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Review Article

STELLAR EVOLUTION AND NUCLEOSYNTHESIS: THE ROLE OF AGB MASS

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A R T I C L E I N F O

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A B S T R A C T

A former paper of me investigated the conditions which are required to get back the abundance of nuclei (Kiss 2014). According to this investigation the required neutron density (10^{10} cm^{-3}-10^{15} cm^{-3}) is available at the asymptotic giant branch (AGB) stars. How much is the AGB contribution, what part of stellar mass goes through the AGB evolution phase? From this what part returns into the interstellar medium (ISM)? Where is the Galactic Fe-60 formed? In this paper these questions are examined. The result is that most stellar matter was or is in AGB stars. The AGB contribution of interstellar medium is greater than the supernovae (SNII) contribution: that is, much more mass goes through AGB stars than core collapsing supernovae.

INTRODUCTION

Based on the analysis of individual abundance (abundance of nuclei), it seems that the m-process with medium neutron density, Kiss (2014) [1], could be an important scene for nucleosynthesis with neutron capture. Here, the m-process starts at $10^{10}\,\mathrm{cm}^{-3}$ neutron density and lasts until the r-process neutron density. It is important to note that there is no s-path, r-path or m-path; formation always occurs in bands Kiss 2010 [2]. It would be better to speak about s-ridge, r-ridge and m-ridge that indicate the place of the greatest formation within the band Kiss 2014 [1]. It would also be expedient to speak about s-band, r-band and m-band. The m-process could basically be identical with the i-process introduced by Cowan in 1977 [3]. Significant investigations can be seen at Malaney 1986 [4]. New investigations are by Lugaro and Karakas 2008 [5] by Dardelet *et al*. 2014 [6] or Hampel *et al* 2016 [7]

Reviewing the mass dependent possibilities of stellar evolution, the question arises how frequent AGB stars are. Three important questions based on this are:

1. Of all the stars, how many undergoes the AGB phase?
2. What mass undergoes the AGB evolution?
3. What mass returns to the ISM?

The first question was mostly answered by Salpeter in 1955 [8]: it is the initial mass function (IMF). It was also investigated by Kruppa (2001) [9]. The latter was taken as a starting point here.

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The second question is easy to answer by means of calculations that are described here. The third question could be answered if we know how much of the initial mass of the AGB star leaves during the gradual mass losses, and how much remains in the final state of the star: in the white dwarf (WD). Information could be gained on this by S. Catalán *et al* 2008 [10]. Based on this, a linear function final mass – initial mass could be fitted for estimates. Against the background of the function, with the help of the IMF, it could be calculated how much mass remains in WD stars and how much enters the ISM.

Stellar evolution and mass

Nucleosynthesis occurs in stars, except the Big Bang nucleosynthesis, so the elements above lithium are formed in the stars. The evolution of stars depends on their initial mass. There is a lower and upper limit for possible star mass. The mass determines the temperature, the possible processes and the life-time. Consequently, the mass determines the possible nucleosynthesis processes. Heavy elements are formed in neutron capture processes. Thus, it is an important question what neutron sources are available at a given evolutional phase of the stars. What is the main place where the bulk of matter is formed by neutron capture nucleosynthesis?

Stellar evolution begins with gravity. The interstellar gas cloud becomes denser, its temperature and pressure increase. The pressure balances the gravity. If the cloud is massive enough, the temperature will be so high that fusion reactions set on and the cloud becomes a star. It is possible only if the mass is greater than a lower mass limit, $M \geq 0.08 M_{Sun}$. Similarly, balance is not possible between pressure and gravity if the star mass is greater than an upper mass limit. The maximum star mass is about $100 M_{Sun}$ [11].

Nuclear fusion processes support the "light", that is the radiation of stars. According to the Hertzsprung–Russell-diagram, most stars belong to the main sequence (MS). These stars release the energy by proton-proton and/or CNO cycles. This depends on the mass. During these processes, helium is formed from four protons. At this state of stars, the burning process occurs in the core of the star. After the star has burnt 10% of hydrogen to helium, it leaves the main sequence and becomes a red giant. The burning of hydrogen at this phase occurs in the shell between the helium in the core and hydrogen in the envelope.

