Massive star evolution with rotation in LMC

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Abstract

The ZAMS positions of the rotating 15, 20 and 25 $M_{\odot}$ stars with metal abundance compatible with the metallicity of the Large Magellanic Cloud have been investigated by considering two different initial total angular momenta for each mass. The ZAMS positions of studied massive stars have sligthly been changed by rotation.

1 Introduction

The observational properties and theoretical models of massive stars have extensively been studied (Schwarzchild and Harm 1958; Ezer and Cameron 1967; Humpreys and Davidson 1979; Chiosi 1981; Humpreys 1981; Brunish and Truran 1982; Sreenivasan and Wilson 1985; Stothers and Chin 1985; Maeder 1987; Maeder and Meynet 1987, 1989; Arnet 1987). Evolutionary models of these stars were studied under different conditions like with mass loss, overshooting, turbulent diffusion and with different criteria for convection.

Recently, the evolution of massive stars around the mass 20 $M_{\odot}$ has gained importance because of the abnormally strong nitrogen lines in the atmospheres of some early type stars (Schönberner et al. 1988; Kudritzki et al. 1989), and the mass of the progenitor star of SN1987A is expected around this value. Since the progenitor star Sanduleak -69202 is in the LMC, the post main sequence evolution of stars around 20 solar mass with low metallicity was studied by many authors (Truran and Weiss 1987; Langer et al. 1989; Weiss 1989; Arnett 1991; Schaller et al. 1992). However, there has been very few studies of massive stars with rotation (Sackman and Anand 1970; Eryurt-Ezer et al. 1994) in the pre main sequence stage.

The motivation of this work is to show the effect of rotation on massive star evolution, and to investigate the zero age main sequence of rotating massive stars with metallicity abundance compatible with the metallicity of LMC considering the stages of the gravitational contraction and approach to the main sequence. In the next section, we give the computational procedure. Results of stellar evolutionary calculations will be given in section 3 in connection with other massive star evolutions with no rotation. Section 4 is devoted to the discussion and conclusion.

2 Computational procedure

The evolutionary models of 15, 20 and 25 $M_{\odot}$ stars with rotation were constructed with different initial total angular momenta. The evolutionary studies were started at the threshold of energy stability. At this point, the total released gravitational potential energy is just enough to provide the sufficient internal energy of the contracting gas cloud, assuming that rotation is negligible at this point. The first rotating model was obtained from the non rotating model of the same mass. The initial angular velocities at the threshold of stability point were chosen such that they did not exceed the critical rotation when they reached the ZAMS. To find the initial rotating models, 0.7% and 1.5% of the initial critical rotational velocity were taken for the slow and rapid rotations, respectively. The corresponding initial angular momentum relations, as it was done in a previous paper (Eryurt-Ezer et al. 1994), were taken from Kawaler (1987). However it must be quoted that the above mentioned relation, although it was obtained for stars of masses up to 6 $M_{\odot}$, was assumed to be valid for our case too.

The angular momenta were **1.32** 10^{52}, **2.03** 10^{52} and **3.40** $10^{52} gcm^2 s^{-1}$ for slowly rotating models and **2.22** 10^{52}, **4.15** 10^{52} and **7.52** $10^{52} gcm^2 s^{-1}$ for rapidly rotating models of masses 15, 20 and 25 $M_\odot$, respectively. The rapid rotation of 20 $M_\odot$ star was already studied (Eryurt-Ezer et al. 1994).

In our calculations the Cox and Stewart (1970) opacity has been used. Our results will be helpful to compare with earlier studies in the literature. However the evolutionary studies of Stothers and Chin (1993) and Schaller et al. (1992) were resulted with a very small change on the ZAMS positions of stars when they used the OPAL opacity code (Iglesias et al. 1992).

The hydrogen and heavy element abundances by mass were taken as X= 0.732 and Z= 0.008. The choice of LMC metallicity was based on observations of O and B stars as well as SN1987A (Dufour et al., 1982: Schönberner et al., 1988). The evolutionary study was carried out by the Henyey method which was applied from the center all the way to the surface. The basic structure equations which include the changes due to rotation and the method of computations and other physical inputs were given in the study of Eryurt-Ezer et al. (1986) and Eryurt-Ezer et al. (1994). Calculations were stopped when the stars were on the ZAMS that is when stars have minimum luminosity and minimum radius values.

