# Massive Close Binaries as Source of Galactic $^{26}$Al

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## Abstract

We propose a new site for the synthesis of the radionuclide $^{26}$Aluminum which is observed in the Galactic interstellar medium: massive close binary systems. We present the results of an examplary calculation and conclude that — depending on the still somewhat uncertain $^{26}$Al production efficiency in supernovae — massive close binaries may even be the dominant source of $^{26}$Al in the Galaxy.

## 1 Introduction

Most stars appear to be members of binary or multiple systems. The fraction of massive stars being members of *close* binaries — i.e. such in which mass overflow is expected to occur — is estimated to be of the order of 20...40% (cf. Garmany et al. 1989, Podsiadlowski 1997, Mason et al. 1998). Thus, it appears necessary to investigate the effect of binary mass transfer on the overall massive star nucleosynthesis yields: if the mass transfer would increase the yield of an isotope only by a factor of $\sim 3$, then massive close binaries might be the dominant source of this isotope.

Braun & Langer (1998) have studied the nucleosynthesis processes in typical massive close binaries. Fig. 1 gives an example of the evolution of a close $20 + 18\,M_{\odot}$ pair of Case A — i.e. mass transfer occurs during the core hydrogen burning phase of the primary (the initially more massive star) — in the HR diagram. Due to the transfer of most of the hydrogen-rich envelope of the primary to the secondary component, the primary becomes a helium star (cf. point D in Fig. 1) while the secondary evolves into a luminous blue supergiant. In both cases, the core masses evolve differently compared to single stars of the same initial mass (i.e., 20 or $18\,M_{\odot}$ in our example); the primaries' core masses are smaller, that of the secondaries larger.

Then, the primary may, as a helium star, develop strong Wolf-Rayet type winds mass loss (cf. Langer 1989ab, Woosley et al. 1995), further reducing its helium core mass. This can affect the chemical yields of primary isotopes substantially, e.g. the carbon yield is enhanced at the expense of oxygen (cf. Langer & Henkel 1995). As long as the primary's helium core mass remains above $\sim 2\,M_{\odot}$ it will develop a collapsing iron core and become a supernova of Type Ib or Ic (Woosley et al. 1995).

As for the secondary star, which accretes the envelope of the primary during its core hydrogen burning evolution, it is a common assumption that it evolves after accretion exactly like a single star of the corresponding new mass ($\sim 32\,M_{\odot}$ in our example). However, Braun & Langer (1995) found that secondaries may retain significant structural differences compared to single stars, e.g. with the consequence that the supernova explosion occurs in the blue

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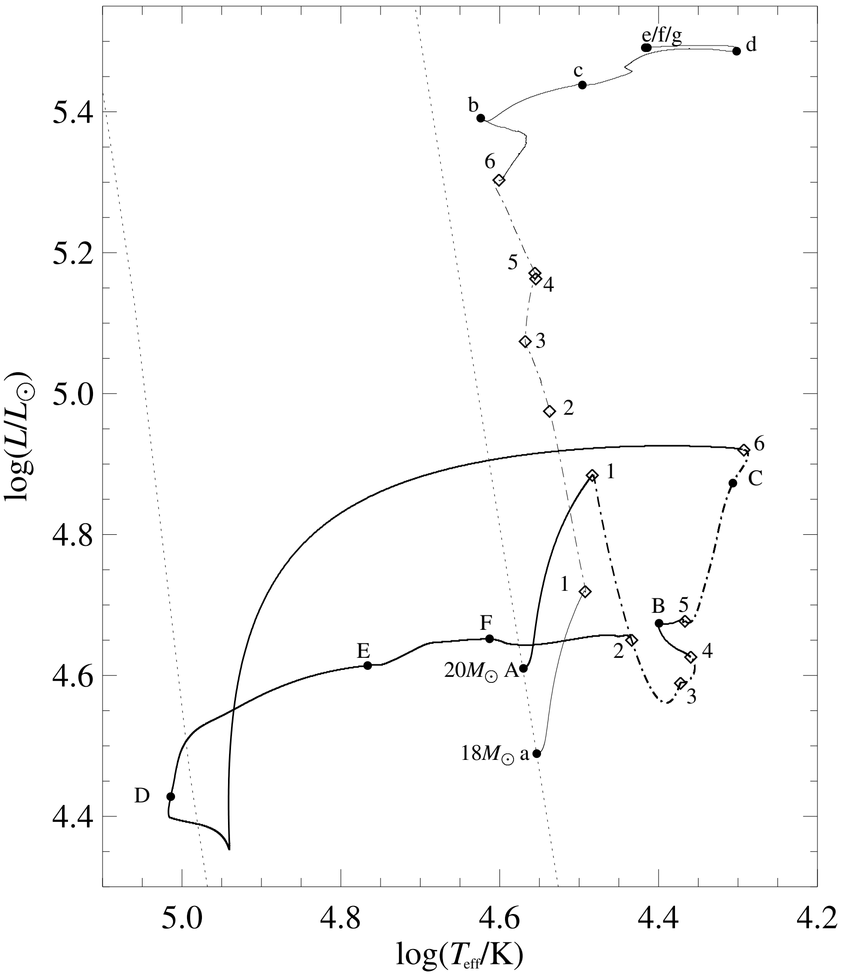


