EVOLUTIONARY TRACK OF AN INTERMEDIATE MASS FIRST-GENERATION STAR

D. Eryurt - Ezer
Department of Physics, Middle East Technical University
Ankara, Turkey

Abstract: An evolutionary track for a metal-free star of intermediate mass with parameters $(M/M_\odot,X,Z)= (3,0.80,0.00)$ has been constructed. The evolutionary behaviour of the star in the theoretical H-R diagram is compared with that of a normal star with the same mass and its implication on the chemical evolution of the interstellar medium is discussed.

On the early enrichment of the Pre-Galactic medium with the nucleosynthesis products the evolutionary lives of the first-generation stars (called Population III or Pregalactic stars) which are supposed to have formed essentially with no heavy elements, play very important role. Very little study has been carried out for the evolution of first-generation stars (e.g.Ezer and Cameron, 1971; Ezer,1972,1981;Guenther and Demarque, 1983; El Eid et.al.1983). The mass ejected from the stars, generally is the surface layers of the stars. There are different processes which are responsible for the changing of the abundances of the surface material during the evolution of the stars. In the study of the evolution of normal stars, Becker and Iben(1979) distinguished three convective dredge-up phases during which the composition of surface layers might be largely affected.

In this paper, the evolutionary history of a first-generation star of $3M_\odot$ has been presented from the main sequence up to the appearance of the first thermal pulse. The evolutionary behaviour of the star during the occurance of the dredge-up phases is examined and its implication is discussed. The method of computation and input physics were given in Ezer (1981).

The result of the evolutionary study is presented in the theoretical H-R diagram in Figure 1 and compared with that of a normal star of the same mass, taken from the works of Becker et al (1977) and Becker and Iben (1979). The positions of the stars on the evolutionary tracks, during which the derdge-up phases occur, are indicated by Romen numbers.

In the evolution of a first generation star of $3M_\odot$, hydrogen burning near the main sequence occurs at a higher temperature via the

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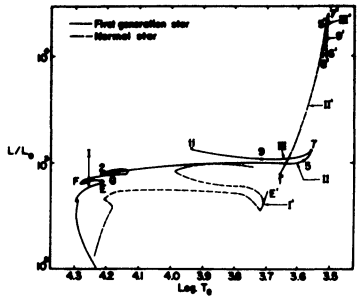

Figure 1. Comparison of the evolutionary track of the first-generation star of $3M_\odot$ with that of a normal star of similar mass, in the H-R diagram.

proton-proton chain until the triple-alpha reactions generate a small amount of C^{12} toward the end of Hydrogen-burning phase. Core-helium burning begins in a slightly degenerate, small convetive core while the star in the blue region of the H-R diagram (Point E). During Core-helium burning the star first evolves to the blue to some maximum temperature (Point F), then proceeds to the right direction, but stays in the blue region until the complete core-helium exhaustion phase (Point G). This is contrary to the situation of a normal star of $3M_\odot$, in which helium burning starts in a larger convective core when the star reaches the tip of the red-giant branch in the evolutionary track (point E'). Therefore, the first convective dredge-up process which takes place during the climb up the red giant branch before core helium ignition, largely effects the surface abundances. (Becker and Iben, 1979,1980). On the other hand, a first generation star with the same mass does not experience the first dredge-up phase, hence no surface abundance changes occur before core-helium burning phase.

In the evolution of a first-generation star of $3M_\odot$, following helium-exhaustion, core contraction is accompanied by envelope contraction. Increased temperature and density at the center of the star favor the emission of neutrinos at that stage of the evolution. This prevents the increase of the energy generation rate in the helium-burning shell. Due to high temperature prevailing inside the star hydrogen-burning shell quite active and largely responsible for the outflow of the energy up to the point 2. The evolutionary track starts to move to the red giant region in the H-R diagram as the strength of helium shell grows and hydrogen burning shell weakens. During the evolution from blue to red, envelope steadily deepens and covers about 30 % of the outer star's mass, when the rate of energy generation in helium-burning shell attains its maximum value, at the point 5. Rapid formation of C^{12} during the high rate of energy generation in the helium burning shell makes the energy production via CN-cycle reaction in the hydrogen-burning shell to become pronounced. The evolution proceed on the asymptotic giant branch up to the point 7 at which the rate of energy generation by the CN-cycle reactions attains its maximum value. As the helium-burning shell declines in strength the energy generation in the hydrogen-burning shell becomes the main source of energy generation in the star, the evolutionary track turns to the left.