If the mass of the star is greater than the half of Sun mass ($M \geq 0.5 M_{Sun}$), burning occurs in the core helium: the 3α (triple-alpha) is the next nucleosynthesis process. After that phase the helium burning is in the shell. The 3α process is more rapid than hydrogen burning. Each helium burning phase takes place in a shorter timescale. If the mass of the star less than $8M_{Sun,}$ double shell burning occurs. Helium shell burning and hydrogen shell burning occur alternately. The helium burning shell is around the helium core, and the hydrogen burning shell is in the inner side of the hydrogen envelope. This is the AGB phase of stars. Here, slow and intermediate neutron capture processes are possible. In the AGB phase some dredge-ups occur, hence the matter of AGB stars is mixed with freshly synthesized nuclei. During the AGB phase, the stars lose mass and eventually become white dwarf (WD) and planetary nebula (PN). Due to the mass loss of the AGB stars, their remaining mass will be less than $1.4M_{Sun}$; that is the Chandrasekhar mass. Consequently, most mass goes into interstellar medium. The end states of these stars are He or CO white dwarf. It depends on their initial mass. Stars with mass 8-11M_{Sun} become ONeMg white dwarfs. The massive stars evolve more quickly, but the less massive stars are still in the main sequence. The nucleosynthesis by fusion at massive stars ends with silicon burning. This nucleosynthesis leads to the iron at massive stars [11].

If the star mass exceeds $11M_{Sun}$, the star eventually becomes core-collapse supernovae (SNII). Another kind of supernovae (SNIa) is formed in a binary system. In SNII with rapid neutron capture processes nuclei heavier than iron and beyond bismuth are formed. However, between iron and bismuth the nuclei can be formed by neutron capture processes in the stars as well. This is possible if neutron sources are available. As mentioned above, the required conditions are present in AGB or more massive red giant stars. Heavier elements than helium – "metals" are not synthesized during the hydrogen burning phase of stars only from the helium burning state.

Neutron source and mass

Neutron capture nucleosynthesis is only possible if there is neutron source. There are two main neutron producing processes:

$${}^{22}_{10}\mathrm{Ne}(\alpha,n){}^{25}_{12}\mathrm{Mg} \quad \text{and} \quad {}^{13}_{6}\mathrm{C}(\alpha,n){}^{16}_{8}\mathrm{O}$$

The first process occurs in massive helium burning stars and in AGB during thermal pulse (TP), the second occurs in AGB stars at the third dredge-up (TDU) following the TP [12,13].

IMF and calculations

For the sake of the goal, we need the corresponding functions and then it is possible to calculate the AGB mass contributions to the stellar evolution. The IMF is well known, only its continuous form is required for the calculations. After that, we need the final mass - initial mass function for the AGB WD calculation. Finally, against the background of the function, with the help of the IMF, it could be calculated how much mass remains in WD stars and how much enters the ISM.

The distribution of stars by mass

What is the contribution of stars with different mass to the neutron capture nucleosynthesis? One must know how many stars there are with given mass. The answer is given by the initial mass function (IMF) Fig 1. The IMF describes the distribution of stars as per their initial mass in a population of stars. The number of stars between m and $m+\Delta m$ in a given population is given:

$\Delta N = f(m)\cdot\Delta m$, where $f(m) = K\cdot m^{-\alpha}$. The α exponent depends on mass [9]:

$$\alpha = \begin{cases} 0.3; & m < 0{,}08 \\ 1.3; & 0{,}08 \leq m < 0{,}5 \\ 2.35; & 0{,}5 \leq m \end{cases}$$

$$K = \begin{cases} 25\,348; & m < 0{,}08 \\ 2061; & 0{,}08 \leq m < 0{,}5 \\ 1000; & 0{,}5 \leq m \end{cases}$$

These K constants are necessary to the continuous ISM function. Here the Sun mass is used as a mass unit. According to the IMF and the AGB mass range, 30% of stars become AGB stars and less than 1% become supernovae.

