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Searching for chromospheric activity cycles in 1111 FGK-type stars from the HARPS GTO planet search program

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Resumen / El monitoreo de muchas estrellas con ciclos magnéticos podría ayudar a un mejor entendimiento de la dependencia de estos con las propiedades estelares y el lugar ocupado por el Sol en este contexto. Hoy en día, existen muchos interrogantes relacionados con el ciclo solar (por ejemplo, la amplitud, forma y las fluctuaciones en la longitud del ciclo), los cuales podrían ser tratados si se incrementara el número de ciclos de actividad detectados en estrellas análogas-solares y gemelas-solares. En este trabajo, realizamos una búsqueda sistemática de ciclos de actividad cromosféricos en una muestra de 1111 estrellas FGK pertenecientes al programa de búsqueda de planetas HARPS GTO. Como resultado, pudimos analizar detalladamente la actividad cromosférica para 600 de estos objetos. Para este fin, calculamos el índice de Mount Wilson para cada objeto y luego las series temporales correspondientes fueron individualmente analizadas mediante el periodograma de Lomb-Scargle generalizado.

Abstract / The monitoring of many stars with magnetic cycles could help for a better understanding of their dependence with the stellar properties and the place occupied by the Sun in this context. Up to now, there are many questions related with the solar cycle (for example, amplitude, shape and length cycle fluctuations), which could be addressed if the number of stellar activity cycles detected in solar-analogues and solar-twin stars were increased. In this work, we performed a systematic search for chromospheric activity cycles in a sample of 1111 FGK stars belonging to the HARPS GTO planet search program. As a result, we were able to analyse in detail the chromospheric activity for 600 of these objects. To this end, we calculate the Mount Wilson index for each object and then the corresponding temporal series were individually analysed by using the generalised Lomb-Scargle periodogram.

Keywords / stars: solar-type — activity — chromospheres

1. Introducción

Wilson (1978) showed for the first time that, as the solar case, long-term chromospheric variations in the Ca II H&K lines can be found in other stars. This was followed by several studies (Vaughan et al., 1978; Duncan et al., 1991; Baliunas et al., 1995; Henry et al., 1996; Baliunas et al., 1998). Another important pioneer research was carry out by Baliunas et al. (1995), who grouped a sample of 111 FGK-type stars into three classes according to their variability type (i.e. cyclic, erratic and flat stars). These activity studies have important implications on different fields. In particular, studying a range of stars with physical characteristics similar to the Sun (solar-analogues and solar-twins) across a range of ages and other parameters could be very useful to place its ~11 yr cycle in context (e.g. Hall et al., 2007, 2009).

The Sun monitoring reveals that its 11 yr activity cycle varies in amplitude, shape and length (e.g. Charbonneau, 2010; Hathaway, 2010). However, the origin of these fluctuations is not clear yet.

In order to address these open questions, it would be suitable the monitoring of many stars similar to our Sun. In this way, we could answer if these cycle fluctuations are common in other stars and also we could explore their possible source. Frequently, new activity cycles are reported in literature (e.g. Metcalfe et al., 2010; Buccino et al., 2014; Egeland et al., 2015; Flores et al., 2017; Egeland, 2017). However, only a relatively low percentage of these stars are in fact solar-analogues or solar-twins stars (e.g. Hall et al., 2007; Egeland et al., 2015; Flores et al., 2016, 2018). For this reason, we have an ongoing programme that currently monitors the stellar activity in a sample with these types of stars. We mainly use the extensive database of the High Accuracy Radial velocity Planet Searcher (HARPS) spectra, which are occasionally complemented with CASLEO observations. In particular, we have been working with a sample of 1111 FGK stars observed in the context of the HARPS GTO (Guaranteed Time Observations) programs. Both the quality and the quantity of the available spectra, allow us to carry out detailed activity studies (e.g. Flores et al., 2016, 2017, 2018).

