THE INITIAL/FINAL MASS RELATION FOR STELLAR EVOLUTION WITH MASS LOSS

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The relation between initial and final masses is discussed under consideration of changing theoretical concepts and new empirical data on masses of white dwarfs and nuclei of planetary nebulae. It is concluded that presently adopted schemes of evolution need revision, and that no universal relation exists.

The strongest evidence for large amounts of mass loss during stellar evolution has been provided by the existence of white dwarfs - with masses typically of 0.6 m ($m = M/M_\odot$), much below the galactic turn-off masses - and by the phenomenon of planetary nebula production before a star descends into the white dwarf region.

Knowledge of final masses, m_f , for white dwarfs (WD), or central stars of planetaries (NPN), can thus provide important constraints on theories of mass loss, if the initial masses, m_i , are known. The total mass loss is equally important for models of galactic evolution.

Our view of the m_i/m_f relation has changed considerably during the last decade. According to Paczynski's scheme - which was used widely in models of galactic evolution (Ostriker et al.,1975) - sudden mass ejection by dynamical instability of the red giant envelope caused the m_i/m_f relation to run steeply from m_i=0.8, m_f=0.6 to the critical mass m_f=1.4 at m_i=3.5, with carbon detonation supernovae occuring beyond. When steady mass loss was shown to be important (Reimers,1975) it was incorporated into evolutionary calculations by Fusi-Pecci and Renzini (1976), Mengel (1976), Scalo (1976), resulting in a shift of the critical mass m_f=1.4 towards larger values of m_i,depending on the size of the Reimers scale factor η_R , to typically m_i=5 for η_R=1. These results together with empirical data have been displayed in Fig.1 of my paper on mass loss towards the white dwarf stage (1977). The Hyades position in the m_i/m_f plane was still uncertain, but already then it appeared that the empirical mass losses were higher than those predicted by theory.

In the meantime a full analysis of all observational data for the DA white dwarfs with new model atmospheres (Koester,Schulz,Weidemann,1979) has shown the mass distribution to be extremely narrow, confined to ±0.1m, and also provided Hyades locations which fall into the average WD range.

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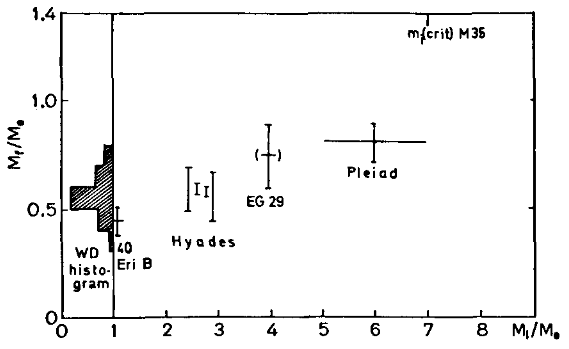

Fig.1. m_i/m_f plane for white dwarfs.

The present situation is displayed in Fig.1. The WD histogram, on the left, and the data on individual WDs are from Koester et al.(1979). The single WD in the Pleiades shows indeed a higher mass, from surface gravity as well as radius (via the mass-radius relation), however m_i is rather uncertain. The Hyad LB 227 (EG 29) may not be a member. Of crucial importance will be spectroscopic confirmation of WD members in open clusters with large turn-off masses. Romanishin and Angel (1980) have provided some first photometric examples, from which they estimate WD production up to $m_i = 7$, certainly above 5. The surprisingly narrow mass distribution is also evident from the HR diagram (Weidemann, 1978, Koester et al.1979) for those WD with well determined parallaxes.

Similarly surprising are recent results for the mass ditribution of NPN. As Schönberner and Weidemann (1981) have demonstrated, the masses of all but 4 of the observed $\sim$70 NPN fall into the extremely narrow interval $0.55 < m_f < 0.64$, the 4 exceptions being very faint, perhaps examples of the short evolution time scales for higher mass NPN (Renzini,1979).

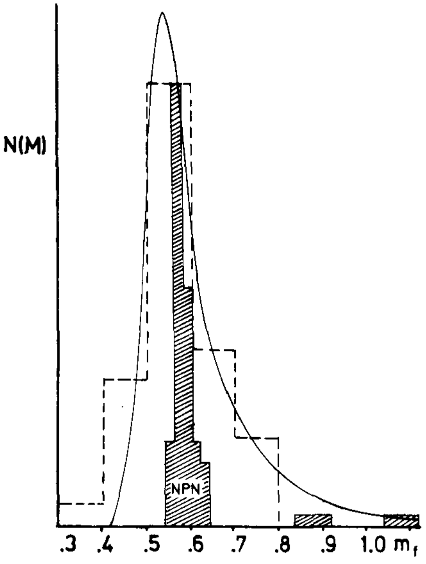

Fig.2. Mass distributions , for WD --- observed, — calculated (text) and for NPN (shaded) (Schönberner and Weidemann, 1981).

