THE ROLE OF THE RADIATION PRESSURE GRADIENT IN GIANT AND SUPERGIANT STAR EVOLUTION

Wendee M. Brunish, Arthur N. Cox, Stephen A. Becker,
and Keith H. Despain
Los Alamos National Laboratory,
Los Alamos, New Mexico 87545

Since some of the earliest evolutionary calculations it has been found that post main sequence stars become red giants (e.g. Sandage and Schwarzschild, 1952). However the exact physical processes that lead to and determine the rate of redward evolution are not completely understood.

We hypothesized that the redward evolution might be due to an increase in radiation pressure somewhere in the star that causes the layers above it to be pushed outward, resulting in an expanded envelope and a cooler surface temperature. If the radiative luminosity somewhere in the star approached the Eddington limit, the outer layers would obviously expand. However, due to the presence of gas pressure, the critical value for expansion would be somewhat less than the Eddington limit.

We define the ratio of the radiative luminosity to the critical Eddington luminosity δ, where

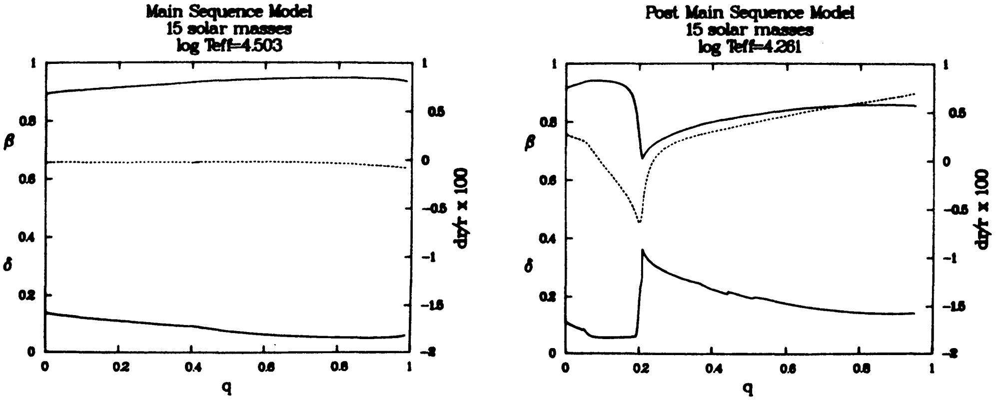
$$\delta(r) = \frac{L_{rad}(r)}{L_{crit}(r)} = \frac{L_{rad}(r)\ K(r)}{4\pi cG\ M(r)} .$$

Presumably, then, when δ somewhere in the star reaches some critical value, δ_{max}, the layers above it will expand.

We found that the maximum value of δ increased with the initial mass of the star, which is understandable since $\beta = (P_{gas}/P)$ decreases and radiation pressure plays a larger role (see Table 1). In massive stars, ($M_i \geq 15\ M_\odot$) a sharp increase in δ appeared shortly after hydrogen exhaustion in the core. The position of the increase coincided with the base of the convective shell which is associated with hydrogen burning shell. Also, this behaviour coincided with a change in sign of the slope of dr/r (the change in radius) as the contraction slowed and began to turn around due to the increased radiation pressure (see Figure 1).

A. Maeder and A. Renzini (eds.), Observational Tests of the Stellar Evolution Theory, 89–91.

https://doi.org/10.1017/S007418090003059X Published online by Cambridge University Press



Figures 1a and b. Plotted are β, δ and dr/r × 100 versus mass fraction q for a 15 $M_{\odot}$ main sequence and post main sequence models. The upper solid curve is β and the lower solid curve is δ. The dotted (center) curve represents dr/r × 100.

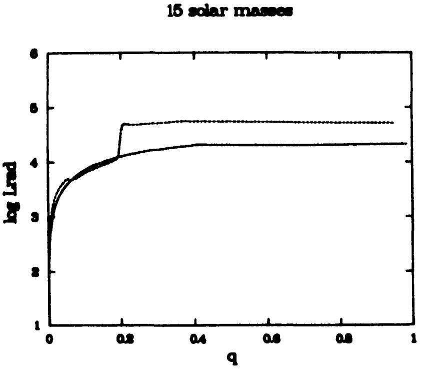


Figure 2. The log of the radiative luminosity plotted versus mass fraction q for 15 $M_{\odot}$ models. The solid line shows the luminosity profile for the main sequence model (log T_{eff} = 4.503) while the dashed line represents the post main sequence profile (log T_{eff} = 4.261).

https://doi.org/10.1017/S007418090003059X Published online by Cambridge University Press

Table 1

M_i	(X_i, Z_i)	$\dot{M}_{ave}$ $(10^{-6}$ $M_\odot/yr)$	δ_{max}
40 $M_\odot$	(0.70, 0.02)	0.0	0.652
40 $M_\odot$	(0.70, 0.02)	2.3	0.536
20 $M_\odot$	(0.70, 0.02)	0.11	0.440
15 $M_\odot$	(0.70, 0.02)	0.0	0.369
15 $M_\odot$	(0.70, 0.02)	0.032	0.363
15 $M_\odot$	(0.69, 0.03)	0.011	0.346
15 $M_\odot$	(0.78, 0.02)	0.020	0.314
15 $M_\odot$	(0.799, 0.001)	0.060	0.309
9 $M_\odot$	(0.78, 0.02)	0.0	0.110
6 $M_\odot$	(0.70, 0.02)	0.0	0.05
0.6 $M_\odot$	(0.749, 0.001)	0.0	0.001

In stars with a high mass loss rate, when the mass of the hydrogen exhausted core exceeds some critical value, the peak in δ disappears and the star contracts and returns to the blue.

In low and intermediate mass stars the peak (though much smaller) in δ still appears and also coincides with the base of the hydrogen burning shell. However in intermediate mass stars undergoing blue loops, the peak in δ does not disappear (or even become smaller). We must conclude that in these stars radiation pressure does not play a critical role and that gas pressure may be much more important.

The increased energy generation due to the combination of the contraction of the hydrogen exhausted core and ignition of the hydrogen burning shell leads to a sharp rise in the radiative luminosity (see Figure 2). We are investigating further how the physical conditions (i.e. pressure, temperature, density) in the interior cause this and how they affect the rate of redward evolution and subsequent blueward evolution in massive stars with high rates of mass loss.

Reference

A. Sandage and M. Schwartzschild, 1952, Ap. J. 116, 463.