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A possible long-term activity cycle for ι Horologii: First results from SPI-HKα project

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ABSTRACT

In order to detect stellar activity cycles and study possible star–planet interactions (SPIs), we have been developing the HKα and SPI-HKα projects since 1999 and 2012 respectively. In this work, we present preliminary results of possible SPIs from studies of chromospheric activity and look for possible correlations between stellar activity and stellar/planetary parameters. We find that for stars with a similar $T_{\rm eff}$, stellar activity increases with the mass of the planet, similar to results from previous works. However, stellar ages can also play a role, and a larger stellar sample is needed to verify these trends. We also note that some of these stars present a remarkably high level of chromospheric activity, comparable even with RSCvn or BY Dra active stars. In addition, we do not observe any correlation between stellar activity and semi-major axis. We present the first long-term activity study of the star ι Horologii, a young solar-type star that hosts a non-transiting Jovian planet and exhibits a high activity level. We analysed our own spectra, obtained between 2002 and 2015, in conjunction with public HARPS (High Accuracy Radial velocity Planet Searcher) observations. We calculated the Ca II indexes derived from the 987 Complejo Astronómico El Leoncito (CASLEO) and HARPS spectra and converted them to the Mt Wilson scale. We found a long-term activity cycle of ∼5 yr which fits the *active* sequence of Böhm-Vitense. The amplitude of this longer cycle is irregular, as was also observed for the shorter cycle. This phenomenon could be attributable to an antisymmetric distribution of active regions on the stellar surface.

Key words: planet–star interactions – stars: activity – stars: individual: ι Horologii.

1 INTRODUCTION

In 1966, Olin Wilson initiated the most-extended program dedicated to the study of the chromospheric activity of several late-F to early-M stars by monitoring the cores of the H and K Ca II lines at 3968 and 3934 Å (for details see Baliunas et al. 1995). This program, undertaken at Mt Wilson Observatory between 1966 and 2003, together with other similar studies, allowed the detection of chromospheric activity cycles in several stars of different spectral types, with periods ranging between 2.5 and 25 yr (e.g. Wilson 1978; Baliunas et al. 1995; Buccino & Mauas 2008; Flores et al. 2016). The model usually used to interpret these stellar cycles is the $\alpha\Omega$-dynamo, which proposes that the generation and intensification of magnetic fields in these stars is produced by a global-scale dynamo action arising from the coupling of convection and rotation (Parker 1955; Robinson & Durney 1982).

Using a sample of stars with well-determined rotation and activity-cycle periods, Saar & Brandenburg (1999) examined the relationship between these two frequencies and found that most cycles fall onto two branches, which they classified as the *active* and *inactive* sequences. In particular, a few stars exhibit cycle periods on both branches simultaneously. For instance, the star HD 190406 (G0V) shows signatures of a short secondary cycle of 2.6 yr superimposed on its much longer primary cycle of 16.9 yr (Hall, Lockwood & Skiff 2007). Other stars with multiple activity cycles

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were reported by Oláh et al. (2009), who studied the time variations of 20 cyclic active stars from decade-long photometric and spectroscopic observations. These authors found that 75 per cent of them present multiple cycles with variable cycle lengths. More recently, Metcalfe et al. (2013) detected two simultaneous cycles with periods of 2.95 and 12.7 yr in the K2V star ε Eridani (HD 22049). In interpreting the $P_{\rm cyc}$–$P_{\rm rot}$ bimodal distribution, Böhm-Vitense (2007) suggested that probably two different dynamos are operating inside these stars: one driven by rotational shear in the near-surface layers and responsible for the longer cycle (active branch), and the other one driven by a so-called tachocline at the base of the outer convection zone and responsible for the shorter cycle.

ι Horologii (HD 17051 = HR 810, $V = 5.4$, $B - V = 0.57$) is a young solar-like F8V star. Kürster et al. (2000) detected a non-transiting Jovian planet (2.26 $M_{\rm Jup}$) at a distance of $a = 0.925$ au orbiting ι Hor with an orbital period of 320.1 d. Although ι Hor is a southern star, Vauclair et al. (2008) found evidence from the acoustic oscillation frequencies of the star that it evaporated from the primordial Hyades cluster, as Montes et al. (2001) had previously deduced from a kinematic analysis. Vauclair et al. (2008) estimated the age of ι Hor as 625 Myr. Furthermore, Metcalfe et al. (2010) estimated a rotation period of between 7.9 and 8.5 d for ι Hor, consistent with the mean rotational period of solar-type stars in the Hyades cluster (Radick et al. 1995). Because of its short rotation period and young age, it is expected that ι Hor will exhibit a higher level of activity than the Sun, consistent with the close connection widely believed to exist between rotation and activity (Noyes et al. 1984).

