Symbiotic stars in Gaia DR3

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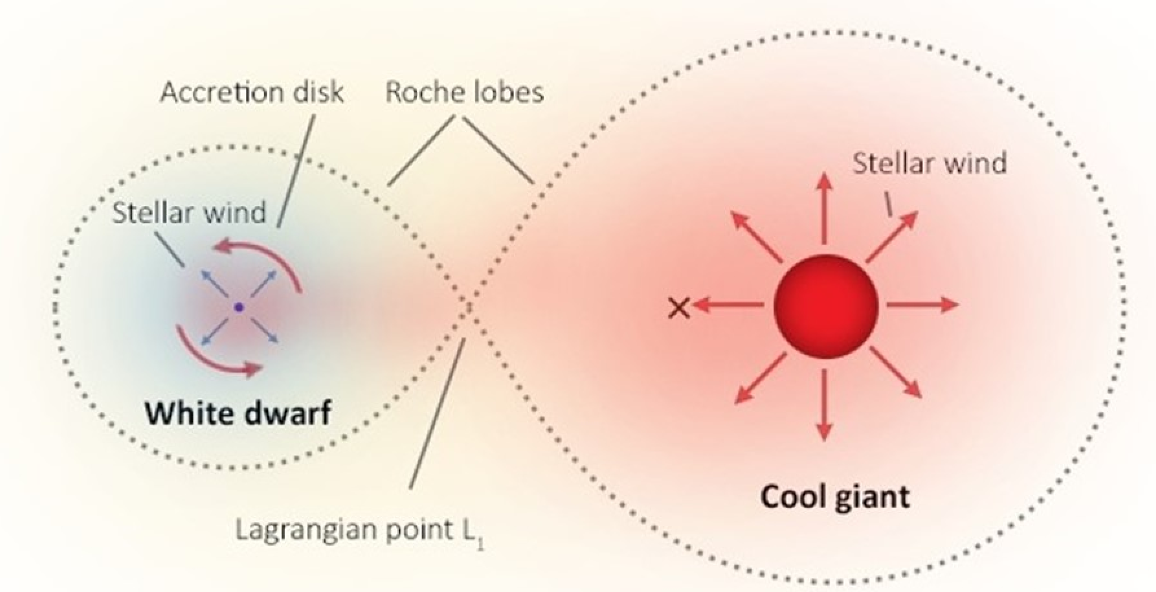
Introduction

