THE EVOLUTION OF THE PROGENITOR OF SN 1987A

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1. INTRODUCTION

It is now almost certain that the progenitor of SN 1987 is the B3 supergiant Sk $-69^{o}202$ (e.g. Walborn et al. 1988). This provides us with valuable constraints on the SN precursor: According to West et al.(1987) the star has M_V=-6.8. Using the calibrations of Humphreys and McElroy (1984) we find that the precursor had T_{eff} = 13000 - 16000K, $-M_{bol}$= 7.7 - 8.1 ($\log L/L_\odot = 5.04$) and a radius of 48 - 60 $R_\odot$.

The SN precursor was not a red supergiant, but a rather blue supergiant, which also explains the peculiar form of the light curve (Woosley, 1988; Schaeffer et al. 1987). However, standard evolutionary calculations would expect such stars to explode as red supergiants.

2.CONSTRAINTS ON THE PROGENITOR

If we compare the HRD position of the progenitor to evolutionary tracks (keeping in mind that the luminosity is nearly constant after helium ignition) we see that the progenitor had a mass between 15 and 20 $M_\odot$ (Fig.1). Depending on the inclusion of overshooting in the model computations, the mass at explosion may vary from 12.5 $M_\odot$ (overshooting) to 17.5 $M_\odot$ (Schwarzschild). Table 1 summarizes some data on both models. They are compatible with the findings of Woosley (1988).

Table 1: parameters of the progenitor of SN1987A

	Schwarzschild[1]		Overshooting[2]	
Initial Mass	17.9	20.0 $M_{\odot}$	16.2	18.6 $M_{\odot}$
Helium core mass	5.4	6.5	7.3	9.0
Mass at end of H-burning	17.3	19.1	12.9	14.3
Mass at explosion	16.8	18.1	12.3	12.9

(1) Maeder and Meynet, 1987
(2) Pylyser et al., 1985

3. WHY WAS THE PROGENITOR BLUE?

In order to determine what effects cause a star to be a blue supergiant instead of a red supergiant we calculated a number of envelopes of stars, varying the hydrogen content and the metallicity. We chose a star of 12 $M_{\odot}$, of which the outer 6 $M_{\odot}$ are modeled. The luminosity was fixed at 10^5 $L_{\odot}$.

The results are shown in Fig. 2. We immediately see that envelopes with larger hydrogen content and/or large metallicity produce red supergiants. For a given metallicity, the stellar radius decrteases rapidly if the hydrogen content drops below a certain value (e.g. $Z = 0.03$, below $X = 0.6 - 0.5$). Moreover this threshold value is larger for smaller metallicity.

When a star has evolved into a red supergiant its atmospheric hydrogen content decreases because the mass loss exposes helium rich layers at the surface. It is well known (e.g. Maeder, 1981) that galactic red supergiants return to the blue when the hydrogen content drops below 0.5. Since for smaller metallicity this threshold is larger, less mass loss in the red supergiant stage is needed to produce a blue supergiant. If the metallicity is low enough, it may be that no mass loss is required.

In the model by Maeder (1988), the red supergiant is peeled off until the atmospheric hydrogen abundance is low enough to make the star blue. The models of Maeder evolve along a line of constant Z in Fig.2 The same is true for the models of Wood (1988).

On the other hand the models of Arnett (1987) and Truran et al. (1987) exploit the low metallicity. Z is so low that red supergiants are never produced.

https://doi.org/10.1017/S0252921100093982 Published online by Cambridge University Press

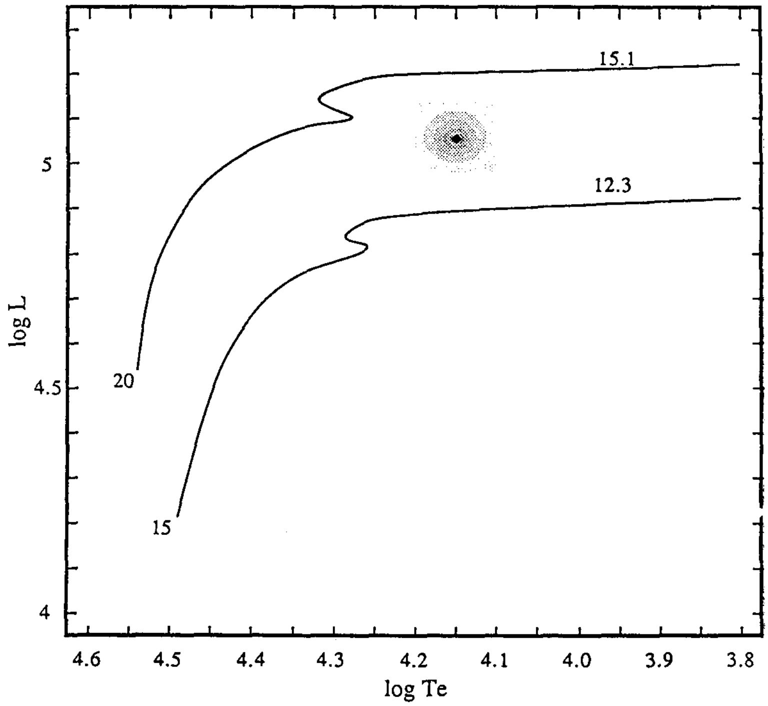

Fig. 1: The position of the progenitor of SN1987A, compared to the evolutionary tracks of a 15 $M_\odot$ and a 20 $M_\odot$ star.

