Determination of convective turnover times in young stars

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Abstract. We have investigated how different ways of evaluating the convective turnover time τ_{conv} may influence the relationship between X-rays emission level and Rossby number $R_0 = P_{rot}/\tau_{conv}$, using a sample of Hyades stars as a test case.

1. Computing the convective turnover time

For the aim of this work we have used and compared the convective turnover times obtained with the empirical iterated function of Noyes *et al.* (1984) for main-sequence stars, with the theoretical models computed by Kim & Demarque (1996), and with the new evolutionary models of Ventura *et al.* (1998). The evolutionary tracks of Kim & Demarque (1996), computed for $0.5 \leq M/M_{\odot} \leq 1.2$ with Z = 0.019, adopt mixing length parameter $\alpha = 1.86$, OPAL opacities (Iglesias & Rogers, 1991), Kurucz (1992) model atmospheres for boundary conditions, and use the Yale Rotating Stellar Evolution Code improved in the treatment of microscopic diffusion (Chaboyer *et al.*, 1995). The evolutionary tracks of Ventura *et al.* (1998) (ATON 2.0 code) have been computed with Y = 0.27 and Z = 0.017, using either the classical mixing-length theory of convection (**MLT**) (mixing length parameter $\alpha = 1.89$), or the new full spectrum of turbulence (**FST**) theory ($\beta = 0.1$). Local convective turnover times τ_{conv} are evaluated at a distance $R_b + \alpha H_p/2$ where R_b is the distance of the base of the convection zone from the stellar center, and H_p is the pressure scale height at $r = R_b$.

In Fig. 1 we compare the τ_{conv} obtained from the above models with the empirical ones evaluated according to Noyes *et al.* (1984), based on the correlation of mean chromospheric H-K flux ratios with rotational periods for 41 Main-Sequence stars. Different functional shapes of τ_{conv} vs. $B-V$ are predicted by the structure models with respect to the Noyes et al. empirical formula.

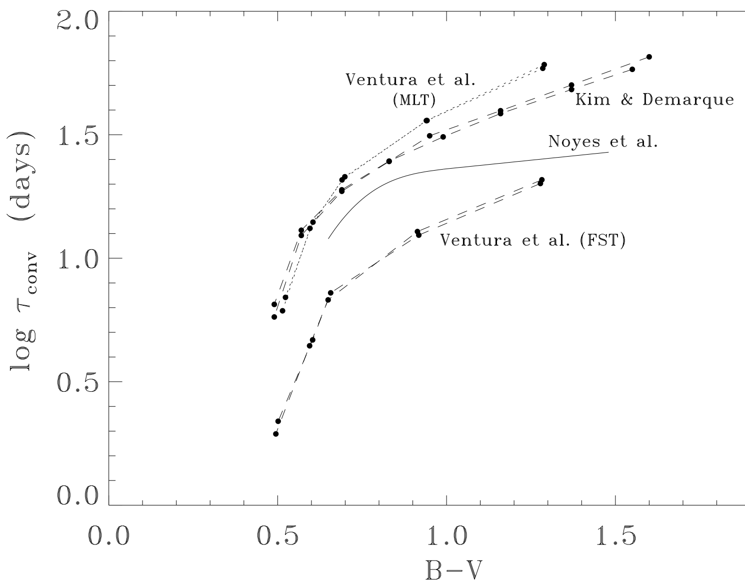

Figure 1. The convective turnover time τ_{conv} as a function of $B-V$ color, for two isochrones at $2{\cdot}10^8$ yr and 10^9 yr, according to the models of Ventura *et al.* (1998) and Kim & Demarque (1996), and according to Noyes *et al.* (1984) empirical formula.

2. The case of the Hyades cluster

To explore whether the differences in the convective turnover time can be observationally tested we have selected 37 stars in the Hyades open cluster with $0.61 \leq B-V \leq 1.63$, 16 of them with known periods (Radick *et al.*, 1987) and 21 with measured v sin$i$ (Prosser *et al.*, 1995; Stauffer *et al.*, 1997). For the latter ones periods have been computed evaluating radii from $B-V$ colors (Allen, 1973) and assuming $< sini >= \pi/4$. 24 stars of the sample were observed during the ROSAT All Sky Survey (Stern *et al.*, 1995) and 13 in ROSAT PSPC pointed observations (Pye *et al.*, 1994). L_x/L_{bol} were computed using L_{bol} evaluated from $B-V$ colors with the $B-V$ to BC transformation by Flower (1996).

We have computed the linear regression of Log (L_x/L_{bol}) vs. Log (P_{rot}), using the Schmitt (1985) binned method in the ASURV package (La Valley *et al.*, 1992) (Fig. 2, left). The deviations of the data points with respect to the regression curve, sorted vs. $B-V$ color (Fig. 2, right) are characterized by a large scatter and by some systematic dependence on the $B-V$ index.

Using the same algorithm we have then correlated Log (L_x/L_{bol}) with Log (R_0), following the four different computations of the convective turnover time (Fig. 3). We have investigated how different determinations of the τ_{conv}

influence the slope of the regression curve, the distribution of the residuals Δ Log (L_x/L_{bol}) vs. $B-V$ color, and their standard deviation σ (for detections only).

