THE EVOLUTION OF PLANETARY NEBULAE(PN) AND FADING TIME ACCORDING TO SYNTHETIC MODEL

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Abstract

Planetary nebulae (PN) represents the short phase in the life of stars with masses (0.89-7) $M_\odot$. Several physical processes taking place during the red giant phase of low and intermediates-mass stars. These processes include :1) The regular (early) wind and the envelope ejection, 2) The thermal pulses during Asymptotic Giant Branch (AGB) phase. In this paper it is briefly discussed how such processes affect the mass range of Planetary Nebulae(PN) nuclei(core) and their evolution, and the PN life time, and fading time for the masses which adopted. The Synthetic model is adopted. The envelope mass of star (M_{eN}) and transition time (t_{tr}) calculated respectively for the parameter (M_{eR} =1.5,2, 3×10^{-3} $M_\odot$). Another time scale is of capital importance for the understanding of PN and their nuclei, it is the fading time (t_f). The results indicated that for each observed nebulae($t_{tr} < t_{PN}$) also the fading time is sensitive to mass core(M_H) of star, the mass with 1.2 $M_\odot$ takes only (25 yr) to fading, while the mass with (0.66 $M_\odot$) takes about (4715 yr) years to fading. The calculations showed that (t_{tr}) increases with the increasing of final mass(M_f). The initial nebulae radius will also increase with (M_f) thus will correlate with the location of nucleus on the HR diagram.

نشوء السدم الكوكبية (PN) وزمن الخفوت وفقا الى النموذج التركيبي

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الخلاصه

السدم الكوكبية تمثل مرحلة قصيرة من حياة النجوم التي كتلها تتراوح بين(0.89-٧) كتلة شمسية($M_\odot$). هنالك عدة عمليات فيزيائية تحدث خلال مرحلة نجوم العمالقة الحمر ذات الكتل الواطئة والوسط. هذه العمليات تحدث في طورين ١- المرحلة المبكرة المنتظمة ونزع الغلاف ٢-مرحلة النبضات الحرارية خلال طور التقارب العملاق AGB.

في هذا البحث تمت مناقشة كيفية تأثير مدى الكتلة لنوى (اللب) السدم ونشوئها وحياة السدم وزمن الخفوت للكتل التي اعتمدت بالاعتماد على النموذج التركيبي. كتلة الغطاء ألنجمي (M_{eN}) وزمن الانتقال أجريت حسابهما بالاعتماد على معلمات الكتلة المتبقية بقيم مختلفة (M_{eR} =1.5,2, 3×10^{-3}).هناك مدى زمني أخر تمت دراسته له اهمية خاصة في فهم السدم ونشوئها هو زمن الخفوت. (t_f)أوضحت النتائج انه لكل السدم المبينة زمن الانتقال اصغر من زمن حياة السديم ($t_{tr} < t_{PN}$) وان زمن الخفوت(t_f) يتأثر بكتلة اللب الهيدروجيني(M_H) حيث ان الكتل بقيم (1.2 $M_\odot$) تحتاج (25yr) لخفوتها بينما الكتل بقيم(0.66 $M_\odot$)تحتاج (4715 yr) لكي تخفت. الحسابات التي أجريت بينت ان زمن الانتقال (t_{tr}) يتزايد مع زيادة الكتلة النهائية(M_f) كذلك نصف قطر السديم يتزايد مع الكتلة النهائية لذلك فهو مرتبط مع موقع نوى السدم فى مخطط HR diagram .

Introduction

Planetary nebulae (PN) consists mainly of gas ejected slowly by a red giant. The nebular phase represents just short phase in life of those stars which ultimately become white dwarfs, and therefore the understanding of most properties of PN and their central stars is necessarily rooted to the study of the previous evolutionary history of these objects[1]. In particular, an impressive body of observational evidence now shows that red giants and supergiant are indeed losing mass with the appropriate expansion velocities (10~20 km/s) and in some cases, with the appropriate rate for the production of PN [2]. In a recent series of papers (Kwok 2008, Margio 2006,2003,2001) [1], and previous papers (Wood and Kahn 1977,Renzini and Voli 1983, Iben and Renzini 1983) arguments are given indicating that at least two distinct mass loss regimes must operate in Asymptotic Giant Branch (AGB) stars[3,4]:

