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The activity of possibles Maunder minimum candidates

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Abstract. Among several aspects related to the Sun activity history, there was a period of the Sun evolution with a low chromospheric activity level and a low number of observed sunspots. This period was between 1645 and 1715, (well known as Maunder Minimum period, MM), and remains as a puzzle for the stellar evolution theory. In this work, we investigate the evolutionary status of 30 sun-like type stars that are possible MM candidates due to their low chromospheric activity as compared with stars at same evolutionary status. These stars present activity index measurements along 50 yrs from the Mount Wilson program and others. They have very low chromospheric activity as $\log R'_{HK} \leq 5.0$, $< S > \simeq 0.15$ and $(B-V)$ between 0.61 and 0.71 (for the Sun the $< S >_{\odot} = 0.167$ and a color index $(B-V)_{\odot} = 0.65$). At this phase, we also revisited CoRoT and Kepler databases to enhance the number of Maunder minimum candidate stars presenting flat light curves and low activity profile.

Resumo. Dentre os vários aspectos relacionados com o histórico de atividade do Sol, houve um período da evolução do Sol com baixa nível de atividade cromosférica e um baixo numero de manchas solares observadas. Esse período foi entre 1645 e 1715, (conhecido como mínimo de Maunder, MM), e permanece como um enigma para a teoria da evolução estelar. Neste trabalho, nós investigamos o status evolucionário de 30 estrelas do tipo solar que são consideradas possíveis candidatas MM devido aos seus baixos níveis de atividade cromosférica ao longo dos últimos 50 anos. Estas estrelas apresentam índices de atividade extremamente baixos, tais como: $\log R'_{HK} \leq 5.0$, $< S > \simeq 0.15$ e $(B-V)$ entre 0.61 e 0.71 (para o Sol $< S >_{\odot} = 0.167$ e o índice de cor $(B-V)_{\odot} = 0.65$). Neste estágio, nós também revisaremos as bases de dados dos satélites CoRoT e Kepler para aperfeiçoarmos o número de estrelas candidatas MM, que apresentem curvas de luz "flat" e perfil de baixa atividade.

Keywords. Stars: activity – Stars: evolution – Stars: chromospheres

1. Introduction

The problem of extremely low activity in main sequence stars is a puzzle for the stellar astrophysics. It is known that young stars have a strong activity. When these stars present an extremely low activity, along many years, it could be the first evidence of Maunder Minimum (MM hereafter), which defines a phase of the solar activity during 70 yrs between XVI and XVII centuries when almost no sunspots have been observed (see Fig.1).

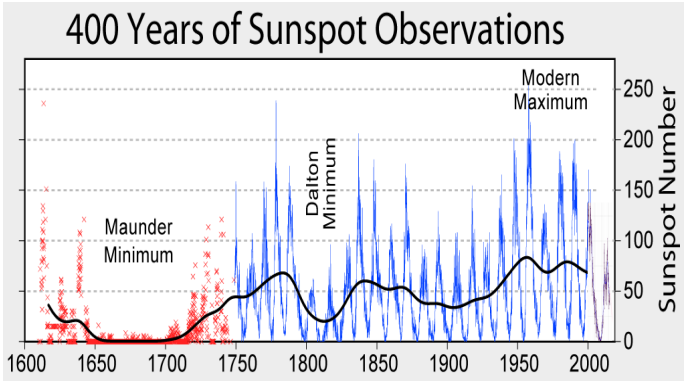

Figure 1. *All measurements for sunspots along 400 yrs. The red dots show the MM period. We also have the others minimums in this figure.*

Many surveys in Sun-like stars have been a good opportunity to study the Sun's activity history (Wright (2004)). They are very important to detect extremely low activity analogous to MM period in young stars. In fact, the MM state has been investigated since 1970's (Eddy (1976)). Through the Mt. Wilson (MW) program (see Fig. 2) and the California and Carnegie Planet Search program, it has been possible to analyze the activity evolution along the last 50 yrs. The S-index of MW is the standard index of activity and has been very useful to investigate the activity evolution of these stars.

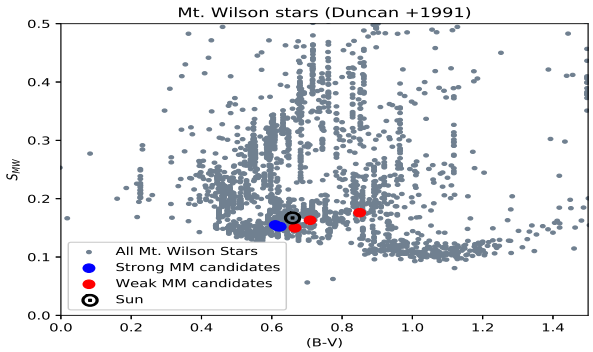

Figure 2. In this figure, we can see the MW sample stars. The inferior envelope contains the MM candidates, divided into strong MM candidates and weak MM candidates according to the literature (Ferreira et al. 2018, in prep.)