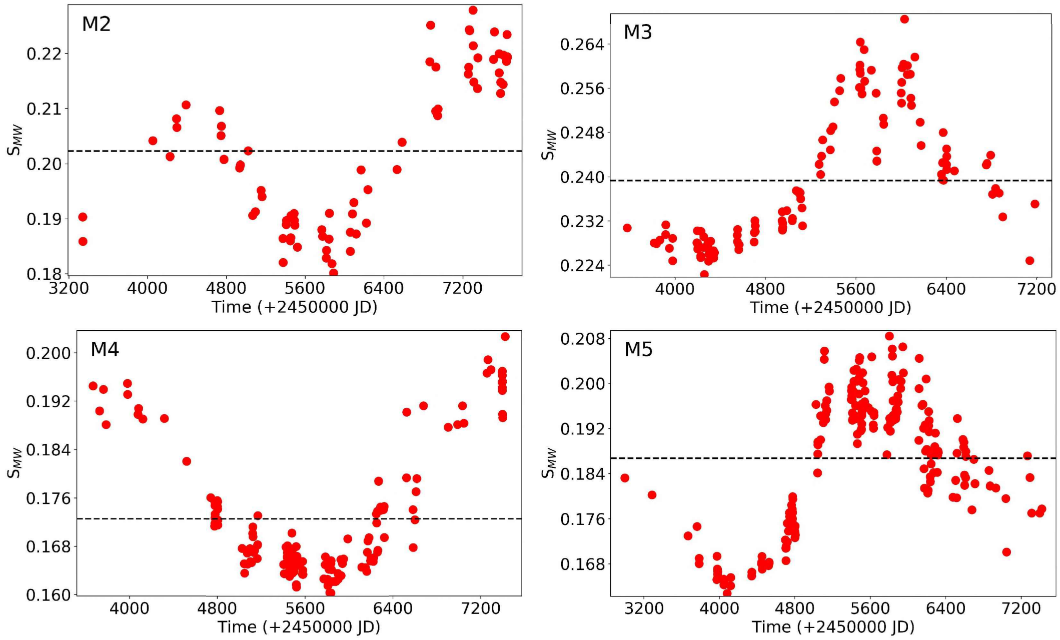

Figure 1: Time series of S_{MW} index for some stars with clear cyclic behaviour. Dashed lines indicate the $\langle S_{MW} \rangle$.

2. Observations and data reduction

The spectra of the 1111 FGK-type stars used here were downloaded from the European Southern Observatory (ESO) archive* (Mayor et al., 2003). They were acquired with the HARPS spectrograph (R∼115000), attached to the La Silla 3.6 m (ESO) telescope, and are part of the HARPS GTO programs: HARPS-1 (Mayor et al., 2003); HARPS-2 (Lo Curto et al., 2010) and HARPS-4 (Santos et al., 2011). These data have been automatically processed by the HARPS pipeline**, and cover a spectral range between 3782—6913 Å. After discarding those spectra with a low signal-to-noise ratio (∼S/N < 100), we normalised and cleaned from cosmic rays and telluric features using IRAF*** routines.

In order to measure the standard Mount Wilson index S_{MW}, first we integrated the flux in two windows centred at the cores of the Ca II H&K lines (3968.47 Å and 3933.66 Å, respectively), weighted with triangular profiles of a 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 20 Å width centred at 3891 and 4001 Å. Then, we used the calibration procedure of Lovis et al. (2011) to derive the S_{MW} indexes from HARPS spectra (see Flores et al., 2017).

*`http://archive.eso.org/wdb/wdb/adp/phase3_spectral/form?phase3_collection=HARPS`

**`http://www.eso.org/sci/facilities/lasilla/instruments/harps/overview.html`

***IRAF is distributed by the National Optical Astronomical Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

3. Results

Previous to computing the S_{MW} index for the whole sample of 1111 FGK stars, we excluded those stars with less than ten spectra****. As a result, we obtained 600 stars (out of 1111, corresponding to 54 % of the sample) available to analyse. Then, in order to study the long-term chromospheric activity for these 600 FGK stars, we computed the generalised Lomb-Scargle (GLS) periodogram and the false-alarm probability (FAP) of the periods, following Zechmeister & Kürster (2009). For the detection of reliable periodicities, we use a cut-off in FAP of 0.1 per cent (0.001). As a result, we detected clear chromospheric activity cycles in 30 stars (out of 600, corresponding to 5 % of the sample). Some of these chromospheric activity cycles have already been published by our group (Flores et al., 2016, 2017, 2018). The 570 remaining objects of the sample were classified as erratic ($(\sigma / < S_{MW} >) > 2$ %) or flat ($(\sigma / < S_{MW} >) < 1.5$ %), following the Baliunas et al. (1995) criteria. In addition, a high percentage of stars remains, at the moment, as unclassified.

Due to space constraints, in Fig. 1 we only show the time series corresponding to four (out of 30) of the objects with clear cyclic behaviour, these four stars have a resulting FAP $< 10^{-15}$. Both the periods and the mean Mount Wilson activity indexes ($\langle S_{MW} \rangle$) are shown in Table 1.

