ROTATING STELLAR MODELS AND LITHIUM DEPLETION

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ABSTRACT. The ATON stellar evolution code has been modified to include rotation, in the approximation by Endal & Sofia (1976). As a preliminary application of this improved code, we have run some rotating stellar models to investigate the effects of rotation on the Lithium depletion of low mass, pre-main sequence stars. The models were run with rigid body rotation, no angular momentum loss and redistribution, and under two prescriptions for convection, namely the mixing length theory [MLT] and the turbulent convection model by Canuto & Mazzitelli (1991) [CM]. The calculations show that rotation *increases* the Lithium depletion for both MLT and CM, a result which is expected from the theory since rotating stars behave as non-rotating stars of lower mass and so must experience greater lithium depletion. This result shows that some other parameter controls lithium depletion in pre-main sequence stars, as it is necessary to explain the observational data on low mass, pre-main sequence stars such as those from the Pleiades (García López *et al.* 1994) and the α-Persei clusters (Balachandran *et al.* 1988, 1996).

1. Introduction

The ATON stellar structure code (Mazzitelli 1989) has been modified in order to introduce rotation. We chose to follow the approach taken by Endal & Sofia (1976), which in turn adopts the Kippenhahn & Thomas (1970) method with an improved potential function that includes a third term related to the distortion of the figure of the star. Three rotation laws have been implemented, namely: rigid body rotation, local conservation of angular momentum throughout the whole star, and local conservation of angular momentum in radiative regions and rigid body rotation in convective ones. For all three rotation laws, our results confirm earlier findings from other researchers (e.g. Sackmann 1970; Pinsonneault *et al.* 1989; Martín & Claret 1996): the evolutionary tracks of rotating stars shift towards lower effective temperatures and luminosities, simulating the evolutionary path of a non-rotating star of lower mass (the so-called *mass-lowering effect*; see Sackmann 1970). However, we have also found that these differences are very small, being considerable only for high initial angular momentum. Figure 1 shows the evolutionary tracks of a 1.0 $M_\odot$ with solar chemical composition, for both rotating (with rigid body rotation) and non-rotating cases.

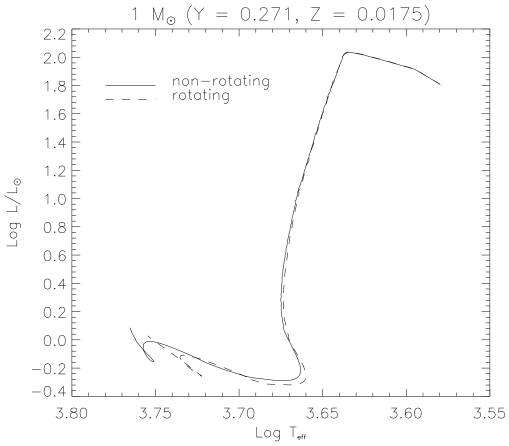

Fig. 1. Evolutionary tracks for rotating and non-rotating models of 1 $M_\odot$. The convection model is that from Canuto & Mazzitelli (1990, 1992), and the initial angular momentum is 3.93×10^{50} g cm^2 s^{-1}.

2. Lithium depletion and rotation

The nowadays observational picture indicates that lithium depletion on low mass, pre-main sequence stars is related to rotation in such a way that rapid rotators have smaller lithium depletion than slow rotators (Balachandran *et al.* 1988, 1996; García López *et al.* 1994; Cunha *et al.* 1995). On the theoretical side, so far very few attempts have been made to include rotation in evolutionary codes, and even less to check the effects of rotation on lithium depletion. Pinsonneault *et al.* (1990) have found that rotation increases the lithium depletion, while Martín & Claret (1996) claimed that their rotating models deplete less lithium than the non-rotating ones, in accordance to the observational picture. As these theoretical models are conflicting, it is important indeed to sort out whether the structural differences between the rotating and non-rotating models work towards confirming the observational constraints or not. In the latter case, the differences in lithium depletion must be entirely attributed to the phases of angular momentum transport and associated chemical mixing.

As a preliminary application of the ATON code with its new feature, we have run a series of rotating models of 1.2, 1.1, 1.0, 0.9 and 0.8 solar masses to check the structural effects of rotation on the lithium depletion of low mass, pre-main sequence stars. The input physics used for the models is as follows. The opacities were taken from Iglesias & Rogers (1993), supplemented by those at low and intermediate temperatures from Alexander & Ferguson (1994) or Kurucz (1993). The chemical composition was set to Y = 0.271, Z = 0.0175. For the convection treatment we have used both the mixing length theory (MLT), with $\alpha = 1.5$, and the turbulent convection model of Canuto & Mazzitelli (1991, 1992) (CM). For comparison purposes, we have chosen rigid body rotation with initial angular momentum estimated according to the relations given by Kawaler (1987) for stars of spectral type later than F2.

