THE MASS DISTRIBUTION OF WHITE DWARFS AND CENTRAL STARS OF PLANETARY NEBULAE

Volker Weidemann
Institut f. Theoretische Physik und Sternwarte
Universität Kiel, Fed. Rep. Germany

Recent results on mass distributions for white dwarfs and planetary nebulae are presented and compared with current theoretical predictions. Whereas single star evolution leads to final masses predominantely in a narrow interval around 0.6 $\mathcal{M}_\odot$ which can be explained by current mass loss schemes degenerate stars in binaries present a larger range of masses. The average mass of the primaries in cataclysmic binaries seems to be more around 0.7 than 1 $\mathcal{M}_\odot$.

Analysis of spectroscopic and photometric data for DA white dwarfs (i.e. the majority) during the last years have yielded the interesting result that the mass distribution is rather narrow, around 0.6 $\mathcal{M}_\odot$. This is apparent as well from the HR-diagram (Weidemann, 1978) if one assigns weights to parallaxes, resulting in a mass distribution $\mathcal{M}$(R) - which is obtained from the radius distribution via the mass-radius relation - confined to $\mathcal{M}(R) = 0.58 \pm 0.10\ \mathcal{M}_\odot$ (Koester, Schulz, Weidemann, 1979, -KSW-, Fig. 9b) as also from the two-color diagrams in the Strömgren (Graham, 1972, Wegner, 1979) or multichannel system (Greenstein, 1976) which enable sensitive surface gravity determinations (Weidemann, 1971, KSW, Figs. 2, 4 and 6, Shipman and Sass, 1980). The corresponding mass distribution, $\mathcal{M}$(g) for 122 DA white dwarfs KSW, Fig. 8b) has recently been confirmed by a careful study of 20 DA stars by Schulz and Wegner (1981). The (15 - 30%) non-DA white dwarfs (spectral type DB, DC, C2), although less certain, seem to occupy the same narrow mass range (Koester et al. 1981), (Wickramasinghe, 1981, Weidemann, 1981a).

The situation is similar for the nuclei of planetary nebulae (NPN). Consideration of evolutionary tracks in the HR-diagram by Weidemann (1977b, Fig. 2) and by Renzini (1979, Fig. 1) suggested a new method of mass determination in which the time scale of evolution as measured by nebular expansion is compared with luminosities of NPN as predicted by evolutionary tracks for different masses (Schönberner and Weidemann, 1981). These tracks differentiate very effectively between NPN masses, essentially since the core mass in the pre-PN stages at the asymptotic (second) giant branch is highly sensitive to luminosity (core mass-

Z. Kopal and J. Rahe (eds.), Binary and Multiple Stars as Tracers of Stellar Evolution, 403–408.

luminosity relation), (Schönberner and Weidemann, 1981, Fig. 6). Comparison with a local ensemble - less biased by observational selection - confirms the narrow distribution with few if any massive NPN at very low luminosities (Schönberner, 1981). The NPN distribution cuts off at $\mathcal{M} = 0.55\ \mathcal{M}_\odot$ - not surprisingly, since stars with smaller core masses do not reach the asymptotic giant branch and will not produce PN (Sweigart et al. 1974, Weidemann, 1975). However it was more surprising that it falls also off very steeply for higher masses, $\mathcal{M} > 0.64\ \mathcal{M}_\odot$. This contradicts canonical stellar evolution which predicts dredgeup and PN enrichment not below progenitor masses of $3\mathcal{M}_\odot$ or core masses above $0.7\ \mathcal{M}_\odot$. Schönberner's material shows PN of all enrichment classes (Schönberner, 1981, Fig. 13/14).
Thus single stars seem in general not to produce larger degenerate core masses than about $0.65\ \mathcal{M}_\odot$. This conclusion has been supported by recent downward revisions of Mira (pre-PN) luminosities (Robertson and Feast, 1981, Willson, 1981) and by the C star luminosity distribution in the Magellanic clouds (Richer, 1981), which also show enrichment at small core masses - a fact which has lead Iben (1981) to dicuss the "carbon star mystery".
The PN results have independently confirmed by NPN spectroscopy and NLTE analysis at Kiel (Mendez et al., 1981, Kudritzki et al., 1981), again by a comparison with Schönberner tracks in g-T_{eff} diagrams.

