ON THE CONSEQUENCES OF MASS LOSS FROM INTERMEDIATE-MASS STARS[1]

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I. INTRODUCTION

There are two major effects of mass loss from stars of intermediate mass. First, the ultimate fate of such stars--whether they become supernovae of the type that leave no condensed remnant or whether they become white dwarfs--is extremely sensitive to the rate at which they lose mass during the last portion of their nuclear-burning lives. Second, the contribution of intermediate-mass stars to the enrichment of the interstellar medium in helium, carbon, nitrogen, s-process isotopes, and possibly also in iron-peak elements and r-process isotopes is similarly sensitive to mass-loss rates during this last, quiet phase of nuclear burning.

Apart from the T-Tauri phase, during which the star contracts gravitationally onto the main sequence, significant mass loss from intermediate-mass stars is confined almost exclusively to the last, asymptotic giant branch (AGB) phase when the star consists of a highly condensed electron-degenerate core, a very rarified, extended envelope, and two nuclear burning shells located between the core and the envelope. If, as is customary, we normalize all masses to the main-sequence phase, then mass loss during the T-Tauri phase is irrelevant.

In the context of this review, intermediate mass is taken to encompass all stars that achieve and maintain the AGB structure for an extended period. In practice this means stars with an initial main-sequence mass between about $1M_{\odot}$ and about $8M_{\odot}$. Stars initially much less massive than $1M_{\odot}$ become white dwarfs either after the phase of core hydrogen burning or after the phase of core helium burning. Stars more massive than about $8M_{\odot}$ do not develop an electron-degenerate core immediately following core helium burning, but continue to burn successive nuclear fuels at their centers until developing a fuel-exhausted core. Thereupon, the core collapses to a neutron star and the outer envelope is expelled by a shock. We believe that such theoretically calculated events correspond to type II supernovae.

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II. MASS LOSS PRIOR TO THE AGB PHASE

One check on the extent of mass loss prior to the AGB phase is a comparison between estimates of Cepheid masses that are made by two independent means. One method makes use of the period-luminosity-mass-surface temperature relationship given by pulsation theory. The other procedure involves the use of the mass-luminosity-composition relationship given by the theory of stellar evolution without mass loss. Most Cepheids are in the core helium-burning phase immediately after which they become AGB stars. Thus, an estimate of a Cepheid's current mass relative to its main-sequence mass indicates the extent of mass loss prior to the AGB phase. Quite a few papers have been written on this topic (see Cox 1980 for a review) and the current consensus is that, within the uncertainties, most Cepheids have essentially the same masses as their progenitors.

Pulsation theory gives a relationship of the form (e.g., Iben and Tuggle 1975)

$$M_{pulsation} = AL^{\alpha} P^{-\beta} T_e^{-\gamma} \tag{1}$$

where $M_{pulsation}$ = mass, R = radius, P = period, and the constants A, α, β, and γ are obtained from detailed calculations. In rough approximation $\alpha \sim 1.37$, $\beta \sim 1.61$ and $\gamma \sim 5.39$. Evolutionary theory (e.g., Becker, Iben, and Tuggle 1977) gives

$$M_{evolution} \cong B\, L^u , \tag{2}$$

where B is weakly dependent on composition and $u \sim 0.3$, both parameters, of course, being determined by detailed calculations. If a Cepheid is in a complex whose distance can be determined by some independent means (if, for example, it is in the LMC or in Andromeda or in a Galactic open cluster), then L can be estimated and both $M_{evolution}$ (after an estimate of composition) and $M_{pulsation}$ (after obtaining P and estimating T_e) can be determined. The two estimates agree, in most instances, to within 20 percent.

III. MASS LOSS DURING THE AGB PHASE

After helium is exhausted in the stellar core, <u>all</u> stars with an initial main-sequence mass M_{MS} less than a critical mass $M_{crit} \sim 8$-$10\ M_{\odot}$ (the precise value depends on the composition) develop an electron-degenerate core made primarily of carbon and oxygen. At the same time, the envelope of the star expands greatly and the star appears as a red giant (low mass) or supergiant (high mass). We say that the star is on the "second red giant branch" or on the "asymptotic giant branch" (AGB). The intial AGB mass of the core M_c is a strong function of M_{MS}; it increases with M_{MS} and also depends somewhat on the initial composition.

Considerable time is spent in the "pre-thermally pulsing" phase while the core density distribution adjusts to that of a very hot white dwarf of the same mass. During this phase, the star brightens at nearly constant surface temperature, beginning at a luminosity that is quite close to its main-sequence or core helium-burning luminosity and continuing to brighten until

$$L_* \sim 5.9 \times 10^4 \, L_\odot \, (M_c/M_\odot - 0.5) \qquad (3)$$

(Paczynski 1970, Uus 1970), whereupon the star begins to thermally pulse (Schwarzschild and Härm 1965, Weigert 1965).

