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# Photometric search for solar analogs and solar twins in the GAIA catalog

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**Abstract.** Solar-type stars are fundamental for investigating how the Sun fits among the stars of the solar neighborhood. They are characterized by low mass, belong to the main sequence, and exhibit spectral types F, G, and K. Among the stars, there are solar twins and solar analogs. Solar twins are objects identical to the Sun in all their physical properties, while solar analogs possess photometric parameters, $T_{\rm eff}$, $\log g$, and [Fe/H] similar to those of the Sun. The research aims at the identification of solar analog and twin stars, using data from the Gaia DR3 catalog within 60 pc. For the research, 63 stars were selected from Porto de Mello et al. (2014), with a high photometric similarity index to the Sun with the colors $(B-V)$, $(B-V)_{Tycho}$, $(b-y)$, and $m_1$. From this, the photometric parameters in Gaia DR3 were obtained for the 63 stars. Based on solar color indices, the photometric similarity index $S_C$ was calculated. Those with $S_C \leq 1.5$ were considered candidates, totaling 15 stars. Subsequently, a search box by colors $(G_{BP}-G_{RP})$, $(G_{BP}-G)$, and $(G-G_{RP})$ was defined, resulting in 143 objects, of which, after analyses, 136 remained. With additional absolute magnitude criteria, the sample was reduced to 94 stars, of which 53 satisfied the criterion of $S_C \leq 1.5$. The current phase of the project is concentrated on refining the sample based on existing data in the literature, on spectroscopic observations, and on the search for complementary data that allow bypassing the degeneracy of the Gaia data.

**Resumo.** As estrelas de tipo solar são fundamentais para investigar como o Sol se encaixa entre as estrelas da vizinhança solar. São caracterizadas por baixa massa, pertencem à sequência principal e apresentam tipos espectrais F, G e K. Dentre as estrelas, existem as gêmeas solares e análogas solares. Gêmeas solares são objetos idênticos ao Sol em todas as suas propriedades físicas, enquanto análogas solares possuem parâmetros fotométricos, $T_{\rm eff}$, $\log g$ e [Fe/H] semelhantes aos do Sol. O objetivo da pesquisa é a identificação de estrelas análogas e gêmeas solares, utilizando dados do catálogo Gaia DR3 dentro de 60 pc. Para a realização da pesquisa, foram selecionadas 63 estrelas de Porto de Mello et al. (2014), com alto índice de similaridade fotométrica com o Sol com as cores $(B-V)$, $(B-V)_{Tycho}$, $(b-y)$ e $m_1$. A partir disso, foram obtidos os parâmetros fotométricos no Gaia DR3 das 63 estrelas. Com base nos índices de cor solares, calculou-se o índice de similaridade fotométrica $S_C$. Foram consideradas candidatas aquelas com $S_C \leq 1.5$, totalizando 15 estrelas. Em seguida, definiu-se uma caixa de busca por cores $(G_{BP}-G_{RP})$, $(G_{BP}-G)$ e $(G-G_{RP})$, resultando em 143 objetos, dos quais, a partir de análises, restaram 136. Com critérios adicionais de magnitude absoluta, a amostra foi reduzida a 94 estrelas, das quais 53 satisfizeram o critério de $S_C \leq 1.5$. A fase atual do projeto está concentrada no refinamento da amostra com base em dados já existentes na literatura, nas observações espectroscópicas e na busca por dados complementares que permitam contornar a degenerescência dos dados do Gaia.

**Keywords.** Solar-type – Fundamental parameters – Photometric – Catalogs – Solar neighborhood

## 1. Introduction

The Sun is the most fundamental and reliable reference object in stellar astrophysics (Porto de Mello et al. 2014), and to explore the Sun's potential reference status as a star, we must correctly position it within observational parameters (Porto de Mello et al. 2014), such as its colors and magnitudes.

Solar-type stars are fundamental for investigating how the Sun fits among the stars of the solar neighborhood (Castro et al. 2016); (Castro 2021). They are characterized by low mass, belong to the main sequence, and exhibit spectral types F, G, and K. Among solar-type stars, there are solar twins and solar analogs.

Solar twins are objects identical to the Sun in all their physical properties (Cayrel de Strobel & Bentolila 1989), while solar analogs possess photometric parameters, $T_{\rm eff}$, $\log g$, and [Fe/H] similar to those of the Sun (Porto de Mello et al. 2014); (Cayrel de Strobel 1996).

