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SN2008S and SN2008ha: is there a role for the super-asymptotic giant branch stars?

M.L. Pumo

INAF - Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy

Abstract. Among the different scenarios proposed to explain the faint transients SN2008S and SN2008ha, we have focused on the mechanism of core collapse supernova (CC-SN) triggered by electron-capture reactions (so-called EC-SN) involving a super-asymptotic giant branch (super-AGB) star, in order to verify if such a mechanism is compatible with the observations regarding these transients. Our results show that both SN2008ha and SN2008S could be explained in terms of EC-SNe from super-AGB progenitors having a different configuration at the collapse. The impact of our results on the interpretation of other underenergetic and unusual SNe is also briefly discussed.

Key words. supernovae: general — supernovae: individual (SN2008ha, SN2008S) — stars: evolution — stars: AGB and post-AGB

1. Introduction

In recent years a growing number of underenergetic and unusual supernovae (SNe) have been discovered. The faint transients SN2008S and SN2008ha represent two of these peculiar events, whose nature is still ambiguous and extensively debated. In particular SN2008S received a SN designation by Stanishev et al. (2008), but Steele et al. (2008) considered it as a SN "impostor", and Smith et al. (2009) as an exotic eruption of a luminous blue variable (LBV) object with a relatively low-mass, highly obscured progenitor ($\lesssim 15 M_{\odot}$). An eruptive origin was invoked also for two other similar transients (M 85 OT2006-1 and NGC 300 OT2008-1; Kulkarni et al. 2007; Berger et al. 2009; Bond et al. 2009). However, work based on multi-wavelength follow-up of the transients and mid-IR images analysis of the pre-explosion environments not only did not rule out a SN origin (Pastorello et al. 2007; Prieto et al. 2008) but even suggested that they may be EC-SNe involving a super-AGB[1] star (Thompson et al. 2008). The long-term multiwavelength monitoring of the SN2008S and new comparisons with the two similar aforementioned tran-

Send offprint requests to: M.L. Pumo

[1] The term super-AGB was coined by García-Berro & Iben (1994) to refer to stars that, developing electron-degenerate cores made of matter which has experienced H-, He- and C-burning, can be considered high-mass equivalent to "standard" AGB stars. Being unable to evolve through all nuclear burning stages, super-AGB stars end their life either forming a Ne-O white dwarf or going through an EC-SN becoming a neutron star, if electron-capture reactions are efficiently activated (for details on the evolutionary properties of these stars see e.g. Pumo 2007, and references therein).

sients seem to support the EC-SN interpretation (Botticella et al. 2009, B09 hereafter).

An EC-SN explanation has been suggested also for SN2008ha (Valenti et al. 2009, V09 hereafter), which at first was included among the SN2002cx-like variety of peculiar type Ia SNe (Li et al. 2003; Jha et al. 2006; Phillips et al. 2007). In fact, the distinguishing observed features of the SN2008ha have led V09 to review the thermonuclear scenario on the basis of its photometric and spectroscopic similarity to low-luminosity CC-SNe, concluding that all SN2002cx-like objects could be indeed faint stripped-envelope CC-SNe, and that SN2008ha represents the faint tail in the luminosity distribution of this SN family. However Foley et al. (2009) did not definitively rule out the thermonuclear origin of the SN2002cx-like objects, and proposed to explain the peculiarity of SN2008ha in terms of an "accretion-induced" collapse (so-called AIC mechanism; see Metzger et al. 2009, for details).

Among the different scenarios proposed to explain the faint transients SN2008ha and SN2008S, we focus on the EC-SN mechanism involving a super-AGB star, in order to verify if such a mechanism is compatible with the observations regarding these transients, thanks to the determination of super-AGB progenitors configuration at the explosion, which is crucial for a comparison with SN observables.

