14^th European Workshop on White Dwarfs
ASP Conference Series, Vol. 999, 2005
D. Koester, S. Moehler

Hydrogen-deficient stars in pre-WD stages

Wolf-Rainer Hamann and Götz Gräfener

Lehrstuhl Astrophysik der Universität Potsdam, Am Neuen Palais 10, D-14469 Potsdam, Germany

Abstract. Among the Central Stars of Planetary Nebulae, about 20% are hydrogen-deficient at their surface (spectral types [WC], wels, PG1159). Because of strong mass-loss, their spectra are formed in a stellar wind and require adequate modelling for their analysis. Corresponding Non-LTE model atmospheres have been developed in the last decade. They have been applied extensively for analyzing the spectra of these hydrogen-deficient white dwarf progenitors, establishing their stellar parameters and surface compositions. The results provide the basis for the discussion of their evolutionary status and have initiated efforts to develop new calculations for the post-AGB evolution which account consistently for diffusive mixing and nuclear burning.

A significant number of planetary nebulae have a central star (CSPN) with Wolf-Rayet type spectra of the carbon subclass, denoted as [WC] (Fig. 1). Other carbon-rich spectra with less pronounced mass-loss characteristics are classified

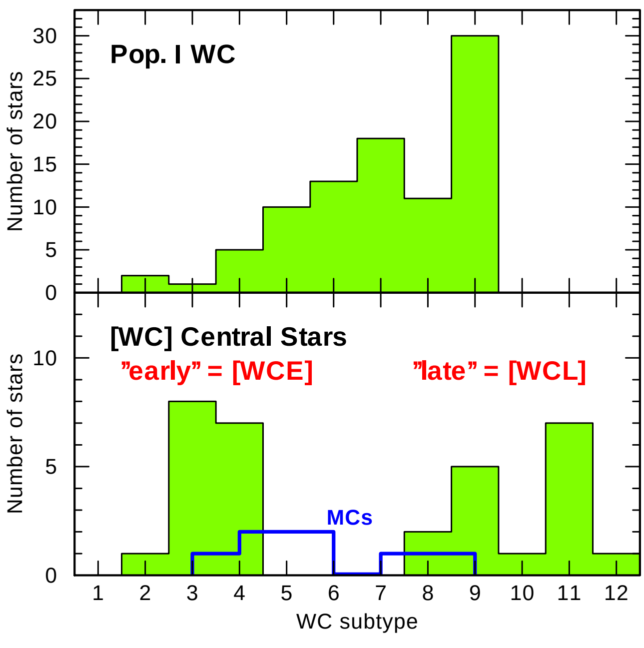

Figure 1. The subtype distribution of Wolf-Rayet type central stars ([WC2] ... [WC12]) is bimodal, in contrast to massive WC stars which prefer intermediate subtypes. The few [WC] stars in the Magellanic Clouds might have their own subtype distribution.

as “wels” (weak emission line stars) or PG 1159 type. The quantitative analysis of emission line spectra requires adequate models for expanding atmospheres in non-LTE. After having developed such models, the Kiel/Potsdam group has analyzed many [WC]-type central stars, two “weak emission line stars” (wels) and four PG 1159 stars. Evolutionary models suggest that those hydrogen-deficient post-AGB stars evolve from late ([WCL], i.e. [WC12] ... [WC8]) to early ([WCE], i.e. [WC4] ... [WC2]) subtypes. However, empirical chemical abundances apparently rule out such scenario, as it has been found that the carbon mass fraction in [WCL] amounts to about 50%, but is only 15...30% in [WCE] stars, typically (see Fig. 2). One might wonder if these results are due to systematic error of the spectral analyses, e.g. because of the neglection of iron line blanketing.