Using Ca II H and K observations obtained between 2008 and 2010, Metcalfe et al. (2010) reported a 1.6-yr chromospheric cycle for this star, which is one of the shortest chromospheric cycles reported for solar-type stars.[1] Following the reasoning of Böhm-Vitense (2007), these authors associated this short cycle with the *inactive* branch of the $P_{\rm cyc}$–$P_{\rm rot}$ diagram and suggested that the cycle corresponding to the *active* branch would be close to 6 yr. Sanz-Forcada, Stelzer & Metcalfe (2013) also detected this 1.6-yr cycle in the X-ray emission, which is the first coronal cycle reported in a solar-like star. They also proposed that this short coronal cycle is probably modulated by a longer one. However, this possible longer activity cycle has not been reported in the literature to date.

The discovery of activity cycles in stars with physical characteristics similar to the Sun across a range of ages and other parameters is important for an understanding of how typical the Sun is. Furthermore, an understanding of stellar activity is necessary in order to discriminate between stellar activity and planetary signals in radial velocity surveys (e.g. Robertson et al. 2013; Carolo et al. 2014). For instance, Boisse et al. (2011) separated stellar and planetary signals in the radial velocity measurements of ι Hor. In order to do this, they carried out a simultaneous modelling of stellar activity and planetary parameters for this star. As a result, the authors excluded the presence of a second planet in this system. This study reveals the importance of monitoring the chromospheric stellar activity of stars.

In order to study the long-term activity in solar-type stars, in 1999 we developed the HKα project, an observing program at the Argentinian Observatory Complejo Astronómico El Leoncito (CASLEO) dedicated to periodically obtaining medium-resolution echelle spectra of a sample of F to M southern stars (for details see Buccino et al. 2011). Since then, we have systematically observed more than 150 main sequence stars from F5.5 to M5. To date, we have more than 5500 mid-resolution echelle spectra ($R \sim 13\,000$) ranging from 3890 to 6690 Å (Vieytes, Mauas & Cincunegui 2005; Díaz, Cincunegui & Mauas 2007a; Buccino & Mauas 2008; Vieytes, Mauas & Díaz 2009; Metcalfe et al. 2013). Based on our long spectra database, we found the first chromospheric activity cycles in M stars (Cincunegui, Díaz & Mauas 2007a; Díaz et al. 2007b; Buccino et al. 2011, 2014).

In addition, the detection of extrasolar planets around solar-type stars prompted new discussions related to the possible influence of a planet on the level of activity of its host star. On average, 7 per cent of these exoplanets confirmed to date are hot Jupiters (orbital period of less than 7 d, semi-major axis less than 0.1 au, and a minimum mass greater than 0.2 times the mass of Jupiter) in orbits around F to K solar-type stars.[2] Over the past decade, several studies (Shkolnik et al. 2008; Walker et al. 2008; Donati et al. 2008; Krejčová & Budaj 2012; Poppenhaeger & Wolk 2014) have shown that the level of activity of a host star can be influenced by its interaction with an exoplanet. In order to explore the star–planet interactions (SPIs) in southern stars, in 2012 we launched the SPI-HKα project, a branch of the HKα program focusing specifically on stars with hot Jupiters or massive planets in eccentric orbits, which are the best candidates for studying SPIs. In order to compare the levels of activity of the exoplanet host stars, we have also obtained spectra of stars of similar spectral types without planets.

In particular, we have been monitoring the activity of ι Hor since 2002, and as a result we have a long time series of Mt Wilson indexes obtained between 2002 and 2015. This series provides useful information that can be used to search for the possible longer activity cycle suggested by Metcalfe et al. (2010) and Sanz-Forcada et al. (2013). In this paper, we present a complete analysis of these data, organized as follows. In Section 2 we give an overview of our data, which are supplemented with data obtained with HARPS and by the SMARTS survey. In Section 3 we describe our results, and finally in Section 4 we provide a discussion.

