Abstract. We investigate FUSE spectra of three PG1159 stars and do not find any evidence for iron lines. From a comparison with NLTE models we conclude a deficiency of 1–1.5 dex. We speculate that iron was transformed into heavier elements. A soft X-ray Chandra spectrum of the unique H- and He-deficient star H1504+65 is analyzed. We find high neon and magnesium abundances and confirm that H1504+65 is the bare core of either a C-O or a O-Ne-Mg white dwarf.

1. Iron deficiency in PG1159 stars

The origin of hot hydrogen-deficient post-AGB stars (spectral types [WC] and PG1159) is supposed to be a late He-shell flash. Detailed summaries on their spectroscopic characteristics and quantitative analyses, and relevant evolutionary calculations can be found e.g. in Werner (2001) and Herwig (2001), respectively.

In the last white dwarf workshop, held in Delaware two years ago, we presented for the first time clear evidence for iron deficiency in a PG1159 star (Miksa et al. 2001). Because PG1159 central stars are very hot ($T_{\text{eff}} > 75,000$ K), the metals are highly ionized. The dominant ionization stage of iron in the line formation region is FeVII and most of its lines are located in the FUV spectral region. Contrary to our expectation we were not
able to detect any Fe VII line in the FUSE FUV spectrum of the pulsating central star of K1-16, which means that iron is deficient by at least one dex. This has initiated an effort to utilize archival IUE and HST spectra as well as new FUSE spectra to look for iron in other PG1159 stars (Miksa et al. 2002). It turned out that IUE and HST spectra do show a hint of iron deficiency in some other objects, but the data quality is not sufficient for reliable quantitative analyses. The same holds for a number of FUSE spectra from PG1159 stars. However, in two more cases, where FUSE spectra with sufficiently high S/N were obtained, we were successful in proving that iron is deficient. The first one is the central star of NGC 7094, which is classified as a hybrid-PG1159 star, because it exhibits H Balmer lines. No iron lines were detected and we concluded that iron is depleted by at least 1.5 dex (Miksa et al. 2002). The next case is the central star of Abell 78, which is classified as one of the rare [WC]–PG1159 transition objects. For Abell 78 we find an iron deficiency of 1.5 dex from the lack of iron lines as well (Werner et al. 2002a).

What is the origin of the iron deficiency? We think that iron has been transformed to heavier elements. The high C and O abundances in PG1159 stars result from envelope mixing caused by a late He-shell flash. This event also modifies the near-solar abundance ratios of iron-peak elements in the envelope by dredging up matter in which s-process elements were built-up by n-capture on $^{56}\text{Fe}$ seeds during the AGB phase. This scenario can and will be tested by analyzing the resulting Fe/Ni abundance ratio, because it is significantly changed in the intershell region in favor of Ni by the conversion of $^{56}\text{Fe}$ into $^{60}\text{Ni}$. More quantitative results from nucleosynthesis calculations in appropriate stellar models have been presented recently (Herwig et al. 2002) and inclusion of nuclear networks in evolutionary model sequences will become available in the near future.

Interestingly, Asplund et al. (1999) have found that in Sakurai’s object, which is thought to undergo a late He-shell flash, iron is reduced to 0.1 solar and Fe/Ni≈3. This and other s-process signatures should also be exhibited by Wolf-Rayet type central stars and PG1159 stars. And in fact, latest results confirm that iron deficiency among H-deficient post-AGB stars is not restricted to PG1159 stars. It appears that three Wolf-Rayet type central stars are iron deficient, too. Gräfener et al. (2002) report a low iron abundance in SMP 61, an early type [WC5] central star in the LMC. Its abundance is at least 0.7 dex below the LMC metallicity. Crowther et al. (2002) find evidence for an iron underabundance of 0.3–0.7 dex in the Galactic [WC] type central stars stars NGC 40 ([WC8]) and BD+30°3639 ([WC9]). In this context it is also interesting to remark that the hot DO white dwarf RE 0503-289 is iron deficient and rich in nickel (Barstow et al. 2000). If this is related to the iron deficiency in PG1159 stars is an open question.
2. Chandra spectroscopy of H1504+65

H1504+65 is the most extreme PG1159 star, not only because of its extraordinarily high effective temperature, which is close to 200,000 K. We have shown that H1504+65 is not only hydrogen-deficient but also helium-deficient. From optical spectra it was concluded that the atmosphere is primarily composed of carbon and oxygen, by equal amounts. Neon lines were detected in soft X-ray spectra taken with the EUVE satellite and in an optical-UV Keck spectrum, and a neon abundance of 2–5% (mass fraction) was derived (Werner & Wolff 1999).

H1504+65 was observed with Chandra on Sep. 27, 2000, with an integration time of 7 hours. Flux was detected in the range 60 Å–160 Å and the spectral resolution is about 0.1 Å. The spectrum displays astonishing details (Fig. 1). At first sight the spectrum appears to be rather noisy, but comparison with model spectra suggests that most absorption features in the observation are probably real. Mg lines are discovered for the first time in H1504+65 (see Werner et al. (2002b) for more details). Exploratory models including opacities of heavy metals (Ca–Ni) were computed. This
introduces a very large number of additional lines, however, identifying individual heavy metal lines will be problematic or even impossible, because the vast majority of lines in the available lists have uncertain wavelength positions.

The Mg abundance is of the order 2%, similar to the Ne abundance determined earlier. This allows two alternative interpretations. Either we see a naked C-O white dwarf with 3α processed matter, which is, according to evolutionary models, dominated by C and O with an admixture of $^{22}\text{Ne}$ and $^{25}\text{Mg}$ of the order 1%. Or we see a naked O-Ne-Mg white dwarf which has undergone carbon burning. A comparison with the respective evolutionary models (Ritossa et al. 1999) suggests that we could look onto such a naked remnant where $^{20}\text{Ne}$ and a mixture of several Mg isotopes ($^{24}\text{Mg},^{25}\text{Mg},^{26}\text{Mg}$) should be present. We have already speculated earlier, that the onset of C burning and subsequent evolutionary processes might explain the uniqueness of H1504+65. In order to confirm this idea, we will also look for Na absorption lines, because the stellar models predict a relatively high amount of $^{23}\text{Na}$ in this case.

To conclude, H1504+65 might have been one of the “heavyweight” intermediate-mass stars ($9\,M_\odot \leq M \leq 11\,M_\odot$) which form white dwarfs with electron-degenerate O-Ne-Mg cores resulting from carbon burning. This speculation is corroborated by the fact that H1504+65 is one of the most massive PG1159 stars known ($0.86 \pm 0.15\,M_\odot$).

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