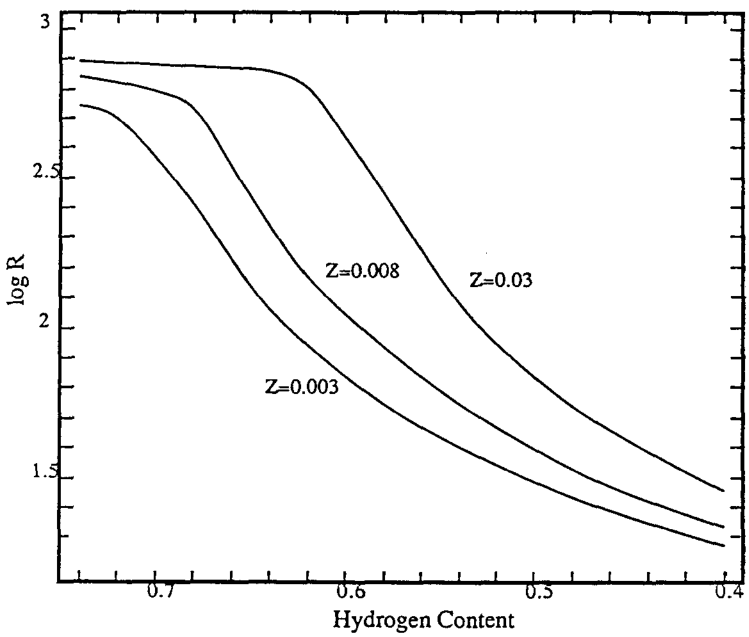

Fig. 2: The radius of supergiant envelopes calculated with varying hydrogen content X and metallicity Z.

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4. A REVIEW OF SOME CALCULATED MODELS

a) MAEDER (1988)

This model starts from a 20 $M_{\odot}$ star, adopting a moderate amount of overshooting (d_{OV} = 0.3 H_p) and a mass loss rate of 3/5 of the values of de Jager et al. (1987) for the Galaxy. The evolution is followed up to the end of carbon burning.

During hydrogen burning the star loses about 0.5 $M_{\odot}$. It then evolves to the red supergiant region, loses a large part of its hydrogen envelope and returns to the blue.The final masses range between 8.6 and 10 $M_{\odot}$, depending on the (huge) mass loss rate as a red supergiant.

There is a large sensitivity of the final radius on the mass loss rate: if the mass removed is not large enough, the star remains a red supergiant, if too much mass is removed the star "shoots over" to the left and becomes a hot Wolf-Rayet like-star. The reason for this is the presence of a composition gradient at the surface at the time of explosion. This graqdient is left behind by the retreating convective core during hydrogen burning. Removing a little bit more matter from the star produces a much lower atmospheric hydrogen content at the time of explosion, which, according to Figure 1 causes the large dependence of the radius at explosion on the mass lost during the lifetime of the star.

b) WOOD AND FAULKNER (1988)

This model starts from a 17.5 $M_{\odot}$ star, without overshooting, and evolves after extensive mass loss in the red supergiant stage into a 5.4 $M_{\odot}$ blue supergiant at the time of explosion. The HRD position is less dependent on the mass loss rate: because no overshooting is adopted, the composition gradient, left behind by the convective hydrogen burning core, is leveled out by an intermediate convective zone. Lateron, mass is removed until this plateau is exposed. Since there is no composition gradient near the surface at the timne of explosion, a little

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more or less mass loss does not change the atmospheric hydrogen abundance and the radius.

c) ARNETT (1987) AND TRURAN ET AL.(1987).

The basdic idea of these models is that 15 - 20 $M_\odot$ models with a low metallicity do not become red supergiants, but remain blue supergiants until the explosion (cf. discussion on Fig.1). Taken at face value these models are in direct contradiction with the HRD of the Magellanic Clouds (Humphreys and McElroy (1984): in both the LMC and the SMC red supergiants are observed in the mass range 15 - 20 M_O. The models of Arnett (1987) and Truran et al. (1987) must therefore represent exceptional stars in the LMC: a very low metallicity and no mass loss at all. Although the presence of such stars in the LMC is not excluded (there may be a large spread in metallicity), these factors make the model less plausible.

4. CONCLUSIONS

The evolution of the progenitor of SN1987A is by far not clear. There are two "classes" of models: without mass loss and with a large mass loss. The first models rely on the fact that low metallicity induces bluewards evolution. But the Woosley (1988) model only has limited convection - a matter of debate - while the other nodels of this class do not produce red supergiants - difficult to reconmcile with the observed characteristics of the HRD.

The second class of models relies on mass loss to peel off the star until helium rich layers are exposed and the star turns from a red- into a blue supergiant. All computed models need a huge mass loss rate durinmg the red supergiant phase - much larger than suggested by the observations. A way out of this would be the inclusion of a large amount of overshooting: only 0.6 $M_\odot$

of matter has to be removed to expose the appropriate layers. But in this case the mass loss rate has to be timed in a very delicate way, because of the very steep composition gradient at te surface at the time of explosion.

We may conclude that all models for the progenitor evolution of SN1987A require some special conditions: either a huge mass loss or no mass loss at all or an exceptionally low metallicity. If one of these models represents the reaslity of nature, SN1987A was indeed an exceptional event.

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