These stars are fundamental for the calibration of photometric scales and atmospheric models (Porto de Mello et al. 2014), for investigations regarding the formation of planetary systems similar to ours (Di Bartolo 2005), and for understanding whether the Sun is a typical or peculiar star.

The identification of analogs and twins is not trivial. Although photometry is the initial tool, it is subject to photometric degeneracy (different combinations can produce practically identical colors), leading to misidentifications. This makes the use of complementary photometry and spectroscopy necessary.

Photometric parameters serve as preliminary indicators of fundamental stellar properties such as $T_{\rm eff}$, $\log g$, and [Fe/H]. In this context, Porto de Mello et al. (2014) developed a photometric similarity index $S_C$ as a metric to compare the photometry of a star with that of the Sun—which, by definition, has $S_C = 0.00$—using a cutoff criterion of $S_C \leq 1.5$. Therefore, a low $S_C$ indicates high photometric similarity to the Sun.

While the survey by Porto de Mello et al. (2014) relied on $(B-V)$ and $(b-y)$ colors to select candidates, the current Gaia DR3 catalog offers a significantly more precise photometric and astrometric basis, enabling the distinction of solar analogs with greater rigor than previous surveys.

## 2. Methodology and Results

For this research, 63 stars were selected from the study by Porto de Mello et al. (2014), categorized as strong candidates for solar twins. Subsequently, a search for parameters was conducted in the (Gaia Collaboration et al. 2023) database, specifically for the $G_{BP}$, $G_{RP}$, and $G$ magnitudes of the selected stars. In addition to the stellar parameters, it was necessary to obtain the solar color indices, determined as: $(G_{BP}-G_{RP})_\odot = 0.818 \pm 0.029$, $(G_{BP}-G)_\odot = 0.324 \pm 0.016$, and $(G-G_{RP})_\odot = 0.494 \pm 0.020$, according to Gaia DR3 data. The photometric similarity method

$S_C$ (Eq. 1) was applied, now using Gaia colors, to all these stars, resulting in only 15 stars meeting the criterion of $S_C \leq 1.5$.

$$S_C = \alpha \sum_{C_i} \left\{ \frac{(C_i^{\star} - C_i^{\odot})^2}{(\sigma_{C_i})^2} \right\} \quad (1)$$

The $S_C$ index expresses a simple sum of squared differences relative to the adopted solar colors, weighted by the mean error of each color. Here, $C_i^{\star}$ represents the color indices $(G_{BP} - G_{RP})$, $(G_{BP} - G)$, and $(G - G_{RP})$; $C_i^{\odot}$ represents the solar color index; $\sigma_{C_i}$ is the mean error associated with the colors; and $\alpha$ is an arbitrary normalization constant.

Based on the 15 stars, color index intervals (Fig. 1) were defined corresponding to $\pm 2\sigma$ within the sample ($G_{BP} - G_{RP}$ [0.81221 – 0.82398], $G_{BP} - G$ [0.31934 – 0.32717], and $G - G_{RP}$ [0.49183 – 0.49902]). Absolute magnitude values $M(G)$ were also calculated for each star, defining intervals within $\pm 2\sigma$ ($M(G)$ = [4.3166 – 4.9384]).