Fourteen of the cyclic stars found here are G-type stars, which allow us to compare their cycle properties directly with the solar one. For example, it can be observed that the star M2 seems to show an activity cycle with variable amplitude, which is also showed by the solar cycle.

****As previously mentioned, the S/N of the selected spectra must be greater than or equal to 100.

Table 1: Cycle length and mean activity levels corresponding to the stars of Fig. 1 and Fig. 2.

Ref.#	HIP	Cycle (days)	$\langle S_{MW} \rangle$
M1	27435	3755±200	0.173±0.001
M2	42291	3316±650	0.202±0.002
M3	90656	3274±700	0.239±0.002
M4	57172	4170±870	0.172±0.001
M5	86765	3401±820	0.186±0.003

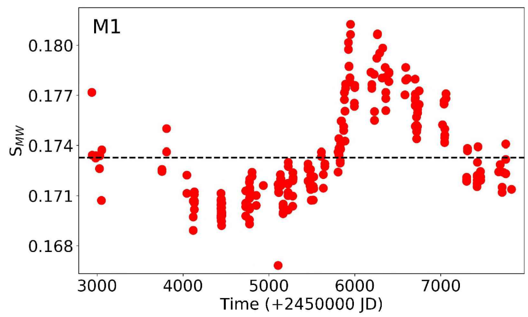

Figure 2: Time series of S_{MW} index for the star HIP 27435. The dashed line indicates the $\langle S_{MW} \rangle$.

Another object of interest within these fourteen G-type stars, is showed in the Fig. 2. Here, we present a long-term activity cycle of 10.2 yr (see the corresponding GLS periodogram of Fig. 3) found in a solar-analogue star (e.g. Delgado Mena et al., 2014). This cycle has not yet been reported in literature. In addition to the similarity between this activity cycle with the solar one, their mean activity levels are also very similar to each other $\log(R'_{HK})$=-4.94 vs. $\log(R'_{HK})$=-4.94/-4.91, according to the solar values derived by Hall et al. (2007) and Mamajek & Hillenbrand (2008). These similar patterns indicate that this solar-analogue star would be a good candidate, if we want to explore several solar cycle properties.

4. Conclusions and future work

The HARPS database has also proven to be a good tool for the search of chromospheric activity cycles. The quantity and quality of spectra available have allowed us to detect new activity cycles in several stars, in particular, in solar-analogues and solar-twins (see Flores et al., 2016, 2017, 2018).

Our mail goal is to study these new activity cycles in order to compare them with the solar cycle properties. In this same direction, those stars with signatures of flat activity which could be in a Maunder Minimum state†, are also important if we want to know a little more about the solar cycle and its properties.

Both the search of activity cycles and the characterisation of the types of variability in this sample of 600 objects, are affected by the large number of stars that remains, at the moment, as unclassified. In this case, we are referring to stars with few observations, those with

†The period between 1645 and 1715 during which solar activity was greatly reduced (e.g. Eddy, 1976).

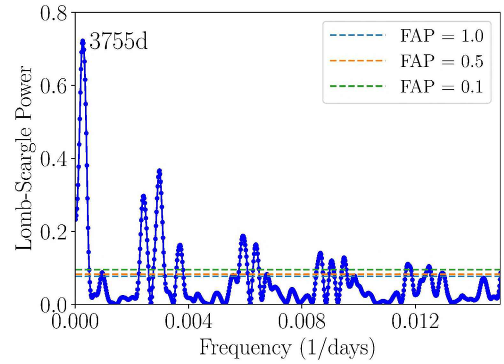

Figure 3: GLS periodogram for the Mount Wilson indexes data of the star M1. Horizontal dashed lines correspond to a FAP of 0.1, 0.5 and 1 (per cent), respectively.

high FAP's in their temporal series, stars with very noisy temporal series or not very dense and also stars with a limited sampling. The statistical, when possible, will be improved with CASLEO observations.

We are now working with the solar-analogue star M1, which has an activity cycle and a mean activity level very similar to the solar values. Beside the variation detected in the Ca II H&K lines, M1 also shows other spectral lines with signs of appreciable variations (e.g. H_α and Fe II). It is an interesting finding because these lines might be used, for instance, to detect a possible activity cycle in those surveys that do not include the classical Ca II H&K lines in their spectra. These results will be promptly published.

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