This work is organized as follows: in section 2 we present our sample of stars, in section 3 we show many results and discussion about some selected stars of our sample, finally the last session is the conclusion and perspectives.

2. The sample

Our sample presented in Fig. 2 is composed by Sun-like stars (see Duncan et al. (1991); Hall et al. (2009); Isaacson & Fischer

(2010); Lubin et al. (2010); Pace (2013)). We use the long-term programs for monitoring the activity along many years. The most important was the MW project. Currently, there are some short-term activity programs, that observe stars for some days only.

The better MM candidates in the sample					
Star	Type	log n (Li)	B-V	$< S >$	Age [Gyr]
HD 10307	G2	1.92	0.618	0.152	7.00
HD 43587	G0	1.83	0.610	0.155	6.12
HD 95128	G0	1.81	0.624	0.152	7.11
HD 3651	K0	0.59	0.850	0.176	6.91
HD 115617	G5	1.20	0.709	0.163	6.53
HD 217014	G5	1.32	0.666	0.150	7.24

3. Results and discussion

We investigate about 30 Sun-like stars that have a flat activity profile and may be considered MM candidates to according to Lubin et al. (2010) and others. From the spectroscopic S-index measurements variability, we calculate the Long-Scargle Periodograms (Horne & Baliunas (1986)) and we found several possible periods of activity. We first investigate the star HD 43587, that was a primary CoRoT target. After this, we found five more stars that can be considered MM candidates.

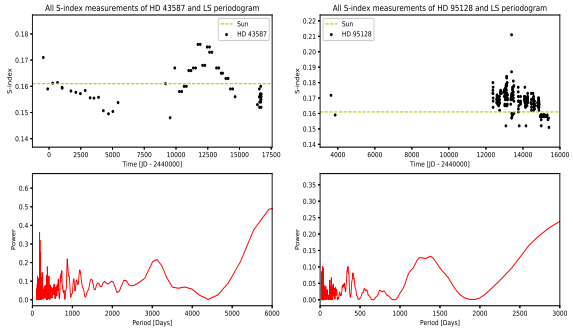

Figure 3. All S-index spectroscopic measurements for HD 43587 and HD 95128 (above) with its respectively Lomb-Scargle (LS) periodograms (below).

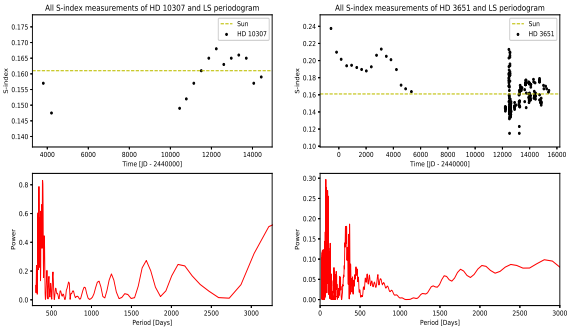

Figure 4. All S-index spectroscopic measurements for HD 10307 and HD 3651 (above) with its respectively Lomb-Scargle (LS) periodograms (below)

Lubin et al. (2010) analyse the MM candidates under the perspective of lithium abundances and classified three of these stars as strong MM candidates and Weak MM candidates according to the standard deviation of log n(Li). Here, we show the Lomb-Scargle periodogram for the "strong" MM candidates, from the activity measurements of long-term programs (see Figs. 3,4,5).

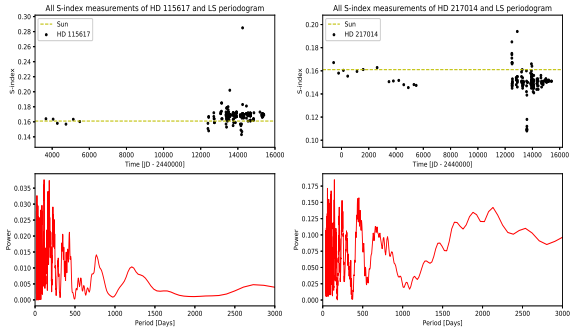

Figure 5. All S-index spectroscopic measurements for HD 115617 and HD 217014 (above) with its respectively Lomb-Scargle (LS) periodograms (below)

4. Conclusion and perspectives

These stars are considered strong MM candidates by many authors and they have lithium abundance that is within the normal range for their color (Lubin et al. (2010)). The analyze of the lithium abundances suggests that stars with normal lithium abundance and low activity profile are good MM candidates. In addition, it is not possible to determine the activity cycle period, which is an indication that the star is in a long period of flat activity. We pretend to continue with the time-series spectroscopic measurements and proposals for long-term observational campaign.

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