Figure 1: Evolutionary tracks in the HR diagram of the components of a 20+18 $M_\odot$ case A close binary system with a metallicity of $Z_\odot/4$ and an initial period of 2.5 days. The path of the primary component (initial mass 20 $M_\odot$) is marked by the thick line and upper case letters, that of the secondary by the thin line and lower case letters. Mass transfer stages correspond to the dot-dashed parts of the lines. The thin dotted lines designate the zero age main sequence and the location of pure helium stars (helium main sequence). The letters designate beginning and end of nuclear burning stages, i.e. core hydrogen burning (a/A – b/B), core helium burning (c/C – d/D), core carbon burning (e/E – f/F). g/G marks the beginning of core neon burning. Numbers designate mass transfer events for both stars. 1: beginning of Case A mass transfer, 2: maximum of mass transfer rate, 3: start of slow phase of Case A mass transfer, 4: end of Case A mass transfer, 5: start of Case AB mass transfer, 6: end of Case AB mass transfer. The final masses of the primary and secondary are 3 and 32 $M_\odot$, respectively.

supergiant stage (cf. Fig. 1) — as in the case of the progenitor of SN 1987A — rather than in the red supergiant stage.

However, independent of this phenomenon, Braun & Langer (1998) found that substantial differences in the synthesis of secondary CNO isotopes do occur in the secondary components of massive close binaries, due to the interplay between CNO burning and so called thermohaline mixing. This mixing process does occur in the whole hydrogen-rich envelope of the secondary from the surface down to the convective H-burning shell since the star accretes helium enriched matter from the primary component (i.e. matter with a higher mean molecular weight is lying above matter with lower mean molecular weight). As the time scale for thermohaline mixing — which is for the first time treated as a time dependent process by Braun & Langer (1998) — and CNO processing at the bottom of the mixed zone are comparable, the production particularly of $^{13}$C and $^{14}$N is boosted in the whole H-rich envelope, increasing the yield of these isotopes by factors of the order of 2...3.

## 2 Production of $^{26}$Aluminum in close binaries

The synthesis of $^{26}$Al in secondary components of close binaries was found to deserve special attention. The reason is that for $^{26}$Al, as it is $\beta$-unstable with a mean life time of $1.03\,10^6$ yr ($\tau_{1/2} = 7.2\,10^5$ yr), not only the amount which is synthesized matters, but also the time of the synthesis if one wants to explain the observed $\gamma$-ray line emission from the decay of $^{26}$Al in the Galaxy. We can only see the decay of $^{26}$Al nuclei in the interstellar medium; the decay inside stars is unobservable. Therefore, the $^{26}$Al which is observed should either be produced during supernova explosions or shortly before. From the spatial distribution of the $\gamma$-ray line emission (Prantzos & Diehl 1996) we know that it originates from massive stars. Supernovae are in fact the currently favored production site, although the corresponding yields are very uncertain (Weaver & Woosley 1993, Woosley & Weaver 1995, Timmes & Woosley 1997).

However, $^{26}$Al is also produced during hydrostatic hydrogen burning, by proton capture on $^{25}$Mg. Although very massive stars, through extremely strong stellar winds, can eject $^{26}$Al generated during H-burning and contribute to the Galactic $^{26}$Al (Langer et al. 1995, Meynet et al. 1997), the hydrogen burning contribution of less massive stars (say 10...30 $M_\odot$) is not considered as important (though see Langer et al. 1997) since the major fraction of the $^{26}$Al decays inside the star before it is released in the course of the supernova explosion.

Braun & Langer (1998) found this to be different in massive close binary secondaries. Fig. 2 shows the time dependence of the amount of $^{26}$Al generated by hydrogen burning in the interior of the secondary component of the 20+18 $M_\odot$ system shown in Fig. 1. Obviously, the $^{26}$Al mass, although $10^{-5}\,M_\odot$ initially, would be of the order of $10^{-8}\,M_\odot$ at the end of the evolution if no mass accretion would occur. However, since fresh fuel — i.e. also fresh $^{25}$Mg — is mixed into the core due to the mass accretion process (cf. Braun & Langer 1995) the amount of $^{26}$Al is increased by orders of magnitude at that time.