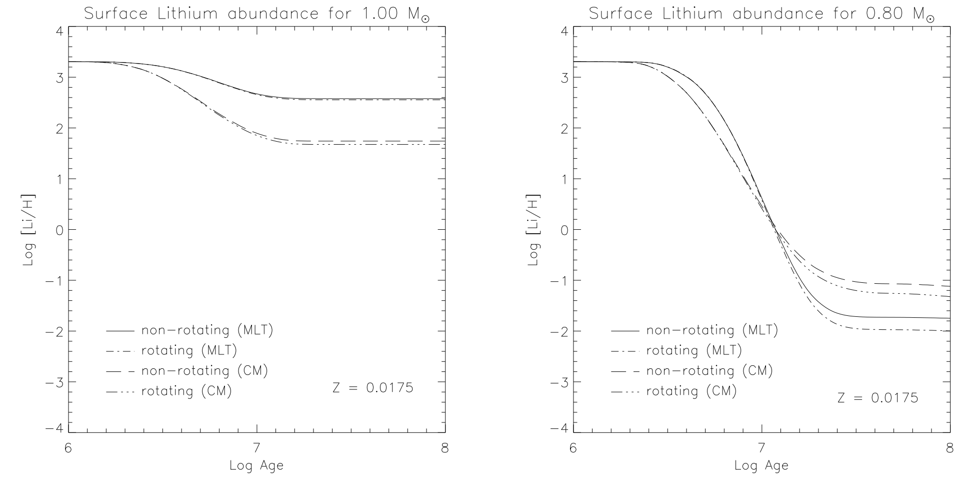

Fig. 2. Lithium depletion as function of age for masses of 1.0 $M_\odot$ (left) and 0.80 $M_\odot$ (right) with a metallicity of Z = 0.0175.

3. Main results and discussion

Figure 2 shows the run of lithium concentration (in the scale $N[\mathrm{Li}] = 12 + \log \frac{N[\mathrm{Li}]}{N[\mathrm{H}]}$) as a function of age, for 1.0 and 0.8 $M_\odot$. The initial lithium abundance was set to $\log N[\mathrm{Li}] = 3.31$. We see that rotation indeed *increases* the lithium depletion. Since lithium burning is a function of the temperature at the bottom of the convective envelope, greater depletion means higher temperatures, and we can see from figure 3 that actually this is the case.

Martin & Claret (1996) attributed the differences of their results, with respect to those of Pinsonneault *et al.* (1990), mainly to the adopted opacities, as the latter authors used the older Cox & Stewart (1970) libraries. However our results – obtained with updated opacities – are qualitatively similar to those of Pinsonneault *et al.* . We cannot trace back why the results of Martin & Claret differ from ours and from those of Pinsonneault *et al.* but we stress that (1) rotation cannot, by itself, *reduce* lithium depletion, and (2) recent opacities *increase* lithium depletion in both standard (non-rotating) and non-standard (rotating) models. These facts, and the need to fit the observational constraints, lead us to conclude that other physical mechanisms must play a role.

If *structural* effects are to be looked for, it seems worthy recalling that we do not consider the effect of the dynamo-induced magnetic field on the convection. It is possible that the larger field induced in rapid rotators inhibit turbulent mixing (Spruit 1987).

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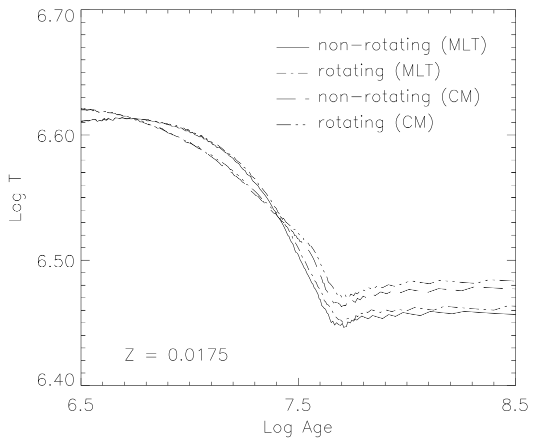

Fig. 3. Temperature at the bottom of the convective region for rotating and non-rotating models of 0.8 $M_\odot$.

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