The effect of stellar activity on the stellar parameters of the young solar twin HIP 36515

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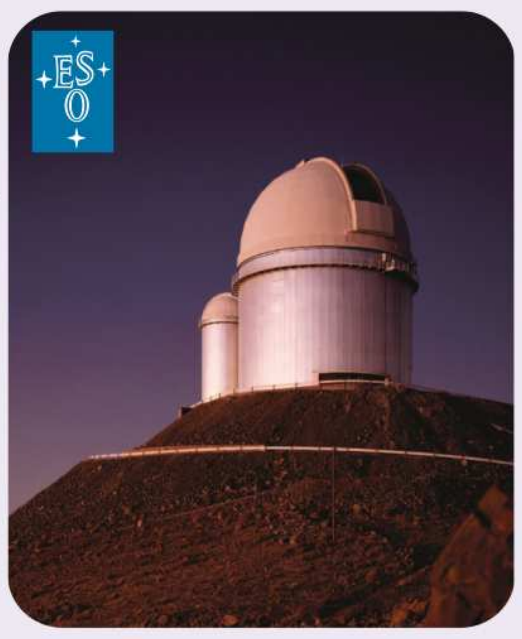
ABSTRACT

Spectroscopic equilibrium allows us to obtain precise stellar parameters in Sun-like stars. It relies on the assumption of the iron excitation and ionization equilibrium. However, several works suggest that magnetic activity may affect chemical abundances of young active stars, calling into question the validity of this widely-used method. We have tested for the first time variations in stellar parameters and chemical abundances for the young solar twin HIP 36515 (~0.4 Gyr) along its activity cycle. This star has stellar parameters very well established in the literature and we estimated its activity cycle in ~6 years. Using HARPS spectra with high resolving power (115 000) and signal-to-noise ratio (~270), the stellar parameters of six different epochs in the cycle were estimated. We found that the stellar activity is strongly correlated with the effective temperature, metallicity, and microturbulence velocity. The possibility of changes in the Li I 6707.8 Å line due to flares and star spots was also investigated. Although the core of the line profile shows some variations with the stellar cycle, it is compensated by changes in the effective temperature, resulting in a non variation of the Li abundance.

OBSERVATIONS



The spectra of the Sun (reflected light from the Vesta asteroid) and HIP36515 were taken with the HARPS spectrograph at La Silla Observatory (3.6 m telescope) between 2014 to 2019.

Each spectrum was automatically reduced by the HARPS data reduction software. The spectra have high resolving power R = 11500 0 and cover a spectral range 3782 - 6913 Å. The red and blue part of the spectra were carefully normalized using the continuum task in IRAF, and then combined in order to obtain the highest possible SNR (~270 at 6500 Å).

DATA ANALYSIS

(1) Stellar Activity Cycle:

The HARPS-S index (hereafter $S_{\rm HK}$) was estimated measuring the chromospheric emission in the cores of the Ca II H and K lines ($\langle S_{\rm HK}\rangle = 0.33 \pm 0.02$). The cycle period ($P_{\rm cycle}$) is estimated through Gaussian process(GP) fitting to account the quasi-periodic trends of stellar activity, represented in this case by $S_{\rm HK}$(see panel (a) of Figure 1.

(2) Equivalent Widths (EWs):

The EW of iron lines were measured along these epochs using the splot task in IRAF, fitting the line profiles with Gaussians. The mean uncertainty of the EW in each epoch is ~0.7 mÅ (panel (b) of Fig. 1). Pseudo-continuum regions were obtained in a window of 6 Å. The analysis is based on the line-by-line equivalent width technique. We also estimated the formation heights of the iron lines (see Figure 2).

(3) Stellar Parameters:

We determined the iron abundances using the MOOG code and the Kurucz ODFNEW model atmospheres. The stellar parameters along the stellar cycle were estimated through the spectroscopic equilibrium using the qoyllur-quipu code (q^2). The method was purely differential between the Sun and HIP 36515 (Fig. 3). The ages, masses, and radii were estimated using the q^2code, which uses a combination of grid of Yonsei-Yale isochrones and parallaxes from GDR2.

(4) Lithium abundance:

In order to find the abundances, we fitted synthetic spectra generated with the MOOG code to the observed spectra, and with χ^2 minimization found the LTE abundances along the activity cycle. We estimated the EW of the synthetic line of the best abundance by measuring the synthetic line, instead of directly measuring the observed spectra, due to blends in the Li line (panel (c) of Figure 1).

