EVOLUTION OF A 30 $M_\odot$ STAR WITH MASS LOSS

H. J. Falk and R. Mitalas
University of Western Ontario

ABSTRACT. Evolutionary tracks for a 30 $M_\odot$ star with mass loss rates (0.0, 1.0, 2.5, 5.0, 10.0)x10^{-7} $\dot{M}_\odot$/yr have been calculated. The effect of the different rates on the main sequence lifetime and on the effective temperature of the core He burning is discussed.

Evolutionary calculations employing the Schwarzschild convective stability criterion indicate that constant mass stars more massive than 15 $M_\odot$ begin core He burning as blue supergiants (BSG). The stars then evolve redward on a nuclear timescale, becoming red supergiants (RSG) only in the last phases of core helium burning (Simpson, 1971; Stothers and Chin, 1976). Helium ignition as a BSG is attributed to the H burning shell encountering a convective shell which appears just beyond the hydrogen exhausted region (Iben, 1966; Barbaro et al. 1971). Since mass loss affects the convective stability of the regions outside the burning core (Chiosi and Nasi, 1974; Chiosi et al. 1978), it is pertinent to investigate the effects of mass loss on this convective shell and on the stars' position in the HR diagram during core helium burning.

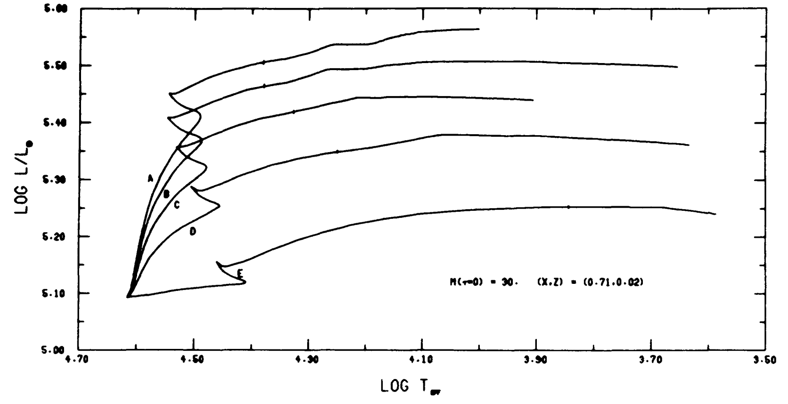

Fig. 1 Theoretical HR diagram for 30 $M_\odot$ star with initial mass loss rates of (0.0, 1.0, 2.5, 5.0, 10.0)x10^{-7} $M_\odot$/yr for tracks A,B,C,D,E,

P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 371–374.

respectively. Core He ignition is indicated by a tick on each track.

Evolutionary tracks with different initial mass loss rates were constructed for a star with initial mass of 30 $M_\odot$ and $(X,Z)=(0.71,0.02)$. The Schwarzschild criterion for convective stability was used; semi-convection was treated in a manner similar to that of Robertson (1972). McCrea's (1962) mass loss algorithm, $\dot{M}=kLR/M$, was adopted, where k was chosen to give the desired mass loss rate on the ZAMS.

Fig. 1 shows the evolutionary tracks for the 5 different initial mass loss rates listed in table 1. As shown by Chiosi and Nasi (1974), de Loore et al. (1977), and Chiosi et al. (1978) the tracks become

TABLE 1

Track	Main Sequence						Helium Ignition			Final Model			
	$\dot{M}$ (10^{-7} $M_\odot$/yr)	τ_{ms} (10^{+6} yr)	$\frac{M}{M_\odot}$	Semi-convection	X_{sc}	$\frac{M_{sh}}{M_\odot}$	τ (10^{+6} yr)	$\frac{M}{M_\odot}$	Log T_{eff}	$\frac{M}{M_\odot}$	Y_c	Log T_{eff}	$\dot{M}$ (10^{-6} $M_\odot$/yr
A	0.0	5.804	30.00	Important	0.44	9.609	5.808	30.00	4.379	30.00	.096	4.002	0.0
B	1.0	5.707	28.66	Important	0.43	8.798	5.710	28.66	4.380	22.98	0.024	3.654	4.8
C	2.5	5.677	26.87	Still significant	0.41	8.194	5.680	26.87	4.328	20.77	0.322	3.897	3.6
D	5.0	5.734	23.89	Not important	0.34	7.455	5.738	23.87	4.251	19.15	0.899	3.634	20.
E	10.0	6.093	17.51	Totally unimportant	0.22	6.089	6.099	17.38	3.845	17.17	.980	3.585	37.

less luminous as the mass loss rates increase, due to the decreasing mass of the star. The final masses after the hydrogen burning phase for each track appear in column 4 to illustrate the amount of the main sequence mass loss associated with each initial rate. Because the luminosity is reduced in mass losing stars, the rate of hydrogen consumption is also decreased. Hence, one would expect the main sequence lifetime (τ_{ms}) to increase. However, as shown in table 1, this is not exactly true. With small mass loss rates, τ_{ms} actually decreases while for large rates it increases. The semiconvective zone, which is attached to the convective core during most of the core H burning phase, adds hydrogen to the burning region and thus extends the τ_{ms}. The de-creasing importance of semiconvection as higher mass loss rates are imposed is manifested in a decrease in τ_{ms}. For the 30 $M_\odot$ case, it was

