The Effect of Metallicity on the AGB Stars Evolution by Using Synthetic Model

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Abstract

Stars whose initial masses are between (0.89 - 8.0) $M_\odot$ go through an Asymptotic Giant Branch (AGB) phase at the end of their life. Which have been evolved from the main sequence phase through Asymptotic Giant Branch (AGB). The calculations were done by adopted Synthetic Model showed the following results: 1- Mass loss on the AGB phase consists of two phases for period (P <500) days and for (P>500) days; 2- the mass loss rate exponentially increases with the pulsation periods; 3- The expansion velocity V_{AGB} for our stars are calculated according to the three assumptions; 4- the terminal velocity depends on several factors likes metallicity and luminosity. The calculations indicated that a super wind phase (S.W) developed on the AGB phases, operates only during the latter part of the quiescent phase. The results indicate that the time scale of mass loss depends on the metallicitiy of stars and mass core.

Keyword. Stars: Evolution stars- AGB & Post AGB stars, interstellar structure, circumstellar matter, expansion velocity

تأثير المعدنية على نشوء نجوم طور التقارب العملاق باستعمال النموذج التركيبي

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الخلاصة

النجوم ذات الكتل الابتدائية (0.89–8) كتلة شمسية تنشا خلال مراحل طور التقارب العملاق (AGB) في نهاية حياتها, حيث تنشا من طور التتابع الرئيسي مرورا بطور ال AGB. الحسابات أجريت باعتماد النموذج التركيبي وأعطت النتائج التالية: 1- إن الخسارة بالكتلة خلال AGB تتألف من مرحلتين وهما ل P<500 و P>500 يوم, 2-الخسارة بالكتلة تزيد مع فترة الخسارة بالنبضة, 3- سرعة تمدد نجوم ال AGB حسبت وفقا إلى ثلاثة افتراضات,4- سرعة التمدد تعتمد على بعض التأثيرات مثل المعدنية واللمعانية . النتائج أوضحت أيضا إن مرحلة سرعة تمدد الرياح الفائق(S.W) تعمل وتسيطر خلال الجزء الأخير من مرحلة نشوء النجم, وبينت النتائج أيضا ان زمن الخسارة بالكتلة يعتمد على المعدنية للنجوم وكتلة لب النجم.

Introduction

Asymptotic giant branch (AGB) stars are low- to intermediate-mass between 0.89$M_\odot$ and 8.0$M_\odot$) stars that have reached the last stages of their lives as stars [1]. As stars ascend along the AGB, it appears that they begin to pulsate when their effective temperatures drop below a certain level and the luminosities increase to a certain value [2]. When the amplitude tends to increase with decreasing temperature and appreciable periodicity for stars in a high radial overtone drops gradually into a lower overtone, the stars approach the Mira stage. At the top of the AGB, Mira variables (Miras) have carbon cores, surrounded by helium-rich layers, which in turn are surrounded by hydrogen-rich envelopes, and they are the coolest and the most luminous AGB stars. Mass loss is of very great importance for the final phases of stellar evolution.

Stars with initial mass up to 8 $M_\odot$ seem to loose so much mass during their red giant phase that they end up as white dwarfs mostly within a narrow mass rang of between (0.89- 0.8)$M_\odot$, [3]. Planetary Nebulae (PN) are the most evident indicators for previously acting or still continuing stellar winds. Already Shklovisky (1956) suggested a qualitative picture for the formation and expansion of PN: a pre-nebular envelop is formed by the separation of the extended envelope of a red super giant, the expanding gaseous shell then will be ionized by the remaining hot stellar core and a PN will become more and more visible, [4]. Physical description emerged only during recent years; a fast very tenuous stellar wind interacts with much denser and slower matter that has been expelled before at the tip of AGB stara, [5]. The stellar evolution as well as involved much physical process (stellar winds gas dynamical and kinematics) as shown in Fig. (1). Synthetic model represents the basic model to determine the evolution of PN by describes the means of reasonable and necessary factors including:

1-Mass loss rate and terminal velocity of AGB phase (super and slow wind).

2- The luminosity for period before and after super wind.