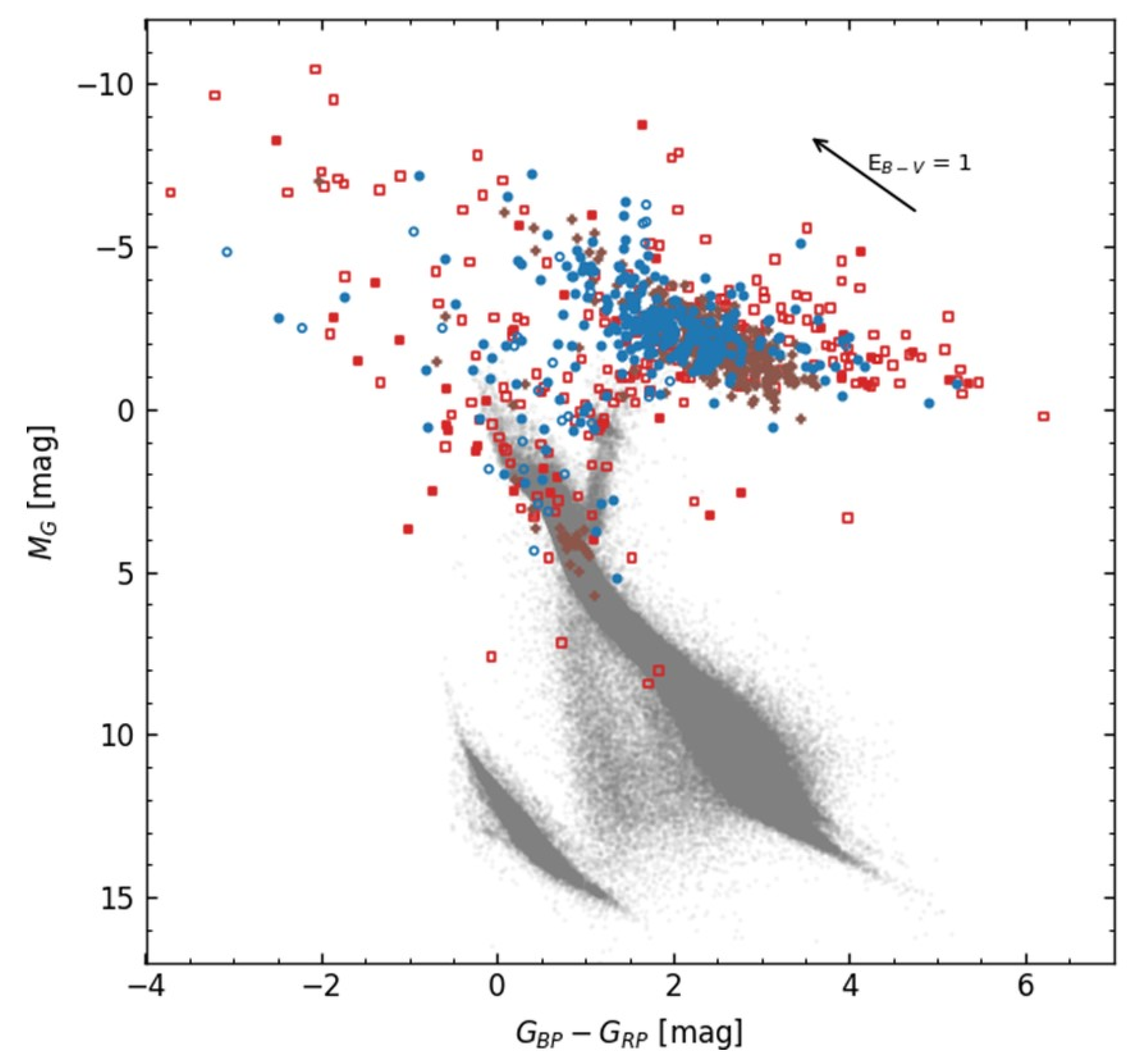
Symbiotic stars are strongly **interacting binary systems** composed of a **cool red giant** and a **hot white dwarf** (or a neutron star in a few cases), on orbits between **hundreds and a few thousands of days** embedded in the dense circumbinary nebula [1,2]. Because of the unique evolutionary state and the interactions between the two stellar components, such systems represent laboratories for studying **astrophysical processes** which still lack a proper inclusion in **stellar models** and are observed in other classes of objects as well, such as mass transfer and its accretion, stellar winds and their collision, formation and collimation of jets, production and destruction of dust, stellar pulsations, or thermonuclear outbursts. Symbiotic stars also have an important role in **stellar (and binary) evolution**, particularly as they were proposed as possible progenitors of **supernovae Ia** [3,4].

Despite the significance of symbiotic binaries as astrophysical laboratories, the **current number** of known objects of this class in the Milky Way (283 in the latest version of the **New Online Database of Symbiotic Variables**; NODSV; [5]) falls **far short of estimates** for the size of the overall population that has been reported in the literature (in order of tens or hundreds of thousands; e.g., [6] and references therein). This is largely due to the fact that most previous discoveries of symbiotic binaries have been **serendipitous**, and the **targeted search** for symbiotic stars started only in the last two decades.

In this poster, we discuss some of the results obtained from *Gaia* DR3 for known symbiotic stars from the New Online Database of Symbiotic Variables. We focus especially on the **astrophysical parameters and variability** of known symbiotic stars. Additionally, we describe new symbiotic candidates which were published in the scope of *Gaia* DR3 and the possible way to search **for new symbiotic systems**.



Simplified model of the symbiotic system consisting of a white dwarf as an acrretor and a cool giant as a donor of matter.



***Gaia* DR3 HR diagram** for known symbiotic stars and candidates from the New Online Database of Symbiotic Variables (blue and red symbols respectively) and new candidates from *Gaia* DR3 (brown symbols).

Symbiotic binaries in *Gaia* DR3

The *Gaia* mission [7] launched in December 2013, already belongs to the most successful space probes ever built. The main goal of the satellite is **astrometry with unprecedented precision**. However, the repeated quasi-simultaneous photometric measurements in three filters (G, G_{BP}, and G_{RP} also serve as an **all-sky photometric survey**. In addition, thanks to the **low-resolution spectroscopy** in broad BP and RP bands (R ~ 20 - 60) covering the optical-IR region and medium-resolution spectra (R ~ 11500) in the near IR (RVS), it also provides **astrophysical parameters** for huge numbers of sources. The observations and data products from the satellite have already been made available in several data releases.