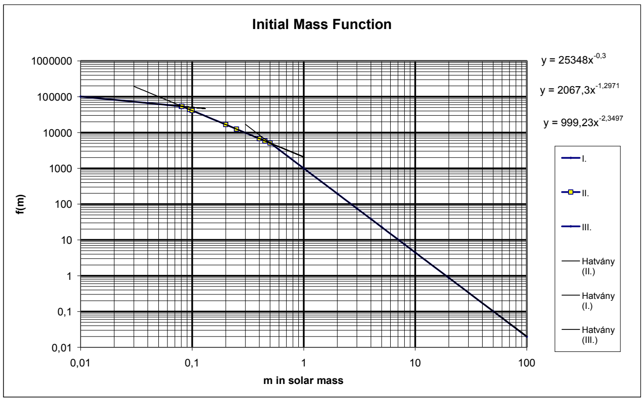

Figure 1 The fitted logarithmic IMF by Kroupa's exponents [9]

The final mass of an AGB star

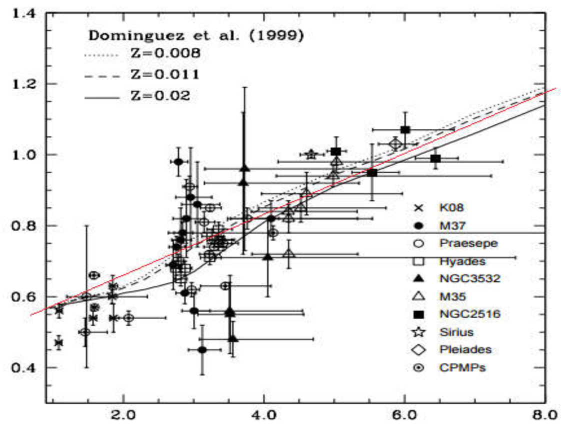

Figure 2 Final masses versus initial masses of the available cluster [10,14] with a linear fit line

The initial-final mass relationship of white dwarfs links the mass of a white dwarf with the mass of a main sequence star which is its progenitor in the main sequence. [10]

For a white dwarf the minimal mass is 0.4 $M_\odot$ and the maximal mass is less than the Chandrasekhar mass (M_{Ch}). The Chandrasekhar mass is $1.4 M_{Sun}$.

There is a semi empirical formula between the initial mass of an AGB star and the final mass of the WD star. For this, the available data are needed to be fitted linearly. (Fig 2). [14]. The result of this fitting is:

$$M(\text{final}) = 0{,}0988 \cdot M(\text{initial}) + 0{,}4087 \cdot M_{Sun} \quad (1)$$

With this formula it is possible to calculate the total mass loss of the AGB star. With this fit the remaining mass are a bit overestimated. There is a better fitting result at Catalan at al. [10].

How much matter (mass) was in an AGB star?

As is mentioned above, the number of stars between m_1 and m_2 can be calculated from IMF:

$$\Delta N = \int_{m_1}^{m_2} f(m)dm = \int_{m_1}^{m_2} K \cdot m^{-\alpha} dm = K\left[\frac{m^{1-\alpha}}{1-\alpha}\right]_{m_1}^{m_2} = \frac{K}{1-\alpha}\left(m_2^{1-\alpha} - m_1^{1-\alpha}\right) \quad (2)$$

It is also possible to calculate how much mass is in stars between m_1 and m_2 mass range. The mass distribution of stars is (Fig 3.):

$$\Delta m = \int_{m_1}^{m_2} m \cdot f(m)dm = \int_{m_1}^{m_2} K \cdot m^{1-\alpha} dm = K\left[\frac{m^{2-\alpha}}{2-\alpha}\right]_{m_1}^{m_2} = \frac{K}{2-\alpha}\left(m_2^{2-\alpha} - m_1^{2-\alpha}\right) \quad (3)$$

And how much mass remains in the WD from the initial AGB star? It can be derived from the final mass- initial mass relation (1).

