ON THE STRUCTURE OF PRE-WHITE DWARFs

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White dwarfs (WD) are the final configurations of all stars up to initial masses between 5 and 9 M⊙. Two feeder channels for the creation of single WDs can be distinguished: Either evolution through the asymptotic giant branch (AGB) and the following planetary-nebula (PN) phase, or evolution from the horizontal branch through the hot subdwarf region. Prelimary estimates by Drilling and Schönberner (1985) and Heber (1986) indicate that the creation of WDs via the horizontal-branch channel is rather insignificant (few percent of the total WD birthrate) and can be neglected. Thus the evolution through the AGB determines the internal structure of single WDs, and the study of the PN stage serves to elucidate the inital conditions for the white-dwarf evolution.

Schönberner (1981) has presented the first evidences that hydrogen-burning post-AGB models of about 0.6 M⊙ explain well all observed properties of central stars of planetary nebulae (CPN). Although this case has been strengthened further, it remained debatable because of the well-known distance uncertanties. Therefore it is desirable to investigate the PN stage by distance-independent means. A first step into this direction has already been made by Schönberner (1986) and Szczerba (1987). Both anthors made a statistical study of the nebular line strength of He II 4686 Å relative to Hβ and came up with essentially the same results as Schönberner (1981).

In this communication we report on recent results of a similar study where the line ratio [OII] 3727 Å/ [OIII] 4959 Å has been used. We calculated the detailed photoionization in PN models of selected

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evolutionary sequences computed by Schmidt-Voigt and Köppen (1987). Computational details will be given elsewhere (Schönberner and Tylenda, in preparation). The advantage of using [OII]/[OIII] instead of HeII/Hß is a greater sensitivity to changing degrees of ionization and an insensitivity to the spectral shape in the ultraviolet (HeII 4686 depends heavily on the 228 Å edge).

We concentrated our efforts on the later phases of the CPN evolution, viz. on the region above and below the turn-around point of the evolutionary tracks in the H-R diagram. Hydrogen-burning post-AGB models are expected to drop very rapidly in luminosity by more than a factor of 10, forcing the planetary to recombine. The [OII]/[OIII] line ratio will then vary accordingly. The following three sequences from Schmidt-Voigt and Köppen (1987) have been selected:

1. $M = 0.64\ M_\odot$, $M_{PN} = 0.19\ M_\odot$,
2. $M = 0.60\ M_\odot$, $M_{PN} = 0.27\ M_\odot$,
3. $M = 0.57\ M_\odot$, $M_{PN} = 0.30\ M_\odot$.

The CPN models are those of Schönberner (1981, 1983), with the evolutionary ages of both the CPNs and PNs taken as proposed there. Table 1 presents the results at some relevant points along these evolutionary sequences. It contains also one calculation for a low-luminosity 0.89 M⊙ post-AGB model of Wood and Faulkner (1986). The nebular masses are only mean values since these sequences assume mass accretion from the old AGB wind, and the expansion velocities vary between 25 and 40 km/s (see Schmidt-Voigt and Köppen, 1987, for details). A slighthy varying mass has only negligible influences on the nebular ionization.

It can be seen from the Table 1 that the rapid luminosity drop of the post-AGB models (0.64 and 0.60 M⊙) forces the planetary to recombine, leading to a corresponding increase of I(3727)/I(4959). As the model's evolution slows down, the continuing nebular expansion leads to some reionisation as indicated by the decreasing line ratio. The ionization remains, however, rather low. In the extreme case of a slowly evolving model (0.57 M⊙) together with a fast expanding nebula, recombination does not occur at all. The 0.89 M⊙ represents the other extreme, viz. the combination of a massive CPN with a massive PN.