From then on, the mean luminosity obeys equation (3) as the core mass grows in response to the nearly continuous conversion of hydrogen into helium in one shell and the sporadic conversion of helium into carbon and oxygen in another shell. The helium-burning region is unstable to repeated thermonuclear runaways during which the helium-burning luminosity briefly reaches values as high as $10^7 L_\odot$. None of this energy reaches the surface, but the consequent expansion and cooling of matter in layers immediately above the intensely burning region effectively extinguishes the hydrogen-burning shell for a time and the energy escaping the star is provided by the release of gravitational potential energy from contracting outer layers (e.g., Iben 1975a).

Following a pulse, whose duration is approximately one percent of the duration of the interpulse phase, the hydrogen-burning shell is reignited and the rate, L_{He}, of energy generation by helium-burning reactions drops far below the rate, L_H, of energy generation by hydrogen-burning reactions. In good approximation, $L_H \cong L_*$,as given by equation (3). This allows one to determine the rate at which the core mass grows:

$$\dot{M}_c \cong 6 \times 10^{-7} \, M_\odot yr^{-1} \, (M_c/M_\odot - 0.5) X_H^{-1}, \qquad (4)$$

where X_H = abundance by mass of hydrogen in the stellar envelope.

Mass loss from the star is important to the extent that it occurs at a rate $\dot{M}_*$ that is (in absolute value) comparable to or greater than $\dot{M}_c$ given by equation (4). To first order, the structure of the interior of the star is unaffected by $\dot{M}_*$ unless it is (in absolute value) much larger than $\dot{M}_c$.

Not enough is known observationally about mass loss from AGB stars to be able to construct a fully acceptable quantitative relationship between $\dot{M}_*$ and other stellar parameters. We do know that there seem to be at least two components, a steady or "wind" component that is common to all red giants, and a rapid, or "ejection," component that is confined to a particular phase and effectively terminates the further nuclear-burning evolution of the star.

One frequently-used estimate of the steady component is that devised by Reimers (1975):

$$\dot{M}_* \cong - \alpha\, 3.8 \times 10^{-13} M_\odot \mathrm{yr}^{-1}\, L_* R_* M_*^{-1}, \tag{5}$$

where R_* and M_* are, respectively, stellar radius and mass in solar units, and α is a constant. An expression such as equation (5), useful as it is for permitting an explicit exploration of the consequences of mass loss from AGB stars, cannot at this stage be viewed as anything other than an order of magnitude estimate, even insofar as the dependence on L_*, R_*, and M_* are concerned. From comparisons with the observations, one may infer that, at least for low-mass stars on the red-giant branches, α is on the order of 1/3 (Fusi-Pecci and Renzini 1975a,b; 1976; Renzini 1981, this volume).

Note that, according to equation (5) with $\alpha \sim 1/3$, a typical AGB star with, say, $L_* \sim$ few $\times\ 10^4$, $M_* \sim$ few, $R_* \sim 300 - 1000$, will lose mass at a rate of $\dot{M}_* \sim -$ few $\times\ 10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$. This is quite comparable to the rate at which, according to equation (4), the core mass is increasing when $M_c \gtrsim M_\odot$. Thus, a star in the lower portions of the intermediate-mass range (say, $M_{MS} \lesssim 3\ M_\odot$) might be expected to lose its entire envelope mass before its core reaches the Chandrasekhar limit ($M_* \cong 1.4\ M_\odot$, Chandrasekhar 1931), even if no additional mode of (more rapid) mass loss is invoked.

The ejection component of $\dot{M}_*$ is still under active discussion (see Wood and Cahn 1977; Wood 1981; Willson 1980a, 1981). Willson (1981, this volume) argues from observational properties that, when (and if) an AGB star becomes a Mira variable, the mass-loss rate (for whatever reason) becomes very large (on the order of $10^{-5}\ M_\odot\ \mathrm{yr}^{-1}$) and that the entire envelope of the star is blown off in the course of 10^5 yr or so. Wood and Cahn (1977) achieve consistency between the statistics on Mira variables (number versus period) by assuming that $\dot{M}_*$ is given by equation (5) and that the Mira phase is terminated by the ejection of a planetary nebula when

$$\log\,(L_*/L_\odot) \geq 4.13 + 0.33\,(M_*/M_\odot - 1). \tag{6}$$

This last equation is actually an approximation to the Wood-Cahn prescription that was devised by Iben and Truran (1978).

To first order, and for the purpose of determining the distribution of final stellar states and the contribution of stellar nucleosynthesis to Galactic nucleosynthesis, whether one adopts a finite, but rapid mass-loss rate <u>during</u> the Mira phase or whether one chooses a catastrophic ejection to <u>terminate</u> the Mira phase makes very little difference, certainly at the current exploratory stage. Either choice limits the life of a low-mass star to much less than it would enjoy in the absence of any mass loss at all.

