Astrobiologically interesting stars within 20 parsecs of the Sun

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Introduction

The blueprint of life as we know it on Earth, based on carbon polymers and liquid water, requires specific planetary surface conditions, defining the so-called habitable zone, which dictates the maintenance of surface liquid water over time scales of several billion years.

This definition depends on multiple factors, the main ones being the planet's distance from the host star, and the star's mass and chemical composition, which determine the rate of evolution of its luminosity and, consequently, the lifespan of its planets within the habitable zone. (Porto de Mello et al. 2006)

We aim to identify and characterize a complete sample of stars with astrobiological interest within 20 parsecs of the Sun, using data from the Hipparcos and Gaia catalogs and creating a composition and an intersection between these two catalogs.

The main objective is to characterize optimized targets for future interferometric orbital probes, which will attempt to detect biosignatures in exoplanets through the infrared spectroscopic signature of ozone, water, and methane. The selection criteria include mass, age, evolutionary stage, chemical composition, and chromospheric (or isochronal) age. We consider as suitable all systems with age > 2-3 Gyr, approximately.

Methodology

The idea of creating a sample of astrobiologically interesting stars was inspired by the Catalog of Nearby Habitable Systems (HabCat) by Turnbull et al. (2003a). This catalog was developed from the Hipparcos Catalogue by analyzing stellar parameters interesting for the study of tecnosignatures.

While Turnbull's catalog focuses on a broader range of stars near the Sun (within 140 pc), our sample concentrates on a smaller, yet more detailed, subset using data from both the Hipparcos and Gaia Catalogues.

Since Gaia is significantly more precise than Hipparcos, the vast majority of the stars in our sample come from Gaia, with only a few exceptions. The intersection of stars from both catalogs allows us to construct Hertzsprung-Russell diagrams, which help us better analyze and identify the types of stars we aim to study—specifically, F, G, and K-type stars.

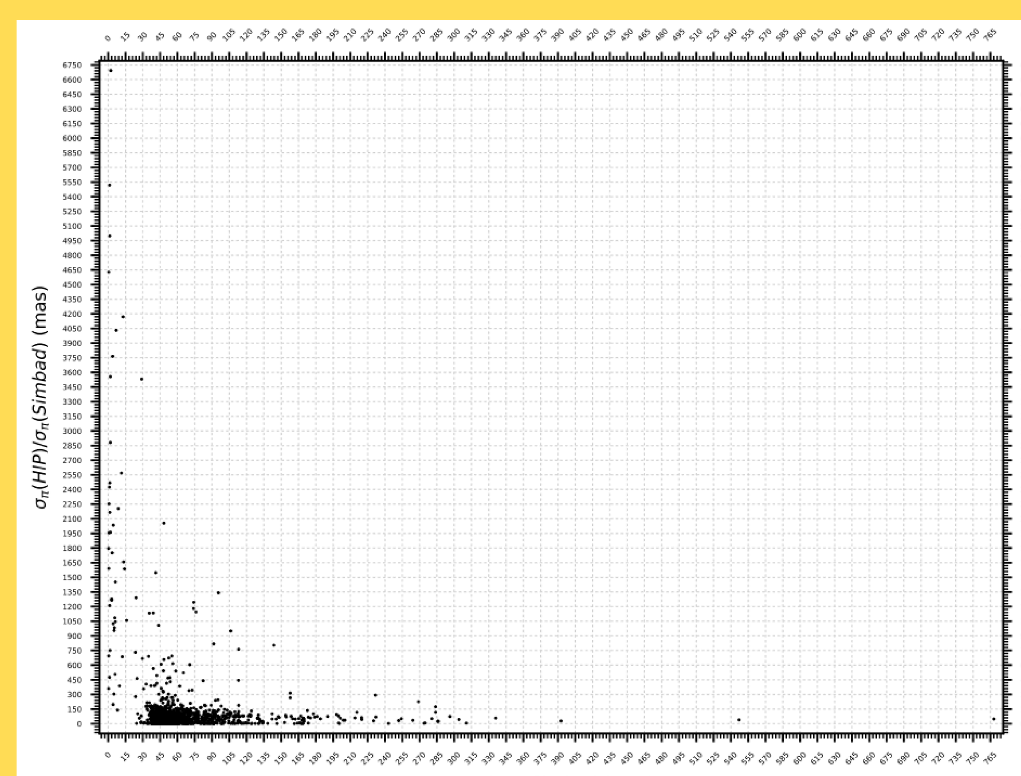

Figure 1: A comparison of the errors from Gaia and Hipparcos. The Y-axis shows the ratio of Hipparcos errors to Gaia errors, while the X-axis displays Gaia parallaxes obtained from SIMBAD. Note that, on average, Hipparcos errors are approximately 100 times larger than those of Gaia.