2 OBSERVATIONS

The observations were obtained at the Argentinean Observatory Complejo Astronómico El Leoncito (CASLEO, San Juan) with the REOSC[3] spectrograph located in the 2.15-m telescope. The CASLEO spectra were reduced using standard IRAF[4] routines, which carry out the usual reduction processes including bias subtraction, spectral order extractions, wavelength calibration and other operations. All the spectra from the HKα and SPI-HKα projects are flux-calibrated. In order to do this, for each star we also acquired a long-slit spectrum, which was flux-calibrated using a set of spectrophotometric standard stars. This spectrum was then used to obtain a sensitivity function. As a final step, we combined the flux-calibrated echelle orders in order to obtain a one-dimensional spectrum (see Cincunegui & Mauas 2004, for details).

In Table 1 we show the Mt Wilson $S_{\rm MW}$ index, which essentially is the ratio of the flux in the core of the Ca II H and K lines to

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[1] Recently, using spectropolarimetric observations, Mengel et al. (2016) detected a chromospheric activity cycle of ~0.32 yr in the exoplanet host star τ Boötis (F7V), which is the shortest detected cycle to date.

[2] http://exoplanets.eu

[3] http://www.casleo.gov.ar/instrumental/js-reosc.php

[4] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

Table 1. Observational data and derived Mt Wilson activity indexes for the star ι Hor from the HKα and SPI-HKα projects.

Date*	JD (+2,450,000)	$S_{\rm MW}$	σ_S
0603	2803	0.213	0.0070
0607	4282	0.232	0.0078
0608	4640	0.243	0.0083
0706	3926	0.231	0.0078
0710	5402	0.237	0.0080
0802	2517	0.201	0.0066
0805	3597	0.250	0.0086
0813	6537	0.255	0.0088
0903	2895	0.222	0.0074
0904	3274	0.247	0.0085
0905	3636	0.246	0.0084
0906	3989	0.224	0.0075
0908	4732	0.222	0.0073
0910	5455	0.246	0.0084
0911	5820	0.240	0.0082
0912	6171	0.228	0.0076
0912	6196	0.224	0.0075
0913	6564	0.257	0.0089
0914	6905	0.276	0.0097
1214	7004	0.265	0.0093
1009	5107	0.242	0.0083
1013	6592	0.253	0.0087
1102	2602	0.195	0.0063
1112	6254	0.244	0.0083
1203	2979	0.225	0.0075
1207	4447	0.230	0.0077
1208	4821	0.234	0.0079
1210	5547	0.248	0.0085
1212	6283	0.225	0.0075
0915	7273	0.223	0.0074

Note. * Month and year of the observation (e.g. 1102 correspond to November 2002).

the nearby continuum (Vaughan, Preston & Wilson 1978). In order to compute $S_{\rm MW}$, for each spectrum we integrated the flux in two windows centred at the cores of the Ca II lines, weighted with triangular profiles of 1.09 Å full width at half-maximum (FWHM), and computed the ratio of these fluxes to the mean continuum flux, integrated in two passbands of width 20 Å centred at 3891 and 4001 Å. Finally, we used the calibration between the Ca II indexes derived from the CASLEO spectra and the Mt Wilson indexes obtained by Cincunegui, Díaz & Mauas (2007b).

We complement our analysis with public high-resolution spectra ($R \sim 115.000$) taken between 2003 and 2015 with the HARPS (High Accuracy Radial velocity Planet Searcher) spectrograph, installed at the 3.6-m ESO telescope, under the programs listed in Table 2. These spectra cover the spectral range 3781–6912 Å and were automatically processed by the HARPS pipeline.[5] We carefully selected only those spectra with a high signal-to-noise ratio (S/N) to measure precisely the Ca II H and K line-core fluxes. Then, we derived the Mt Wilson S indexes for 957 spectra with a mean S/N $\sim$ 175 at 6490 Å. In order to do this, we used the calibration procedure explained in Lovis et al. (2011).

In addition, we also included the Mt Wilson indexes obtained between 2008 and 2010 by Metcalfe et al. (2010), and those acquired between 2010 and 2013 presented in Sanz-Forcada et al. (2013). These indexes were derived from spectra taken with the RC spectrograph ($R \sim 2500$) on the SMARTS (Small and Moderate Aperture Research Telescope System) 1.5-m telescope at Cerro Tololo Interamerican Observatory (CTIO), and reduced with a standard procedure (for details see Metcalfe et al. 2010).

Table 2. ID programs of ι Hor observations used in this work.