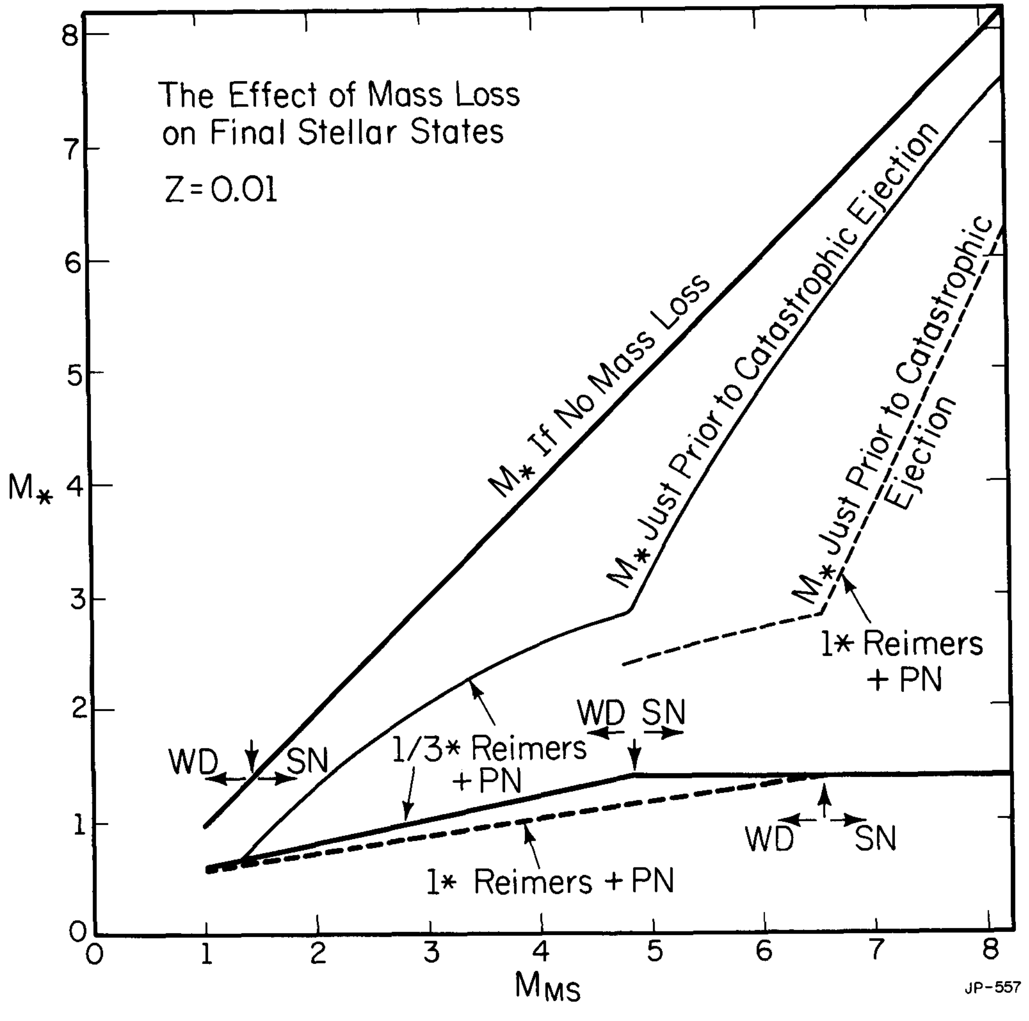
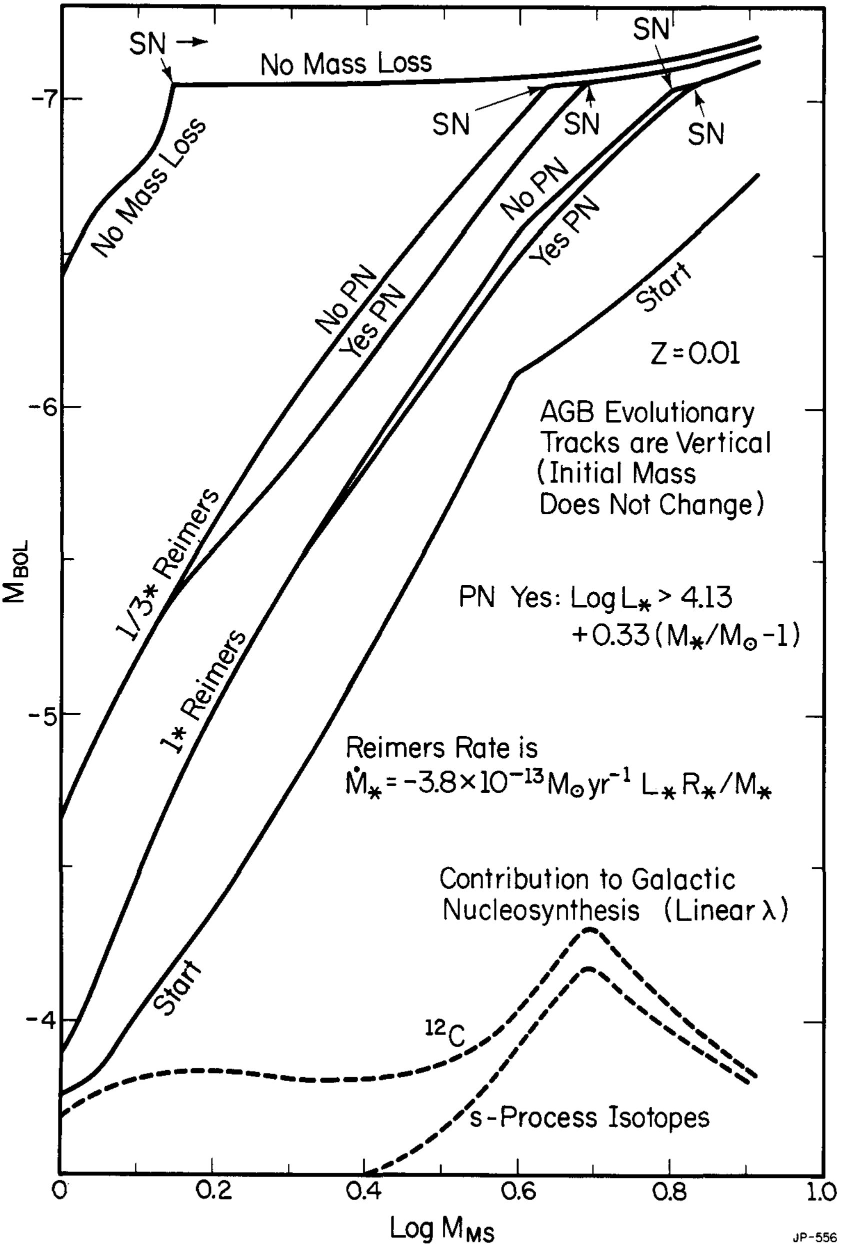


