A New Light on the Relation Between Rotation Periods and Cycle Lengths of Stellar Activity

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Abstract.
Solar analogs and twins shed a new light on the relation between rotation period and cycle length of stellar activity. The question of how typical the Sun is within the class of solar-type stars has been the subject of active investigation over the past three decades. Some previous work has suggested that the Sun's magnetic cycle period Pcyc is unusual compared with similar stars, falling between sequences of active and inactive stars. The HARPS planet-search has been gathering high-precision Ca II H&K chromospheric activity measurements for many years, and has measured a large number of new Pcyc. We collect the most robust cycles among these for stars which are solar analogs (main-sequence stars with $0.8M_{\odot}$ < mass < $1.2M_{\odot}$) or solar twins twins (stars with T_{eff}, $[Fe/H]$ and mass indistinguishable from the Sun). Combining this new sample with older data, we revisit the relation between rotation periods Prot and Pcyc. Our preliminary analysis shows that the Sun does not have a special position between the active and inactive sequences, but instead follows the a new solar-analog sequence proposed here.

1. Introduction

Over three decades, since O.C. Wilson at the Mt. Wilson Observatory in the 1960s, the chromospheric activity of a large number of solar-type stars, include the Sun, has been monitored in their Ca II line emission. As a well-known proxy indicator for stellar magnetic activity, long-term variations in the chromospheric Ca II emission can provide information on the nature and strength of magnetic activity. The Mt. Wilson monitoring programme (cf., Baliunas et al. 1995) is the longest-running program to monitor stellar activity cycles and demonstrated that the Sun is not the only star with a periodic activity cycle, but rather such periodic behavior is quite common, among the solar type stars. This programme has been monitoring stars continuously since 1966. At the same time, many solar-like stars do not show any periodic activity cycles like. Wilson (1978), Baliunas & Vaughan (1985), Baliunas et al. (1995), and others have devoted major parts of their research efforts to the determination of Pcyc and Prot, studying the variations of the Ca II emission. Brandenburg et al. (1998) critically discussed the available data. Saar & Brandenburg (1999) judged the reliability of the available data and graded them accordingly. In recent years stellar activity surveys have been produced a huge quantity of Ca II H & K observations from the Doppler exoplanet programs and new studies have been conducted to investigate magnetic activity of solar-type stars (Santos et al. 2000; Wright et al. 2004; Hall et al. 2007). The Mt. Wilson sample mainly consists of solar-type, main-sequence (MS) stars and the crucial question in this context is clearly which stars can be considered comparable to the Sun from their mass, effective temperature, metallicity and rotation rate. Using new cycle lengths of stellar activity from Mt. Wilson and HARPS FGK high-precision sample (Udry et al. 2000, Lovis et al. 2011) which include some stars nearly indistinguishable from the Sun (Cayrel de Strobel 1996) we can study today how typical is the Sun's magnetic cycle length.

2. The work sample evolutionary status and mass

In this section, we discuss about the sample evolutionary status characteristics of the observational data used in this study. Our analysis is based on the high-quality data as selected by Saar & Brandenburg (1999), Lorente & Montesinos (2005), Lovis et al (2011) and collected by do Nascimento et al. (2014). The Fig.1 shows the HR diagram with the evolutionary tracks computed with Toulouse-Geneva Evolution Code (TGEC, do Nascimento et al., 2009) for different metallicity values ([Fe/H] = 0.15, 0.0, -0.20, and -0.40), and presented here only for [Fe/H] = 0.0, which encompasses most of the stars contained in the present working sample. The work sample is composed for stars with masses between $0.6M_{\odot}$ and $1.5M_{\odot}$. Crosses indicate stars on the Active sequence, and asterisks indicate stars on the Inactive sequence as in Böhm-Vitense (2007). The star 18 Sco is represented by a square and was the first star identified as a solar twin by Porto de Mello & da Silva (1997). 18 Sco has been observed for chromospheric activity (e.g. Hall et al. 2007), magnetic fields (Petit et al. 2008). 18 Sco which has physical characteristics similar to solar, a lithium abundance about three times solar (Melendez & Ramírez 2007), a younger age (Baumann et al. 2010), Prot of 22.7 days (Petit et al. 2008) and a Sun-like activity cycle of 7 years (Hall et al. 2007).