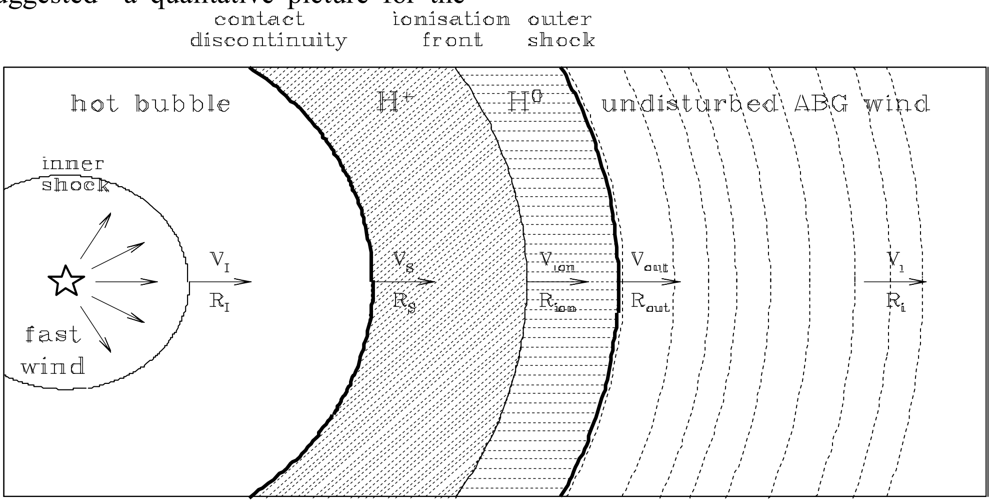

Figure 1- The Processes Which Flows As Core Star Formation, According To Synthetic Model [6].

Model Details

The aim of this paper is the determination of the physical processes that effect on the evolution of the AGB stars, these processes includes mass loss and expansion velocity. The programming results and figures were performed by using Matlab package.

The AGB phase is described by detailed Synthetic model covering the evolution of low and intermediate mass stars from the first thermal pulse up to complete ejection of the envelope, [6]. From synthetic model the mass of the central star (Mc) as a function of initial mass (Mi) was derived with metallicity (Z) of progenitor.

Mass loss on the AGB is included according to the formalism developed by Vassillades and Wood (VW93), which combines observations of variables AGB star with standard predictions of pulsation theory, [7]. In complementary model, synthetic model it is convenient to sketch general scheme of several different processes which is considered:

1–Start with detailed Synthetic model of AGB stars for varying initial masses (0.89- 7.0 $M_\odot$) and various values for metallicity (Z).

2-The central star peeled off of its envelope, is assumed to evolve along the AGB track determined by its initial mass at different values (Z).

3-Most of the stellar envelope is ejected during the last super wind stages.

4-We attribute proper expulsion velocities to the AGB ejecta and follow their expansion during all the subsequent evolution.

The time scale of mass loss is considered with the effect of nuclear burning rate for the core masses which adopted.

Simple equation was found to correlate the effect of metallicity on the time scale of mass loss. At first the Velocity during AGB phase were be studied, then the effect of the metallicity results on time scale of mass loss will be indicated.

a-The Maximum Velocity

Several factors affect the expansion velocity of AGB wind (V_{AGB}). Observational of long variable stars indicate that V_{AGB} may range over a relativity large range from 8-30 km/s, with typical mean values of 14-15 km/s for galactic variables [8], and possibly lower for variables belonging to more metal poor galaxies (Large Magellan Clouds LMC).

On the basis of all these a aforementioned elements, some prescriptions were be adopted for $V_{AGB,}$ namely:

1- V_{AGB}= constant, say 15 km/s regardless of any other parameters.

2-V_{AGB} =f (Z) =6.5(Z/0.008) +0.0022P ---- (1)

Where: P is the period of pulsation for AGB stars. Which includes a metallicity dependences according to an empirical calibration based on (RV variables of the Galaxy and Large Magellanic Cloud) [9]. Such prescription has been employed in the AGB Synthetic calculations adopted here. For typical values of P>500-2000 days we get V_{AGB}~8-11 km/s for Z=0.008, and V_{AGB}~14-17 km/s for Z= 0.016, V_{AGB}~17-20 km/s for Z=0.02.

