Insight into AGB and post-AGB stellar evolution with FUSE

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Abstract. FUSE spectroscopy has proved that extremely hot hydrogen-deficient post-AGB stars (PG1159 stars) display matter on their surface that usually remains hidden in the region between the H- and He-burning shells of the former AGB star. Hence, the spectral analysis of PG1159 stars allows to study directly the chemistry of this intershell region which is the outcome of complicated burning and mixing processes during AGB evolution. Detailed abundance determinations provide constraints for these processes which are still poorly understood. With FUSE we have discovered high neon and fluorine overabundances. There is also a significant iron deficiency, which may be caused by s-process neutron capture transforming iron into heavier elements.

1. Introduction

PG1159 stars are hot hydrogen-deficient (pre-) white dwarfs ($T_{\text{eff}}$ between 75 000 and 200 000 K, log $g=5.5–8$; Werner 2001). They are probably the outcome of a late He-shell flash, a phenomenon that drives the currently observed fast evolutionary rates of three well-known objects (FG Sge, Sakurai’s object, V605 Aql). Flash-induced envelope mixing produces a H-deficient stellar surface (Herwig et al. 1999). The photospheric composition then essentially reflects that of the region between the H- and He-burning shells in the precursor AGB star. The He-shell flash transforms the star back to an AGB star (“born-again AGB star”) and the subsequent, second post-AGB evolution explains the existence of Wolf-Rayet central stars of planetary nebulae and their successors, the PG1159 stars.

PG1159 stars provide the unique possibility to study the chemistry in the intershell region between the H- and He-burning shells that is created after complicated and still poorly-understood burning and mixing processes during the AGB phase. Usually the intershell material remains hidden within the stellar interior. During the third dredge-up on the AGB, however, intershell material can get mixed into the convective surface layer and appears on the stellar surface, though in rather diluted abundances. Nevertheless, this process defines the role of AGB stars as contributors of nuclearly processed matter to the Galaxy. Our motivation to study PG1159 stars is based on the fact that these objects directly display their intershell matter. However, the quantitative interpretation of the abundance analyses is still premature because evolutionary calculations through a final He-shell flash including a full nuclear network are not available, yet.
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Figure 1. Discovery of a neon line (left panels) and a fluorine line (right panels) in the hydrogen-deficient PG1159-type central star PG 1520+525 (top panels) and in the hydrogen-normal central star of NGC 1360 (bottom panels). The neon and fluorine abundances in the PG1159 star (given as mass fractions in the panels) are strongly enhanced, namely 20 times and 250 times solar, respectively, whereas they are solar in NGC 1360. Note the strong Fe VII line (not included in the models) at 1141.4 Å in NGC 1360, which indicates a solar iron abundance (Hoffmann et al. 2005). It is not detectable in the PG1159 star, probably due to a subsolar Fe abundance.

Before the advent of FUSE with its outstanding FUV capabilities we have performed spectral analyses of almost all known PG1159 stars based on optical and HST-UV spectra. We determined $T_{\text{eff}}$, log $g$, and abundances of the dominant elements, namely He, C, and O. Typical values are He=33%, C=50%, O=17% (by mass). Traces of nitrogen (1%) or considerable amounts of residual hydrogen (about 25%) were found in a few stars, and in a few cases, optical as well as Chandra X-ray identifications of neon were successful (2%).

2. Most important results from FUSE spectroscopy

Generally, FUSE spectra of PG1159 stars show only few photospheric (absorption) lines, mainly from He II, C IV, O VI, and Ne VII. Some of them show shallow NV lines and in many of them we see sulfur. The S VI 933/944 Å doublet in K1-16 suggests a solar abundance, which is in line with the expectation that S is not affected by the s-process. We also identify silicon in some objects (Reiff et al. 2005), but detailed abundance analyses remain to be done.

The first surprising result of FUSE spectroscopy was the detection of a significant iron deficiency (1–2 dex) in the three best studied PG1159 stars (Miksa et al. 2002). Apparently, Fe was transformed to heavier elements in the inter-shell region of the AGB star by n-captures from the neutron source $^{13}\text{C}(\alpha,n)^{16}\text{O}$ (Herwig et al. 2003). Subsequently, several other studies have also revealed an Fe-deficiency in [WC] type central stars (see Werner et al. 2003), which matches our picture that these stars are immediate PG1159 star progenitors.