ESO HARPS programs
078.D-0067(A)
077.C-0530(A)
079.C-0681(A)
078.C-0833(A)
060.A-9036(A)
072.C-0531(B)
072.C-0488(E)
074.C-0012(A)
073.C-0784(B)
076.C-0878(A)
091.C-0853(A)
060.A-9700(G)

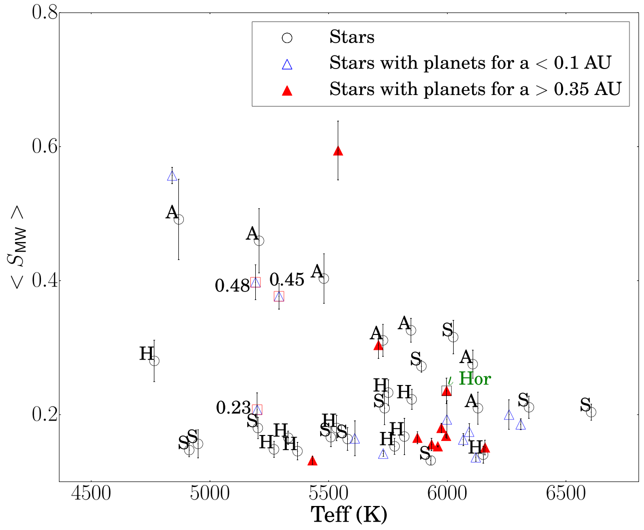

Figure 1. Mean activity level $<S_{\rm MW}>$ versus $T_{\rm eff}$ for stars with and without planets. Empty blue triangles denote stars with hot Jupiter-type planets ($a \leq 0.1$ au). Stars with planets located at a greater orbital separation are indicated with solid red triangles ($a > 0.35$ au). Empty black circles correspond to stars without planets (single, labelled with an 'S'), very active BY Dra and RSCvn stars (labelled with an 'A') and stars with a high proper motion (labelled with an 'H'). Empty blue triangles inside red squares indicate those stars of similar $T_{\rm eff}$ ($T_{\rm eff} \leq 5500$ K) with hot Jupiter-type planets that show high activity levels (labelled with their planetary masses). The star ι Hor is indicated with a solid red triangle inside a black square.

3 RESULTS

3.1 The first SPI-HKα project results

In Fig. 1 we present the mean Mt Wilson index $\langle S_{\rm MW} \rangle$ distribution of exoplanet host stars under study as a function of the effective temperature. All stellar and planetary parameters (e.g. effective temperature $T_{\rm eff}$, semi-major axis a, etc.) were obtained from *The*

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[5] http://www.eso.org/sci/facilities/lasilla/instruments/harps/

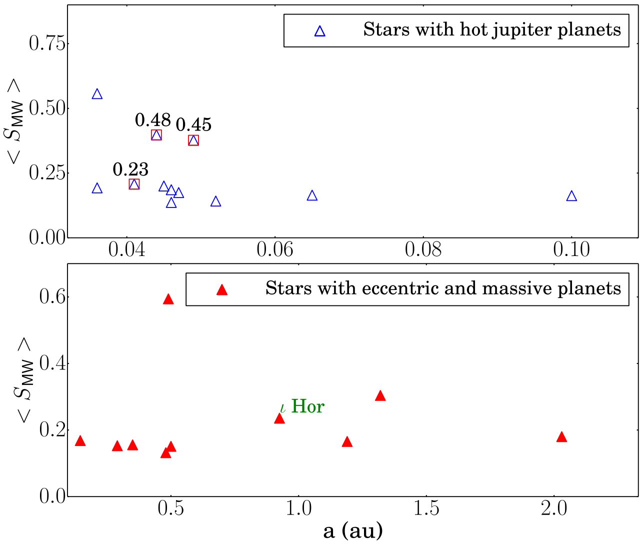

Figure 2. Mean activity level versus semi-major axis for stars with planets. Top panel: empty blue triangles correspond to stars with hot Jupiter-type planets. Empty blue triangles inside red squares with labels indicate the position and the planetary masses of the stars with similar $T_{\rm eff}$, as plotted in Fig. 1. Lower panel: stars that host massive planets in eccentric orbits are shown with solid red triangles. The position of the star ι Hor is also indicated.