Fig.(2) and Table (1) express this relation with three values of metallicites, this figure shows that as metallicity decrease the luminosity of star will be increases that is due to as opacity decreases the star is able to radiate away its energy with greater efficiency, the stellar luminosity is therefore increase.

3- V_{AGB}= f (L) =A (log (L)) ^{2}+B (log (L)) +C----------- (2)

Which include luminosity (L) dependence according to the results of super wind calculations, [10]. For dust driven wind the fitting coefficients A=-16.7282; B=164.1858; C=-366.0314. In order to specify V_{AGB} in Synthetic model, it may be reasonable to keep the relative trend with stellar luminosity as predicted by Kruger, and scale it by a proper multiplicative factor. Fig (3), Represents the relation between V_{exp} (V_{AGB}) and luminosity (L) of stars.

For different values of metallicity (Z) and initial masses from 0.89 $M_\odot$, -3 $M_\odot$, the values of expansion velocity taken from Table (2).

Table 1- Represents The Values Of Expansion Velocity Related To Three Values Of Metalicity(Z) During Super Wind Phase P>500.

P(day)	V_{AGB}(Z=0.008)Km/s	V_{AGB}(Z=0.016)Km/s	V_{AGB}(Z=0.02)Km/s
600	7.856	14.356	17.6
700	8.08	14.58	17.8
800	8.308	14.8	18.05
900	8.534	15	18.28
1000	8.75	15.2	18.51
1100	8.98	15.4	18.73
1200	9.210	15.7	18.96
1300	9.450	15.9	19.18
1400	9.664	16.16	19.414
1500	9.890	16.39	19.64
1600	10.116	16.61	19.866
1700	10.342	16.84	20.092
1800	10.568	17.06	20.318
1900	10.79	17.294	20.054
2000	11.02	17.5	20.07

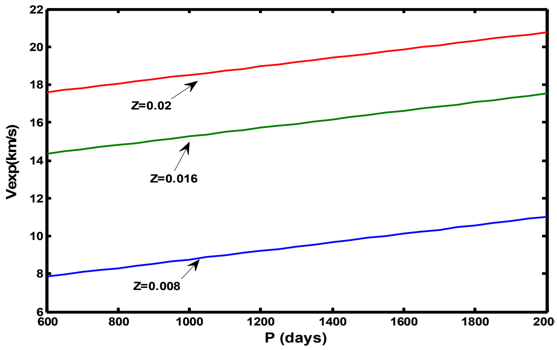

Figure 2-The Relation Between V_{AGB} And Pulsation Period For Three Values Of Metalicities Z.

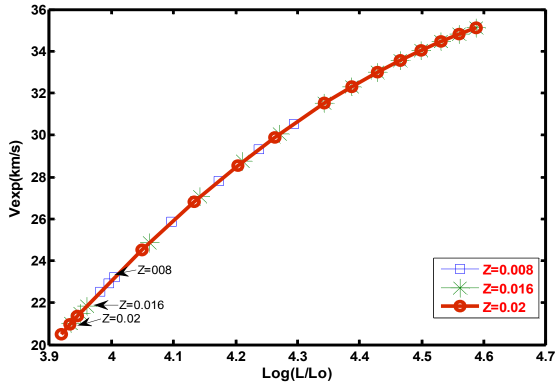

Figure 3-The Relation Between Expansion Velocity V_{AGB} In (Km/S) And Luminosity (L/L⊙) At Different Metallicities (Z) Values. For Initial Masses (0.89-3) M⊙.