In summary; the observational evidence presented points to a very flat initial-final mass relation (Weidemann, 1981 b, Fig. 1) for which progenitors with masses up to the limit of the degenerate core range ($\sim 8\ \mathcal{M}_\odot$) may produce white dwarfs (Weidemann, 1977a, 1979). Koester and Reimers (1981) have recently confirmed at least partly the prediction of Romanishin and Angel (1980) that white dwarfs are present in young clusters with turn-off masses larger than $4\mathcal{M}_\odot$. Wegner (1981) reaches are similar conclusion by consideration of white dwarfs in binaries whose age and progenitor masses are estimated from kinematical properties of the system.
On the theoretical side the only mechanism proposed yielding the needed high mass loss rates is shock ejection in late giant stages (Barkat and Tuchman, 1980). It must be combined with a fairly large steady mass loss rate (Reimers factor $\eta \sim 1.4$) in order to reproduce the flat empirical initial-final mass relation. Schönberner (1981, Fig. 10) has demonstrated that the Barkat-Tuchman PN ejection line indeed predicts the sharply peaked NPN mass distribution observed.

We now turn to the topic of this Conference: evolution in binary and multiple stars and ask how our picture will be changed. White dwarfs occur in quite a variety of binary stars which we shall consider in turn.
a) Wide binaries, comprising astrometric and visual binaries, and common proper motion pairs. There are 7 white dwarfs in binaries within 10 pc (compared with 13 single WDs) with separations between 16 and 100 AU - thus there will be many more at larger distances which have not get been found, staying too close to be visible and having too long periods for spectroscopic detection. However there is the

possibility to detect the hotter ones in the ultraviolet.
About 20 % of all WD listed are wide binaries or cpm objects with separations between 100 and typically several thousand AU. We do not expect them to have been influenced during evolution by the existence of the companion (red giant radii remain smaller than 10 AU) and thus they may be counted as single stars. Luyten (1969) has given lists and also proposed 15 candidates for double white dwarfs, from which 5 have been confirmed up to now. Although it will be difficult in many cases to detect duplicity of degenerates the number of double WDs is surprisingly small. A last category in this group comprises the unseen companions - remember that our classical WD Sirius B has been an unseen companion first! - about which we obtained in formation at this Conference by Prof. Van de Kamp and Dr. Abhyankar. In some cases there are suspected white dwarf companions with masses between 0.5 and 1 $\mathcal{M}_\odot$, worth an effort of search with the IUE or the Space Telescope.
b) Close binaries. We distinguish three categories:
b1) degenerates in detached systems, partly found by eclipses, partly by heating, EUV or X radiation. We list as examples (periods in brackets) F 24 (4^d), V 471 Tau = BD+16°516 (0.5^d), GK Vir = PG 1413+01 (0.34^d), and the polars AM Her (0.13^d), EF Eri = 2A 0311-227 (0.06^d) with separation between 1.5 and 6 $R_\odot$, and thus products of common envelope evolution (Paczynski, 1981) but now with comparatively little interaction.
b2) the cataclysmic variables, with degenerate primaries, Roche lobe overflow of the secondaries and accretion disks, periods from typically half a day down to about 80 minutes with separations of the order of 1 $R_\odot$. Much effort has been devoted to a better determination of the physical parameters of these systems, and better understanding is at hand. (Reference to the contributions by Ritter, N. Vogt, and others at this Conference). Whereas earlier mass determinations have yielded white dwarf masses around 1 $\mathcal{M}_\odot$ (see Robinson , 1976) recent data, collected by Ritter (1980) give often smaller masses. I have studied the literature up to today and summarize the present situation in Fig. 1, where the estimated uncertainties are indicated by the size and width of the quadrangles in each case. Summed up over the mass intervals I obtain the mass distribution of Fig. 2. It is evident that the average mass of the degenerates in cataclysmics is around 0.7 $\mathcal{M}_\odot$ rather than 1 $\mathcal{M}_\odot$.

The new result appears more reasonable in view of what has been outlined for single star evolution: it may even be possible that the WD masses are actually equal. Of course there are cases in which mass transfer stops the core evolution before it reaches the critical values for single star mass loss, however it is difficult to imagine how mass exchange might increase the core masses beyond those reached by single star evolution. The fact that furthermore the WD masses in cataclysmics are not dependent on the period (Fig. 1) - i.e. that there seem to be no significant differences for WD masses above and below the period gap, or between post-novae and dwarf novae - speaks also for a general integrated scheme of evolution like that outlined by Vogt at this Meeting. In any cases I strongly recommend not to use

