NEW MASSIVE CLOSE BINARY MODELS AND THE ^{26}AL YIELD OF THE WR COMPONENT OF γ VEL

H. BRAUN and N. LANGER
MPI für Astrophysik, Karl-Schwarzschild-Straße 1, D-85740 Garching, B.R. Deutschland

Abstract. We present new models of massive close binary evolution, using an up-to-date hydrodynamic binary code which includes time dependent mixing of chemical species in the stellar interior, and nuclear reaction networks for the CNO cycles as well as for the NeNa and MgAl cycles. Some of our models, tailored to fit γ Vel, provide for the first time detailed results for the production and ejection of ^{26}Al into the interstellar medium by WR binaries. From our results one can estimate the contribution of WR stars to the amount of ^{26}Al presently seen in the Milky Way by γ-ray satellites.

1. Introduction

The evolution of stars in a massive close binary systems offers an important channel to originate WR stars. According to Podsiadlowski *et al.* (1992) and Vanbeveren & de Loore (1993) a fraction of 20-40% of WR stars forms in massive close binaries. Maeder & Meynet (1994) conclude that this fraction is well below 10% for high metallicities, but the majority of WR stars with low metallicities forms through the binary channel. These results raise the question in which way WR stars in a binary system are different from those evolving from single stars.

Here we focus on the aspect of the production and ejection of the radioactive isotope ^{26}Al. We present models for massive close binaries of solar metallicity with initial masses 20+18 $M_\odot$ and 50+45 $M_\odot$ as well as two models for a 40 $M_\odot$ star, one of which evolves similar to a primary in a case B binary system. This work is related to recent observations of the 1.8 MeV γ-ray line by the *COMPTEL* instrument on the *Compton Gamma Ray Observatory* (*CGRO*, Gehrels *et al.* 1993). This line is produced by the β^+-decay of ^{26}Al, an isotope for which WR stars are suggested to be a major production site (Prantzos 1991). The observations indicate the possibility of a discrete γ ray line source in direction of the WC+O binary system γ Vel (WR11, Diehl *et al.* 1994). Although the measured flux (corresponding to $\sim 10^{-4}$ $M_\odot$ ^{26}Al, Oberlack 1994) has no strict statistical significance it is important to ask, whether WR stars are at all able to release enough ^{26}Al to explain the observations, and how the binarity can effect the ^{26}Al yield.

2. Input physics

For our investigations we use a hydrodynamical stellar evolution code which includes mass loss according to Kudritzki *et al.* (1987) and Nieuwenhuijzen

K. A. van der Hucht and P. M. Williams (eds.), Wolf-Rayet Stars: Binaries, Colliding Winds, Evolution, 305–308.

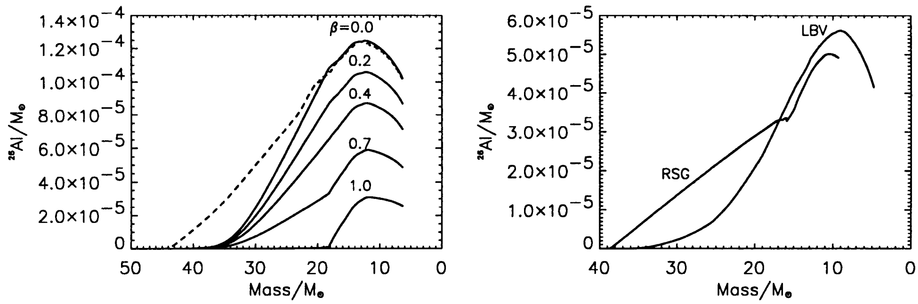

Fig. 1. a) ^{26}Al abundance in the circumstellar medium for a 50+45 $M_\odot$ system as a function of the remaining mass of the primary. The parameter β is the fraction of mass lost by the primary that is accreted on the secondary. The dotted line indicates the ^{26}Al abundance of a 50 $M_\odot$ single star with an LBV phase after core hydrogen burning. b) same as (a) but for 40 $M_\odot$ single stars evolving through a RSG or through an LBV phase.