Table 2- Represents The Relation Between Luminosity (L/L⊙) And Expansion Velocity At Different Values Of Metallicity(Z)

M_i / M⊙	**Mc/ M⊙**			**log(L/L⊙)**			**V_{AGB} (km/s)**		
	Z1	**Z2**	**Z3**	**Z1**	**Z2**	**Z3**	**Z1**	**Z2**	**Z3**
	0.008	**0.016**	**0.02**	**0.008**	**0.016**	**0.02**	**0.008**	**0.016**	**0.02**
0.89	0.669	0.651	0.646	3.982	3.923	3.910	22.50	20.40	19.66
0.95	0.674	0.656	0.651	3.993	3.949	3.933	22.90	21.42	20.85
1	0.678	0.661	0.655	4.005	3.960	3.945	23.20	21.82	21.17
2	0.762	0.745	0.739	4.172	4.142	4.132	27.78	27.80	26.72
3	0.846	0.829	0.823	4.293	4.270	4.263	30.51	30.21	30.32
4	0.930	0.913	0.907	4.387	4.369	4.363	32.30	32.18	31.87
5	1.014	0.997	0.991	4.465	4.449	4.440	33.56	33.52	33.18
6	1.098	1.081	1.075	4.530	4.517	4.513	34.45	34.49	34.23
7	1.188	1.165	1.159	4.587	4.576	4.572	35.51	35.10	35.06

b- Mass Loss along AGB Phase

In brief mass – loss during the AGB consist of two phases. Initially for P<500 days, the mass loss rate are exponentially increase with pulsation period P, [4]:

$$\log \overset{*}{M} = -11.4+0.0124P \text{ --------------- } (3)$$

Where: $\overset{*}{M}$ is the mass loss from stars before super wind , in (M⊙yr^{-1}) unit.

P is the pulsation period

For longer periods it attains and maintains nearly constant values, typical of the super wind regimes (P>500).

$$\overset{*}{M} = 6.0723\times10^{-3}\times B\times(L/cV_{AGB}) \text{ ------- } (4)$$

Where:

L is the luminosity of AGB star; c is the velocity of light (3×10^8 m/s)

B=1.13(Z/0.008),[9]. In table (3) the values of mass loss before super wind is calculated by dependence on pulsation period (P<500 days). Fig. (4) represents the relation between period P and mass loss before and after super wind for different masses mass like (M_i=(0.89-7 M⊙), this figure indicated that mass loss is linearly increasing before super wind(P<500 days) while it attains and nearly constant typical values for super wind (P>500days). In equation (4) $\overset{*}{M}$ is given in (M⊙yr^{-1}) unit, the stellar luminosity L is expressed in $L_\odot$, and the pulsation period P in days [6,11]. The values of mass loss after super wind and during radiation pressure were indicated in table (4), these results showed that the mass loss get more and more as the star climb AGB phase in a good agreements with the results by Marigo (2003) were mass loss calculated for one mass (5 $M_\odot$) while the present work were be done for different values of masses for stars (0.89-7 $M_\odot$).

The wind expansions velocity V_{AGB} in (km/s) is calculated as a function of pulsation period, [6].

V_{AGB}= -13.5 +0.056 P ------------- (5)

Table (3) represents the values of expansion velocity related to periods (P) before super wind phase, and mass loss. Fig. (5) Represents the relation between mass core (M_c) with luminosity (L) for different initial values of mass (M_i) at metallicity values ($Z=10^{-3}$-0.05). In VW93, the mass of central star (M_C) is assumed to be evolve along AGB track, the relation between initial mass and mass core (M_C) can be define as [11]:

$M_c/M_\odot=0.473+0.084(M_i/M_\odot)-0.058\text{Log}(Z))$ ------------- (6)

Where: M_C is the mass core of the star; M_i = initial mass of adopted stars; Z is the metallicity of the star.

The relation between mass core of star and luminosity can be defining along horizontal part of evolution track [6] :

$L/L_\odot= 56694(M_c/M_\odot -0.5)$ ------------- (7)