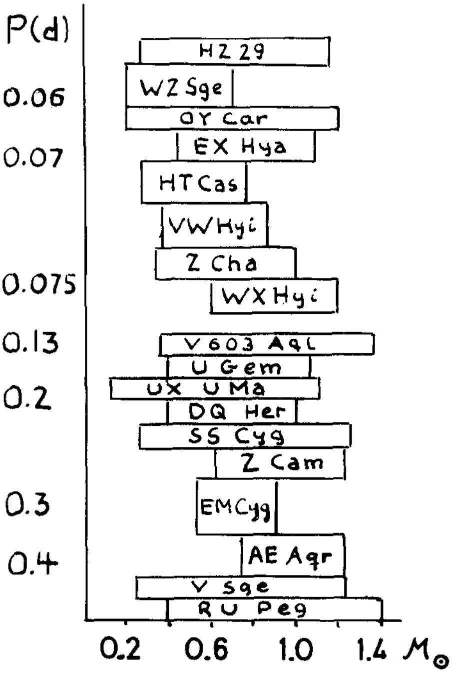

Fig. 1. Masses of degenerate primaries for 18 cataclysmic variables, ordering according to period (P) in days (d), see text

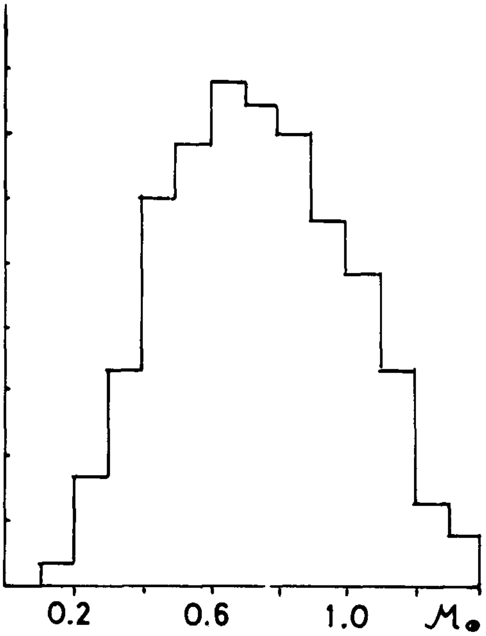

Fig. 2. Mass distribution of degenerate primaries in CB's, derived from Fig. 1

1 $\mathcal{M}_\odot$ any more as the typical WD mass value in all kind of model calculations for novae and dwarf novae. If, on the other hand, the average WD mass in CBs will turn out to be really higher than in the single star case - or if there are individual cases with definitely higher masses - we are forced to look for very massive progenitors in order to build up the higher core masses in red giant stages. Examples are given by Law and Ritter at this Conference: they need a helium primary star of 0.8 to 3.3 $\mathcal{M}_\odot$ to begin with, and total masses above 10 $\mathcal{M}_\odot$ in order to obtain higher mass white dwarfs in CBs. So, if WD masses are high, progenitor masses must have been even higher, such as to make the formation of progenitor systems a comparatively rare event in the galaxy. The WD mass is thus indeed crucial to the question of the origin of CBs! If massive progenitor systems are acceptable statistically or not depends of course on the longevity of the CBs, a problem which has not yet been solved, although predictions are being made (Taam et al., 1980, Paczynski and Sienkiewicz, 1980, Rappaport et al., 1981)

b3) the last category comprise the two extremely short period binaries GP Com = G 61-29 (46^m) and HZ 29 (16^m) which both show only helium in the system and which are probably double degenerates with a small incipient black dwarf secondary of 0.02 resp. 0.04 $\mathcal{M}_\odot$. The secondary will be soon eroded and the system will appear as a single white dwarf of spectral type DB (Nather et al., 1981). The fraction of the DB stars which is formed in this way depends on the lifetime and space density of these systems which are both very uncertain.

It is however interesting to note that according to current theories low period CB evolution with periods increasing again from a minimum around 80^m will also lead to erosion of the secondary with a DA white dwarf remaining. So there would be no way for evolution via the normal CB stage to these strange systems. We further want to emphasize that within the present schemes CB evolution will not lead to mass increase of the degenerate primary and thus not to supernovae (type I) events caused by collapse on reaching the Chandrasekhar mass limit.

If one finally takes into account what has been discussed by Webbink (1979) about possible channels of binary evolution, noting that all contact binaries on the main sequence evolve into coalescence and thereby finally follow single star evolution one is lead to the conclusion that the ultimate fate even in the cases of binary evolution with mass exchange does not differ so much from that of single stars after all! I have estimated in my Rochester Lecture (1979) that about 70 % of all stars in the main progenitor range $(1 < \mathcal{M} < 8\, \mathcal{M}_\odot)$ follow single star evolution. The remaining 30 % may undergo mass exchange and common envelope evolution. Paczynski (1981) expressed the view that detached systems like V 471 Tau, might be the normal result of common envelope evolution and that cataclysmics are formed only if they lose additional mass and angular momentum. This depends very much on the fate of the detached systems (b1): will they survive at the present separations or get in contact again by magnetic braking or stellar wind leading them into the CB channel? We are not yet at the end of the road!