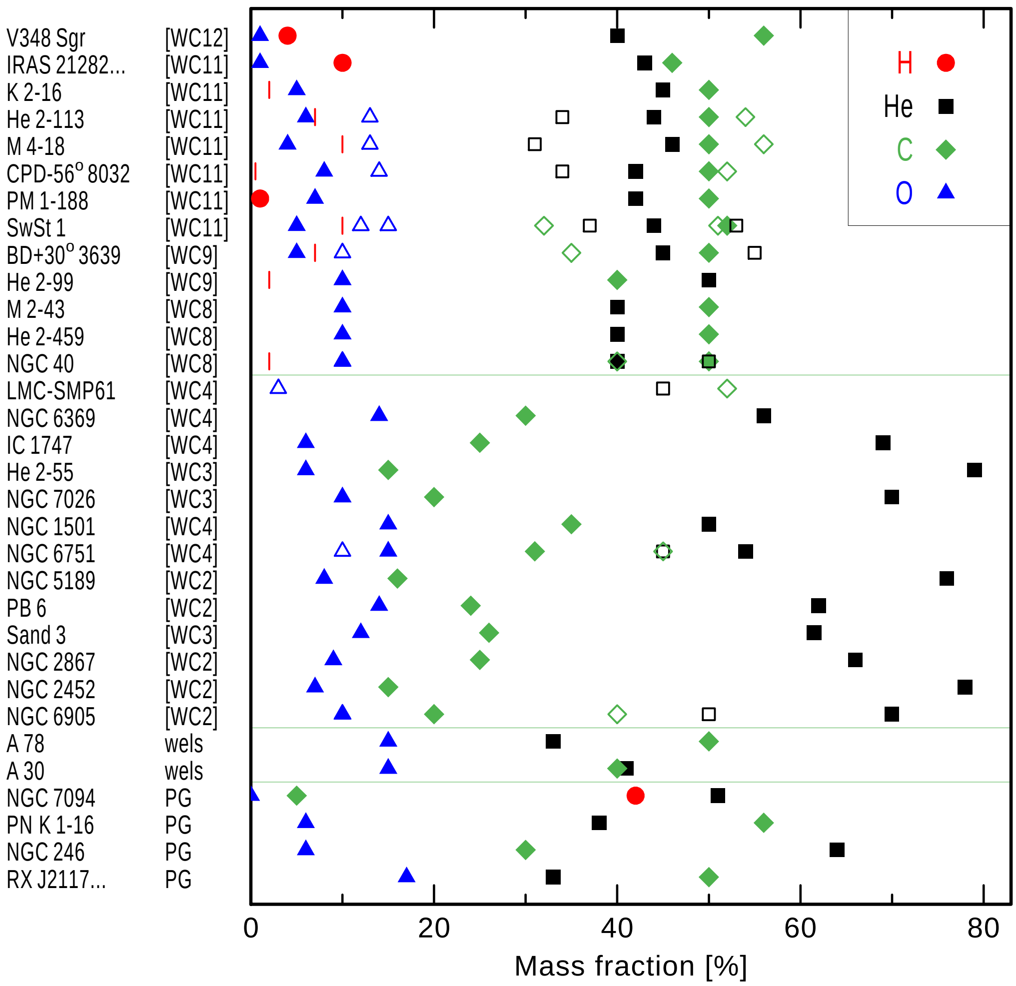

Figure 2. Atmospheric abundances in hydrogen-deficient central stars obtained from spectral analyses. Filled symbols are based on studies with unblanketed model atmospheres, while open symbols represent values obtained more recently with line-blanketed models. Small vertical bars indicate upper limits of the hydrogen abundance.

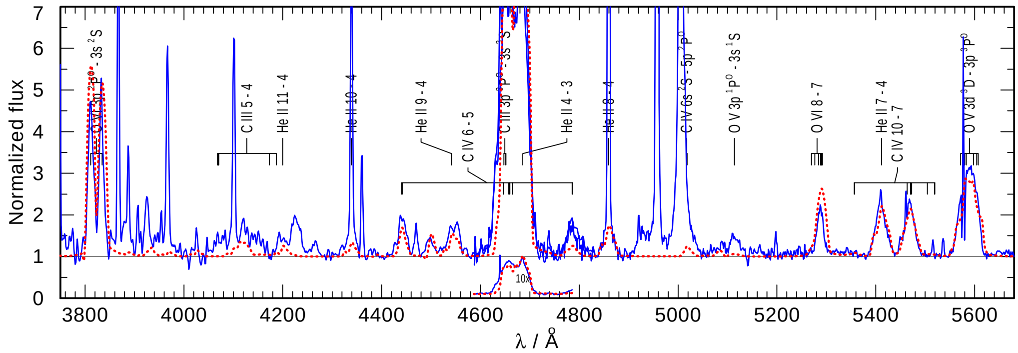

Figure 3. Preliminary spectral fit of NGC 6369. The observations (solid lines) are compared to an iron-blanketed model (dotted) with $T_* = 160\,\mathrm{kK}$, and $v_\infty = 1200\,\mathrm{km/s}$. The abundances ratio He:C = 56:30 (by mass) as obtained from the previous, unblanketed analysis are confirmed in this case, as can be seen from the diagnostic line pair He II 5412 and C IV 5470

.

Only the more recent analyses were based on blanketed model atmospheres (Crowther et al. 2003). Their results confirmed the high carbon abundance in four [WNL] stars, but in two cases revised them downwards (Fig. 2). On the other hand, line-blanketed [WCE] analyses tend to higher carbon. We are presently repeating all our previous [WCE] analyses with the recent line-blanketed version of the Potsdam Wolf-Rayet (PoWR) model atmospheres (see, e.g., Fig. 3) and expect the abundance discrepancy to resolve.