1- The regular wind (early AGB)
2-Superwind (tip AGB)

The idea that Planetary Nebulae (PN) originated from outer layers of red giant goes back to Shklovsky(1956)[5]. This hypothesis was supported by Abell and Goldriech(1966) who argued convincingly that red giants are the most likely progenitor of PN. Although this is generally accepted today [1, 4]. The details of the transition from red giant to PN remain in controversy Paczynski pointed out that the PN progenitors must have similar luminosities to central stars of PN, and therefore are likely to be late types supergiant undergoing double-shell burning. There are several pieces of evidence of observation:

1- The observed expansion velocities of PN (20-50 km/s) are higher than stellar wind velocities from AGB stars (3-20km/s)[6].
2-The observed densities of PN are higher than the expected densities in the remnants of red giant envelope.
3- Many PN have well defined shell like structures whereas red giant envelope do not. The shell is dynamically constrained by two winds, the regular wind and super wind [7].
4- Fast winds (1000-3000 km/s) from central stars of PN have also been detected by recent International Ultraviolet Explorer (IUE) observations[4]. Mass loss rate of Asymptotic Giant Branch (AGB) stars is in the range (10^{-6}-10^{-5} $M_\odot$/yr). The mass of the shell increases with the nebulae size[1,7].

1- Wind and Super Wind in AGB Stars

Most red giants (including Asymptotic Giant Branch (AGB) stars) are losing mass at rate which is conveniently expressed by the Reimer formula stars whose mass loss rate (MLR) follows the Reimers expression are considered in the regular wind regime, and evolutionary studies show that AGB stars can reach MLR's of at most a few 10^{-6} $M_\odot$/yr [8,9]. In fact, combining current estimates of the mass, radius and expansion velocity of PN, one derives that the MLR during the process leading to the PN ejection should be at least several 10^{-5} $M_\odot$ /yr, and possibly much higher. Both wind and super wind processes are currently parameterized in evolutionary calculations, through a numerical coefficient η placed in front of the Renzini's formula (eq.2), and parameter b entering into the expression for the envelope mass M_{PN} (eq.1) at the starting of super wind regime[8].

$$\mathbf{M_{PN} = b.\ f(M_H / M_\odot)} \text{ -----------------------------} \mathbf{(1)}$$

Where M_H is the mass inside the location of the hydrogen-burning shell (so called core mass), and $f(M_H)$ is an appropriate function. M_{PN} is clearly the mass ejection by super wind process [3].

2- Masses of PN Nuclei and the Mass Range of Producers

Coupling evolutionary calculations and parameterized mass loss algorithms, Iben and Renzini (1983) gave the following expression relating the stellar final mass M_f [3]:

$$M_f = 0.53\eta^{-0.082} + 0.15\,\eta^{-0.35}\,(M_i/ M_\odot - 1) \text{ ---- (2)}$$

This expression is most accurate for $1/3 < \eta < 2$, and is insensitive to $1/2 < b < 1$[3]. Note that the final mass M_f (the mass of white dwarf remnant) is also practically identical to the mass of the central star during the PN phase. Of great interest is also the critical initial mass (M_w) below which the hydrogen-rich envelope is actually ejected before the core mass can reach the Chandrasekhar limit (1.4 $M_\odot$) and above which this limit is attained, carbon is ignited in the electron-degenerate core, thus leading to a supernova explosion. Therefore in the mass range $0.85 \leq M_i \leq M_w$ are those which eventually produce white dwarfs and then likely to experience a PN stage [8].

$$M_w/ M_\odot = 1.0 + 9.33\eta^{0.35} - 3.53\eta^{0.27} + 0.8\,(b - 1.0) \text{ ----------------------------------(3)}$$

Which implies a range for M_w from (4.7 – 8) $M_\odot$, for η values in the range (1/3 – 2) and (b=1 for Renzini model). By using these information we found the critical mass before reaching the Chandrasekhar limit to be equal $M_w = 7.9\ M_\odot$ (by adopting b=0.55) as shown in (Figure 1). This value of (b) represents the best value for critical initial mass $M_w = 7.9\ M_\odot$ and Chandrasekhar limit (1.4 $M_\odot$).