References

Barkat, Z., Tuchman, Y.: 1980, Astrophys. J. 237, 105 - 110

Graham, J.A.: 1972, Astron. J. 77, 144-149

Greenstein, J.L.: 1976, Astron. J. 81, 323 - 338

Iben, Jr., I.: 1981, Astrophys. J. 246, 278-291

Koester, D., Schulz, H. Weidemann, V.: 1979, Astron.Astrophys.76, 262 - 275

Koester, D., Reimers, D.: 1981, Astron. Astrophys. 99, L8 - 11

Koester, D., Schulz, H., Wegner, G.: 1981, Astron.Astrophys. in press.

Kudritzki, R.P., Méndez, R.H., Simon, K.P.: 1981, Astron.Astrophys. 99, L15 - 17

Méndez,R.H., Kudritzki, R.P., Gruschinske, J., Simon, K.P.: 1981, Astron. Astrophys. in press.

Nather, R.E., Robinson, E.L., Stover, R.J.: 1981, Astrophys. J. 244, 269 - 279

Paczyński, B.: 1981, Acta Astronomica 31, 1 - 11

Paczyński, B., Sienkiewicz, R.: 1981, preprint

Rappaport, S., Joss, P.C., Webbink, R.E.: 1981, preprint

Renzini, A.: Stars and Star Systems, IAU Regional Meeting, Uppsala, B.E. Westerlund, Ed. Reidel, Dordrecht, pp. 155 - 169

Richer, H.: 1981, Astrophys. J. 243, 744 - 755

Ritter, H.: 1980, private communication

Robertson, B.S.C., Feast, M.W.: 1981, preprint

Robinson, E.L.: 1976, Ann. Rev. Astr. Astroph. 14, 119 - 142

Romanishin, W., Angel, J.R.P.: 1980, Astrophys. J. 235, 992 - 998

Schönberner, D.: 1981, Astron. Astrophys., in press.

Schönberner, D., Weidemann, V.: Physical Processes in Red Giants I. Iben Jr., A. Renzini: Eds. D. Reidel, Dordrecht, pp. 463 - 468

Schulz, H., Wegner, G.: 1981, Astron. Astrophys. 94, 272 - 279

Shipman, H.L., Sass, C.A.: 1980, Astrophys. J. 235, 177 - 185

Sweigart, A.V., Mengel, J.G., Demarque, P.: 1974, Astron. Astrophys. 30, 13 - 19

Taam, R.E., Flannery, B.P., Faulkner, J.: 1980, Astrophys. J. 239, 1017 - 1023

Webbink, R.E.: 1979, IAU Coll. 53, White Dwarfs and Variable Degenerate Stars, H. Van Horn, V. Weidemann Eds. Univ. Rochester, pp. 426 - 447

Wegner, G.: 1979, Astron. J. 84, 1384 - 1394

Wegner, G.: 1981, Astron. J. 86, 264 - 270

Weidemann, V.: 1971, IAU Symp. 42, White Dwarfs, W.J. Luyten Ed. D. Reidel, Dordrecht, pp. 81 - 96

Weidemann, V.: 1975, Problems in Stellar Atmospheres and Envelopes, B. Baschek, W.H. Kegel, G. Traving, Eds. Springer, Berlin, pp. 173 - 203

Weidemann, V.: 1977a, Astron. Astrophys. 59, 411 - 418

Weidemann, V.: 1977b, Astron. Astrophys. 61, L 27 - 30

Weidemann, V.: 1978, IAU Symp. 80, The HR Diagram, A.G.D. Philips, D.S. Hayes, Eds. D. Reidel, Dordrecht, pp. 121 - 124

Weidemann, V.: 1979, IAU Coll. 53, White Dwarfs and Variable Degenerate Stars, H.M. Van Horn, V. Weidemann Eds. Univ. Rochester, pp. 206 - 222

Weidemann, V.: 1981a, Lecture at 4th Europ. Workshop on White Dwarfs, Paris, 1981

Weidemann, V.: 1981b, IAU Coll. 59, Effects of Mass Loss on Stellar Evolution, C. Chiosi, R. Stalio Eds. D. Reidel, Dordrecht, pp. 339 - 344

Wickramasinghe, D.T.: Contributed paper at the 4th Europ. Workshop on White Dwarfs, Paris, 1981

Willson, L.A.: 1981, Physical Processes in Red Giants I. Iben Jr., A. Renzini, Eds. Reidel, Dordrecht, pp. 225 - 230