 2007 – the FUSE failure on July 12, 2007 prevented them. Thus, at the moment, we cannot determine the photospheric metal abundances of the O(He) stars reliably.
3. Evolutionary Scenarios and Conclusions

The group of four known O(He) stars divides into two sub-groups, two high-mass ($M \approx 0.8 \, M_\odot$, the central star (CS) of the planetary nebula (PN) LoTr 4 and HS1522+6615) and two low-mass ($M \approx 0.5 \, M_\odot$, CSPN of K1−27 and HS2209+8829) members. It is possible that different evolutionary scenarios are valid for each group.

![Figure 1. Positions of the four known O(He) stars and related objects in the log $T_{\text{eff}}$–log $g$ diagram compared to theoretical evolutionary tracks for born-again post-ABG stars of Blöcker (1995, full lines) and Miller Bertolami & Althaus (2006, dashed). The tracks are labeled with the respective stellar masses (in M$_\odot$).](image)

The low-mass O(He) stars may be so-called post early-AGB stars, i.e. they experienced the first thermal pulse (TP) after their departure from the asymptotic giant branch (AGB). Miller Bertolami & Althaus (2006) calculated an evolutionary track for a $M = 0.512 \, M_\odot$ post early-AGB star which closely matches the positions of the CSPN of K1−27 and of HS2209+822 in the log $T_{\text{eff}}$–log $g$ plane (Fig. 1). Due to an artificially increased mass-loss rate (ten times higher than predicted by radiation-driven wind theory), a strong H deficiency is achieved. Spectral analysis of the FUSE spectra has shown that the mass-loss rates of O(He) stars are not higher than predicted by radiation-driven wind theory (Pauldrach et al. 1988) and therefore, any change of the surface composition due to a stellar wind is unlikely. Moreover, for the H abundance in these O(He) stars, presently only upper limits are known (Tab. 1). Therefore a further, detailed investigation on a distinct “sdO(He) → O(He) → DO white
dwarf” evolutionary channel (cf. Rauch et al. 1998) is necessary. However, it is worth to note that the DO-type CSPN PG 1034+001 (cf. Werner et al. 1995, Fig. 1) may be a descendant from low-mass O(He) or PG 1159 stars.

The high-mass O(He) stars appear to follow the “normal” born-again scenario (Iben et al. 1983) where a (very) late TP causes the H-deficiency. However, it is worthwhile to note that both known objects, the CSPN of LoTr 4 as well as HS 1522+6615, show remaining H in their spectra (Tab. 1). Since their surface gravity $g$ is relatively low, gravitational settling during their following evolution might turn them into H-rich (DA) white dwarfs. Therefore, it is unclear whether the extremely hot DO white dwarf KPD 0005+5106 (Fig. 1, cf. Werner et al. these proceedings) is a successor of high-mass O(He) stars.

An alternative O(He) scenario is that of double-degenerate mergers. Similar H/He surface compositions suggest that O(He) stars are the progeny of RCrB stars (Rauch et al. 2006) and they follow a “RCrB $\rightarrow$ O(He) $\rightarrow$ DO white dwarf” sequence. Available FUSE spectra of O(He) stars do not show isolated metal lines and thus, allow to give upper limits for metal abundances only. Iron-group abundances are probably solar.

In order to make progress, further UV observations with COS or STIS are highly desirable in order to determine C, N, O, and Si abundances precisely in order to corroborate a possible link to RCrBs.

Acknowledgments. T.R. is supported by the German Astrophysical Virtual Observatory project of the German Federal Ministry of Education and Research (BMBF) under grant 05 AC6VTB. E.R. is supported by DFG grant We1312/30−1. J.W.K. is supported by the FUSE project, funded by NASA contract NAS5–32985.

References

Blöcker, T. 1995, A&A, 299, 755
Herwig, F., Blöcker, T., Langer, N., & Driebe, T. 1999, A&A, 349, L5
Iben, I. Jr., Kaler, J. B., Truran, J. W., & Renzini, A. 1983, ApJ, 264, 605
Méndez, R. H. 1991, IAU Symp. 145, Kluwer, Dordrecht, p. 375
Miller Bertolami, M. M., & Althaus, L. G. 2006, A&A, 454, 845
Pauldrach, A., Puls, J., Kudritzki, R. P., Méndez, R. H., & Heap, S. R. 1988, A&A, 207, 123
Rao, N. K., & Lambert, D. L. 1996, The ASP Conference Series Vol. 96 (San Francisco: ASP), p. 39
Rauch, T., Köppen, J., & Werner, K. 1994, A&A, 286, 543
Rauch, T., Köppen, J., & Werner, K. 1996, A&A, 310, 613
Rauch, T., Dreizler, S., & Wolff, B. 1998, A&A, 338, 651
Rauch, T., Reiff, E., Werner, K., Herwig, F., Koesterke L., & Kruk J. W. 2006, in: Astrophysics in the Far Ultraviolet, Five Years of Discovery with FUSE, eds. G. Sonneborn, H. W. Moos, B.-G. Andersson, The ASP Conference Series Vol. 348 (San Francisco: ASP), p. 194
Werner, K., Dreizler, S., & Wolff, B. 1995, A&A, 298, 567
Werner, K., Deetjen, J. L., Dreizler, S., Nagel, T., Rauch, T., & Schuh, S. L., 2003, in: Stellar Atmosphere Modeling, eds. I. Hubeny, D. Mihalas, K. Werner, The ASP Conference Series Vol. 288 (San Francisco: ASP), p. 31