On the contrary of the evolution of normal stars, as the hydrogen burning shell becomes the main source of energy for the second time, the evolution does not proceed on the asymptotic giant branch; the star only experiences an abbreviated second dredge-up phase, while hydrogen burning can occur via CN-cycle reactions in the hydrogen-burning shell. However the convective envelope never reaches into the region of variable hydrogen abundance.Therefore, there is no change in surface composition as a consequence of the second dredge-up phase which takes place during short climb up the asymptotic giant branch. Once the hydrogen burning by the p-p chain reaction mostly become responsible for the energy flux in the shell and as the shell moves toward larger mass fractions, the evolutionary track follows horizontal path toward the leftward direction in the H-R diagram until the rate of energy generation by the p-p chain reactionsreaches its maximum value (Point 11). After the point 9, the hydrogen-burning shell is constantly becoming thinner and helium burning rate becomes strong enough to produce a convective region in the upper part of the helium burning shell. The first major thermal pulse appears at the point 9.

In the evolution of normal stars with the same mass, following helium exhaustion, the path followed in the H-R diagram is from blue to red with luminosity L reaching a minimum value at the point 1'. The star, then, begins its ascent of the asymptotic giant branch. The rate of energy generation in the helium-burning shell reaches its maximum value at the point 5'. (Corresponding to the point 5). From there on, helium-burning shell declines in strength, but evolutionary path proceeds on the asymptotic giant branch. The base of the convective envelope starts to move outward in mass at the point 7'. The first major thermal pulse appears at the point 9'. Third dredge-up phase occurs during that part of evolutionary track.It should be noted that the properties of the model at the occurence of the first major thermal pulse are quite different from that of the first-generation star. (See Ezer,1981). The internal structure and location of the first generation star in the H-R diagram during the occurence of the third dredge-up phase suggest that following each helium shell flash any significant amount of He^4 and C^{12} would possibly not convected to the surface.

The evolutionary behaviour of the first generation stars should be properly taken into account for the further evolutionary study of the star. Such a study might effect the occurence of heavy-element enrichment in the helium zones of the stars and the nucleosynthetic yield in the study of the chemical evolution of the Galaxy.

References

Becker,S.A.,Iben,I.Jr.,and Tuggle,R.S.:1977,Ap.J.218,pp.633-653
Becker,S.A.,and Iben,I.Jr.,:1979,Ap.J.232,pp.831-853
Becker,S.A.,and Iben,I.Jr.,:1980,Ap.J.237,pp.111-129
El,Eid,M.F.,Fricke,K.J.,and Ober,W.W.,:1983,Astr.Ap.119,pp.54-60
Ezer,D.,and Cameron,A.G.W.,:1971,Ap.Spa.Sci.10,pp.52-70
Ezer,D.:1972, Ap.Sp.Sci.18,pp.226-245
Ezer-Eryurt,D.:1981, Ap.Sp.Sci.79, pp.265-287
Guenther,D.B., and Demarque,P.:1983,Ast.Ap.118,pp.262-266.

DISCUSSION

Becker: I wonder if the author has an explanation why her model evolves off the asymptotic giant branch shortly after it reaches the double-shell burning phase?

Eryurt-Ezer: Hydrogen-shell burning occurs via p-p chain reactions and CN-cycle reactions. Evolution proceeds on the asymptotic giant branch as the hydrogen-burning shell source is dominating energy source for the star in which the carbon cycle being more dominant over the proton-proton chain. But the operation of CN-cycle depends on the formation of ^{12}C by the 3α-reactions in the evolution of the first giant stars. While the shells move toward the larger mass fractions, the carbon amount formed by the 3α-reactions abruptly decreases, hence the amount of energy generation by the CN-cycle reactions. As the low temperature-sensitive p-p chain reactions becomes main source of energy generation in the shell, the star evolves off the asymptotic giant branch.

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