Extrasolar Planets Encyclopaedia.[6] For purposes of comparison, we also include in the figure both the mean Mt Wilson indexes of single stars (without planets) of similar spectral type and those corresponding to very active stars such as RSCvn- and BY Dra-type stars. The index $\langle S_{\rm MW}\rangle$ was calculated from the CASLEO spectra. From Fig. 1, we note that those stars with $T_{\rm eff} \leq 5500$ K that host close-in (a $\leq$0.10 au) and more massive exoplanets show elevated activity levels (empty blue triangles inside red squares), similar to that suggested by Krejčová & Budaj (2012). They suggested that the stars with massive close-in exoplanets may be more active. In particular, they found statistically significant evidence that the Ca II K line emission of the host star (for $T_{\rm eff} \leq 5500$ K and a $\leq$0.15 au) increases with the mass of the planet. However, this result could be related to the close association that is widely believed to exist between rotation (age) and activity. On the other hand, the activity levels of hotter stars ($T_{\rm eff} \geq 5500$ K) with planets are in an intermediate activity zone, between very active RSCvn- or BY Dra-type stars and single stars (without planets) of similar spectral type. In particular, ι Hor (solid red triangle inside a black square in Fig. 1) is one of the most active exoplanet host stars of our sample. In Section 3.2 we analyse its long-term activity in detail.

Cuntz, Saar & Musielak (2000) suggested that planets located at distances $\leq$0.1 au could affect their host stars by magnetic and/or tidal SPI, increasing the star's chromospheric activity. In order to search for observational evidence of this increase, in Fig. 2 we plot $\langle S_{\rm MW}\rangle$ versus the semi-major axis *a* for a set of 12 stars with hot Jupiters observed at CASLEO. It can be seen that there is no significant correlation between stellar activity and semi-major axis. These are, however, preliminary results that need confirmation from future observations.

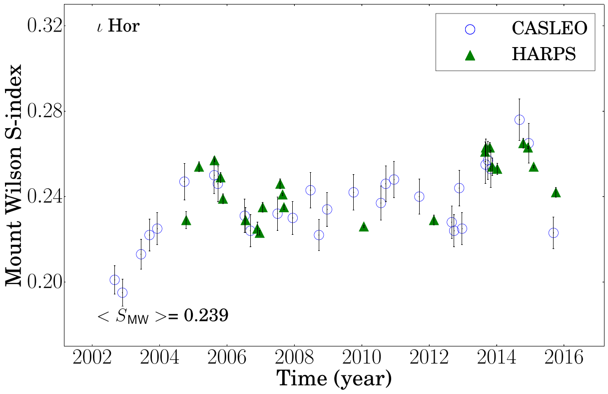

Figure 3. Time series of the Mt Wilson index for ι Hor from combined observations. The CASLEO data set is denoted by empty blue circles, and the HARPS monthly means by solid green triangles.

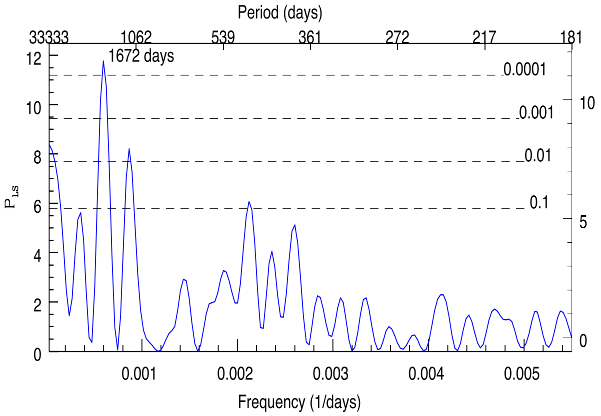

Figure 4. Lomb–Scargle periodogram of the $S_{\rm MW}$ index from the combined data plotted in Fig. 3.

3.2 Long-term activity of ι Hor

Fig. 3 shows the entire data set collected between 2002 and 2015 for ι Hor at CASLEO, combined with the Mt Wilson indexes derived from HARPS spectra obtained between 2003 and 2015. We resampled the HARPS data using monthly means.

We estimated the uncertainty of each CASLEO index as the nightly variation during an observing run. In order to do this, we observed ι Hor during five consecutive nights in 2012 November and December. We ascertained that the Mt Wilson index varied between 1 and 3 per cent. Therefore, we considered a conservative uncertainty of 3 per cent for each single observation. However, we included the average values of HARPS observations associated with the same observing season (HARPS monthly means). Error bars of the average values correspond to the standard deviation of the mean. For those cases with only one observation in a month, we adopted the typical rms dispersion of other bins. Fig. 3 shows a clear agreement between the two time series (CASLEO and HARPS).

