

Theoretical evolution of Rossby number for solar analog stars

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Abstract. Magnetic fields of late-type stars are presumably generated by a dynamo mechanism at the interface layer between the radiative interior and the outer convective zone. The Rossby number, which is related to the dynamo process, shows an observational correlation with activity. It represents the ratio between the rotation period of the star and the local convective turnover time. The former is well determined from observations but the latter is estimated by an empirical iterated function depending on the color index ($B - V$) and the mixing-length parameter. We computed the theoretical Rossby number of stellar models with the TGEC code, and analyze its evolution with time during the main sequence. We estimated a function for the local convective turnover time corresponding to a mixing-length parameter inferred from a solar model, and compare our results to the estimated Rossby number of 33 solar analogs and twins, observed with the spectropolarimeters ESPaDOnS@CFHT and Narval@LBT.

Keywords. solar analogs, magnetic field, Rossby number

1. Evolutionary models

Stellar evolution calculations were computed with the Toulouse-Geneva stellar evolution code TGEC. Details of the input physics used in our models can be found in do Nascimento *et al.* (2013). The evolution of the angular momentum is calculated with the Kawaler (1988) law, and for the initial rotation rates, we adopted the relation (3) in Landin *et al.* (2010). The calibration method of the models is based on the Richard *et al.* (2004) prescription: a solar model is calibrated to match the observed solar radius and luminosity at the solar age. The parameter K of the angular momentum evolution law is adjusted to give the solar rotation period ($P_{\text{rot}} = 27.1$ d) at the solar age. Evolutionary models of masses 0.81, 0.85, 0.90, 0.95, 1.00, 1.05, and 1.10 M_{\odot} were calculated from the ZAMS to the top of the RGB. The input parameters for the other masses are the same as for the 1.00 M_{\odot} model.

2. Stars sample

To compare with our models, we use a sample of 33 sun-like stars observed with the spectropolarimeters ESPaDOnS at the Canada-France-Hawaii Telescope (Mauna Kea, USA) and NARVAL at the T el escope Bernard Lyot (Pic du Midi, France). Longitudinal magnetic field of the stars were determined with the technique of Least-Square-Deconvolution (LSD, Donati *et al.* 1997). Rotation periods of the stars, determined from chromospheric activity, were found in the literature (Noyes *et al.* 1984, Wright *et al.* 2004, Lovis *et al.* 2011).

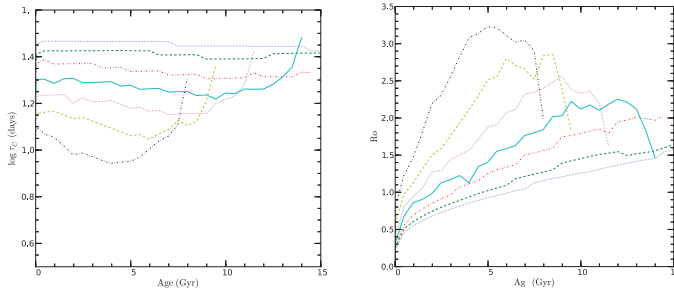


Figure 1. $\log \tau_c$ (left) and Rossby number Ro (right) as a function of age for our models of 0.81 (dotted), 0.85 (dashed), 0.90 (dot-dashed), 0.95 (continuous), 1.00 (thick dotted), 1.05 (thick dashed), and 1.10 (thick dot-dashed) M_{\odot} .

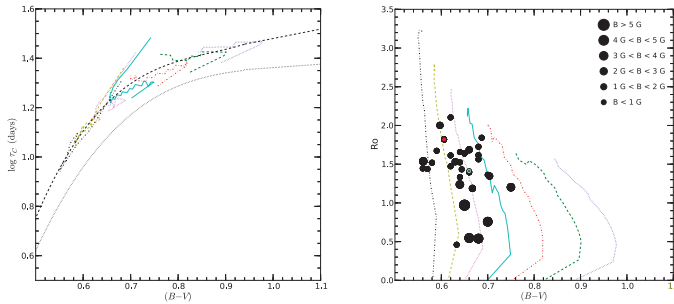


Figure 2. *Left:* $\log \tau_c$ as a function of $(B - V)$. The dashed line is the polynomial regression of the models tracks. The dotted line is the polynomial regression found by Noyes *et al.* (1984). *Right:* Rossby number Ro as a function of $(B - V)$ for our models limited to the main sequence. Filled black circles are observed stars, the size depends on the strength of the magnetic field.

3. Rossby number

For all the models, we calculated the Rossby number $Ro = P_{rot}/\tau_c$ where P_{rot} is the rotation period, and τ_c the local convective turnover time, calculated at a distance of one pressure height scale H_P above the base of the convective zone. Its value is computed through the equation $\tau_c = \alpha H_P/v$, where v is the convective velocity. In Fig. 1, we plot the evolution of $\log \tau_c$ (left panel) and Ro (right panel) as a function of the stellar age.

In the left panel of Fig. 2, we show the $\log \tau_c$ of our models as a function of $(B - V)$. A cubic fit through these curves (dashed line) defines an empirical function $\log \tau_c(B - V)$, given by: $\log \tau_c = -5.468 + 22.810(B - V) - 25.637(B - V)^2 + 9.796(B - V)^3$. From this equation, we determine the τ_c of the stars of our sample, and then a Rossby number Ro . In the right panel of Fig. 2 we plot the Rossby number as a function of $(B - V)$ for our models and for the stars of our sample, determined from the observed rotation period and the convective turnover time inferred from the above equation.

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