3. Rotation Periods and Cycle Lengths of Stellar Activity relation

In Fig. 2 we present the lengths of the activity cycles, Pcyc in years as a function of the rotation periods in days. From the reliable data from Saar & Brandenburg (1999) and by Lorente & Montesinos (2005) Böhm-Vitense (2007) found a distinct segregation of active and inactive stars into two approximately parallel bands A(active) and I (inactive) sequences. Here we use the same observational data as used by Saar & Brandenburg (1999) and by Lorente & Montesinos (2005), but with new Pcyc and Prot from Lovis et al. (2011). 18

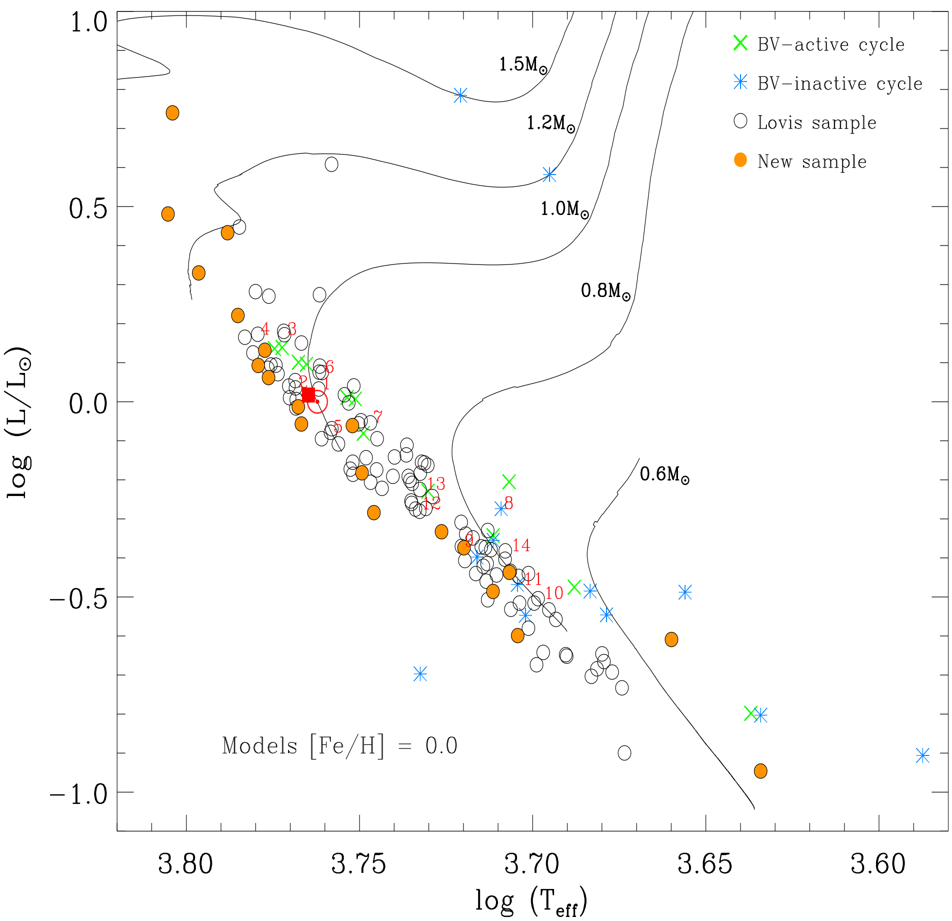

Figure .1: The distribution of the analog sample stars in the Hertzsprung-Russell diagram. Luminosities have been derived from the Hipparcos parallaxes. Evolutionary tracks at [Fe/H] = 0 are shown for stellar masses between $0.6M_{\odot}$ and $1.5M_{\odot}$. Crosses indicate stars on the Active sequence, and asterisks indicate stars on the Inactive sequence as in Böhm-Vitense (2007).

Sco is found here that along border line of the Inactive sequence. The letter H indicates Hyades group stars, crosses indicate stars on the A sequence, and asterisks indicate stars on the I sequence. Squares around the crosses show stars with (B - V) < 0.62. Triangles indicate secondary periods for some stars on the A sequence. The solar point is represented by the usual symbol. Inactive I sequence, as defined by Böhm-Vitense (2007) are composed by cooler and more slowly rotating stars. An intermediate branch is presented between the two I and A sequences and as a function like $P_{cyc} = 0.84 + 0.36P_{rot}$.