In order to study the long-term chromospheric activity for the combined data sets we computed the Lomb–Scargle periodogram (Horne & Baliunas 1986) as well as the false alarm probability (FAP) of the periods, which were obtained using a Monte Carlo simulation as described in Buccino & Mauas (2009). We observed a long-period modulation of the activity with a cycle of 1672 ± 51 d ($\sim$4.57 yr) with a Monte Carlo FAP of 2×10^{-5} (Fig. 4). However, we do not detect a significant peak near 1.6 yr, which is the one detected by Metcalfe et al. (2010).

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[6] http://exoplanets.eu

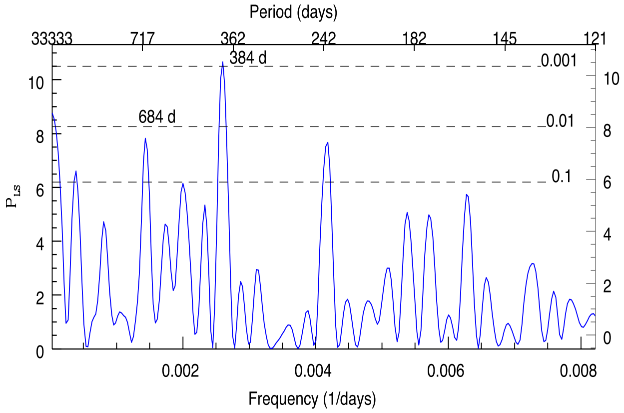

Figure 5. Lomb–Scargle periodogram of the HARPS and CASLEO spectra after removing the harmonic curve of the 1672-d period.

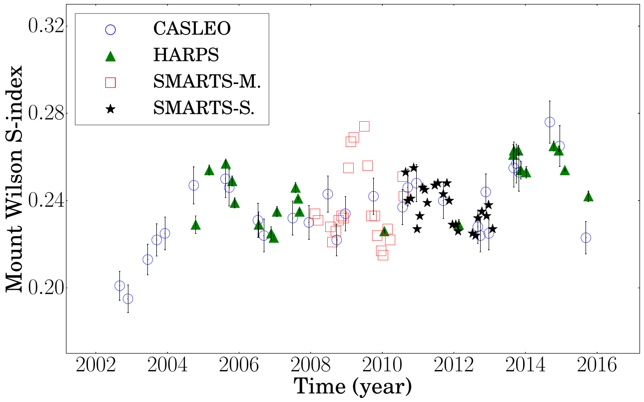

Figure 6. Time series of chromospheric activity indexes for ι Hor from combined observations. CASLEO data are shown with empty blue circles, and the HARPS monthly means with solid green triangles. SMARTS data from Metcalfe et al. (2010) and from Sanz-Forcada et al. (2013) are shown with empty red squares and black stars, respectively.

According to Böhm-Vitense (2007), in stars with deep convective zones two active dynamos could be operating simultaneously in different regions of the star and, as a consequence, give rise to two different chromospheric activity cycles. Considering the 8.1-d rotation period of ι Hor, if the 1.6-yr cycle detected by Metcalfe et al. (2010) corresponds to the *inactive* branch, the 4.57-yr period detected in this work could correspond to the *active* branch, within the statistical dispersion of the data plotted in fig. 1 of Böhm-Vitense (2007).

In order to look for short-term variations, we studied the HARPS and CASLEO indexes after removing the harmonic curve of the 1672-d period (see Fig. 5). We obtained a significant period $P = (384 \pm 2)$ d with FAP = 0.0007. However, we suspected that the 384-d period was an artefact. In order to explore this hypothesis, we used the daily sunspot numbers taken from the National Geophysical Data Center[7] between 1700 and 2016. We took a sample of the solar data with the same phase intervals as in our data, we added Gaussian errors of 10 per cent at each point, and we computed the Lomb–Scargle periodogram. To take different phases of the solar cycle, we repeated this procedure 1000 times with different starting dates. For each periodogram, we considered the period with maximum significance (or minimum FAP) as the detected period. We obtained 72 per cent of the detected period between 9.12 and 13.03 yr with FAP < 0.001, which corresponds to the solar cycle, and in 670 of these 1000 periodograms significant periods with FAP < 0.10 between 326 and 441 d (384 d ± 15 per cent) are also present. This result supports the supposition that the 384-d peak detected is an artefact.