The behavior of the wind velocity from AGB through to the PN phase can be determined the radiation pressure driven mass lose limit which corresponds to the situation where all the momentum of stellar radiation field is transferred to a wind (Kwok, 2005):

$$\dot{M}_{\lim} = \frac{L}{cv} \quad \text{------------ (8)}$$

Where v is the terminal velocity beyond the AGB phase

The transition from the AGB to the PN phase involves a change from slow dense wind to a fast wind; mass loss is a crucial factor controlling timescales beyond the AGB. Many estimates of mass-loss rates have been made in the AGB and PN phases, in adaptive model the mass loss formula had been used involving the terminal stellar wind velocity, which is moderately well known across the H-R diagram. The calculations showed that mass loss rate for the preceding AGB phase of evolution such that $\dot{M} \le \dot{M}_{\lim}$. Fig.(5) showed the mass loss during the two phases Post-AGB phase and PN phase. The calculations span a range in metallicity from solar through to values suitable for studies of the Magellanic Clouds. The He burning PN population appears to be more significant, particularly at large core masses, in the Magellanic Clouds than in the galaxy. The values of mass loss for period <500 can be estimated in Table (3).

Table 3- Represents the relation between period and mass loss before super wind

P(days)	$\log(\overset{*}{M})$	**V_{AGB}(km/s)**
200	-9.1	0.5
250	-8.9	3.3
300	-7.71	16.
350	-7.094	8.9
400	-6.48	14.5
450	-5.86	14.8
500	-5.25	15.055

Table 4-The mass loss limit and mass loss during super wind and expansion velocity (V_{AGB} (L)) (according to eq.(2)) for masses (0.89-7 M⊙) at different metallicity(Z)

Mc	V_{AGB} (km/s)			$\log(\dot{M})$			$\log(\dot{M}_{lim})$		
	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3
	0.008	0.016	0.02	0.008	0.016	0.02	0.008	0.016	0.02
0.89	22.50	20.40	19.66	-5.063	-5.073	-5.077	-3.860	-3.856	-3.885
0.95	22.90	21.42	20.85	-5.056	-5.068	-5.085	-3.840	-3.852	-3.868
1	23.20	21.82	21.17	-5.053	-5.065	-5.081	-3.830	-3.850	-3.864
2	27.78	27.80	26.72	-4.963	-4.983	-4.989	-3.762	-3.763	-3.757
3	30.51	30.21	30.32	-4.945	-4.900	-4.906	-3.661	-3.647	-3.680
4	32.30	32.18	31.87	-4.810	-4.829	-4.833	-3.590	-3.582	-3.615
5	33.56	33.52	33.18	-4.754	-4.767	-4.769	-3.534	-3.495	-3.552
6	34.45	34.49	34.23	-4.703	-4.712	-4.712	-3.500	-3.491	-3.495
7	35.51	35.10	35.06	-4.651	-4.658	-4.666	-3.431	-3.441	-3.449

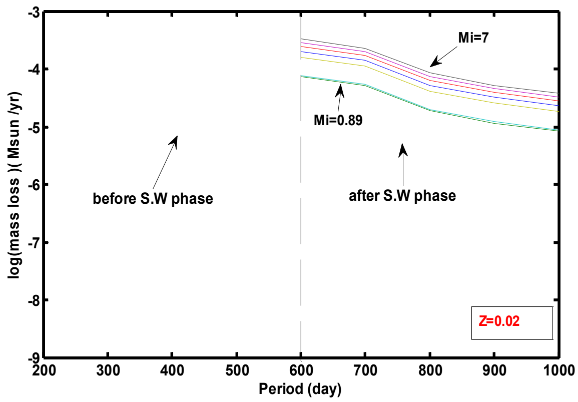

Figure 4-The relation between mass loss and expansion velocity (V_{AGB}) before and after super wind for solar metallicity. Mass loss rate plotted against period for Galactic Mira variables of spectral type M(O rich stars) and C(C rich stars), and for pulsating OH/IR stars in the Galaxy.