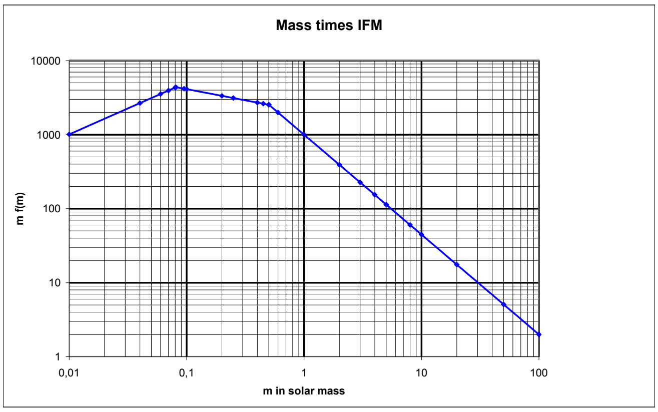

Figure 3 The logarithmic IMF multiplied by the mass

$$\Delta m = \int_{m_1}^{m_2} m_{final} \cdot f(m)dm = K\int_{m_1}^{m_2} (am + b) \cdot m^{-\alpha} dm =$$

$$= K\int_{m_1}^{m_2} a \cdot m \cdot m^{-\alpha} dm + K\int_{m_1}^{m_2} b \cdot m^{-\alpha} dm = Ka\left[\frac{m^{2-\alpha}}{2-\alpha}\right]_{m_1}^{m_2} + K \cdot b\left[\frac{m^{1-\alpha}}{1-\alpha}\right]_{m_1}^{m_2} =$$

$$= \frac{a \cdot K}{2-\alpha}\left(m_2^{2-\alpha} - m_1^{2-\alpha}\right) + \frac{b \cdot K}{1-\alpha}\left(m_2^{1-\alpha} - m_1^{1-\alpha}\right) \quad (4)$$

All calculations are in solar mass as units. The results of these calculations can be seen in Table 1:

Table 1

End state	Mass range	Minimum time (year) on main sequence	The age of universe 1,3E+10Y	Piece percent	Mass percent
Brown Dwarf	0-0,08	1,5E+13		7,33	4,44
He WD	0,08-0,25	5,5E+11	still on main sequence	61,91	13,37
He WD	0,25-0,5	7,4E+10	still on main sequence	28,52	15,20
CO WD	0,5-1	1,0E+10	possible	1,36	17,11
CO WD	1-2	1,3E+09	possible	0,53	13,42
CO WD	2-4	1,8E+08	possible	0,21	10,5
CO WD	4-8	2,5E+07	possible	0,082	8,26
ONeMg WD	8-11	9,8E+06	possible	0,019	3,17
SN II	11-20	1,7E+06	possible	0,019	5,08
SN II	>20	-	possible	0,014	9,41

From the whole initial mass of a star population, during the stellar evolution, 81% were or are in an AGB star. During the elapsed time 52% went through the AGB evolution, and due to the mass loss, 30% mass returned into the ISM. At SNII, out of the initial mass, only 14.5% mass returned to the ISM. From the mass of evolved AGB stars, 58% of the total initial mass returned to ISM and 41% are in the WD stars. Of course SNI contribution is important as well.

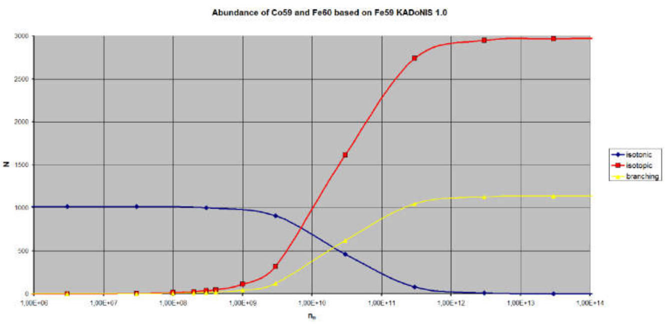

Figure 4 The Co 59 (isotonic channel) and Fe 60 (isotopic channel) abundance at different neutron density [1]

SUMMARY AND CONCLUSIONS

Our investigation shows that our hypothesis deriving from analyzing the individual abundance and rates (Kiss 2014) is possible. Most stars undergo the AGB evolution. At the TP (thermal pulse) state of this, the intermediate $n = 10^{10} - 10^{15}\,cm^{-3}$. neutron density is present, which is typical of the m-process (or i process). Since a significant part of the material (81%) were or are in AGB stars, and 58 % of this returns to the ISM so the AGB stars play an important role in the nucleosynthesis of heavy elements and have important contribution to interstellar medium as well.