& de Jager (1990), OPAL opacities (Rogers & Iglesias 1992) and WR mass loss rates according to Hamann (1993) and Langer(1989). Our models are calculated with the Ledoux-criterion for convection and include time dependent semi-convective mixing of the chemical species (Langer *et al.* 1983). The nuclear network includes all relevant reactions to cover hydrogen and helium burning and those needed to follow the production of ^{26}Al (NeNa and MgAl cycles). The initial periods of the calculated systems have been chosen to imply Case B mass transfer (Kippenhahn & Weigert 1967), *i.e.*, the primary star fills its Roche lobe after core hydrogen exhaustion. We do not follow the evolution of the secondary component which is treated as point mass.

3. Results

The interaction of massive stars in binary systems may influence the ^{26}Al yield in several respects. RLOF mass transfer is usually assumed to be not conservative, *i.e.*, only some fraction β ($0 \leq \beta \leq 1$) of the transferred mass is accreted on the secondary. Only the fraction $1 - \beta$ of matter leaving the system contributes immediately to the ^{26}Al abundance in the circumstellar medium. Fig. 1a shows the ^{26}Al abundance in the ISM for our 50+45 $M_\odot$ model as function of the remaining mass of the primary for various values of the parameter β. For $\beta = 0$ the ^{26}Al abundance is very similar to that of a $50 M_\odot$ single star that becomes a WR star through an LBV phase since both models loose their envelope shortly (compared to the lifetime of ^{26}Al of $\sim 10^6$ yr) after core hydrogen exhaustion. Fig. 1a shows that the ^{26}Al yield of a WR star binary component is possibly *smaller* than that of a single star of the same initial mass if this mass is above the mass limit for the LBV

TABLE I

Total mass of ^{26}Al in 10^{-6} $M_{\odot}$ ejected into ISM by massive stars. Single and binary models are indicated in the first column.

	mass/$M_{\odot}$	20	25	35	40	50	60
B	this work $\beta = 0.0$	1				120	
B	this work $\beta = 0.5$	0.6				70	
S	this work LBV				56		
S	this work RSG				50		
S	Prantzos (1991)				20	33	50
S	Meynet & Arnould (1993)						75
S	El Eid (1993)		6	40			

scenario, but it cannot be larger. Only for stars with masses $\lesssim$ 40 $M_{\odot}$, binarity has the potential to increase the ^{26}Al yield compared to the single star case (depending on the parameter β). These stars lose much more mass in an interacting binary system than as single stars, and furthermore ^{26}Al will be ejected earlier into the ISM, *i.e.*, it does not decay unobserved in the stellar envelope (*cf.* Fig. 1b).

Table 1 shows the values of the total mass of ^{26}Al ejected into the ISM by our models. In comparison, the values of Prantzos (1991) and Meynet & Arnould (1993) for single WR stars are also listed. The much higher values of our calculations are not due to the binarity of the star but can be explained by the different assumptions concerning overshooting and mass loss in the models. This strong dependence of the ^{26}Al yields on the stellar model parameter is confirmed by El Eid (1993), who also obtains very high values (see Tab. I).

4. Conclusion

The mass of WR11, the WC type binary component of γ Vel, has been determined as 21 $M_{\odot}$ (St-Louis *et al.* 1988). Although this figure is quite uncertain, it indicates that a progenitor model of WR11 more massive than 50 $M_{\odot}$ might be more appropriate, since our model produces only a 14 $M_{\odot}$ WC star. Keeping in mind that a more massive star will produce more ^{26}Al, our models are in agreement with the estimates from observations. With this important result one may hope, that more precise future measurements of circumstellar ^{26}Al masses in WR binaries will offer the opportunity to limit the range of model parameters considerably. From the values in Table I it can be seen, that even a direct estimate of the parameter β might be possible.

Prantzos (1991) gives an estimate for the contribution from WR stars and

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supernovae of $\lesssim 20\%$ and 50%, respectively, to the total mass of $\sim 3\ M_\odot$ of ^{26}Al observed in our galaxy. From the results of our calculations one can conclude that the ^{26}Al yields of WR stars may have been considerably underestimated in the past. The total amount of ^{26}Al in our galaxy may well be explained by the production of this isotope in WR stars and supernovae.

It should be noted, that it will be difficult to give an estimate for the contribution of ^{26}Al from binaries system, because the value of the parameter β in binary calculations is still a matter of debate (*e.g.,* Meurs & van den Heuvel 1989) and the fate of the fraction of the ^{26}Al which is accreted onto the secondary depends on the further evolution of this component. This adds additional complications to the problem, like *e.g.,* the effect of semi-convective mixing on the chemical structure of the mass accreting star (Braun & Langer 1993).

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