While using Renzini value (b=1) gives higher value for critical initial mass, $M_w = 8\ M_\odot$, and also higher value for Chandrasekhar limit (1.4 $M_\odot$). According to eq.(2) PN nuclei should have masses ranging from slightly more than 0.50 $M_\odot$ (for $M_i = 0.85$) up to 1.4 (for $M_i = M_w$). (Figure 2) indicated that the exact value of η (~1.65) is applicable be for getting the value of 1.4 $M_\odot$. Schonberner and Wiedemann indicated that all stars with $M_i < M_w$ leave remnants with $M_f = 0.6$. Their analysis neither invalidates the arguments of Renzini, nor implies that all stars with $M_i < M_w$ generate post AGB stars with essentially the same mass, a claim which, in any case, would be hard to justify in terms of stellar evolution theory, that's argument agree with the Kaller (1982) idea [2,3].

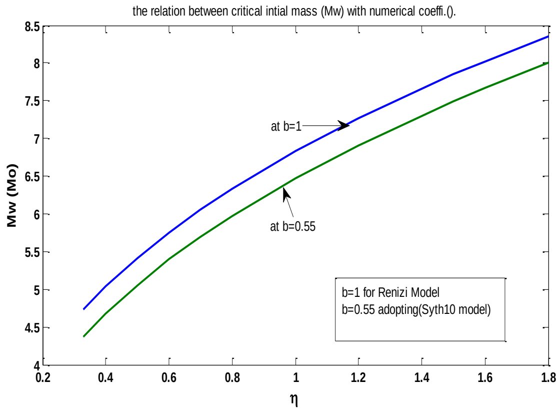

Figure 1: The relation between critical mass and η parameter with two values adopted.

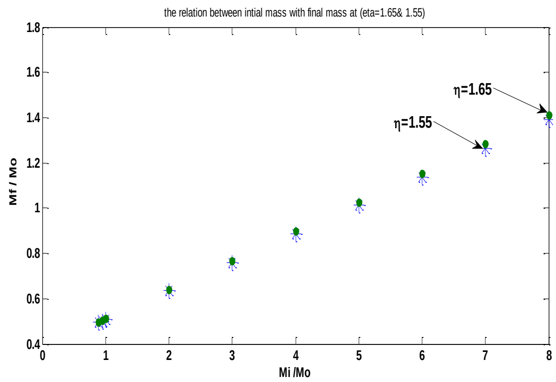

Figure 2: At two values of η(1.65&1.55) when final mass reach Chandrasekhar limit(1.4Mo).

3- The Super Wind Phase

The fact that the amount of the central star of PN can considerably vary depending on M_i may have important consequences for the PN life time. Also the super wind phase represents the beginning of a fast decrease in the envelope mass M_{eN} of AGB stars[8].

Stellar structure calculations indicate that the average location on the HR diagram of an AGB star will at first move to the right, towards larger radii and increasing the radius, the super wind instability will most likely be enhanced. This tendency to larger radii (lower effective temp.) is reversed when M_{eN} falls below a critical value of M_{eD}, marking the departure of the star from the Hayashi line. The value of M_{eD} very small and should be in the range (0.001 - 0.01) $M_\odot$

depending on the actual value of M_H as indicated by Paczynski(1971) with Vasslaides and Wood (VW2003)[7]. Since the star is now contracting the super wind instability may become less violent, and suddenly gets quenched leavening a residual envelope mass M_{eN} ($\leq M_{eD}$). This quantity plays a crucial role in the subsequent evolution of the stars, in particular the nebulae phase, follow from [3]:
i) The fact that $M_{eR} << M_{PN}$ ii) The hydrodynamic nature of the super wind process, and iii) Episodic character of the super wind.