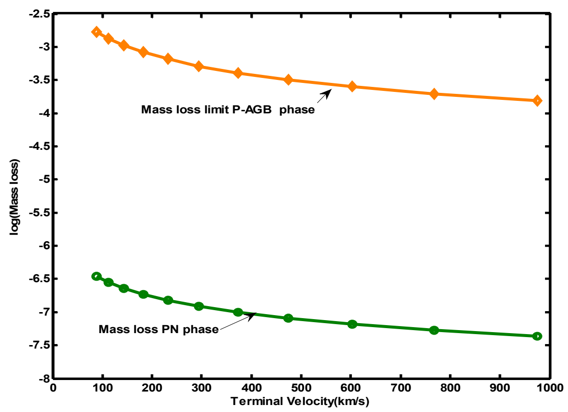

Figure 5-Mass loss as a function of terminal velocity during two phases: Post-AGB and PN phases.

c- The Effect of Metallicity on Stellar Evolution

The effect of metallicity on stellar evolution is illustrated by series calculation for a model of solar mass and metalicity (Z) with He aboundance(Y) values of 0.0001,0.24), (0.001,0.24), (0.018,0.29), (0.05,0.30) and (0.1,0.30) other physical parameter remaining fixed. From Fig.(6) we note that an increase in metalicity has similar effect to decrease in initial stellar mass (0.89-7 M⊙) are lower and durations of evolutionary phase are longer. For example, the (main squances) MS phase lasts up to over 3 times longer, when Z increases. This result is mostly the consequence of the dependence of opacity on composition at lower metalicity, the opacity decreases, the star is able to radiate away its energy with greater efficiency, the stellar luminosity is therefore higher and time scales are corresponding shorter. The core mass thus grows all the time and because the luminosity is proportional to the core mass, the luminosity increase as well this growth is exponential with a time scale for stars of all masses, $t_{nuc} = 10^6$ yr. In other word the evolution of star depends on two main factors: 1- mass loss 2- growing core.

The time scale of mass loss for the crossing of the H-R diagram (t_{ml}) is determined by the total amount of available fuel and the fuel consumption rate (nuclear burning rate [3].

$$t_{ml} = \frac{M_C}{\dot{M}_C} \qquad \text{---------- (9)}$$

Where M_C is the mass core of the stars in the range (0.6 -1.37) M⊙; $\dot{M}_C$ is the nuclear burning rate. M_C is determined by the equation (6) while mass loss burning core is givin by:

$$\dot{M}_C = 3\times10^{-7}(M_C - 0.44) \qquad \text{------------- (10)}$$

The time scale of mass loss is very strong function of core mass [12].

The relation between time scale of mass loss and effect the metallicity can be considered as shown in Figs.(7&8&9). By using mean of times and standard deviations can be correlate the effect of Z with the time of mass loss corresponding to mass core of star in general equation. This equation was estimated with fitting line as shown in Fig.(8). At each value of metallicity can be concluded there are two regions as shown in Fig.(9):

A-Represents the regions which limit the effect of mettallicity for example at Z=0.0001 the time of mass loss will be in the range ((5-8.5) × $10^{6)}$ yr for different masses core, while the time of mass loss for Z=0.05 may be in range ((5-11) × 10^6) yr.

F-Represents the forbidden region for the effect of mettalicity on the time of mass loss .The body of observational and theoretical information allows us to establish empirical relations according to which the mass loss rates are seen to decrease with the metallicity on the basis on could perhaps argue that as long as the surface layer keep the original composition, mass loss can not occur.

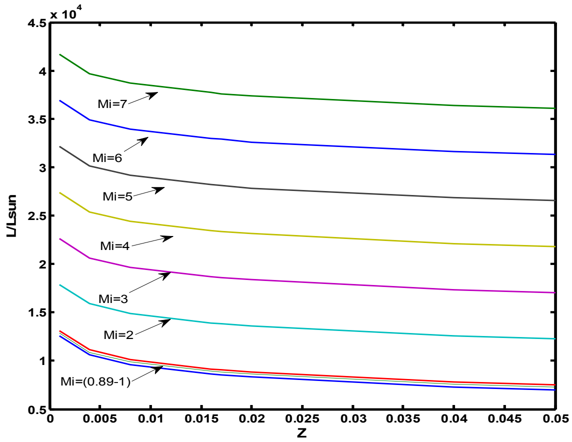

Figure 6-Represents the relation between Metallicity and luminosity for different initial mass (Mi).