Fig. 1. Stellar mass at the end of AGB evolution as a function of initial main-sequence stellar mass. The 45 degree line results if no mass loss occurs. The two curves consisting of two segments joining in an angle which is acute with respect to the upper left hand corner of the diagram describe the mass of AGB stars just prior to catastrophic ejection. For initial masses to the left of the angles, white dwarfs result and, for initial masses to the right, supernovae result. The mass in the electron-degenerate carbon-oxygen core when ejection occurs is described by the two curves consisting of two segments joining in an angle which is acute with respect to the lower right hand corner of the diagram.

The results of using crude order-of-magnitude estimates such as those given by equations (5) and (6) or similar ones (Fusi-Pecci and Renzini 1976, Renzini and Voli 1980) is shown in Figure 1. In this figure, constructed for composition parameters Z = 0.01, Y = 0.28, the final stellar mass just prior to "catastrophic" (either planetary nebula ejection or supernova explosion) is shown for several cases of mass loss and for the case of no mass loss. If the core mass reaches 1.4 $M_\odot$, a supernova (SN) explosion is assumed, otherwise a white dwarf (WD) remnant is the final result. The results for two choices of α in equation (5) are shown. The mass of the remnant white dwarf that is obtained when equation (6) is not applied is so close to that found when it is applied that the corresponding curves are not shown.

It is clear that mass loss plays a major role in determining the distribution of white dwarfs and the frequency of supernova explosions. With the algorithms chosen, all stars initially less massive than about $5M_\odot$ (when $\alpha = 1/3$) or 6.6 $M_\odot$ (when $\alpha = 1$) will become carbon-oxygen white dwarfs. Stars more massive than these limits but less massive than $\sim 8M_\odot$, will become supernovae of type "I $1/2$". Such supernovae are qualitatively quite different from supernovae of type II, which we believe derive from stars more massive than $8M_\odot$ and leave a neutron star remnant, and somewhat different from supernovae of type I, which we believe derive from accreting white dwarfs that reach the Chandrasekhar mass with an envelope of negligible mass and which leave no condensed remnant. The type I $1/2$ supernovae are expected to leave no condensed remnant, but are expected to show a high degree of variability (from one SN to another) because of the variability (from one SN progenitor to another) in the mass of the envelope above the exploding core.

Had we neglected mass loss, the predicted frequency of type I $1/2$ supernovae would have exceeded that of type II's by a considerable factor. The distribution of thermally pulsing AGB stars in number versus magnitude would also be considerably different from what is observed, had we neglected mass loss. In Figure 2 is shown, as a function of initial mass, the limits between which such stars would have evolved in the absence of mass loss as compared to the limits derived when mass loss is included in the approximation represented by equations (5) and (6). By folding in an estimate of the rate at which stars are born as a function of initial mass and making use of calculated AGB lifetimes (Iben 1980a) one can obtain, in addition, an expected distribution of thermally pulsing AGB stars in the two instances. The results are shown in Figure 3. The peak in the distribution of AGB stars when no mass loss occurs is nearly two full magnitudes brighter than the peak in the distribution when mass loss is taken into account. Furthermore, there are 2.5 times more thermally pulsing AGB stars in the no mass loss case.



