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The mixing-length parameter, α, for low-mass stars

J. Fernandes [1,2], Y. Lebreton [1] and A. Baglin [1]

[1] *Observatoire de Paris, DASGAL, URA CNRS 335, 92195 Meudon, France*

[2] *Centro de Astrofísica da Universidade do Porto, 4200 Porto, Portugal*

1. Convective flux in low-mass stars

The energy transport in the stellar envelope of low-mass stars is mainly due to convection. In this work we will concentrate on the external region of the envelope : the super-adiabatic region.
In the mixing length theory description of convection (MLT), the energy flux is given by (Cox & Giuli, 1968),

$$F_{conv} = \frac{16\sigma T^4 g}{3\kappa P}\frac{9}{32\mathcal{A}^2}\left[\sqrt{1+4\mathcal{A}^2(\nabla-\nabla_{ad})}-1\right]^3 \quad where \quad \mathcal{A} = \frac{Q^{1/2}c_p\kappa g\rho^{5/2}\Lambda^2}{48\sqrt{2}\sigma P^{1/2}T^3}$$

The current nomenclature is used for $Q, P, T, \rho, \nabla, \kappa, g, c_p$ and σ. $\mathcal{A}$ is the ratio of the convective and radiative conductivities and is proportional to the convective efficiency. Λ is the mixing length, currently defined as $\Lambda = \alpha \times H_p$ where H_p is the pressure scale height and α is the MLT parameter.
In homological approximation for low-mass stars, $\mathcal{A}$ can be written as $\mathcal{A} \sim (\frac{\mathcal{M}}{\mathcal{M}_\odot})^{-5} \times \alpha^2$. Then for the lowest masses, $\mathcal{A}$ becomes infinite and the convective flux reaches a limit $F_{conv/Max}$ (Figure ??) such as,

$$\frac{F_{conv}}{F_{conv/Max}} = \left(\frac{\sqrt{1+\mathcal{X}^2\alpha^4}-1}{\mathcal{X}\alpha^2}\right)^3 \quad and \quad \mathcal{X} \sim \left(\frac{\mathcal{M}}{\mathcal{M}_\odot}\right)^{-5}$$

2. Testing the α-value for lox mass stars

The solar calibration in the HR diagram indicates that $\alpha \approx 1.7$. Is this α-value the same for other stars ? Is α dependent on mass ?
It is known that if the α value is changed, the effective temperature of the stellar model is changed but the luminosity is only slightly modified. Moreover Figure ?? indicates that the sensitivity to α decreases with decreasing mass. For masses lower than $\approx 0.4\mathcal{M}_\odot$ the convective envelope is fully adiabatic : the location in the HR diagram is independent of α. So,

- The slope of ZAMS obtained with different values of α differ (Chieffi et al. 1995);
- The ZAMS shape is modified if an hypothetical dependence of α with mass is assumed on a given ZAMS (Figure ??).

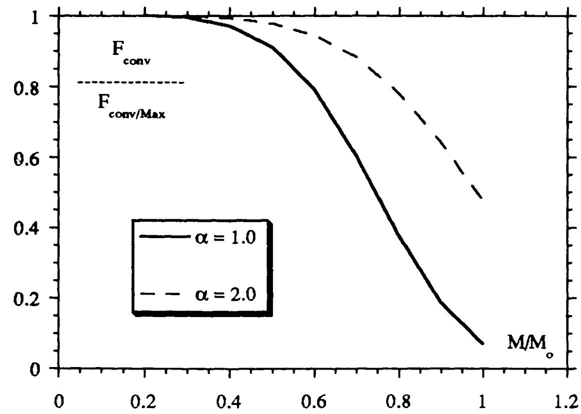

Figure 1. $\frac{F_{conv}}{F_{conv/Max}}$ as function of $\mathcal{M}/\mathcal{M}_\odot$ for α=1 (solid line) and α=2 (dashed line)

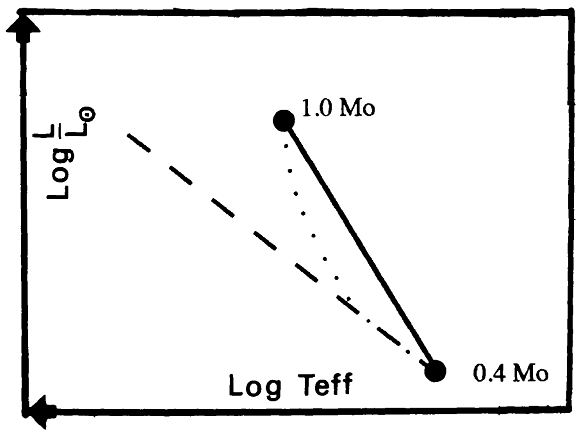

Figure 2. HR location sensitivity to α changes. ZAMS with $\alpha = \alpha_\odot$ (solid line), ZAMS with $\alpha \geq \alpha_\odot$ (dashed line) and ZAMS with $\alpha = \alpha_\odot \times (\frac{\mathcal{M}}{\mathcal{M}_\odot})^{-1}$ (dotted line)

The α value and its mass dependence could be tested if the observational ZAMS line was known through precise observations of mass, metallicity and HR diagram location of individual stars, such as nearby visual binary stars (see also Noels et al. 1991).

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References

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