Results

We first used the Gaia catalog to examine all stars within 20 parsecs of the Sun, then complemented the dataset with Hipparcos. Subsequently, we selected only FGK-type stars with astrobiological interest. This selection resulted in a sample of 379 stars—referred to as “biostars”—sourced from both Gaia and Hipparcos. These biostars range from low-mass F-type stars ($\lesssim$ 1.4 M☉) to high-mass K-type stars ($\gtrsim$ 0.7 M☉).

The vast majority of the sample comes from Gaia, with only two stars exclusively from Hipparcos—one of them being Alpha Centauri. It is important to note that this is a preliminary result, as we are still analyzing the sample and collecting data to estimate stellar ages. We aim to determine these ages using either the isochronal method for northern (boreal) stars or the chromospheric method for southern (austral) stars, for which we observe the Hα lines at the Pico dos Dias Observatory in Brazil (OPD).

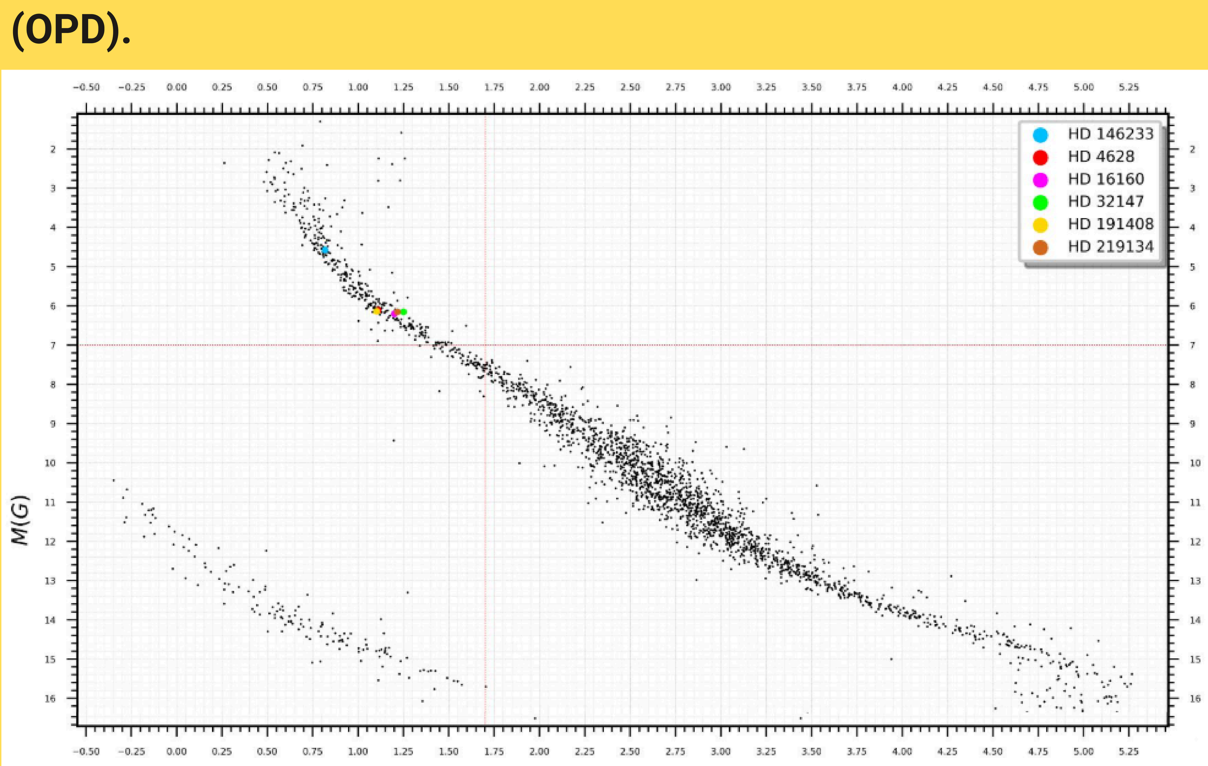

Figure 2: Hertzsprung–Russell diagram of Gaia stars within 20 parsecs. The light blue star marks 18 Sco, a solar twin, to indicate the Sun's position. The other colored stars are typically K2–K3-type stars. The vast majority of stars in this sample are M dwarfs (with Bp – Rp > 1.5), which are not of interest for this project. Gaia provides a highly complete sample of these stars up to ~100 parsecs, while Hipparcos is only complete up to ~5 parsecs. The 'biostars' referenced in the text appear in the upper-left region of the diagram.