SN
No Mass Loss
SN
SN
SN
SN
No Mass Loss
No PN
Yes PN
No PN
Yes PN
Start
Z=0.01
AGB Evolutionary Tracks are Vertical (Initial Mass Does Not Change)
1/3* Reimers
1* Reimers
PN Yes: Log L* > 4.13 +0.33 (M*/M⊙ -1)
Reimers Rate is
Ṁ* = -3.8×10^-13 M⊙ yr^-1 L* R*/M*
Contribution to Galactic Nucleosynthesis (Linear λ)
Start
12C
s-Process Isotopes
MBOL
-7
-6
-5
-4
0
0.2
0.4
0.6
0.8
1.0
Log MMS
JP-556

Fig. 2. Limits in magnitude to the evolution of AGB stars as a function of mass-loss rates. The curve labeled "start" describes, as a function of initial main-sequence mass, the magnitude of AGB stars that have just begun to pulse thermally when Z = 0.01. Final AGB magnitudes are shown for five cases: (1) no mass loss of any kind; (2) and (3), Reimers mass loss rate times 1/3, with and without PN ejection; (4) and (5), full Reimers rate with and without PN ejection. Also shown is the contribution of AGB stars to the enrichment of the interstellar medium in ^{12}C and s-process isotopes when $\dot{M}_* =$ Reimers * 1/3 and planetary nebulae are ejected.

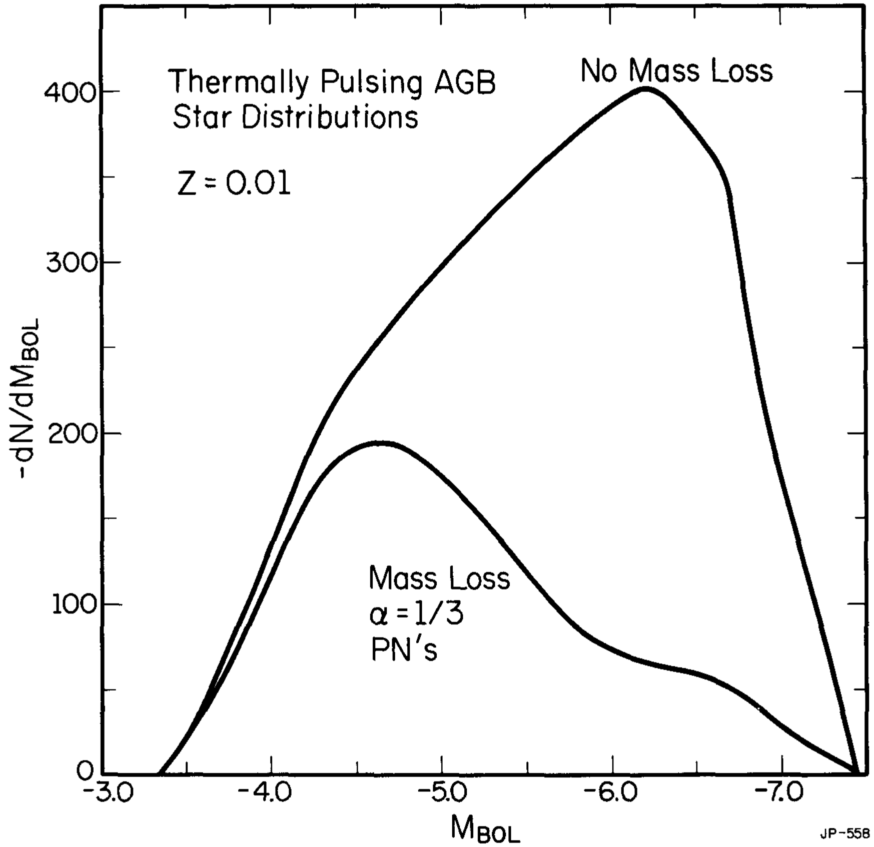


Fig 3. Distribution of thermally pulsing AGB stars in number versus M_{BOL}. In one case, no mass loss of any sort is allowed to occur. In the other, the mass-loss rate is assumed to be one-third of the Reimers rate and the Wood-Cahn prescription for the ejection of a planetary nebula is adopted.

IV. Composition Changes During the AGB Phase

We have demonstrated how mass loss at estimated rates affects the distribution of final stellar states. To show how these rates also strongly influence the contribution of intermediate-mass stars to the element enrichment of the interstellar medium and thus to Galactic nucleosynthesis, it is necessary to digress on the nature of nucleosynthesis in an AGB star.

An AGB star may be thought of as consisting of four parts: core, active shell, envelope, and "surface". Unless and until its mass reaches the Chandrasekhar limit, the core is thermonuclearly inert--it simply grows in mass and shrinks in radius.