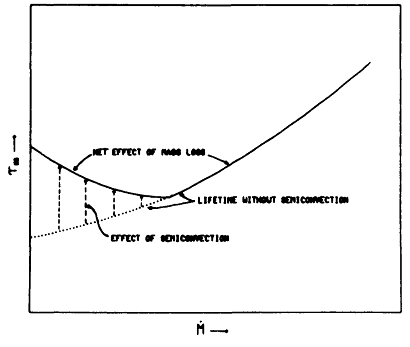

Fig. 2 Schematic illustration of the effects of semiconvection and mass loss on the main sequence lifetime.

https://doi.org/10.1017/S0074180900013747 Published online by Cambridge University Press

found that for mass loss rates greater than about 5.0×10^{-7} $M_\odot$/yr, semiconvection was completely suppressed. The competing effects of semiconvection and mass loss are illustrated schematically in fig. 2.

The hydrogen abundance of the convective shell which breaks out at the end of core hydrogen burning is listed in column 6. The effect of mass loss on the convective shell is shown in the reduced hydrogen abundance. The mass position of the hydrogen shell source at the time of He ignition is also listed.

Following core H exhaustion, the low mass loss rate models (tracks A,B,C) evolve redward in non-thermal equilibrium with the hydrogen shell source locked onto the H discontinuity formed by the convective shell. These stars ignite He as BSGs. Then they evolve to the red on a nuclear timescale, becoming RSGs only at the end of core He burning. Evolution for a 30 $M_\odot$ star with low initial mass loss rates ($\leq 2.5 \times 10^{-7}$ $M_\odot$/yr) behaves much the same as for the constant mass star, except for the occurence of He ignition at a slightly lower effective temperature. The relation between thermal balance and the location of the H burning shell in a massive star as it crosses the HR diagram has been discussed by Barbaro et al. (1971). For the highest mass loss rates (track E) the models never achieve thermal equilibrium as blue or yellow supergiants. These stars evolve across the HR diagram on a thermal timescale and ignite He as RSGs. The hydrogen shell source approaches but never reaches the compostion discontinuity of the convective shell before the stars become RSGs. They will remain RSGs during core He burning unless blue loops occur. Track D is an intermediate case. With this mass loss rate, a star ignites He as a BSG, like the lower mass loss rate stars. However, subsequently it evolves across the HR diagram on a timescale between the thermal and nuclear timescales.

REFERENCES

Barbaro G., Chiosi C., and Nobili L. 1971, Proceedings of the Trieste Colloquium on Supergiant Stars. Ed. M. Hack, p.334.
Chiosi C. and Nasi E. 1974, Astron.Astrophys. 34, p.355.
Chiosi C., Nasi E. and Sreenivasan R. 1978, Astron.Astrophys. 63, p.103.
de Loore C., de Greve J.P., Lamers H.J.G.L.M. 1977, Astron.Astrophys. 61, p.251.
Iben I. 1966, Astrophys. J. 143, p.516.
McCrea W. H. 1962, Astron. J. 71, p.172.
Robertson J. 1972, Astrophy. J. 177, p.473.
Simpson E. 1971, Astrophys. J. 165, p.295.
Stothers R. and Chin C.-w. 1976, Astrophys. J. 204, p.470.

DISCUSSION FOLLOWING FALK and MITALAS

Underhill: How do your results compare with those of Hartwick who used a similar method for a 15 $M_{\odot}$ star?

Chiosi: Perhaps I could reply to this remark by Dr. Underhill. The reason why the present results differ from those of Hartwick (1967) although they both assume the same mass loss rate dependence, can be explained by comparing the time scale involved in mass loss and the evolutionary time scale. The results in fact do not depend on the mass loss dependence but rather on both the amount of mass removed from the star and the evolutionary stage in which most of the mass loss occurs. A too huge mass loss causes in models of not high central concentration a strong decrease of the luminosity, as shown by Hartwick. An empirical reasoning suggests that for any given initial mass only mass loss rates below some critical value are allowed if we wish to fit the models to a number of observational constraints (a strong decrease of the luminosity seems in fact to be unnecessary). In this sense the present results are consistent with the old ones.

Dearborn: Is the slight decrease in main-sequence time scale in your models with a low rate of mass loss due to the size of the convective core decreasing more rapidly than the luminosity?

Falk: No. While the decreasing convective core mass with increasing mass loss rate will cause a decrease in τ_{ms}, the accompanying luminosity reduction is more important, so that the τ_{ms} increases. Calculations show that for models at the same time, but with different mass loss rates (hence different masses), the ratio of convective core mass to total mass is the same; that is, the core mass changes at the same rate as the stellar mass. Since τ_{ms} is roughly proportional to the convective core mass and inversely proportional to the luminosity which varies as the cube of the total mass, the net effect of mass loss alone is to increase τ_{ms}. Therefore the decrease of τ_{ms} at the low mass loss rates is due to the lessening importance of semi-convection as the mass loss rate increases.