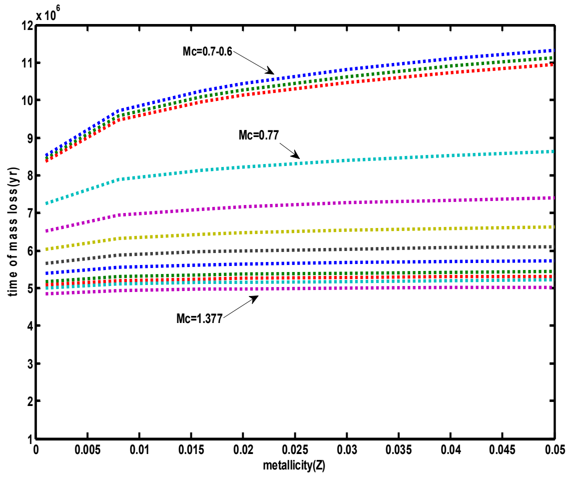

Figure 7-Mass loss time scale as a function of metallicity with different values of mass core.

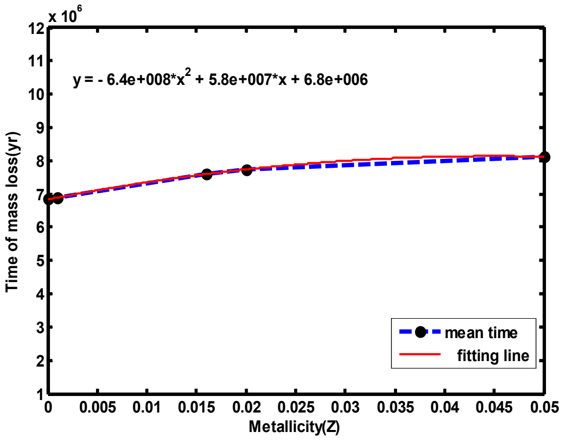

Figure 8- Represents time scale of mass loss as a function of metallicity with the Fitting line equation of mean times was drawn.

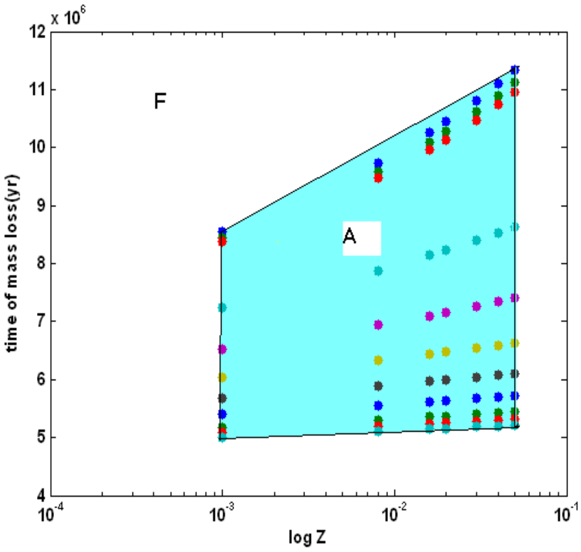

Figure 9-Represents the two regions that indicate the effect of metallicity A: allowed region F: forbidden region with no effect on time scale of mass loss.

Conclusions:

The following conclusions can be estimated**:**

1- According to adopted prescription, mass loss gets more and more efficient as the star climbs the AGB phase.

2- The most of the stellar envelope ejected during the last 'super wind' stages. The expansion velocity increase exponentially as pulsation periods increase.

3-At fix metallicity V_{AGB} is almost constant, due to the week dependence on the pulsation period.

4- In synthetic model mass loss rate was constrained for the preceding AGB phase of evolution such that $\overset{*}{M} < \overset{*}{M}_{\text{lim}}$.

5- The results show that the mass loss along AGB phase about (10^{-6} -10^{-5}) $M_{\odot} yr^{-1}$, while mass loss limit (10^{-4} $M_{\odot} yr^{-1}$) at super wind phase.

6-As shell expands, it continuously accretes matter from the circumstellar layer, ejected at earlier ages and with lower velocities during AGB phase.

7- The scale time of mass loss is a strong function of metallicity. If mass loss exceeds 10^{-6} $M_{\odot} yr^{-1}$ for low mass star, in this case the star will be expelled outer envelope faster that its core can grow until bleed to death.

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