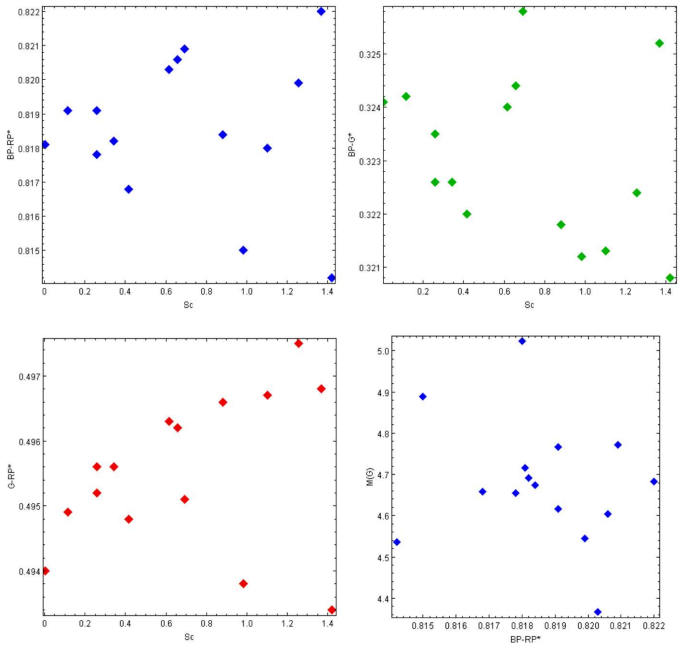


**Figure 1.** Definition of search boxes using an interval corresponding to $\pm 2\sigma$ of the 15-star sample. *(Top left)* Color index $G_{BP} - G$ [0.31934 – 0.32717] vs. Similarity Index $S_C$. *(Top right)* Color index $G - G_{RP}$ [0.49183 – 0.49902] vs. Similarity Index $S_C$. *(Bottom left)* Color index $G_{BP} - G_{RP}$ [0.81221 – 0.82398] vs. Similarity Index $S_C$. *(Bottom right)* Absolute magnitude interval $M(G)$ [4.3166 – 4.9384] of the 15 stars.

Using the values from the color index and absolute magnitude $M(G)$ intervals, a new search was performed, now within the Gaia context, limited to 60 parsecs based on color and magnitude. This yielded 94 possible candidates. Applying the photometric similarity criterion, only 53 possible candidates (Fig. 2) fell within the $S_C \leq 1.5$ criterion, 10 of which were already present in the Porto de Mello et al. (2014) sample.

## 3. Conclusions

In this work, we performed a photometric search for new solar twin candidates using the precision of Gaia DR3 data. The fundamental step was the calibration of solar color indices in the Gaia system, using reference stars from Porto de Mello et al. (2014). The application of the Photometric Similarity Index ($S_C$) allowed refining the initial sample of 63 stars to 15 objects with $S_C \leq 1.5$, thus defining a statistically robust search box based on $\pm 2\sigma$ intervals. By expanding the search to a volume limited to 60 parsecs, we initially identified 94 candidates, of which 53 satisfied the final similarity criterion. Of these, 10 are rediscoveries that validate the method, while 43 represent new potential candidates that lack detailed study.

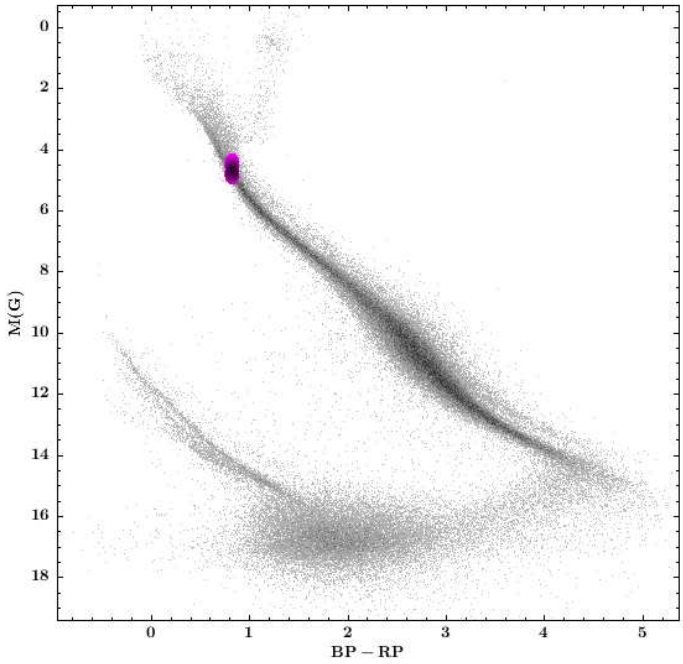


**Figure 2.** Color-magnitude diagram (up to 60 pc). Grey: Stars within 60 pc. Pink: Solar analog candidates.

The continuation of this project focuses on the spectroscopic and evolutionary refinement of these 53 candidates. Future steps consist of searching for complementary data in the literature and via photometry, applying new multi-band based filters, and analyzing chromospheric activity through the calculation of $S_{MW}$ indices based on Ca II H and K lines. These analyses will allow distinguishing which photometric candidates are true solar twins, contributing to a better understanding of stellar evolution and the Sun's context in the Solar Neighborhood.

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