This would already be sufficient to produce as much as $\sim 10^{-6}\,M_\odot$ $^{26}$Al from this star of initially 18 $M_\odot$ — two orders of magnitude more than expected from single star calculations at $Z_\odot/4$ (cf. Langer et al. 1995). However, we find the H-burning shell source in the secondary component to be much more efficient than in corresponding single stars. This leads to the coupling of an extended convection zone to the hydrogen burning shell, and consequently to the enrichment of the whole convection zone with $^{26}$Al. In the end, our secondary star contains almost $10^{-4}\,M_\odot$ of $^{26}$Al which will be liberated during the supernova explosion. As

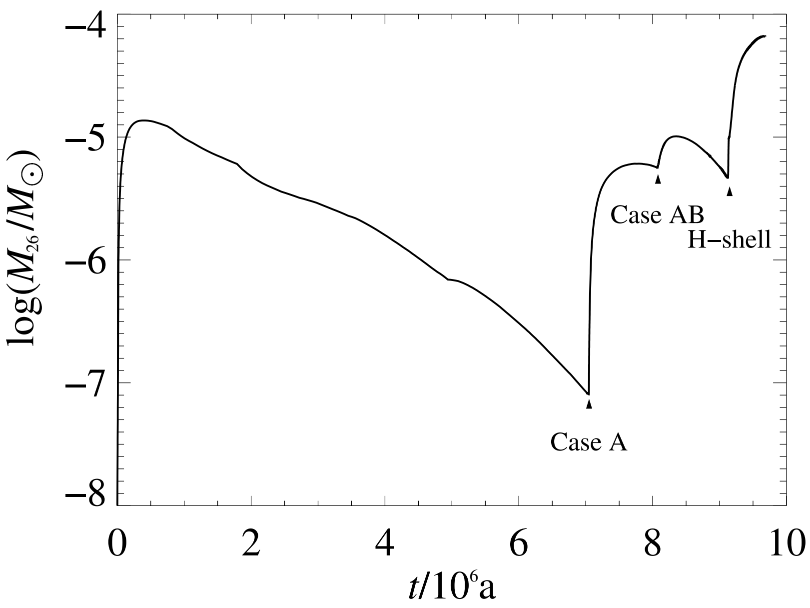


Figure 2: Evolution of the total mass of $^{26}$Al inside the secondary component of a 20+18 $M_\odot$ case A close binary system (cf. Fig. 1) as a function of time (in $10^6$ yr). The beginning of the Case A and Case AB mass transfer phase is indicated, as well as the beginning of hydrogen shell burning which marks the end of the core helium burning evolutionary phase. When the star explodes as a supernova of Type SN 1987A ($t = 9.68\,10^6$ yr) it contains almost $10^{-4}\,M_\odot$ of 26Al. Note that the initial metallicity of the stars is $Z_\odot/4$.

the chosen example appears to be a rather typical case, the Galactic $^{26}$Al production may in fact be dominated by massive close binary systems.

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## References

[1] Braun H and Langer N 1995 A&A **297** 483

[2] Braun H and Langer N 1998 in preparation for A&A

[3] Garmany C D, Conti P S and Massey P 1980 ApJ **242** 1063

[4] Langer N 1989a A&A **210** 93

[5] Langer N 1989b A&A **220** 135

[6] Langer N and Henkel C 1995 *Space Sci. Rev.* **74** 343

[7] Langer N, Braun H and Fliegner J 1995 *Astrophys. Space Sci.* **224** 275

[8] Langer N, Fliegner J, Heger A and Woosley S E 1997 *Nucl. Phys.* **A621** 457c

[9] Mason B D, Gies D R, Hartkopf W I, Bagnuolo W G Jr, Brummelaar T T and McAlister H A 1998 ApJ **115** 821

[10] Meynet G, Arnould M, Prantzos N and Paulus G 1997 A&A **320** 460

[11] Podsiadlowski Ph 1997 in: *Evolutionary Processes in Binary Stars* eds. R A M J Wijers et al. NATO ASI Ser. C Vol. **477** (Dordrecht: Reidel) p 181

[12] Prantzos N and Diehl R 1996 *Phys. Rep.* **267** 1

[13] Timmes F X and Woosley S E 1997 ApJ **489** 160

[14] Weaver T A and Woosley S E 1993 *Phys. Rep.* **227** 65

[15] Woosley S E and Weaver T A 1995 ApJS **101** 181

[16] Woosley S E, Langer N and Weaver T A 1995 ApJ **448** 315