The active region experiences relaxation oscillations, as has already been briefly discussed. During the peak of a pulse, a convective shell is formed in the helium-burning region. This shell encompasses most of the matter between the inert core and the location of the hydrogen-helium discontinuity that marks the base of the envelope. A large variety of nuclear transformations takes place in the shell. First, ^{14}N that has been left behind by the advancing hydrogen-burning shell (as a consequence of the conversion of ^{12}C and ^{16}O into ^{14}N) is converted into ^{22}Ne by a succession of alpha captures and beta decays. Second, helium is converted into ^{12}C, with not too much processing further into ^{16}O. Third, when M_c reaches and exceeds about 0.9 - 1.0 $M_\odot$, the reactions

$$^{22}Ne + \alpha \rightarrow {}^{25}Mg + n \qquad (7)$$

$$n + \text{"Fe"} \rightarrow \text{s-process isotopes}$$

take place. The second "reaction" is a shorthand for a long sequence of reactions that converts ^{56}Fe and its progeny into successively more neutron-rich isotopes. The unique feature of the ^{22}Ne source (Iben 1975b), when coupled with the repetitive characteristic of thermal pulses (Ulrich 1973), is that the s-process elements are made in nearly the solar-system distribution (Truran and Iben 1977; Cosner, Iben, and Truran 1980). This is due essentially to two facts: (1) the number of neutron filters represented by ^{25}Mg and its neutron-capture progeny is equal to the number of neutrons produced, with the consequence that the number of neutrons captured by ^{56}Fe and its progeny per original ^{56}Fe nucleus depends to first order only on the average cross section of the light filters and does not depend on either the abundance of the original ^{56}Fe or on the abundance of the filters; (2) the overlap of successive convective shells means that the fraction of matter residing in any given shell that has been exposed to N bursts of neutrons decreases exponentially with the number N (Ulrich 1973). An exponential distribution of exposures is a well known requirement for the production of s-process elements in the solar system distribution (Clayton, Fowler, Hull, and Zimmerman 1961).

Toward the end of a pulse, shell convection dies down, and envelope convection extends into the region containing freshly made ^{12}C and s-process isotopes (e.g., Iben 1974,1975a,1976; Sugimoto and Nomoto 1975). These isotopes are then distributed evenly in abundance throughout the envelope and the surface composition experiences a corresponding change. Note that this ("third") dredge-up enrichment occurs over and over again until either $M_* \rightarrow M_c$ ($< 1.4\ M_\odot$) or $M_c \rightarrow 1.4\ M_\odot$.

Rather convincing evidence for this enrichment process is given by the distribution of carbon stars in two well-studied fields in the Magellanic Clouds (Blanco, McCarthy, and Blanco 1980; Richer 1980; Frogel, Persson, and Cohen 1980). Carbon stars do not appear at luminosities below those expected of thermally pulsing AGB stars; it is therefore natural to infer that some mechanism that operates during the AGB phase is responsible for the excess of carbon at the surface. It also seems clear from a comparison of the carbon star distribution in the Clouds relative to those in the direction of the Galactic center and in the direction away from the center (Blanco, Blanco, and McCarthy 1978) that the degree of dredge-up is a strong function of composition in the sense that the phenomenon occurs at lower masses for smaller metallicity. This is borne out by the extensive calculations of Wood and Zarro (1980) as described by Wood (1980, this volume), although there is not quantitative agreement between observed carbon star distribution and theoretical distributions (Iben 1980a, 1981).

V. THE EFFECT OF THE MASS LOSS RATE ON GALACTIC NUCLEOSYNTHESIS

In Figure 3, the area under the curve labeled ^{12}C is a measure of the rate at which AGB stars contribute to the enrichment of the interstellar medium in ^{12}C if one adopts the simple algorithms: $\dot{M}_*$ = Reimers rate x 1/3 = equation (5) with $\alpha = 1/3$; PN ejection = Wood-Cahn criterion = equation (6); dredge-up as described by equation (9) in Iben (1980a). The details of the measure are given in Iben and Truran (1978). The contribution of AGB stars to the enrichment of s-process isotopes is similarly shown. Thus, for the composition chosen ($Z = 0.01$) and for the particular set of algorithms chosen to describe mass-loss rates and the particular set of parameters in these algorithms, AGB stars contribute roughly twice as much to the enrichment of ^{12}C as they do to the enrichment of s-process isotopes. Had we doubled Z to $Z = 0.02$, leaving all else unchanged, the contribution to s-process isotope enrichment would also have been nearly doubled. Since, however, the higher the metallicity, the smaller is the probability that an AGB star (of small mass) will dredge up enough carbon to become a carbon star, the contribution of AGB stars to the enrichment of s-process isotopes is expected to increase nonlinearly with Z relative to the contribution of such stars to the enrichment of ^{12}C. This is, of course, consistent with the observational evidence suggesting that ^{12}C is a "first generation" product of

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stellar nucleosynthesis whereas s-process isotopes are "second generation" products, requiring the prior synthesis of Fe and the CNO elements for their production.