The Fe-60 nuclei in higher rate can be formed in intermediate neutron density [1]. The figure 4. (Kiss 2014) shows the possibility of Fe-60's formation in case of different neutron densities. It could be clearly seen that the opening of this channel at $n = 10^{10}\,cm^{-3}$ neutron density is rather significant. It can be found in the article referred to what is worth considering an opening from rate standpoint. The AGB contribution to the Fe-60 synthesis based on this examination is probably very significant. The Fe-60 is very important as it is the fifth nuclei in the order of neutron capture formation of nuclei from Fe-56 Kiss 2017 [15].

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. M. Kiss: Rate Analysis or a Possible Interpretation of Abundances in Proceedings of XIII Nuclei in the Cosmos (NIC XIII), 7-11 July 2014. Debrecen Hungary, On line at https://pos.sissa.it/204/110/pdf arXiv: 1502.03763 [nucl-ex]
2. Miklós Kiss and Zoltán Trócsányi, A unified model for nucleosynthesis of heavy elements in stars, 2010 IOP Publishing Ltd *Journal of Physics:* Conference Series, Volume 202, Number 1 arXiv: 1712.00568 [astro-ph.SR]
3. J. J. Cowan and W. K. Rose: PRODUCTION OF 14C AND NEUTRONS IN RED GIANTS, The *Astrophysical Journal*, 212:149-158, 1977 February 15
4. R. A. Malaney, Heavy -element synthesis in AGB and post-AGB stars of low mass, Mon. Not. R. astr. Soc. (1986) 223, 709-725
5. M. Lugaro, A. I. Karakas Sara Bisterzo Models and observations of the s process in AGB, PoS(NICX)034, 2008
6. Dardelet L, Ritter C, Prado P, Heringer E, Higgs C, Sandalski S, Jones S, Denissenkov P, Venn K, Bertolli M, Pignatari M, Woodward P and Herwig F 2014 in `Proceedings of XIII Nuclei in the Cosmos (NIC XIII). 7-11 July, 2014. Debrecen, Hungary. Online at https://pos.sissa.it/204/145/pdf p. 145. arXiv: 1505. 05500v2 [astro-ph.SR].
7. Melanie Hampel *et al* 2016 ApJ 831 171
8. E. Salpeter, *Astrophysical Journal*, vol. 121, p.161; 01/1955
9. P. Kroupa, Mon. Not. R. Astron. Soc. 322, 231±246 (2001)
10. S. Catalán *et al*, The initial-final mass relationship of white dwarfs revisited: effect on the luminosity function and mass distribution Monthly Notices of the Royal Astronomical Society, Volume 387, Issue 4, 11 July 2008, Pages 1693-1706, https://doi.org/10.1111/j.1365-2966.2008.13356.x
11. S. G. Ryan, A. J. Norton: Stellar Evolution and Nucleosynthesis, Cambridge University Press 2010.
12. H. J. Habing, H. Olofsson: Asymptotic Giant Branch Stars, Springer, 2004
13. Armanda. I. Karakas: Nucleosynthesis of Low and Intermediate-mass Stars, A. Goswami and B.E. Reddy (eds.), Principles and Perspectives in Cosmochemistry, Astrophysics and Space Science Proceedings, DOI 10.1007/978-3-642-10352-0 2, Springer-Verlag Berlin Heidelberg 2010
14. Dominguez *et al*, ApJ, 524, 226, 1999
15. Miklós Kiss (2017) 'Nucleosynthesis Step By Step', *International Journal of Current Advanced Research*, 06(12), pp. 8001-8005. DOI: http://dx. doi.org/ 10.24327/ijcar.2017.8005.1270

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