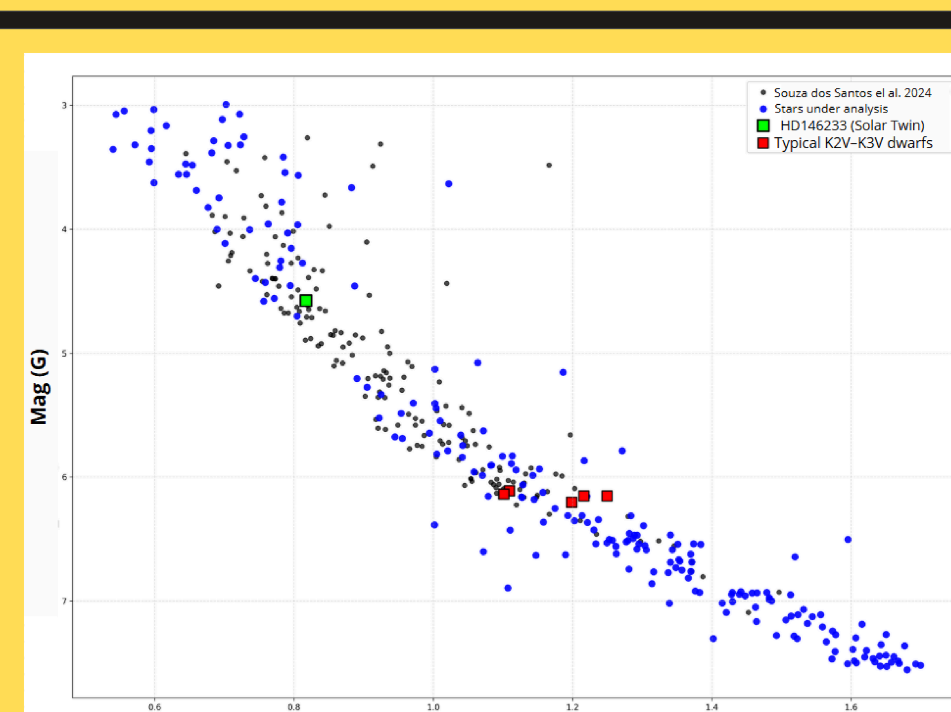

Figure 3: A close-up of the upper-left region of Figure 2, highlighting the “biostars” alongside 18 Sco and typical K-type dwarfs. The grey stars represent those that have already been studied by the group and for which data has been collected. The blue stars indicate those currently under analysis.

From this sample, we will select stars older than a few billion years to ensure sufficient time has passed for potential biosignature development on orbiting planets, as atmospheric oxygenation is estimated to take approximately 2 Gyr (Catling et al. 2005; Hedges et al. 2004). The majority of our sample consists of K-type dwarfs, whose ages are particularly challenging to determine.

We are also computing tidal models to estimate the minimum stellar mass required to ensure that planets in the habitable zone are not affected by tidal issues, such as tidal locking or extremely slow planetary rotation. Our preliminary results suggest that this limiting mass is around 0.7 M☉ (which is around the typical mass of K5) . This value supports our decision to exclude M-type dwarfs from the sample—not only due to tidal concerns but also because of the elevated levels of UV and X-ray radiation these stars emit.

As for the upper mass limit of 1.4 M☉, the justification lies in the stability of the habitable zone over time. We aim to identify stars with planets that can remain within the habitable zone for more than 3 billion years. Since stellar luminosity increases throughout a star’s lifetime, more massive stars evolve more rapidly and do not provide enough time for orbiting planets to stay in the habitable zone long enough to detect biosignatures.

Discussion and Next steps

Although significant progress has already been made, a considerable amount of work remains to be done. This includes spectroscopic observations at OPD of the stars that still lack data in the Hα region, which will be essential for determining chromospheric ages for those stars without observed ⟨S⟩ indices. We also plan to include the Bright Star Catalog (Hoffleit et al. 1991) in our sample selection. As the name suggests, this catalog focuses on bright stars, which Gaia and Hipparcos have limitations in accurately detecting and characterizing these very bright objects. By comparing Gaia and Hipparcos with other catalogs, we aim to reduce the chances of inadvertently excluding important stars, resulting in a more comprehensive sample. Preliminary cross-matching results between different catalogs indicate that there are some issues affecting the completeness of nearby, solar-type bright stars in Gaia — with similar challenges also present in Hipparcos.

The goal of this sample of astrobiologically interesting stars within 20 parsecs is to achieve a comprehensive characterization—including mass, effective temperature, chemical composition, evolutionary stage, multiplicity, and, most importantly, age. This will allow us to estimate the potential lifetimes of exoplanets within their habitable zones. We intend to contribute to stellar age determinations using various chromospheric indicators, which will be especially valuable for the population of K-type dwarf stars. We will also apply a kinematic method to estimate stellar ages based on their U, V, and W space velocities and orbital eccentricities (Almeida-Fernandes et al. 2018). Once the sample is complete—even if not all systems have confirmed exoplanets—we will have excellent targets for future missions searching for biosignatures.

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