RESULTS AND CONCLUSIONS

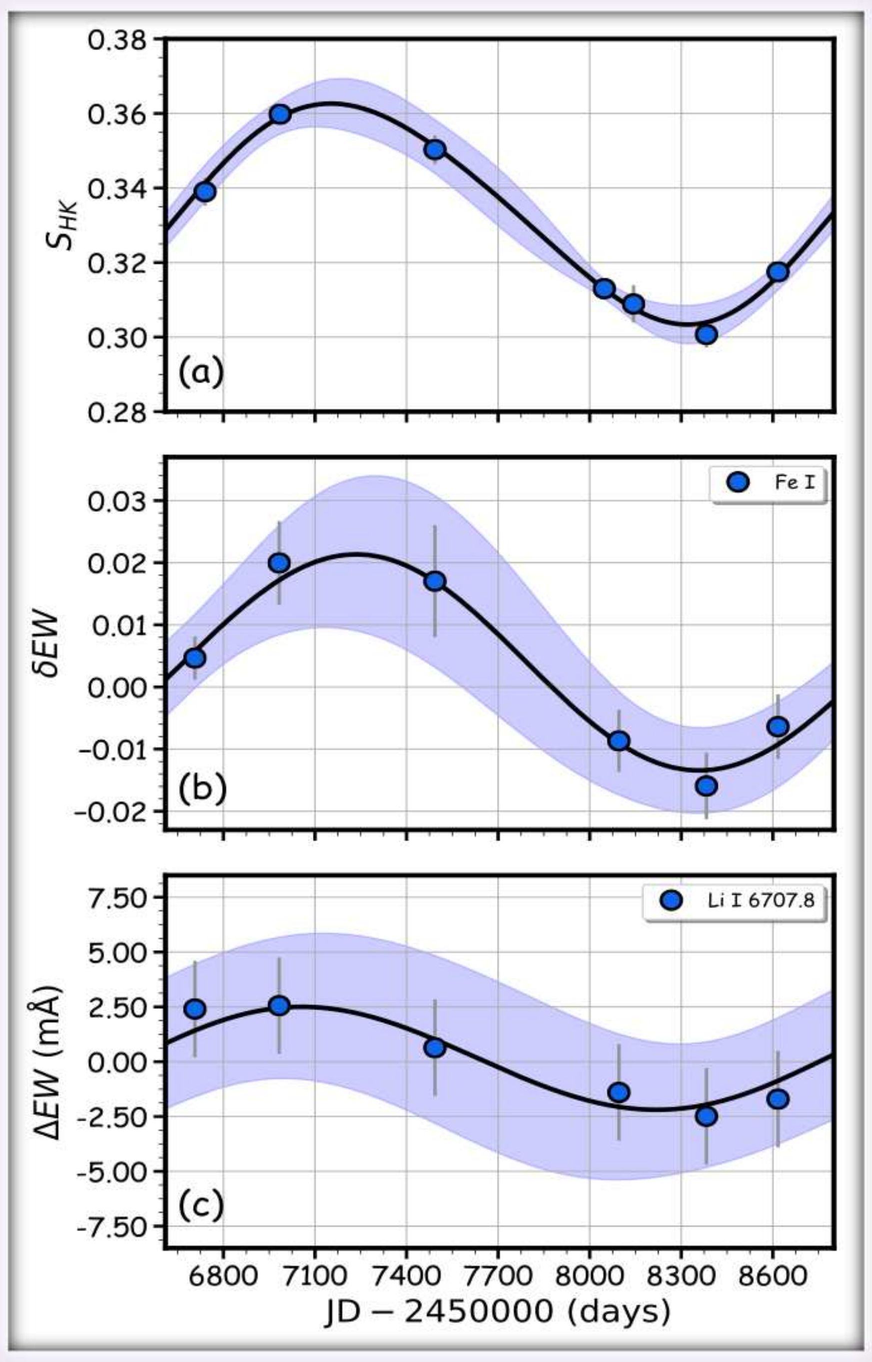


Figure 1

We determined an activity cycle period of ~6 years via Gaussian process fitting.

We report for the first time variations of the $\delta EW^*$of several iron lines with the stellar activity cycle.

We detected variations of the EW of Li, however we found almost no variations of their abundance because the EWs are compensated with the $T_{\rm eff}$ estimated for each epoch of the activity cycle.