Table 1: Properties of selected models

CPN model				PN model			
M/M⊙	L/L⊙	M_V	Age/yr	M_{PN}/M⊙	R/pc	N_H/cm^{-3}	I(3727)/I(4959)
0.64	7675	1.8	3065	0.18	0.08	2300	0.013
	4210	4.2	4240		0.14	500	0.026
	2950	4.7	4440		0.15	420	0.045
	240	6.4	4740		0.16	340	1.9
	160	6.7	5545		0.19	215	2.8
	122	6.9	7870		0.27	75	1.8
	80	7.0	14430		0.49	12	1.0
	68	7.0	20000		0.67	4.5	0.61
0.60	5690	0.3	4780	0.27	0.16	300	0.021
	5145	1.9	6410		0.19	170	0.016
	1300	4.8	9300		0.33	53	0.055
	266	6.2	10530		0.37	37	0.35
	125	6.5	12220		0.43	24	0.89
	113	6.6	17580		0.61	8	0.55
0.57	3730	-0.2	8460	0.30	0.23	220	0.29
	3680	0.0	9250		0.29	90	0.11
	3580	0.7	10750		0.45	25	0.038
	3210	1.8	13750		0.78	5	0.013
0.89	55	8.1	30000	0.58	0.44	47	12

How do these computations compare with observations? To answer this question, we have chosen Kaler's (1983) sample of old PN because these correspond approximately to the models shown in Table 1. We have selected the objects with known [OII] and [OIII] lines (27 objects) and found them to fall into two distinct classes: one with I(3727)/I(4959) $\lesssim$ 0.1 and bright central stars (6 objects), and the rest with 0.3 $\lesssim$ I(3727)/I(4959) $\lesssim$ 2 and faint ($M_V > 5$) central stars (21 objects). All the oldest PN appear to have this low ionization. Inspection of Table 1 then clearly indicates that only PN models illuminated by hydrogen-burning post-AGB models of about 0.6 M⊙ give a very good explanation of the observed ionization in old planetaries. More massive models, say with M $\gtrsim$ 0.7 M⊙, give rise for too much OII during the low-luminosity stage (cf. 0.89 M⊙ model of Table 1). Contrary, a low-mass model (M $\lesssim$ 0.57 M⊙) does not fade fast enough as to allow for recombination in an expanding nebula.

Accepting these post-AGB models of ≈ 0.6 M⊙ as representative for most central stars, we have to face the following properties of pre-white dwarfs:

i) $M \approx 0.6$ M⊙;
ii) hydrogen-rich envelope of $M_e \approx 10^{-4}$ M⊙;
iii) helium inter-shell layer of $M_{is} \approx 10^{-2}$ M⊙.

Note that the residual hydrogen-rich envelope is determined by the shut-down of hydrogen burning. Should mass loss be important, the only effect would be a faster evolution toward this limiting envelope mass. More details on the influence of mass loss on the post-AGB evolution can be found in Schönberner (1987). The helium-rich intershell layer is a consequence of the interplay between the hydrogen-burning and the helium-burning shell and is determined by the stellar structure equations. Its mass is insensitive to even drastic changes of the energy generation rates (Despain and Scalo, 1976), although it varies by about a factor of 2 during one thermal pulse cycle.

References:

Despain, K.H., Scalo, J.M.: 1976, Astrophys. J. **208**, 789.
Drilling, J.S., Schönberner, D.: 1985, Astron. Astrophys. **146**, L23.
Heber, U.: 1986, Astron. Aastrophys. **155**, 33.
Kaler, J.B.: 1983, Astrophys. J. **271**, 188.
Schmidt-Voigt, M., Köppen, J.: 1987, Astron. Astrophys. **174**, 211.
Schönberner, D.: 1981, Astron. Astrophys. **103**, 119.
Schönberner, D.: 1983, Astrophys. J. **272**, 708.
Schönberner, D.: 1986, Astron. Astrophys. **169**, 189.
Schönberner, D.: 1987, Workshop "Late Stages of Stellar Evolution", S. Kwok, S.R. Pottasch, Eds., Reidel, Dordrecht, p. 337
Szczerba, R.: 1987, Astron. Astrophys. **181**, 365.
Wood, P.R., Faulkner, D.J.: 1986, Astrophys. J. **307**, 659.

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