4- Evolution of PN Nuclei

The transition from the AGB to the region of PN nuclei (which follows the super wind phase) is often regarded as practically instantaneous. The transition time t_{tr} is defined as the time interval between the super wind quenching and the instant when the effective temperature of the remnant star reaches 30,000 ○K, i.e. when the central become hot enough to excite the previously ejected envelop. Iben and Renzini (1983) give the following expression for t_{tr} [3,8]:

$$t_{tr} = 1.6 \times 10^6 yr\ (M_{eR}-M_{eN}) / (M_H / M_\odot - 0.44) \quad \text{-- (4)}$$

Where M_{eN} is the envelope mass when the star reaches T_{eff} =30,000 ○K, and from the models of Pyczynski (1971) one can derive M_{eN} [6,9]:

$$M_{eN} \simeq 1.8\times 10^{-5} (M_H^{-8.23} / M_\odot) \quad \text{----------------- (5)}$$

According to Renzini Model and for values of (M_H =0.60, M_{eN} =1.2× 10^{-3} $M_\odot$) and by using Eq.(4), the resulting values of transition time are (t_{tr} =3000,8000,and 17,000 yr), respectively for M_{eR} =1.5,2 and 3.0 ×10^{-3} $M_\odot$. In present calculations, we used the values of (M_H =0.66, M_{eN} =0.489 *10^{-3} $M_\odot$), and the results of transition time are (t_{tr} =7000,10000,17500yr) as shown in (Figures 3 and 4). The age of PN (time since the phase of super wind) is roughly given by[6]:

$$t_{PN} = R_{PN} / v_{exp} \quad \text{----------------------------(6)}$$

By using the last equation, the value of age of PN is about (1000-25000)yr, comparing with theoretical values of t_{PN} in range of (1000-30000 yr) as shown in (Table 1), where R_{PN} is the observed nebular radius for galactic, and v_{exp} is the nebular expansion velocity.

Transition time(t_{tr}) represents the beginning of phtoionzation phase while the fading time represents the end of PN life time, $t_{tr} < t_{PN}$,as shown in (Table 2). (Tables 2, 3 and 4) estimated that values of transition time and fading times by using different values of (M_{eR}). The expression for the fading time is derived from the old Paczynski tracks, and although it is of crucial importance to compute further grids of Post AGB sequences [9].
The stars with large core masses leave AGB phase with small (thin) H envelope but with high burning rate as shown in (Figure 3). Therefore the stars with large mass will be evaluating fastly, and has bright nebulae for a short period then fade. While the stars with low mass core will slow evolution to ionize the surrounding nebulae region before fade.
Fading time is about 4715 yr for core with mass (~0.66 adopted) shown in (Table 2), while core with mass 1.2 will have fading time about 25 yr in compared with Kwok model the fading time for core with mass 0.60 is about 7150 yr while it become for M_H =1.2 $M_\odot$, t_f =30 yr. The beginning of super wind marks the starting of fast decrease in the envelope mass M_{eN} of AGB stars, (Table 2) indicated the values of M_{eN} for the masses which adopted.

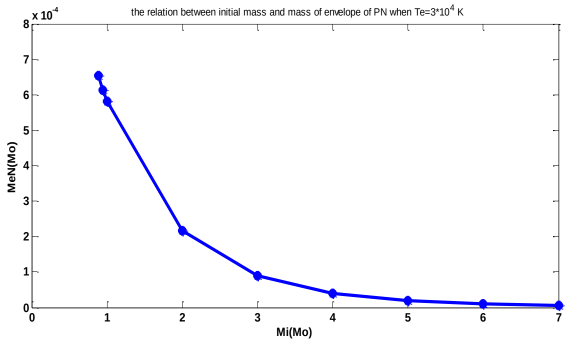

Figure 3: Mass of envelope as a function of the mass stars.

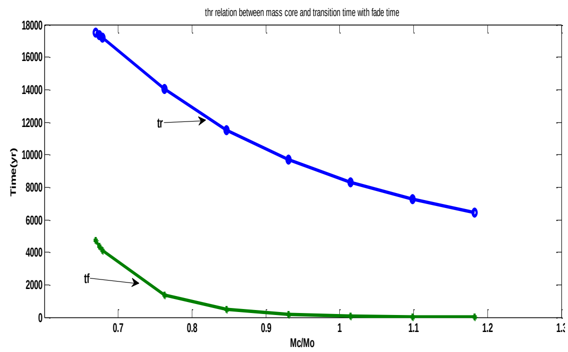

Figure 4: The relation between the time as a function of mass core. (Transition time comparing with fading time).

Table 1:Represents the radii of samples of PN in galgtic plane and the age of PN.