2. Configuration of super-AGB progenitors vs. transients SN2008ha and SN2008S

In Tab. 1 we summarise the main parameters describing the structure of super-AGB stars undergoing EC-SN at the time of explosion. These were built using the approach described in detail in Pumo et al. (2009), with the grids of super-AGB stellar models reported in Pumo (2006) and Siess (2007) as basis.

Data of Tab. 1 show that the two events SN2008ha and SN2008S could find a reasonable interpretation in the EC-SN scenario involving a super-AGB progenitor. In fact, as explained in detail in Pumo et al. (2009), a super-AGB star with initial mass just above M_N (defined as the minimum initial mass for a super-AGB star to evolve into an EC-SN; see e.g. Pumo 2007, for details) has the H-free core mass at the beginning of the thermally pulsing super-AGB (TP-SAGB) phase $M_{core}^{postCB} \sim 1.25$-$1.26 M_{\odot}$ (cf. second row in the sets of models in Tab. 1), while a super-AGB star with initial mass $\sim (M_N{+}0.5) M_{\odot}$ has $M_{core}^{postCB} \sim 1.34$-$1.35 M_{\odot}$ (cf. the row before the last in the sets of models in Tab. 1). As a consequence the time interval Δt_{CH} necessary to the H-free core to reach the threshold value M_{CH} for triggering the EC-SN ($\sim 1.37 M_{\odot}$; Nomoto 1984) is ~ 2.2-$2.5 \cdot 10^5\,yr$ in the former case, and $\sim 5 \cdot 10^4\,yr$ in the more massive star. This difference in the time interval Δt_{CH} reflects on the configuration at the collapse. The super-AGB star with initial mass slightly above M_N has time to expel almost all the envelope and, consequently, gives rise to a faint stripped-envelope SN characterised by an ejecta mass of ~ 0.2-$0.3 M_{\odot}$ with no signatures of prompt CSM interaction, consistently with the observations of SN2008ha (e.g. V09; Foley et al. 2009). In fact, assuming an average wind velocity of $10 \mathrm{km \cdot s^{-1}}$, 90% of the total expelled mass can be at a radial distance greater than $\sim 5 \cdot 10^4 A.U.$ when the EC-SN event takes place, and the mean density of the CSM is expected to be $\sim 5 \mathrm{cm^{-3}}$, that could be sufficiently low not to give rise to significant interaction. On the contrary, the super-AGB star with initial mass $\sim (M_N{+}0.5) M_{\odot}$ loses ~ 1.6-$1.8 M_{\odot}$ in $\sim 5 \cdot 10^4\,yr$ and, besides maintaining a massive ($\sim 7.4 M_{\odot}$) envelope at the collapse, could be embedded within a thicker circumstellar envelope (mean density $\sim 90 \mathrm{cm^{-3}}$), characterised by the formation of a detached shell (see Pumo et al. 2009, for details), as inferred from the observations of SN2008S (B09).

3. Comments

The current understanding of super-AGB stellar evolution is quantitatively consistent with the available data on the faint transients SN2008ha and SN2008S, that may be explained in terms of EC-SNe from super-AGB progenitors having a different configuration at the collapse, without resorting to "exotic" sce-

Table 1. Selected features of the super-AGBs models as a function of the initial stellar mass for initial metallicity Z =0.008 and 0.02. The first row in each set of models with a given Z refers to a super-AGB star with initial mass equal to M_N. The quantities shown are: the H-free core mass at the beginning of the TP-SAGB phase (M_{core}^{postCB}), the time interval from the beginning of the TP-SAGB phase until core mass reaches M_{CH} (Δt_{CH}), the ejected mass at the explosion (M_{ej}), and the maximum distance travelled by the CSM lost during the TP-SAGB evolution (D_{CSM}^{max}). (Table adapted from Pumo et al. (2009)).