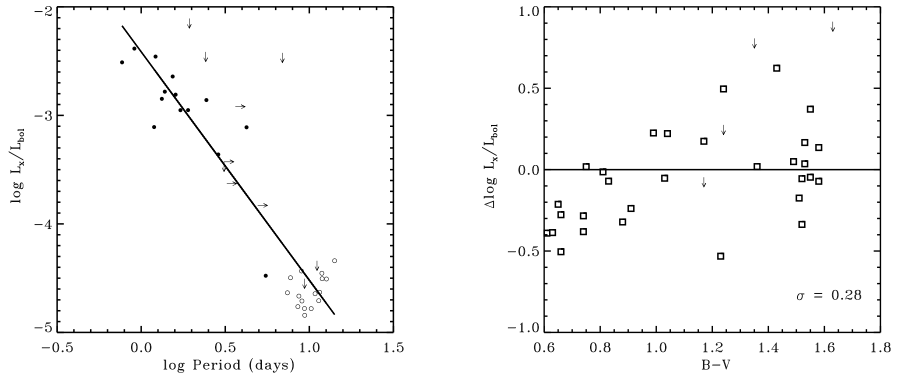

Figure 2. Log (L_x/L_{bol}) vs. Log (P_{rot}) correlation (left) and deviations from the regression curve vs. $B-V$ color (right). In the left panel empty symbols indicate measured periods and filled symbols periods computed from $v \sin i$. The data with lower limits in P_{rot} are not reported in the right panel. Note the large scatter and the dependence on the $B-V$ color index.

3. Results and conclusions

Based on the selected sample of Hyades stars, we have found that large and color-dependent deviations are present with respect to the Log (L_x/L_{bol}) vs. Log (P_{rot}) regression curve. Log (R_0) provide a better correlation with Log (L_x/L_{bol}) (smaller deviations). By comparing deviations with respect to Log (L_x/L_{bol}) vs. Log (R_0) regression curve we found smaller residuals if theoretical τ_{conv} are used instead of those computed according to Noyes *et al.* (1984). The data at hand do not allow us to give preference to one or the other of the stellar evolutionary models.

Possible future prospects involve investigation on the dependence of τ_{conv} on stellar metallicity and investigation of residual dependence of the Δ Log L_x/L_{bol} deviations on $B-V$ color.

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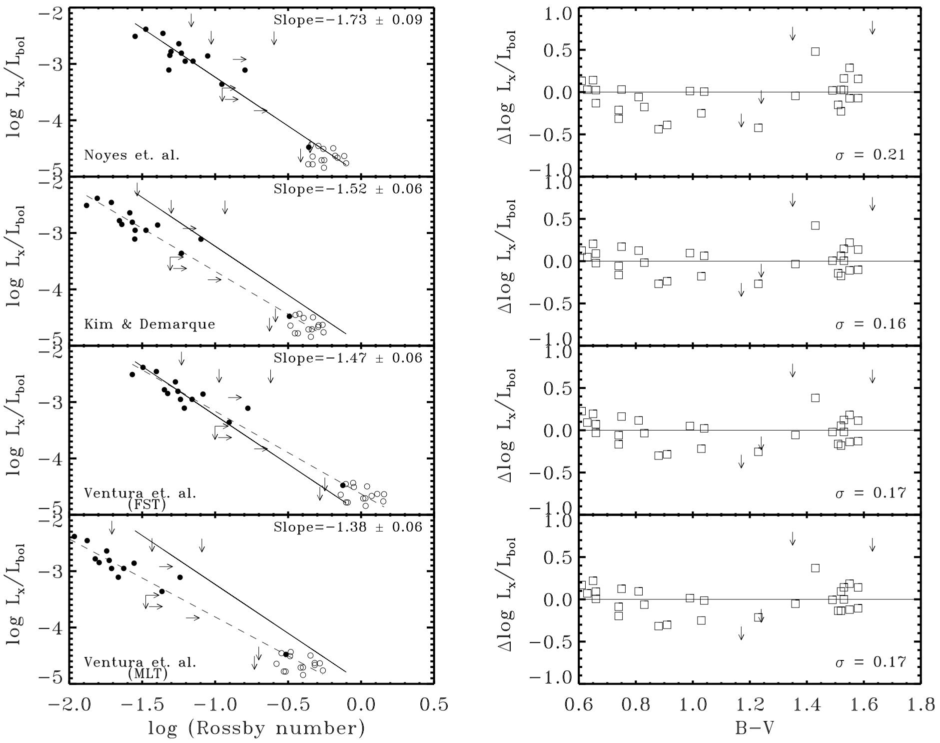

Figure 3. Log (L_x/L_{bol}) vs. Log (R_0) correlation (left) and deviations from the regression curve vs. $B-V$ color (right) following the empirical (solid line) and theoretical (dashed lines) computations of τ_{conv}. The standard deviations, σ, are reported in each case.

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