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The effects of activity on stellar physical properties

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Abstract. Recent analyses show that theoretical models underestimate the radii and overestimate the effective temperatures of low-mass stars in eclipsing binaries but yield luminosities in good accord with observations. A hypothesis based upon the effects of stellar activity has been put forward to explain the discrepancies. Here we present evidence supporting this hypothesis by analyzing a sample of single field stars of spectral types late-K and M. Active stars are shown to be cooler than inactive stars of similar luminosity, therefore implying a larger radius as well, in proportions that are in agreement with those found from eclipsing binaries. This result generalizes the existence of strong radius and temperature dependences on stellar activity to the entire population of low-mass stars regardless of their membership to close binary systems.

Key words. Stars: activity – Stars: fundamental parameters – Stars: late-type – Binaries: eclipsing

1. Introduction

Structure and evolution of stars in the main sequence is generally described by theoretical models to good accuracy. Nevertheless there are still some open issues in the low-mass end of the main sequence. The analysis of M-type eclipsing binary stars (EBs) reveals that models predict ∼10% lower radii values and ∼5% higher effective temperatures than observed, while luminosities are in good agreement (Ribas 2006; López-Morales 2007).

A hypothesis based upon stellar activity has been proposed to explain these discrepancies (Ribas 2006; Torres et al. 2006). Since luminosities are well predicted by models, the overall flux of the star is not substantially modified by activity. Thus, the effect of activity may be a decrease in effective temperature which is balanced by an increase in radius. The mechanism responsible for this effect is not yet fully established but it could be related to a modification of the efficiency of convection (Mullan & MacDonald 2001) or to flux conservation in a spot-covered stellar surface (López-Morales & Ribas 2005).

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Table 1. Mean values of the differences between active and inactive stars for each M_{bol} bin with statistical significance.

M_{bol} bin	$N_{inactive}/N_{active}$	$< \Delta TiO5 >$	$< \Delta T_{eff} >$ (K)	$< \Delta R/R >$ (%)	$<\log(\frac{L_X}{L_{bol}})>_{active}$
7.0 – 8.0	286/13	−0.066±0.038	−128±62	6.9±3.5	−3.11±0.03
8.0 – 9.0	208/12	−0.066±0.018	−107±29	6.3±1.8	−3.19±0.11
9.0 – 10.0	72/13	−0.059±0.012	−118±22	7.3±1.4	−2.87±0.14
10.0 – 11.0	13/5	−0.030±0.026	−59±50	3.8±3.3	−3.30±0.11

In general, Stauffer & Hartmann (1986) showed that inactive and active low-mass stars appear to follow two different sequences in the HR diagram. This result can be put into the context of EBs by assuming that their luminosities are similar (according to the results of Chabrier et al. (2007) and the analysis of EBs) and that the offset in the main sequence is mostly driven by cooler effective temperatures (i.e., redder colours) in active stars. In this work we present an analysis of a sample of late-K and M stars with high statistical significance and a careful treatment of all the involved errors and bias effects.

2. Sample of late-type stars

To test this scenario of the effect of activity on stars, we have used a sample of late-K and M dwarfs selected from the Palomar/Michigan State University survey of nearby stars (hereafter PMSU, Reid et al. 1995; Hawley et al. 1996). We selected 746 stars with trigonometric distance determinations (unbiased by activity) and with measurements of positions, M_V, TiO, CaH and CaOH spectral indices, Hα equivalent widths (EW Hα) and proper motions. This sample was cross-matched with the 2MASS and ROSAT survey catalogs to obtain IR and X band magnitudes.

For the purpose of this study, luminosity (i.e. absolute bolometric magnitude, M_{bol}), and effective temperatures (T_{eff}) as well as an activity indicator are needed. Since the bolometric correction (BC_K) is smoothly dependent on T_{eff} in the K-band, we employed the K magnitude from 2MASS and the distance to compute M_{bol} using the BC_K calibration in Bessell et al. (1998). A relation between the TiO5 spectral index and the spectral subtype of M stars (Sp.Typ. = $-10.775 \cdot$ TiO5 + 8.2, Reid et al. 1995) and a spectral type-temperature scale (Bessell 1991) yielded values for T_{eff}. EW Hα was used as activity indicator (Cram & Mullan 1979), with stars with EW H$\alpha > 0$ being classified as actives.