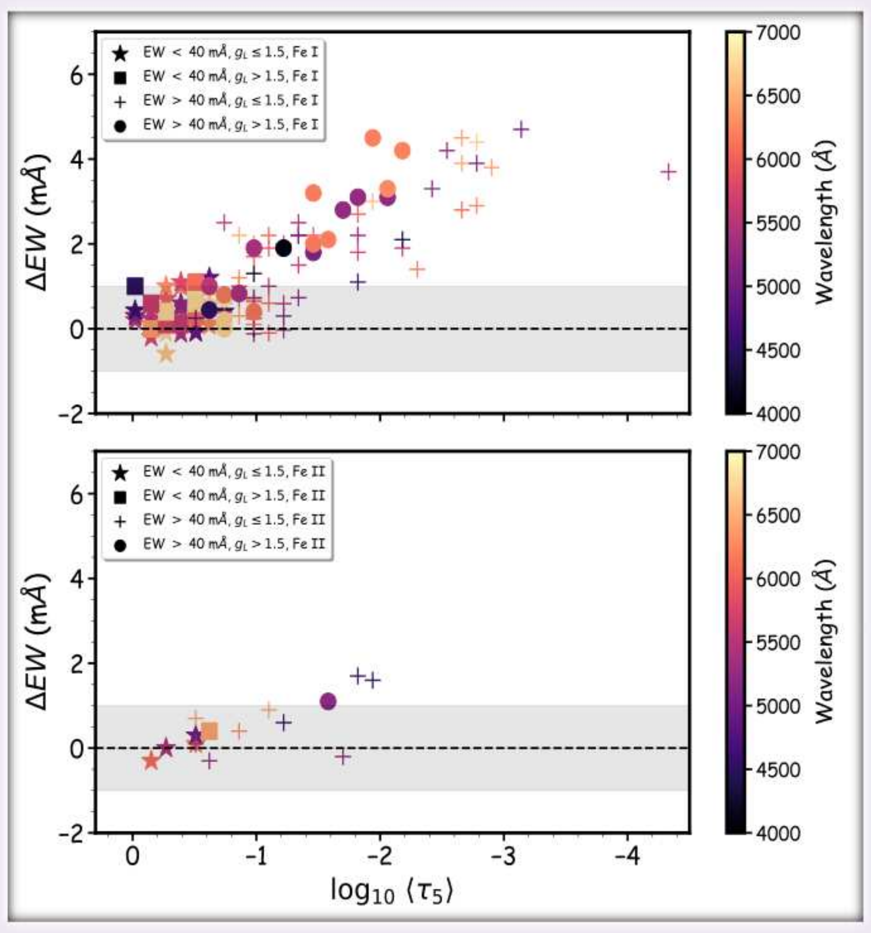


Figure 2

There is a clear impact of stellar activity on the EWs of Fe I and Fe II, and it tends to increase with $\log_{10}\langle\tau_5\rangle$. The Fe I lines with smaller τ_5, meaning those closer to the base of the chromosphere, are the most affected, as they have the largest variations in ΔEW.

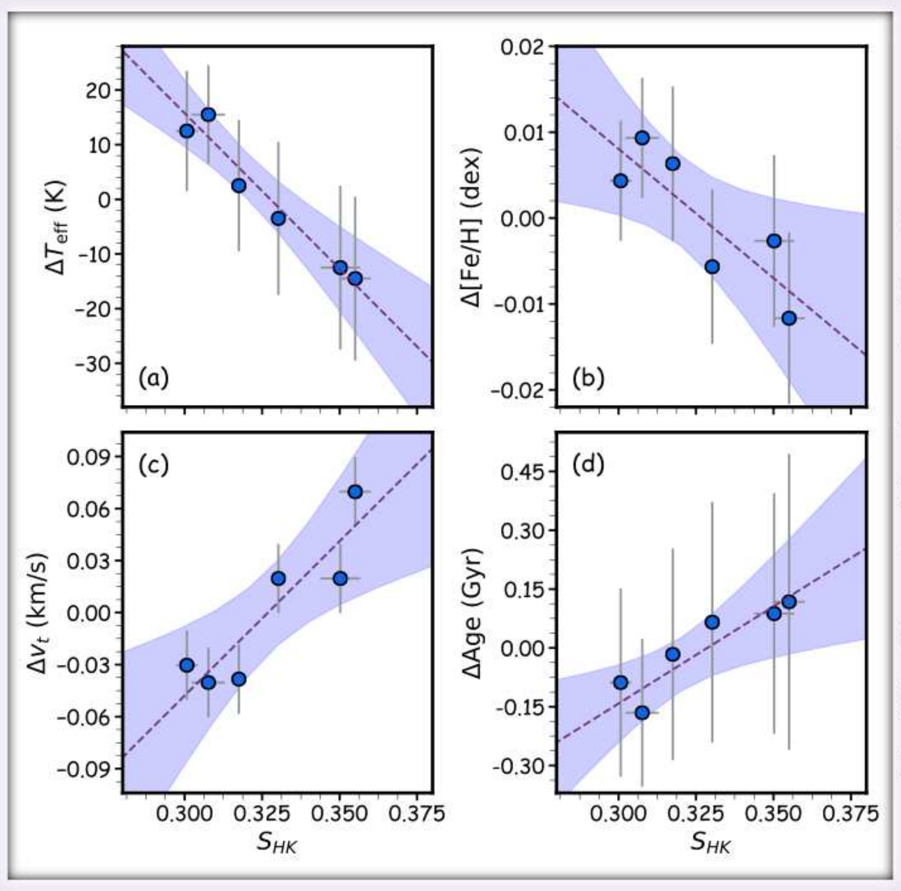


Figure 3

Changes in $T_{\rm eff}$ suggest the presence of active regions on the surface. The [Fe/H]decrease with the activity cycle. And as consequence of these variations the v_t increase with the activity cycle. Other fundamental parameters such as age, mass and radius remain almost invariant within measurement uncertainties.

$^*\delta EW = EW_{\lambda_{ij}}/\langle EW\rangle_{\lambda_i} - 1$

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