In Fig. 5, we also detect a less prominent peak at (684 ± 8) d (1.87 yr) with FAP = 0.016, which could be associated with the short-term cycle detected by Metcalfe et al. (2010).

On the other hand, in Fig. 3 it can be seen that between 2007 and 2012 the $S_{\rm MW}$ index is fairly constant. The Mt Wilson index during this interval varies slightly with an amplitude $\Delta S = 0.013$, from $S_{\rm MW} = 0.248$ to $S_{\rm MW} = 0.222$. However, between 2002 and 2007 the amplitude of the variation is $\Delta S = 0.031$, with a maximum of $S_{\rm MW} = 0.257$ and a minimum of $S_{\rm MW} = 0.195$, and between 2012 and 2015 the amplitude is $\Delta S = 0.026$, ranging from $S_{\rm MW} = 0.224$ to $S_{\rm MW} = 0.276$.

It is widely known that from 1645 to 1715 solar activity was flat and the number of sunspots was extremely reduced, although they did not disappear. During this period, called the Maunder Minimum, it is estimated that the Ca II K emission was 11 per cent lower than during the current Solar Minimum (White et al. 1992). From the analysis of Mt Wilson indexes registered over 30 yr, Baliunas & Soon (1995) reported that 15 per cent of the 111 stars under study are 'flat stars'. Some of them are known to have evolved from the main sequence (Wright 2004), while others are dwarf stars that could be in an inactive phase, similar to in the Maunder Minimum (Judge & Saar 2007). In particular, the active young solar-like star ι Hor could belong to this second group.

Unlike the Solar Maunder Minimum, we observe that the level of activity of ι Hor during the 'flat' interval is larger ($<S_{\rm MW}> \sim 0.237$) than the minima of its cyclic phase, reached in 2002 ($S_{\rm MW} = 0.195$) and in 2015 ($S_{\rm MW} = 0.224$). Similarly, ψ Ser (HD 140538) also showed a transition from a constant period to a cycling mode, and also in this case the Ca II fluxes in the cycle minima were slightly below that observed during the flat phase (Hall et al. 2007).

ι Hor was continuously monitored between 2008 and 2010 by the SMARTS Southern HK project (Metcalfe et al. 2009), which is a time-domain survey of stellar activity variations. In contrast to our results, Metcalfe et al. (2010) detected the 1.6-yr cycle during the 'flat' interval observed in our Fig. 3. These authors continued observing this star until 2013 and confirmed this 1.6-yr cycle, which was also observed in the X-ray (Sanz-Forcada et al. 2013). However, they found that the amplitude of the three 1.6-yr cycles observed between 2008 and 2012 decreased from $A_{\rm cyc} \sim 0.024$ to $A_{\rm cyc} \sim 0.012$ (see fig. 1 in Sanz-Forcada et al. 2013).

In Fig. 6 we show our data combined with the average indexes obtained by SMARTS (Metcalfe et al. 2010; Sanz-Forcada et al. 2013). We performed a period analysis for the combined data set. As a result, we obtained a Monte Carlo FAP of 2×10^{-5} for our $\sim$ 5-yr cycle and a FAP of 3.61×10^{-4} for the shorter one (1.6 yr), which is much more significant than the one detected in Fig. 5. In addition, it can be observed that between 2007 and 2010 (first 1.6-yr cycle) the SMARTS indexes vary with an amplitude comparable to those observed by CASLEO during the intervals 2002–2007 and 2012–2015 ($A_{\rm cyc} \sim 0.029$ versus $A_{\rm cyc} \sim 0.031$ and $A_{\rm cyc} \sim 0.026$. On the other hand, the cycle around 2012 has a much smaller amplitude ($A_{\rm cyc} \sim 0.007$). Therefore, the 'flat' interval observed in Fig. 3 is not a constant phase, but a short activity cycle with a declining amplitude, as suggested by Sanz-Forcada et al. (2013). In other words, the combined time series suggest that the flat period seen in the CASLEO data is caused by sampling.