The next important result was accomplished by the identification of one of the strongest absorption lines seen in FUSE spectra of most PG1159 stars,
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located at 973.3 Å. It is a Ne VII line (Fig. 1) that allowed to assess the neon abundance in a large sample of objects (Werner et al. 2004). It turns out that neon is strongly overabundant, (2%, i.e., 20 times solar). This result clearly confirms the idea that PG1159 stars indeed exhibit intershell matter. Neon is produced in the He-burning environment by two α-captures of nitrogen, which itself resulted from previous CNO burning: \[ ^{14}\text{N}(\alpha, \gamma)^{18}\text{F}(e^+\nu)^{18}\text{O}(\alpha, \gamma)^{22}\text{Ne}. \]

There are still at least ten photospheric lines in the FUSE spectra of PG1159 stars that remain unidentified. Some of them may stem from yet unknown Ne VII lines. The latest identification is a feature at 1139.5 Å, which appears rather strong in some objects. We found that it is a line from highly ionized fluorine (Fig. 1) and derived large overabundances (up to 250 times solar) for a number of PG1159 stars. We also could identify this line in “normal” H-dominated central stars and, in contrast, find about solar fluorine abundances (Werner et al. 2005). This again is a clear proof that we see intershell matter on PG1159 stars. According to recent calculations by Lugaro et al. (2004), their stellar models show an effective fluorine production and storage in the intershell, leading to abundances that are comparable to the observed PG1159 abundances of fluorine. The general problem for fluorine production is that \(^{19}\text{F},\) the only stable F isotope, is rather fragile and readily destroyed in hot stellar interiors by hydrogen via \(^{19}\text{F}(p, \alpha)^{16}\text{O}\) and helium via \(^{19}\text{F}(\alpha, p)^{22}\text{Ne}.\) The nucleosynthesis path for F production in He-burning environments of AGB and Wolf-Rayet stars is \(^{14}\text{N}(\alpha, \gamma)^{18}\text{F}(\beta^+)^{18}\text{O}(p, \alpha)^{15}\text{N}(\alpha, \gamma)^{19}\text{F}.\)

This underlines that AGB stars which dredge up material from the intershell are contributing to the Galactic F content (together with Wolf-Rayet stars and type II SNe). This is completely in line with the detected F overabundances (up to 30 times solar) found in AGB stars (Jorissen et al. 1992). To what extent PG1159 stars themselves return F to the ISM remains to be estimated. The life time of a born-again AGB star is short in comparison to a usual AGB star, however, the F fraction in the mass lost by a wind of the former is much higher.

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References

Herwig, F., Blöcker, T., Langer, N., & Driebe, T. 1999, A&A, 349, L5
Herwig, F., Lagaro, M., & Werner, K. 2003, in Planetary Nebulae, eds. S. Kwok, M. Dopita, R. Sutherland, IAU Symp. 209, ASP, p. 85
Hoffmann, A. I. D., Dreizler, S., Rauch, T., Werner, K., & Kruk, J. W. 2005, in White Dwarfs, eds. D. Koester, S. Moehler, ASP Conf. Series, in press
Jorissen, A., Smith, V. V., & Lambert, D. L. 1992, A&A, 261, 164
Lugaro, M., Ugalde, C., & Karakas, A. I., et al. 2004, ApJ, in press, astro-ph/0407551
Miksa, S., Deetjen, J. L., Dreizler, S., et al. 2002, A&A, 389, 953
Reiff, E., Rauch, T., Werner, K., & Kruk, J. W. 2005, in White Dwarfs, eds. D. Koester, S. Moehler, ASP Conf. Series, in press
Werner, K. 2001, in Low Mass Wolf-Rayet Stars: Origin and Evolution, ed. T. Blöcker, L.B.F.M. Waters, A.A. Zijlstra, Ap&SS, 275, 27
Werner, K., Deetjen, J. L., Dreizler, S., Rauch, T., & Kruk, J.W. 2003, in Planetary Nebulae, eds. S. Kwok, M. Dopita, R. Sutherland, IAU Symp. 209, ASP, p. 169
Werner, K., Rauch, T., Reiff, E., Kruk, J. W., & Napiwotzki, R. 2004, A&A, in press
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