Name PN	Radius PN('')	Radius (km 10^{13})	t_{PN}(yr)
NGC1535	٢٢''	0.1364	٢١٦٢
NGC2452	١٠''	0.3000	٤٧٥٦
NGC2792	٦''	0.5000	٧٩٢٧
NGC2867	٦''	0.5000	٧٩٢٧
NGC3132	٢٤''	0.1250	١٩٨٢
NGC3211	٦''	0.5000	٧٩٢٧
NGC3918	٦''	0.5000	٧٩٢٧
IC4187	٦''	0.5000	٧٩٢٧
IC2448	٤''	0.7500	١١٨٩١
IC2165	٢''	1.500	٢٣٧٨٢

Table 2: represents the values of mass core(Mc) and mass of envelope(M_{eN}),transition time (t_{tr}) ,fading time(t_f), according to value of residual mass (M_{eR}) ~1.5*10^{-3} Mo

M_i/ M⊙	M_H / M⊙	M_{eN} (10^{-3} M⊙)	t_{tr}(10^3)yr	t_f (10^3)yr
0.89	0.669	0.489	7.0467	4.715
0.95	0.674	0.460	7.095	4.388
١	0.678	0.437	7.124	4.134
٢	0.762	0.167	6.608	1.348
٣	0.846	0.070	5.623	0.494
٤	0.930	0.032	4.785	0.199
٥	1.014	0.016	4.1322	0.087
٦	1.098	0.008	3.6232	0.040
٧	1.180	0.004	3.220	0.025

Table 3: Represents the values of mass core and mass of envelope(M_{eN}),Transition time(t_{tr}) ,fading time(t_f), according to value of residual mass(M_{eR}) ~2*10^{-3} M⊙

M_i/ M⊙	**M_H/M⊙**	M_{eN} (10^{-3} M⊙)	t_{tr}(10^3)yr	t_f (10^3)yr
0.89	0.669	0.489	10.534	4.715
0.95	0.674	0.460	١٠.508	4.388
1	0.678	0.437	10.477	4.134
2	0.762	0.167	9.088	1.348
3	0.846	0.070	7.591	0.494
4	0.930	0.032	6.416	0.199
5	1.014	0.016	5.524	0.087
6	1.098	0.008	4.833	0.040
7	1.180	0.004	4.299	0.025

Table 4: Represents the values of mass core (Mc) And mass of envelope (M_{eN}), transition time, fading Time, according to value of residual mass (M_{eR}) ~3*10^{-3}M⊙

M_i/ M⊙	**M_H / M⊙**	**M_{eN} (10^{-3} M⊙)**	**t_{tr}(10^3)yr**	**t_f (10^3)yr**
0.89	**0.669**	**0.489**	**17.510**	**4.715**
0.95	**0.674**	**0.460**	**17.313**	**4.388**
١	**0.678**	**0.437**	**17.182**	**4.134**
٢	**0.762**	**0.167**	**14.040**	**1.348**
٣	**0.846**	**0.070**	**11.525**	**0.494**
٤	**0.930**	**0.032**	**9.677**	**0.199**
٥	**1.014**	**0.016**	**8.309**	**0.087**
٦	**1.098**	**0.008**	**7.268**	**0.040**
٧	**1.180**	**0.004**	**6.454**	**0.025**

Conclusions

1. The shell is dynamically constrained by two winds the mass loss rate of AGB stars (10^{-6}-10^{-5}). The mass of the shell increase with the nebulae size.
2. The super wind marks the beginning of fast decrease in the envelope mass M_{eN} of AGB stars.
3. The results indicated that M_{eN} as a function of mass core estimates that the stars with large core masses leave AGB phase with small (thin) H envelope but with high burning rate.
4. As a results the stars with large mass will fast evolution and bright the nebulae for a short period then fade. While the stars with low mass core will slow evolution to ionize the surrounding nebulae region before fade.
5. The critical initial mass M_W below which the hydrogen –rich envelope is actually ejected before the core mass can reach the Chandrasekhar limit (~1.4 M⊙).
6. The fact that the amount of super wind material around the central stars of PN can considerably vary depending on M_i may have important consequences for PN lifetimes.
7. The central stars evolutionary tracks require a small residual H envelope

mass at the end of Asymptotic Giant Branch (AGB)phase, in order to obtain a reasonable transition time.

8. The nebulae radius increases with the final mass will correlate with the location of nucleus on the HR diagram.

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