STELLAR EVOLUTION WITH TURBULENT DIFFUSION MIXING IN LOW MASS STARS AND $^{12}C/^{13}C$ RATIO IN GIANTS OF THE FIRST ASCENDING BRANCH

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We consider stellar evolution in low mass stars (1-3 M_o) near the main sequence with the hypothesis that mild turbulence is present within the all star. Turbulent transport of the elements is modeled by diffusion equations where the diffusion coefficient is chosen to be $D = R_e^* \nu$ where ν is the kinematical viscosity and R_e^* is a Reynolds number. We consider the effects of the growth of the gradient of the mean molecular weight on turbulence. The main consequences of diffusion on stellar evolution are (1) an increase of the life time near the main sequence and (2) a change of the radial distributions of chemical species (^{12}C, ^{13}C, ^{14}N, ^{16}O) (figure 1). The inhibition of the turbulence, when the gradient of mean molecular weight reaches a certain critical value, allows the evolution towards the red giant branch. When stars evolve towards the giant branch, chemical species are dredged up to the surface. At this stage models with and without diffusion, predict substantially different surface abundances (in particular the $^{12}C/^{13}C$ and C/N ratios). Comparison between models and the available data on giants during the first dredge-up show that abundance anomalies can be explained if turbulent mixing is present during the main sequence phase (figure 2).

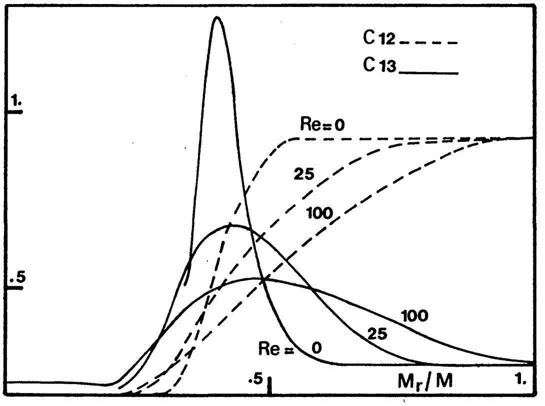

Figure 1. ^{12}C and ^{13}C abundances (in mass fraction) in 1.5 M_o models at T = 1.69 10^9 years for different mixing strength R_e^* = 0, 25, 100.

A. Maeder and A. Renzini (eds.), Observational Tests of the Stellar Evolution Theory, 525–527.

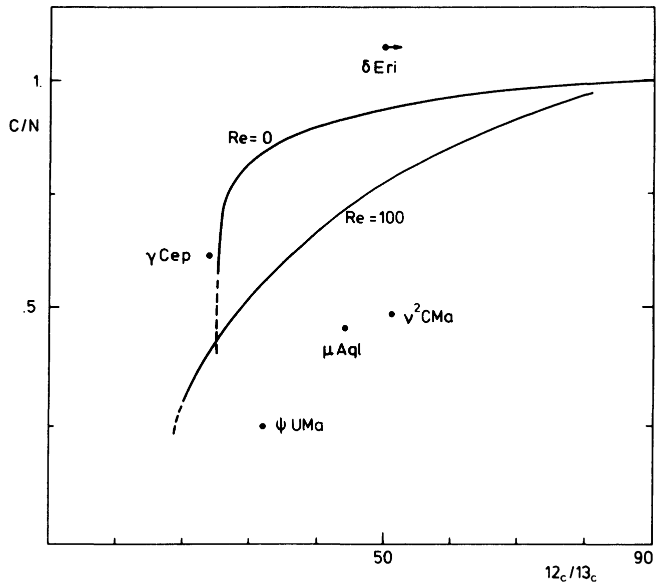

Figure 2. Evolution tracks from the end of the main sequence to the top of the AGB for our 1.5 M_O models. The tracks give the C/N ratios normalized to the solar value versus $^{12}C/^{13}C$ ratios that would be observed at the surface of 1.5 M_O stars for two hypothesis of mixing ($R_e^* = 0$ and 100). Stars plotted are subgiants observed by Lambert et al. (1981).

Bienaymé, O., Maeder, A., Schatzman, E.: 1983, Astron. Astrophys. preprint.

Lambert, D.L., and Ries, L.M.: 1981, Astrophys. J. 248, p. 228.

DISCUSSION

R. Cayrel: If you put the right amount of turbulent diffusion to obtain the observed neutrino emission in the sun, by how much do you increase the life-time of the star on the main-sequence? (in relation with the age of globular clusters compared to the age of the Universe).

Maeder: Among the cases we have computed the one with $R_e^* = 100$ has an MS lifetime of 15 billion years. However, this value of R_e^* is probably too high; for a value of $R_e^* \leqslant 50$, more compatible with observations the increase of the MS lifetime is probably smaller than 30 %.

Cannon: I too would like to know how much the turbulence increases the lifetimes of near main-sequence stars, and whether this makes a discrepancy with the observed numbers of stars in old open clusters?

Maeder: (See answer to Cayrel for the first part of the question).
2) On the contrary, turbulent diffusion may improve the agreement with observations. In particular, stars where turbulent diffusion is always strongly active (due for example to their high differential rotation) may become blue stragglers, objects which have not received any satisfactory physical explanation so far. An important problem remains the determination of when in the course of evolution the μ-gradient is sufficient (for a given degree of differential rotation) to avoid turbulent diffusion and thus allow small mass stars to become red giants. For stars more massive than 1.5 $M_\odot$, there is no problem because the MS lifetime becomes smaller than the characteristic time of turbulent diffusion. But below 1.5 $M_\odot$ it seems that we could have two kinds of evolutionary sequences: one in which turbulent diffusion remains active throughout and leads to blue stragglers, the other in which diffusion is very mild and stopped some time by the μ-gradient which would lead to standard red giant evolution. All the comparisons with observations will of course depend on the exact criterion for the existence or non-existence of turbulent diffusion.

Tayler: Why did you take your turbulent viscosity to be some multiple of the radiative viscosity rather than some multiple of the product of speed of sound and pressure scale height which would depend differently on ρ and T?

Schatzman: The answer can be found in my review paper as well as in the references quoted.