Evolutionary models for the origin of hydrogen-deficient pre-WDs (and WDs!) must in first place explain how the hydrogen-rich stellar envelope could have disappeared. Even more difficult to explain, a small fraction of hydrogen has been detected in a couple of [WCL] atmospheres (also indicated in Fig. 3). Note that [WCE] stars might have some hydrogen as well, which can more easily escape from detection in stars with higher effective temperature.

In the commonly adopted scenario, the carbon-rich material is brought to the stellar surface by the last "thermal pulse". The resulting surface composition depends on whether this event occurs already at the tip of the AGB (Asymptotic giant branch Final Thermal Pulse, AFTP), during the horizontal post-AGB evolution through the CSPN region (Late Thermal Pulse, LTP), or even later after hydrogen burning ceased and the star entered the white dwarf cooling track (Very Late Thermal Pulse, VLTP). It is predicted that those post-AGB stars which are completely free of hydrogen originate from the VLTP, while those objects with a small rest of hydrogen come via the AFTP or LTP channel (Herwig 2001).

"Classical" models of (post-) AGB stars failed totally in producing the observed [WC] compositions in *any* of their interior layers. Only when the effect of diffusive mixing in overshoot layers is taken into account, the models yield appropriate mixtures in some "intershell region" between the helium- and the hydrogen-burning shell (Herwig et al. 1997). Recent evolutionary calculations which account for "simultaneous mixing and burning" (Herwig 2001) predict that many neutrons are produced via ^{13}C in this intershell region. These neutrons are captured by iron and thus help to built up s-process elements. We studied in detail the [WC4] central star LMC-SMP 61 (Stasinska et al. 2004) and found, interestingly, a strong iron *under*abundance. This gives indirect evidence that s-process nucleosynthesis has consumed most Fe by neutron capture.

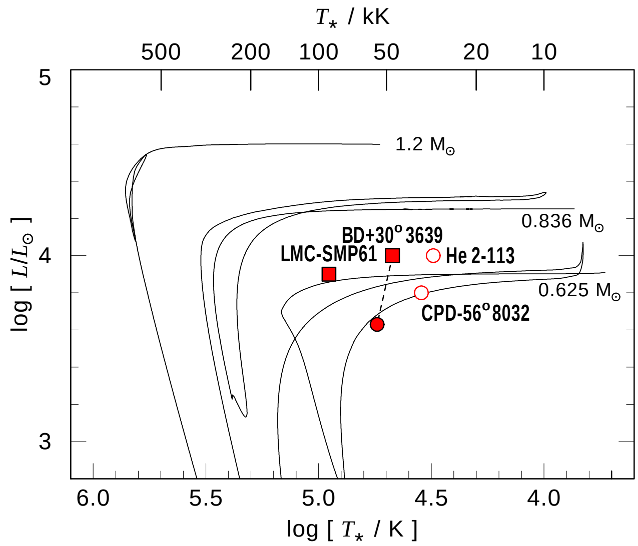

Figure 4. HRD with the few analyzed hydrogen-deficient CSPN with known distance, i.e. reliable luminosity: SMP 61 [WC4] in the LMC, and three Galactic [WC] stars with more (full symbol) or less (open symbols) good distance estimates (squares: our group; circles: from Crowther et al. 2003). Evolutionary post-AGB tracks are shown for rough comparison and reveal that all four [WC]-type central stars have masses around $0.6\,M_\odot$.

Which AGB stars are selected to become hydrogen-deficient later? A comparison of empirical CSPN parameters with evolutionary tracks is difficult. $\log g$ is not available from emission-line spectra. The position in the HRD is also not known in general, because the luminosity cannot be inferred from a spectral analysis alone, but also depends on the adopted stellar distance. Unfortunately, there is not a single Galactic [WC]-CSPN with a precisely known distance, and only few with reasonable distance estimates. Figure 4 reveals that those stars have luminosities corresponding to a mass of $0.6\,M_\odot$, i.e. the typical mass of a white dwarf. Hence the [WC]-type CSPN are not distinguished by their mass. This supports the idea that it is just the random timing of the last thermal pulse at the AGB (or, after having left the AGB) which determines the final fate of a low-mass star.

References

Crowther, P.A., Abbott, J.B., Hillier, D.J., De Marco, O. 2003, IAUS 209, 243
Herwig, F. 2001, Ap&SS 275, 15
Herwig, F., Blöcker, T., Schönberner, D., El Eid, M. 1997, A&A 324, L81
Stasinska, G., Gräfener, G., Peña, M., Hamann, W.-R., Koesterke, L., Szczerba, R. 2004, A&A 413, 329
Hamann, W.-R., Gräfener, G., Koesterke, L. 2003, IAUS 209, 243