4. Summary and Future directions

As seen in Fig.2 the observed relation between rotation periods and lengths of activity cycles for main-sequence G and K stars based on new Pcyc and Prot also shows an intermediate

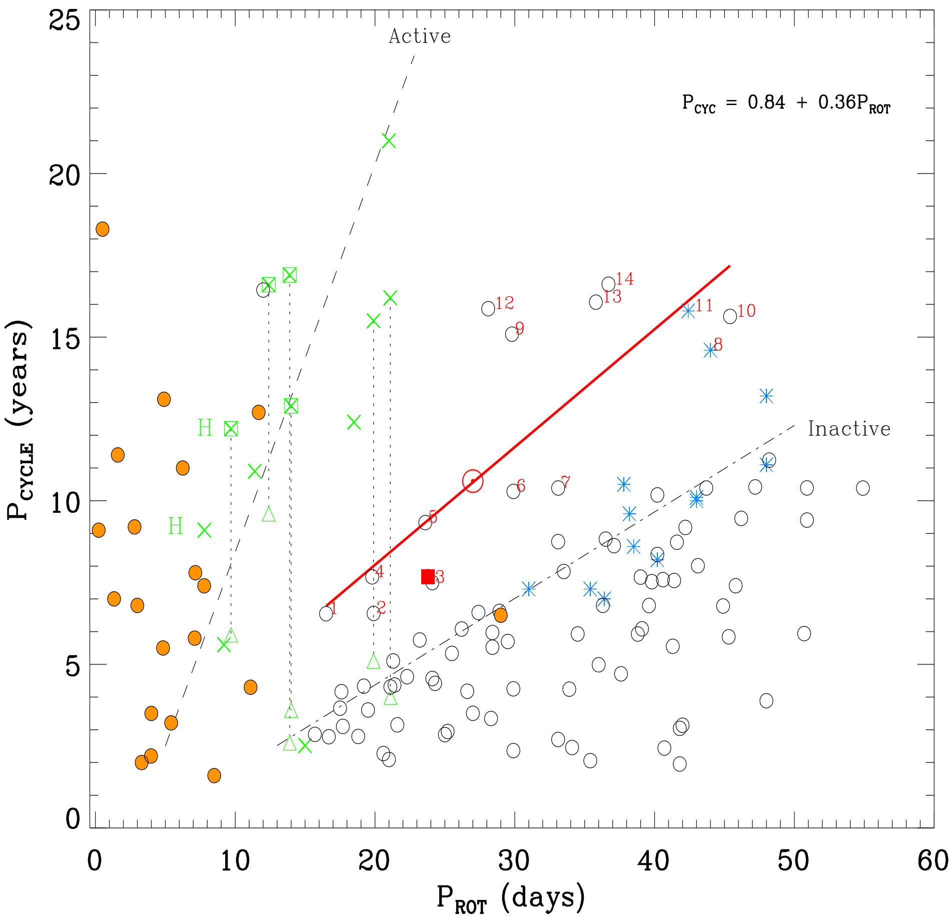

Figure .2: Periods of the activity cycles Pcyc (in years) as a function of the rotation periods Prot (in days). Two sequences are defined by Böhm-Vitense (2007) as relatively young, active A sequence (dashed line) and the older, less active I sequences (dash-dotted line). The letter H indicates Hyades group stars, crosses indicate stars on the A sequence, and asterisks indicate stars on the I sequence. Squares around the crosses show stars with (B - V) < 0.62. Triangles indicate secondary periods for some stars on the A sequence. The solar point is represented by the usual symbol.

new branch, besides the two mainly sequences, which Saar & Brandenburg called the active, A, and the inactive, I, sequences. We suggested a "new branch", that it may be a splitting of the Inactive branch. As a main result, we conclude that the Sun is not anomalous, when compared to the magnetic cycles that have been seen in other stars, but potentially a member of a new intermediate branch. The next step in our study will be evaluated this new Pcyc and determined how reliable they are.

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