$M_\star^{ini}$ $[M_\odot]$	M_{core}^{postCB} $[M_\odot]$	Δt_{CH} $[10^5\,yr]$	M_{ej} $[M_\odot]$	D_{CSM}^{max} $[10^5\,A.U.]$
	Z=0.008			
9.99	1.25	2.39	~ 0.01	5.0
10.01	1.26	2.23	0.3	4.7
10.15	1.28	1.77	2.4	3.7
10.55	1.35	0.46	7.4	1.0
10.65	1.36	0.10	8.8	0.2
	Z=0.02			
10.44	1.24	2.52	~ 0.01	5.3
10.46	1.25	2.47	0.2	5.2
10.55	1.27	2.02	1.8	4.3
10.85	1.34	0.51	7.4	1.1
10.92	1.36	0.10	8.9	0.2

narios that are not free from uncertainties. As for the "special" eruption of LBV of relatively low mass proposed to explain the features of the SN2008S (Smith et al. 2009), in addition to the problems for reconciling the ejecta velocity $\lesssim$ 3000km·s^{-1} with a stellar eruption (B09), it is difficult to explain the fact that the slope of the late-time light curve of SN 2008S (but also that of the similar event NGC300-OT; Bond et al. 2009) is surprisingly similar to that expected in a SN explosion when the main mechanism powering the SN luminosity is the radioactive decay of ^{56}Co into ^{56}Fe. As for the AIC mechanism invoked for the SN2008ha, the main problem concerns the high velocity (~ 0.1-0.2c) not observed in the ejecta and the impossibility to synthesise the observed intermediate-mass nuclei, that are predicted by the "standard" (involving a single degenerate binary system) AIC model. The so-called "enshrouded" AIC model involving the merging of two WDs in a binary system (Metzger et al. 2009) might be somewhat less problematic. However the ejecta velocity, the amount of ^{56}Ni and the production of intermediate-mass elements are still quantitatively poorly defined, and the role of the possible interaction between the disk wind and the outgoing SN shock remains to be explored.

The wide variety of displays expected for EC-SNe may be of interest also in understanding the two unusual events, SN2005E and SN2005cz (Kawabata et al. 2009; Perets et al. 2009). Indeed this scenario can account for many of the observed characteristic of both SNe (namely low explosion energy, very low ejected mass and ejection of small amount of ^{56}Ni), but the possibility to reproduce all the observed properties deserves further investigation.

Furthermore our results may be of interest in interpretation of some relatively "normal" type II SNe (e.g. Chugai & Utrobin 2000; Kitaura et al. 2006), characterised by low luminosity, small amount of ejected ^{56}Ni, extended plateaus (implying envelope mass of several $M_\odot$) and slow expansion velocities (Pastorello et al. 2004, 2006, 2009). To date, only for two objects of this class (SN2005cs and SN2008bk; Maund et al. 2005; Li et al. 2006; Mattila et al. 2008) clear evidence has been found for relatively low mass progenitors on pre-explosion images, but the fact that they are super-AGBs is strongly questionned (e.g. Eldridge et al. 2007). Thus, it remains to be seen what fraction (if any) of low luminosity type II SNe are EC-SNe and what other, instead, are more usual iron CC-SNe that experience less energetic than normal explosions (as, for example, if some of them are sufficiently massive to undergo fallback onto the collapsed remnant; see e.g. Zampieri et al. 2003).

We are aware that large uncertainties of both theoretical and observational nature are still present on the EC-SN mechanism in super-AGB stars. So the actual realization of this mechanism should to be taken with caution. Nevertheless we believe that the scenario herein proposed is promising for understanding an increasing number of underenergetic and unusual SNe. Only a combined effort will solve the issue concerning these SNe. On one side we need more refined future studies on the super-AGB stellar evolution fully describing the TP-SAGB phase, and 3-D simulations for examining in detail the nucleosynthesis processes in EC-SNe. On the other side more accurate observational information about the production of intermediate-mass nuclei (specifically C, O and all the α-elements in general) in low luminosity SN events are desirable.

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