Fig.2 presents the derived mass distribution, in comparison with model calculations for galactic evolution by Koester and Weidemann similar to those published (1980) with an improved initial mass function (Miller and Scalo,1979), for a m_i/m_f relation with $\eta_R = 1$, and an exponential decrease of star formation over 10 Gyrs.

Whereas the WD distribution is reproduced fairly well - although recent attempts to confirm higher mass WDs by spectroscopic methods failed (Weidemann,Koester,1980) - the NPN distribution is striking.

If NPN progenitors are covering a range in m_i , as usually assumed, we must conclude that the m_i/m_f-relation runs very flat, at least up to $m_i = 3$.

How should one then extrapolate towards larger m_i ?

Four different possibilities are discussed in Fig.3 :

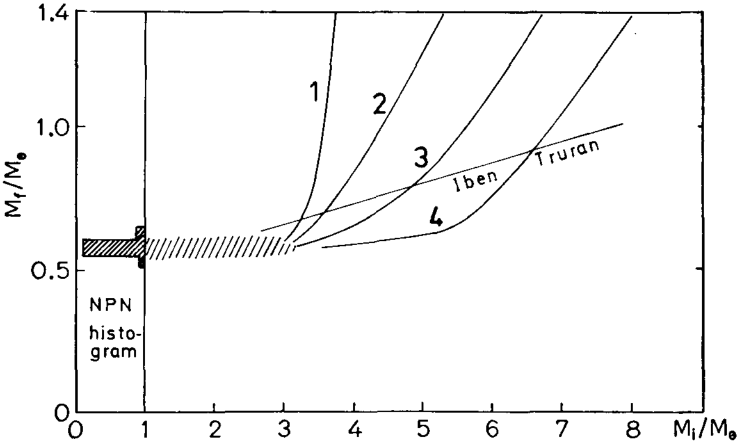

Fig. 3 m_i/m_f relations, with NPN distribution constraint. See text.

(1) vertical turn-up at $m_i = 3$, with SN (supernovae) beyond - a very improbable shape; (2) ending at $m_i = 5$, still difficult, but possible if the resulting PN or NPN are not visible; (3) a more smooth relation with higher steady mass loss rates, η_R larger than 1.4 (the presently favoured value, Kudritzki and Reimers,1978), perhaps no PN ejected or visible; or (4) NPN with $m_f = 0.6$ also for $m_i > 3$ - this would be in serious conflict with established evolution theory, according to which the core masses at the base of the asymptotic giant branch are already larger (thin line in Fig.3, according to Iben and Truran,1978)

Although evolutionary schemes with increased mass loss rates, e.g. due to shock ejection (Tuchman et al.,1979, Barkat and Tuchman, 1980) are somewhat more favorable to smaller m_f than the widely used Mira and PN ejection scheme by Wood and Cahn (1977), they still are not able to explain the narrow mass range and the small value of the average m_f observed. However, Willson (this volume) has revised the evolution scheme in such a way as to obtain strong mass loss during fundamental mode Mira pulsation which - together with the downwards revised Mira luminosities (Feast,1981) - brings forth final masses which fall into exactly the same range of m_f as those derived by Schönberner and Weidemann(1981) for the NPN.

The evolutionary tracks in the mass-luminosity plane, the Mira strip location, and the planetary nebula ejection lines must be correspondingly changed. Since also envelope enrichment appears to occur already for smaller core masses than predicted by evolution theory (Becker and Iben, 1980, Renzini and Voli, 1980)-as demonstrated by the Schönberner/Weidemann results as well as by the low luminosity of C stars (cf. Iben, this volume)-larger revisions seem unavoidable.

Additional parameters, hitherto neglected, like angular momentum and/or magnetic fields, may play a decisive role. Evidence for differential mass loss -e.g. by the horizontal branch or by the existence of population I RR Lyrae stars has been already emphasized (Weidemann, 1977), and "stellar individuality" has been a topic at this Conference.

We therefore do not expect the existence of a single, universal m_i/m_f relation any more. Instead, the m_i/m_f values may fill a wider band - as shown schematically in Fig.4. If so we also have to abandon the concept of a single critical value of m_i and must envisage overlap between the WD and SN production ranges.

