THE INFLUENCE OF CLOSE BINARY EVOLUTION ON THE DISTRIBUTION OF MASSIVE STARS IN THE HR DIAGRAM

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Abstract. A statistical study is presented on the distribution of different kinds of massive star classes in the HR diagram using recent calculations of massive single star and massive close binary evolution. The influence of the mass transfer process during the critical Roche lobe overflow phase of a primary component on the relative frequency of the different classes is outlined. It is shown that without an exact knowledge of how mass transfer takes place, the meaning of an initial mass function determined by classical methods is unclear whereas a direct comparison of the observed and theoretically predicted blue/red star ratio is meaningless. The number of O- and WR-type stars with compact companions is expected to be very low (< 5%). If mass transfer in binaries is largely conservative, the contribution of real single stars to the supernova II population is low (10–25%).

1. Introduction

Usually a star is called 'massive' when gravitational collapse occurs at the end of its life leading to a type II supernova explosion. Without the inclusion of convective core overshooting, gravitational collapse occurs in single stars with mass larger than 9 $M_\odot$ (Woosley and Weaver, 1986) and in close binaries with mass larger than 9–10 $M_\odot$ (van den Heuvel, 1969; Iben and Tutukov, 1985). Using this definition, I will divide the sample of 'massive' stars into four main classes:

Class I: single stars with mass between 9 and 20 $M_\odot$. Within sample, I also include primaries of wide binaries, with periods which are large enough so that the critical Roche-lobe overflow is insignificant for their evolution. Most of the stars in this class have an extended hydrogen-rich envelope (radii of the order of 100–1000 $R_\odot$) prior to the SN explosion explaining the 2–3 months lasting plateau phase in the light curve of many of them (they are usually designated as type IIP).

Class II: non-evolved primaries of close binaries with masses between 9–10 $M_\odot$ and 20 $M_\odot$. Pre-supernova close binary components are very compact (radii 1–10 $R_\odot$) hydrogen deficient stars, their envelope being lost as a consequence of mass transfer due to critical Roche-lobe overflow. Their atmospheric hydrogen abundance is typically a factor 10 lower (by number) than the solar value while the overall hydrogen mass fraction still present in the star is smaller than 10% of remaining stellar mass after mass transfer (cf. van der Linden, 1987; Vanbeveren, 1987).

Class III: evolved accretion stars, eventually with a compact companion. Let us consider the mass evolution of a case B close binary (case B = Roche-lobe overflow...
occurs during the hydrogen shell burning phase) in the case that accretion of the mass gainer during the Roche-lobe overflow of the mass loser is very efficient, e.g., a $9 \, M_\odot + 6 \, M_\odot$ close binary will evolve into a $1.5 \, M_\odot + 13.5 \, M_\odot$ (van der Linden, 1987). The $13.5 \, M_\odot$ secondary star will be observed as a normal early $BV$ single star, the binary nature being hard to detect due to the extreme mass ratio and the low visual magnitude of the $1.5 \, M_\odot$ white dwarf component. As the $BV$ star further evolves, it will reach its own critical Roche lobe and may during the ensuing spiral-in phase also lose its entire hydrogen rich envelope. Again the star will be very compact prior to the SN explosion.

Class IV: stars with mass larger than $20 \, M_\odot$. There are at least two reasons why I prefer to consider stars with mass larger than $20 \, M_\odot$ separately from the lower mass massive stars. First of all, it is yet unclear, if stars in the mass range $> 20 \, M_\odot$ do explode at all (Woosley and Weaver, 1986). Furthermore, many if not all the stars with mass $M > 20 \, M_\odot$ may evolve into WR stars, i.e., many if not all explode (if they explode) as stripped helium cores with no or a very little hydrogen content. Indeed as has been shown in a number of papers (Vanbeveren and de Loore, 1980; Conti et al., 1983; Schild and Maeder, 1984; Vanbeveren, 1987), the bulk of WR stars originates from stars with initial ZAMS mass larger than $\sim 35 \, M_\odot$. However, this does not mean that $35 \, M_\odot$ is a minimum ZAMS mass for WR formation. It may very well be that stars in the mass range $20-35 \, M_\odot$ do reach the WR phase at the end of core helium burning, i.e., their WR phase may be very short in this way not violating the observational fact that most of the observed WR stars are descendants from stars with ZAMS mass larger than $35 \, M_\odot$. However, I do not want to base my conclusions on the foregoing speculations and I, therefore, propose a further subdivision of this fourth class: i.e.,

Class IV, 1: single stars with mass between 20 and $35 \, M_\odot$. Although it remains a matter of faith, they may evolve into a WR phase at the very end of their life just prior to the SN explosion (if they explode).

Class IV, 2: non-evolved primaries of close binaries with masses between 20 and $35 \, M_\odot$. As for class b, they will evolve into compact, stripped helium cores, producing short lived SN phenomena with no or a very little amount of hydrogen.

Class IV, 3: as for class III stars, I will separately consider the accretion stars with mass between 20–35 $M_\odot$. If the foregoing SN explosion did not disrupt the binary system, most of these accretion stars may have a compact companion. They will go through a spiral-in phase losing most of their hydrogen-rich envelope, producing compact stripped helium cores.

Class IV, 4: all stars (i.e., singles, binary primaries and accretion stars) with mass larger than $35 \, M_\odot$. They all evolve into WR stars, i.e., they evolve into compact hydrogen-poor stars prior to the SN explosion.

The purpose of this paper is to make a detailed estimate of the frequency of the classes and subclasses just mentioned, using recent determinations of binary frequencies, recent initial mass functions (IMF) and evolutionary results of close binaries. In Section 2 the results of close binary evolution used in the present paper are briefly summarized. Section 3 deals with observational constraints whereas the method in order to determine