Our planned analysis is only meaningful if the stars we compare are in the same evolutionary state, i.e., both active and inactive stars should be single main sequence stars. Therefore, we removed from the sample objects younger than ~ 200 Myr and binary stars using the lists of young moving groups and associations in López-Santiago et al. (2006) and D. Fernández (priv. comm.) and the cross identifications with SIMBAD and the lists given in Gizis et al. (2002) for the PMSU survey, respectively. Low-metallicity halo stars were also removed using kinematic criteria and the CaH2-TiO5 prescription in Bochanski et al. (2005). Thus, we finally have a sample of 695 single main-sequence stars (48 of them active).

3. Active and inactive stars

To compare the differences between active and inactive stars of the same luminosity we divided the sample in M_{bol} bins of 1 mag to keep statistical significance. We then computed the mean values of the TiO5 spectral index and T_{eff}. The differences between the two samples for each bin are listed in Table 1. The mean values were corrected for a bias arising from the fact that the fraction of active stars detected with the EW Hα criterion increases towards later spectral types.

As can be seen both in Table 1 and in Fig. 1, the mean T_{eff}s of active stars are smaller

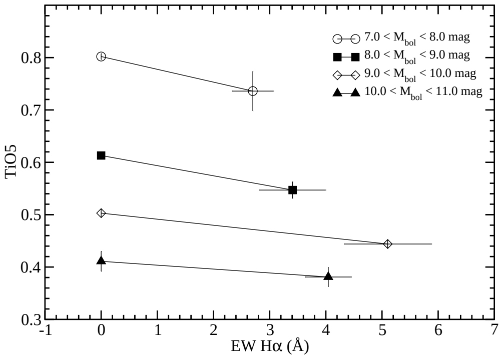

Fig. 1. Mean value of the TiO5 spectral index (directly related to $T_{\rm eff}$) for inactive and active stars.

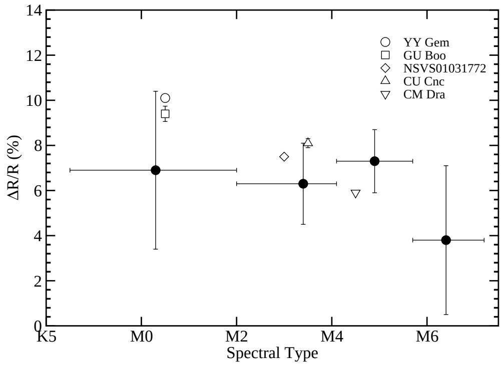

Fig. 2. Radius differences vs. spectral type for the sample used here compared to the discrepancy between observations and models for some of the best EB data (open symbols).

than those of the inactive sample in all cases. The differences in $T_{\rm eff}$ can be translated into radius differences (ΔR) assuming that $L_{\rm active} \simeq L_{\rm inactive}$. The resulting radius values are also listed in Table 1. Figure 2 illustrates how the differences found here for single main-sequence stars are in excellent agreement with the differences observed when comparing low-mass EBs with models. Since the value of $<\log(L_{\rm X}/L_{\rm bol})>$ of our active sample is close to saturation, as also are those of EB components, the results we obtain are representative of the maximum effect that activity can have on stellar properties.

We carried out additional tests to evaluate the presence of any bias caused by metallicity differences between the samples by selecting stars from the thin disk using kinematic criteria in Montes et al. (2001). The results obtained from this reduced subsample are in good accord with those in Table 1, within the error bars, thus indicating that metallicity effects are not significantly affecting our findings.

4. Conclusions

This study reveal that the structure of single main-sequence stars is modified by activity, much in the same way as reported previously for EBs. This result is in agreement with previous CMD analyses (Stauffer & Hartmann 1986). The overall conclusion of our analysis is that current stellar models may not be adequate to describe the properties of active low-mass stars better than 5–10%.

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