Had we assumed no mass loss of any kind, the contribution of AGB stars to the enrichment of ^{12}C and s-process isotopes would have been increased over that shown in Figure 3 by, respectively, a factor of 3 and a factor of 5. This is shown explicitly in Figure 4. These enhancements would far exceed the requirements of Galactic nucleosynthesis (see Iben and Truran 1978) and they thereby provide another powerful, though indirect, demonstration that considerable mass loss must take place on the AGB.

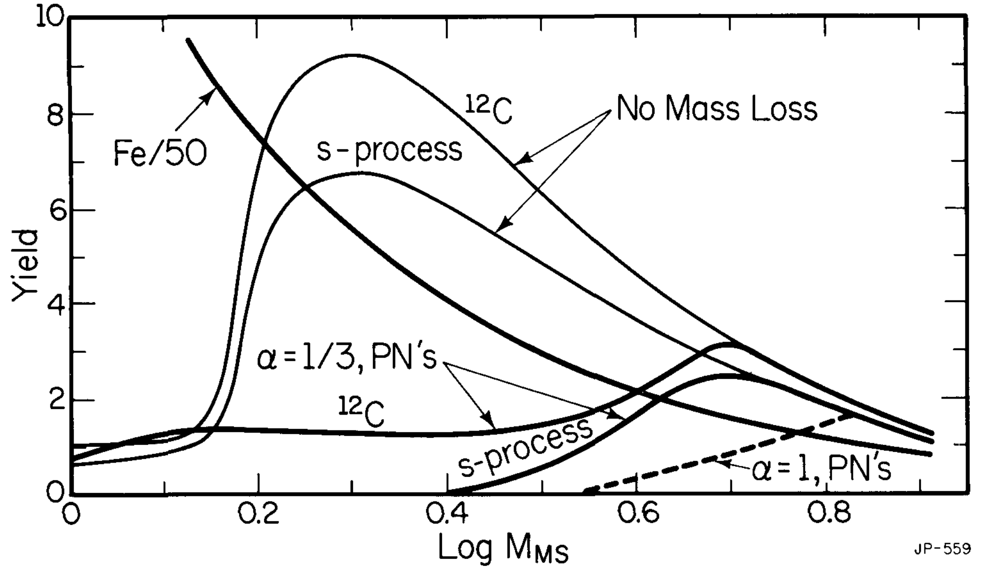

Fig. 4. Contribution of theoretical AGB stars to the enrichment of the interstellar medium in ^{12}C and s-process isotopes in the case of no mass loss (thin solid curves labeled ^{12}C and s) and in the case of mass loss according to the prescriptions described in the caption to Figure 3 (thick solid curves labeled ^{12}C and s). Also shown are the contribution to s-process isotope enrichment when the full Reimers rate is adopted (dashed curve), and the possible contribution (strong deflagration) to the enrichment of iron-peak elements <u>if</u> the star reaches a mass $M_* \cong 1.4\ M_\odot$ (curve labeled Fe/50).

The possible contribution of AGB stars to the enrichment of iron-peak elements may be determined from the exponential curve labeled Fe in Figure 4. This curve has been constructed on the assumption that, once the C-O core mass reaches 1.4 $M_\odot$, a detonation (Arnett 1969) or (more probably) a deflagration (Nomoto, Sugimoto, and Neo 1976) converts most of the matter in the core into iron-peak elements (Arnett, Truran, and Woosley 1971; Bruenn 1972).

Had no mass loss been assumed, all stars initially more massive than ~ 1.4 $M_\odot$ would presumably become supernovae of the detonation or deflagration type and the contribution to the enrichment of Fe would be measured by the area under the Fe curve from log M_{MS} ~ 0.146 to 0.914. This area is approximately 30 times greater than the area under the ^{12}C curve for no mass loss and 40 times the area under the s-process isotope curve for no mass loss. We conclude once again that mass-loss rates must be sufficiently large to prevent most AGB stars from becoming supernovae.

Even if the result of a deflagration is to produce much less than 1.4 $M_\odot$ of iron-peak nuclei, leaving most of the original ^{12}C and ^{16}O in the core intact, we have a strong argument for mass-loss rates on the AGB that are sufficiently large to prevent the majority of such stars from becoming supernovae. For, without mass loss, the predicted enrichment of ^{12}C would be much larger than that given by the area under the ^{12}C curve in Figure 4 for no mass loss (this latter curve assumes no contribution from the C-O core). We have already concluded that this area exceeds the requirements of Galactic nucleosynthesis.

Let us now explore the situation with regard to Fe when we adopt the mass-loss algorithms that lead to the ^{12}C and s-process yields represented by the heavy curves in Figure 4. These choices predict that stars initially more massive than M_{MS} ~ 4.9 persist on the AGB until their core masses reach the Chandrasekhar mass. Their contribution to the enrichment of iron-peak elements should therefore be measured by the area under the iron curve from log M_{MS} ~ 0.69 to the end point, log M_{MS} ~ 0.914. This area is about 9 times greater than the area under the appropriate ^{12}C curve and about 18 times greater than the area under the appropriate s-process isotope curve.

