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Solar analogs and twins: a spectroscopic analysis in the violet and ultraviolet

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Abstract. Solar type stars are fundamental objects in astrophysics. We perform a spectroscopic analysis in the regime bellow 4500 Å of 85 solar type stars aiming to determine which solar analog and twin candidates of our sample, characterized by means of a spectroscopic analysis in the visible, are similar to the Sun in the mentioned region. The violet/ultraviolet region is very sensitive to small variations of the atmospheric parameters of the stars and is still poorly explored in the literature in the context of solar type stars. We use the spectral indexes method with a principal component analysis calibration to derive the atmospheric parameters of a select sample of objetcs and determine that the stars HD 98649, HD 118598, HD 138573 and HD 140690 are the most similar to the Sun between 3995 and 4500 Å. Besides that, we use the molecular features of CN (3850 Å) and CH (4310 Å) to study similarities between a set of stars and the Sun.

Resumo. Estrelas do tipo solar são objetos fundamentais na astrofísica. Reportamos uma análise espectroscópica da região abaixo de 4500 Å de 85 estrelas do tipo solar com o objetivo de determinar quais candidatas a análogas e gêmeas solares da amostra, assim classificadas por análises espectroscópicas no visível, mantêm semelhanças com o Sol no regime mencionado. A região violeta/ultravioleta é muito sensível à pequenas variações dos parâmetros atmosféricos estelares e ainda é pouquíssimo explorada na literatura no contexto de estrelas do tipo solar. Utilizamos o método dos índices espectrais aplicando uma calibração a partir de uma análise de componentes principais para derivar os parâmetros atmosféricos de uma amostra seleta de objetos e determinar que as estrelas HD 98649, HD 118598, HD 138573 e HD 140690 mais se assemelham ao Sol entre 3995 e 4500 Å. Além disso, usamos as bandas moleculares do CN (3850 Å) e do CH (4310 Å) para estudar similaridades entre um conjunto de estrelas e o Sol.

Keywords. Stars: solar-type – Stars: fundamental parameters – Stars: atmospheres

1. Introduction

Stars similar to the Sun are fundamental objects in astrophysics as they play an important role in characterizing the properties of the Sun among the stars; in studies of Galaxy evolution (Edvardsson et al. 1993a,b); and they are astrobiologically interesting objects (Porto de Mello, del Peloso & Ghezzi 2006).

We pay special attention to the so-called solar analogs and twins (Cayrel de Strobel & Bentolila 1989; Cayrel de Strobel 1996). Solar analogs are stars with atmospheric parameters, such as effective temperature, metalicity, surface gravity and photometric colors, similar to the solar ones. Solar twins are objects that have all fundamental parameters — mass, age, effective temperature, chemical composition, surface gravity, luminosity, and others — identical to the Sun within the observational uncertainties.

Although the study of stars similar to the Sun started in the ultraviolet region with Hardorp (1978), the majority of stars classified as solar analogs and twins were characterized by means of a spectroscopic analysis in the visible spectrum. However, the regime below 4500 Å is interesting in solar type stars for their great sensitivity to the atmospheric parameters (Dragon & Mutschlecner 1980). This regime is, therefore, a useful tool in the identification of this kind of stars, being still poorly explored in the literature in this context (Altamore et al. 1990).

2. Methodology

Our sample contains 85 solar type stars, including interesting solar analog and twin candidates (Porto de Mello et al. 2014), and a total of 120 FEROS spectra with atmospheric parameters determined in the literature and compiled in the work of Lorenzo-Oliveira et al. (2016). We first degraded the original resolving power of FEROS of 48000 to 15000 — due to the high density of transitions below 4500 Å and in order to simplify our analysis and increase the S/N — and normalized the spectra.

Thereafter, we identified the spectral indexes visually. A spectral index is a spectral characteristic composed by a group of atomic or molecular transitions showing sensitivity to the variation of one or more atmospheric parameters (Ghezzi et al. 2014). We built a calibration using the principal component analysis method applied to the EW of the 103 best indexes (of a total of 336) and the atmospheric parameters of the calibration sample (it didn't include the solar analog and twin candidates), this result is shown in Fig. 1.

To estimate the EW error we used stars with multiple observations. Then, we applied a Monte Carlo simulation to the measurements of the spectral indexes of the solar analog and twin candidates to generate synthetic measurements of the indexes and build distributions of EWs. With these values we determined their atmospheric parameters and its errors using the calibration.