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[7] https://www.ngdc.noaa.gov/

4 DISCUSSION

Krejčová & Budaj (2012) found evidence that, for stars with $T_{\rm eff} < 5500$ K hosting planets closer than 0.15 au, the stellar activity is correlated with the mass of the planet. In order to check this result, we studied 12 stars with hot Jupiters. We observed that for stars with a similar $T_{\rm eff}$, stellar activity increases with the mass of the planet. Nevertheless, this trend could be related to differences in the stellar age. To explore this possibility, we used the stellar ages computed by Bonfanti, Ortolani & Nascimbeni (2016), which are 11.9, 5.9 and 5.1 Gyr for less to more active stars, respectively (corresponding to the empty blue triangles inside the red squares of Fig. 1). These data suggest that the observed stellar activity increases are probably the product of differences in stellar ages and are not related to the presence of massive planets. However, Pace (2013) recently showed that the reduction in the chromospheric activity with age is limited to stars younger than about 2.0 Gyr. We also show the distribution of $\langle S_{\rm MW}\rangle$ as a function of semi-major axis. We do not observe any correlation between stellar activity and semi-major axis. A larger sample of stars with and without planets is needed to confirm these preliminary results.

We also studied the long-term activity of the exoplanet host star ι Hor. In order to do this, we used the Ca II H and K lines as a proxy for stellar activity. We analysed the line core fluxes of 987 CASLEO and HARPS spectra taken between 2002 and 2015. We detected a long-term activity cycle with a period of 4.57 yr with a Monte Carlo FAP of 2×10^{-5}. Metcalfe et al. (2010) reported the presence of a 1.6-yr chromospheric cycle for this star, which was detected using the Ca II lines from SMART observations. Sanz-Forcada et al. (2013) also found a 1.6-yr cycle in ι Hor in the X-ray emission, which is a direct indicator of the coronal activity of the star.

Considering that some stars show signatures of multiple cycles (e.g. Baliunas et al. 1995; Hall et al. 2007; Oláh et al. 2009; Metcalfe et al. 2013; Rebull et al. 2016) and based on the results of Böhm-Vitense (2007), Metcalfe et al. (2010) and Sanz-Forcada et al. (2013) suggested that ι Hor could be this type of star. They estimated a longer cycle with a period of about 6 yr, which is apparently modulating the shorter one. In fact, from fig. 1 of Böhm-Vitense (2007) a period for the long-term activity cycle (active branch) between 4 and 7 yr can be estimated. The period we found in the present work fits this active branch within the statistical dispersion of the data in Böhm-Vitense (2007). Furthermore, stellar activity cycles are not exactly periodic (e.g. Oláh et al. 2009). For instance, the Sun has an average cycle of almost exactly 11 yr; however, the length of the individual solar cycles fluctuates between 9 and 13 yr with a standard deviation of about 1.16 yr (see details in Hathaway 2010). In addition, it has a longer cycle with a period of 80 $\sim$ 90 yr, called the Gleissberg cycle (see e.g. Hathaway 2015), and quasi-biennial variations as reported by Fletcher et al. (2010).

An interesting aspect of our time series of the Mt Wilson index of ι Hor is the 'flat behaviour' observed between 2007 and 2012. However, Metcalfe et al. (2010) and Sanz-Forcada et al. (2013) found the short cycle for ι Hor during that period. To interpret these differences, we plotted the SMARTS averaged measurements together with the CASLEO and HARPS data sets. First, this figure shows in general good agreement between the different data sets. In fact, we can observe that our new measurements follow the expected increase of the new cycle. Secondly, the analysis of the entire data set confirms the 1.6-yr short activity cycle. These facts suggest that the differences are produced mainly by our sampling, and that frequent observations are necessary in order to better establish the presence of an inactive phase.

Our results suggest that neither the shorter cycle (1.6 yr) nor the longer one (4.57 yr) is regular, which is possibly related to the high inclination of ι Hor ($i \approx 60^\circ$) and the antisymmetric distribution of active regions on the stellar surface, as suggested by Sanz-Forcada et al. (2013).

Kürster et al. (2000) detected a giant planet ($m \sin\, i = 2.26\, M_{\rm Jup}$) orbiting this star, with a period of (320.1 ± 2.1) d. There are several examples in the literature of a long-period chromospheric signal mimicking a planetary signal (e.g. Isaacson & Fischer 2010; Gomes da Silva et al. 2011; Robertson et al. 2013; Carolo et al. 2014). In order to detect a possible second planet for ι Hor, any possible periodic signal should be disentangled in order to correctly identify its planetary origin. In particular, Boisse et al. (2011) excluded the presence of a second low-mass planet with a period between 0.7 and 2.4 d in ι Hor. In our work we clearly identified a possible $\sim$5-yr long-term cycle related to chromospheric activity, which could point towards the exclusion of a second planet with a similar period.

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