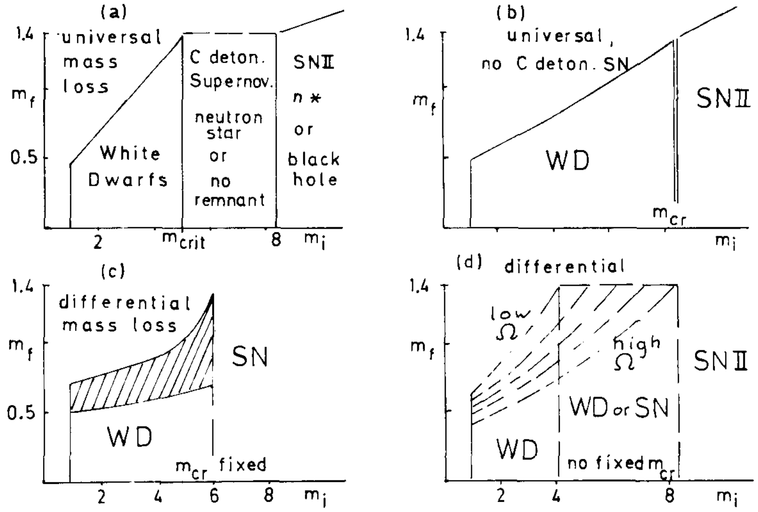

Fig.4 Different possibilities for m_i/m_f relations, schematical:

(a) universal relation, WD production up to fixed value of m_i(crit), range of C detonation SN existing for intermediate mass stars;

(b) universal relation, but WD production up to m_i(crit) ≈ 8-9, where nondegenerate carbon burning occurs, no C detonation SN;

(c) differential mass loss widens m_i/m_f relation, m_i(crit) fixed - improbable, more consistent,

(d) differential mass loss, e.g. determined by angular momentum wide band m_i/m_f relation, no fixed value of m_i(crit) dividing white dwarf and supernova production ranges.

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DISCUSSION

IBEN: Are your distributions of NPN and WD's with regard to N (Mass) consistent? Your WD distribution cuts off at ~ 0.7 $M_\odot$, whereas there are many NPN with $M_{NPN} \sim 1.2\ M_\odot$.

WEIDEMANN: Yes, they are consistent; the NPN distribution appears even narrower. There are only 4 NPN which from their positions in the HR diagram could be more massive than 0.7 $M_\odot$, but these are faint Abell objects and uncertain. The white dwarf distribution might in reality be even narrower due to observational errors, but it seems that it extends down to ~ 0.45 $M_\odot$, whereas the NPN distribution has a lower cut-off at 0.55 $M_\odot$.

DOPITA: The nitrogen enhanced filamentary bipolar P.N.'s studied by Louise Turtle-Webster and myself show high excitation and a preferential distribution towards the galactic plane. There is no visible central star, but evidence for mass loss from a central object abounds. Could these be the high mass P.N. nuclei missing from your observed distribution?

WEIDEMANN: Yes. To make my statement clear: I do not say that the high mass NPN do not exist but that those which are on the observation lists do fall into the narrow mass interval presented.

SERRANO: Indeed in Peimbert & Serrano (1980) PN of Type I (the most massive ones) are 20% of the total number of PN. This has also relation with Renzini's talk. He showed the great difference in the relative momentum of wind and nebulae. There are in fact morphological differences between PN I & PN II, the former being more filamentary and irregular than the latter ones.

WEIDEMANN: I also think that the type I PN might hide some massive NPN. I asked Peimbert about a list of his objects to see how far they fall into our narrow-mass ensemble.

VIOTTI: What of the many schemes of post cool giant evolution you and Renzini were talking about can be applied to the hot subdwarfs? Do you expect that they have a larger mass than PN nuclei?

WEIDEMANN: The nuclei of PN have a narrow mass distribution and I expect the same mass for sdO. My collegues at Kiel are currently working on these stars to derive their masses from spectroscopic data. I think the evolutionary status of the sdO's is not yet clear.

RENZINI: I expect a mass close to 0.6 $M_{\odot}$ again. I strongly suggest astronomers to use the new special techniques with high contrast to try to detect faint nebulae around sdO's.

RENZINI: Why did you not put Sirius B in your diagram?

WEIDEMANN: I think that Sirius A/B has undergone a special binary evolution. It is still debated if there have been phases of mass exchange in the past. In any case, the stars have been much more massive at the beginning, Besides, I cannot plot Sirius B in the M_i/M_f diagram, since it does not belong to a cluster - M_i thus being unknown.

Van der HUCHT: Both Dr. Renzini and you hardly spoke about time scales. Could you inform us about e.g. the lifetime of a Wolf-Rayet type planetary nucleus?

WEIDEMANN: The WR-NPN are found at lower effective temperatures. If the WR-NPN evolve into other special types during evolution - which is not yet clear-they cover about the first four thousand years.