Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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Rotating and magnetic stellar models of intermediate-mass stars up to the AGB

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Abstract. Aiming at investigating the roles of rotation and magnetic fields on AGB stars, the rotating version of the `ATON` stellar evolution code is being extended in order to account for intermediate--mass stars and their later evolutionary stages. Here we report some preliminary results on the effects of rotation and of a large-scale magnetic field on the structure and evolution of 3 and 5 $M_\odot$ stellar models from the pre-main sequence up to the AGB.

Keywords. stars: rotation, stars: magnetic fields, stars: AGB and post-AGB

1. Introduction and Methods

Rotation and magnetic fields can play an important role on evolved low- and intermediate-mass stars. The impact of rotation-induced mixing on the nucleosynthesis, and the driving of the cool bottom processing episode in asymptotic giant branch (AGB) stars are some examples of topics respectively related to those physical properties. To address these issues, the rotating version of the `ATON` stellar evolution code (Ventura *et al.* 1998) is being extended to deal with intermediate-mass stars and their later evolutionary stages, and also to incorporate the effects of a large-scale magnetic field.

Rotation is implemented according to the Kippenhahn & Thomas (1970) method, which essentially replaces the spherical surfaces of non-rotating models by equipotential, non-spherical ones. From these equipotential surfaces one can calculate suitable correction factors f_p and f_t that enter the stellar structure equations of hydrostatic equilibrium and of energy transport, respectively. The `ATON` code currently supports three different rotation laws: solid body rotation, differential rotation at each mass shell, and combined solid body rotation in convective regions and differential rotation in radiative ones.

As for the magnetic fields, we use the method by Lydon & Sofia (1995, hereafter LS95) which treats the magnetic field as a perturbation on the stellar structure equations, by means of a new state variable $\chi = B^2/(8\pi\rho)$ representing the magnetic energy density from which the magnetic pressure $P_\chi = (\gamma - 1)\chi\rho$ can be computed and then introduced in the equation of state. The numerical factor γ crudely commands the transition from the intrinsic 3-D magnetic field geometry to a 1-D approximation. The reader is referred to the LS95 paper for full details regarding this technique.

2. Results

We computed solar metallicity models starting from the pre-main sequence (PMS) and with $\alpha = 1.5$ for the mixing length. The initial rotation rate was taken from Kawaler's

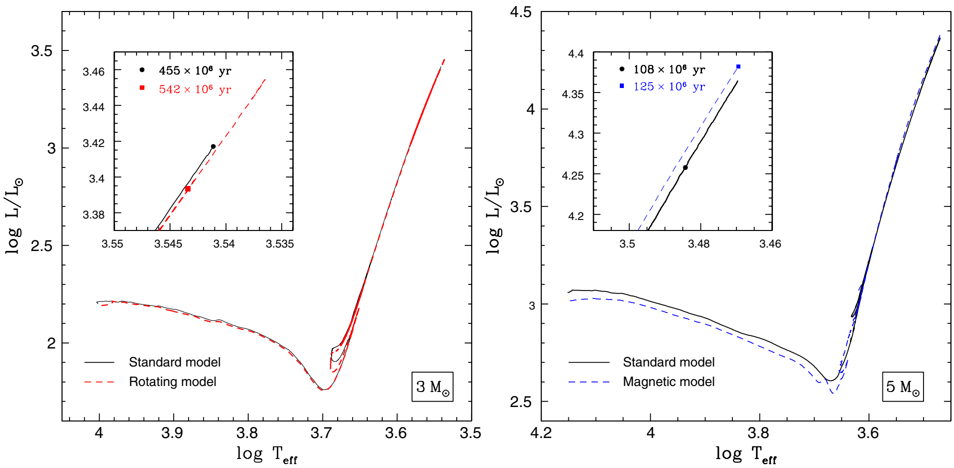

Figure 1. Rotating (left) and magnetic (right) evolutionary tracks of 3 and 5 $M_\odot$ stellar models, respectively, from the main sequence turn-off to the beginning of the AGB.

(1987) mass-radius and mass-moment of inertia relations for low- and intermediate-mass stars. Fig. 1 shows that rotation has a little effect on the evolutionary track of a 3 $M_\odot$ model; the impact of rotation in this case is even smaller than for the 1 $M_\odot$ case, discussed by Mendes *et al.* (2013). In any case, rotating models always reach the AGB at later ages and lower luminosities than standard models, independently of the chosen rotation law.

For models with a magnetic field we considered a field topology whose magnetic force component is perpendicular to the field lines ($\gamma = 2$), and with no magnetic flux associated to the convective motions. The initial surface magnetic field strength $|\mathbf{B}|_{\rm surf}$ is of order 20 G, which is sort of an "average" between the mean solar dipole field of 1 G and the kG values observed in T Tauri stars. The scaling of $|\mathbf{B}|_{\rm surf}$ throughout the stellar interior was treated according to the *constant ratio scaling* (D'Antona *et al.* 2000). As also shown in Fig. 1, the magnetic models have lower luminosities from the PMS up to the middle of the Red Giant Branch (RGB), when this situation reverses, and reach the AGB at later ages than non-magnetic ones. The value of $|\mathbf{B}|_{\rm surf}$ at this point is of order of a few tens of Gauss, which is compatible with the range of 2.2-115 G obtained for some AGB stars through H_2O maser observations (Leal-Ferreira *et al.* 2013). However, an issue with these magnetic models that needs further analysis is the too high, apparently unrealistic interior magnetic field strength (e.g. $\approx 10^{11}$ G in the case of the 5 $M_\odot$ model).

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