3 Results

The initial models are fully convective. As the opacity decreases as a result of increasing temperature and density stars follow an evolutionary path which is determined by radiative equilibrium. When C^{12} begins to burn before reaching the ZAMS, the energy generation is strong enough to develop a convective core at the center of stars. Convective cores reach their maximum sizes for the ZAMS models. The sizes of these cores increase as the mass increases. The sizes are about 0.41, 0.47 and 0.51 M for the slowly rotating stars under consideration. For the rapidly rotating models the convective core sizes drop by about 2 %. The evolution times on the ZAMS are 1.96 10^5, 1.42 10^5 and 0.88 10^5 yr for the slowly rotating models and 1.82 10^5, 1.25 10^5 and 0.85 10^5 yr for the rapidly rotating models of 15, 20, and 25 $M_\odot$ stars, respectively.

The solid body rotation is set up when the stars are fully convective and after the formation of radiative core differential rotation arises. As the radiative region grows stars spin up toward the ZAMS. When they reach the ZAMS, their rotational velocities are 140, 150, and 197 kms^{-1} for slowly rotating models and 240, 296 and 440 kms^{-1} for rapidly rotating models of masses 15, 20, and 25 $M_\odot$, respectively. We found that the ZAMS rotational velocities for rapidly rotating models were 0.45, 0.54, and 0.77, in fractions of the critical rotational velocities at that point.

The slowly rotating models have larger density, temperature and pressure values than the rapidly rotating models at ZAMS. The central densities are 5.84, 4.57, 3.93 gcm^{-3} and central temperatures are 3.30 10^8, 3.47 10^8 and 3.62 10^8 K for the slowly rotating models. The hydrogen amount at the center is around 0.72 for all models.

The ZAMS positions of rotating stars of masses 15, 20 and 25 $M_{\odot}$ with different angular momenta and with LMC metallicities were presented in Fig.1. Squares are for slowly rotating models and circles are for rapidly rotating models of the present study. Whether they are rotating slowly or rapidly the ZAMS positions of stars do not change so much. In Fig.1, we also plotted the data for low metallicity non rotating stars of Truran and Weiss (1987) (Z= 0.01), Arnett (1991) (Z= 0.007) and Schaller et al. (1992) (Z= 0.001) for the mass range 15 - 25 $M_{\odot}$. The change in logarithm of effective temperature is at most 1 % when we compare our data with those of Arnett's (1991). The change is even smaller when the comparison is made with the data of Truran and Weiss (1987). The data of Schaller et al. (1992) which was obtained by using different opacity code (OPAL), differ from our rotating models, in log T_e, by 1 % on the average. It must be stated that the changes due to taking rotation into account are even smaller than those due to the new opacities.

The ZAMS positions of rotating massive stars have resulted very close to those of the non rotating stars', therefore the positions of rotating massive stars do not so much distort the normal ZAMS.

4 Conclusions

The evolution of stars of masses 15, 20 and 25 $M_{\odot}$ with rotation and with metal abundance compatible with the metallicity of the LMC has been studied from the threshold of energy stability point up to the ZAMS. When the rotating massive star models were compared with non rotating stars it has been found that the ZAMS positions were quite similar. Nevertheless, rotation has changed the ZAMS positions of the studied models slightly. This change did not depend on much whether we had slow or fast rotation.

Recently Herrero et al. (1992) have found that the masses of galactic OB stars obtained from a spectral analysis are much lower than those obtained from evolutionary sequences. In Fig.1 we also show the positions of some of their objects of luminosity class V in the interested mass range. Langer (1993) and Weiss (1994) have tried to explain this by the effect of mixing due to rotation. However, they have not taken into account the effects of rotation in the stellar structure equations as we have done in the present work. We thus supplement their results by our finding that rotation without mixing does not alter the ZAMS position of massive stars sufficiently to account for any "mass discrepancy", even in the case of rapidly rotating stars.

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Figure captions

Fig.1. The ZAMS positions of stars of masses 15, 20, and 25 $M_{\odot}$ in the HR diagram. Squares and circles are the results of the present study for slowly and rapidly rotating models, respectively. Plus, cross and triangle signs show, in turn, the data of Truran and Weiss (1987), Arnett (1991) and Schaller et al. (1992). Dots are for the observed data of Herrero et al. (1992) with the indicated masses in solar unit, in the studied mass range.