Moreover, we isolated the region of greater influence of the molecular features of CH and CN — they are the main molecular bands observed in solar type stars and whose sensitivities

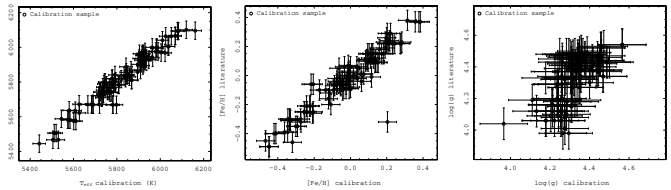


Figure 1. Comparison between the effective temperature, metalicity and surface gravity values, respectively, derived from the calibration and their values from the literature for the calibration sample.

to the atmospheric parameters are high (Hardorp 1978) — in order to quantitatively determine, though in a preliminary manner, similarities between the solar analog and twin candidates and the Sun. We measured the EW of these regions and analyzed its correlation with effective temperature, metalicity and surface gravity.

3. Results

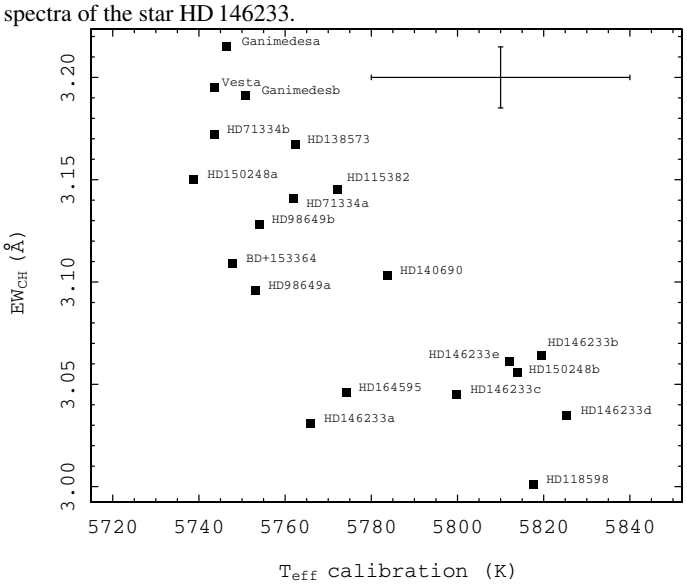
Table 1. Atmospheric parameters of solar analog and twin candidates derived using the 3995 to 4500 Å regime. The letters a, b, c, d, and e hold for distinct observations of the same object, and Ganimedes and Vesta are used as Sun templates.

Identification	$T_{eff} \pm 30$ (K)	[Fe/H] ± 0.051	$\log g \pm 0.120$
HD 71334 a	5762	−0.025	4.384
HD 71334 b	5744	−0.047	4.389
HD 98649 a	5753	−0.038	4.396
HD 98649 b	5754	−0.046	4.387
HD 115382	5772	−0.125	4.415
HD 118598	5818	+0.004	4.366
HD 138573	5762	−0.017	4.390
HD 140690	5784	+0.039	4.353
HD 146233 a	5766	+0.025	4.357
HD 146233 b	5820	+0.038	4.352
HD 146233 c	5800	+0.025	4.342
HD 146233 d	5825	+0.069	4.314
HD 146233 e	5812	+0.032	4.343
HD 150248 a	5739	−0.074	4.399
HD 150248 b	5814	+0.019	4.362
HD 164595	5774	−0.068	4.397
BD+15 3364	5748	+0.070	4.334
Ganimedes a	5746	+0.004	4.387
Ganimedes b	5751	−0.019	4.382
Vesta	5744	−0.018	4.385

We compared the results of Tab. 1 with Porto de Mello et al. (2014) (obtained using the visible region) analyzing the statistical significance of each atmospheric parameter with respect to the literature parameters: in general our results agree with those from Porto de Mello et al. (2014).

Likewise, we performed the comparison mentioned with respect to the Sun (T_{eff} = 5777 K, [Fe/H] = 0.00 and $\log g$ = 4.44), and we also compared the literature values with the solar ones. The result was that all the stars are similar to the Sun in the visible spectrum, suggesting that this regime exhibits a lower capacity to discriminate spectral features. However, using the violet region, we could discriminate more finely between the stars and we found that only the stars HD 98649, HD 118598, HD 138573, and HD 140690 are similar to the Sun in all parameters in 1σ confidence level. This indicates that this domain is potentialy

Figure 2. Relation between CH EW and effective temperature for a set of solar analog and twin candidates. The error bars were evaluated using spectra of the star HD 146233.



very sensitive to discriminate subtle differences of the spectral features in solar type stars.

About the study using CH and CN features, we observed a low correlation between its strenghts and the atmospheric parameters, with the CH showing a small trend with effective temperature as shown in Fig. 2.

4. Conclusions

1. We stablished a tool to analyze the short spectral range of solar type stars.
2. The atmospheric parameters derived using spectral indexes in the violet region are in agreement with those in the visible.
3. The visible domain is poorer than the violet to discriminate between spectral feature differences.
4. The violet regime showed a significant sensitivity, revealing that the stars HD 98649, HD 118598, HD 138573, and HD 140690 are the best solar analog and solar twin candidates of our sample, and we strengthen the classification of these stars as solar analogs.
5. The analysis using the CH and CN features were inconclusive, but they should be explored in more detail.

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