Suppose we leave all else the same, increasing only the rate of the steady component of the mass-loss rate to the full Reimers value. Then, the minimum initial mass for the formation of a SN becomes about 6.6 $M_\odot$. The area under the appropriate segment of the Fe curve is now decreased (by a factor of about 2.5 relative to the case when $\alpha = 1/3$), but the area under the corresponding s-process isotope curve is also reduced (by about the same factor). Thus, increasing the mass-loss rate in order to reduce the yield of Fe peak elements to be consistent with Galactic nucleosynthesis requirements also reduces the yield of s-process isotopes to an unacceptably low value.

One conclusion from all of this may be that cores of AGB stars do not deflagrate when these cores reach the Chandrasekhar mass, but instead implode. In any case, it is clear that: how rapidly mass is lost and when it is lost have a profound effect on the final fate of stars and on their Galacto-nucleosynthetic yields.

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DISCUSSION

DOPITA: Two comments: Firstly, D'Odorico Benvenuti and myself have examined the SN rate in M33 and the LMC from supernova remnants of diameter < 25pc and find similar rates of ~ 1/300 years. This implies (with an assumed initial mass function) a lower mass of 8-10 $M_\odot$ to stars which become supernovae, in good agreement with your figure. Secondly, Puppis A is a good example of a nitrogen enhanced supernova remnant (Dopita, Mathewson and Ford Ap.J. 1977) with N $\gtrsim$10 x solar and enhanced helium.

IBEN: I dont't know what you mean by "agreement with your figure". If you say that the mass of the MS supernova progenitor is 8 - 10 $M_\odot$, this suggests that intermediate mass stars may not form carbon-deflagration SN's and hence may not produce Fe. I do not know what evolutionary models with mass loss and meridional circulation suggest for the composition at the surface of a pre -SN with a massive star ($M > 8$ - 10 $M_\odot$) MS progenitor.

PANAGIA: The supernova you have mentioned in your talk is SN 1979c in in M100 = NGG 4321. This is a type II SN which reached $m_B \sim 12^m$ at maximum in mid-April 1979. The high luminosity allowed us to make a number of IUE observations of the event. (Panagia et al., 1980, MNRAS, 192, in press). Measurements of the UV emission lines reveal that:
1) The shell emitting UV lines is physically detached from the main SN envelope resulting from the explosion. The UV shell is likely to consist of wind material ejected from the progenitor star, possibly a red supergiant. 2) The abundance ratios (by number) we can estimate are N/C ~ 7 (i.e. 30 x solar), O/C < 1 and He/C $\lesssim$ solar. 3) The mass of the UV shell is around 10^{-2} $M_\odot$ and the mass loss needed to produce this shell by stellar wind is around 5 x 10^{-5} $M_\odot$ yr^{-1}.

WOOD: Hyland and McGregor (1980) have made infra-red observations of late-type stars in some of the blue (young) globular clusters in the LMC, and find that these stars extend in luminosity righ up to the theoretical AGB limit of $M_{bol} \sim -7.3$, in contrast to your statement that there appears to be an absence of AGB stars brighter than $M_{bol} \sim -6.5$. In addition, colours of these stars indicate that they are not carbon stars, a result which favours "hot bottom nucleosynthesis" converting dredged-up carbon to nitrogen during the quiescent evolutionary phase.

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IBEN: My statements are based on extremely careful surveys by Blanco, McCarthy, and Blanco in which a concerted effort has been made to be complete. The implications are serious. I have also stated in my talk that the distributions migh be quite different in active regions containing Cepheids. Thus, your presentation of results of new studies of more active regions is welcome. Your statement that what I have said is therefore wrong is not welcome and is incorrect. Whether careful spectral analysis will show the whole sample of stars you mention not to have C/O>1 remains to be seen.

MAEDER: What happens in your scheme with the scenario by Buchler and Mazurek of violent oscillation of the core leading to extreme mass loss at the beginning of the ^{12}C exaustion?

IBEN: Current wisdom is that carbon burning in a degenerate core will lead to a thermal runaway ultimately resulting in a deflagration wave. The net result is total disruption of the star and conversion of a substantial portion of the initial C-O core into iron peak elements.

GOLDBERG: Are the mass loss rates the only uncertain parameter entering into calculations of stellar evolution? For example, what effect do uncertainties in the opacities and other parameters base on the morphology of the HB and AGB?

IBEN: Uncertainties in AGB models of intermediate mass are quite large. They include (a) the treatment of convection, which influences both the extent of nuclear processing in the envelope, but also the location of the star in the H-R diagram and hence the rate of mass loss; (b) opacities when C+N O in the envelope; (c) the degree of dredge-up as a function of core mass, stellar mass, and compositions, (d) many others.

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