The most recent *Gaia* Data Release 3 (DR3) was published on June 13, 2022 [8] and is based on the same dataset collected during the first **34 months of the mission** (July 25, 2014 - May 28, 2017) as *Gaia* EDR3. The astrometric data in *Gaia* DR3 are the same as those of *Gaia* EDR3. However, a **significant number of new data products** were presented in the later release.

We have cross-matched **all the symbiotic stars in our New Online Database of Symbiotic Variables** with the objects published in the ***Gaia* DR3**. Here, we will focus especially on the confirmed symbiotic stars. Of the confirmed galactic symbiotic stars, **98.6% have at least some information** presented in the DR3 (not necessarily the full astrometric solution).

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[7] Gaia Collaboration et al., 2016, A&A, 595, A1
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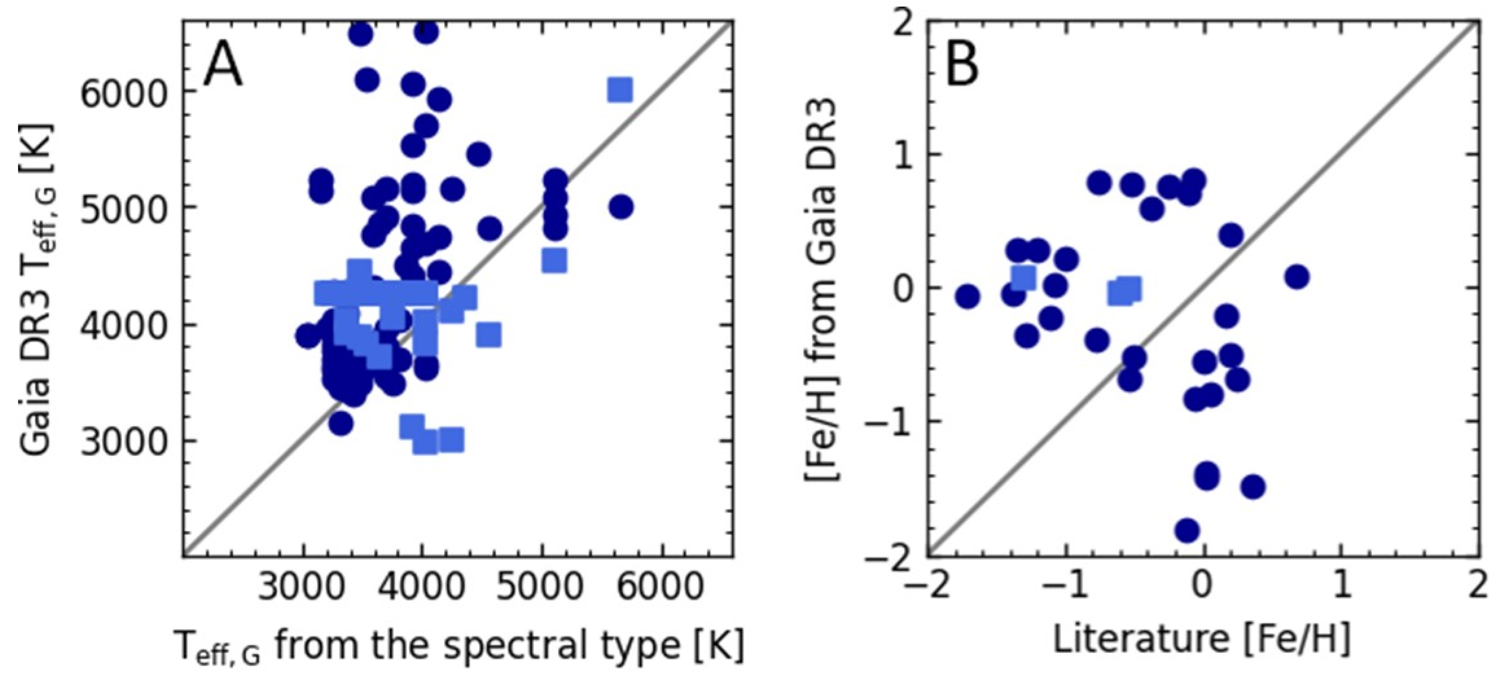
Astrophysical parameters

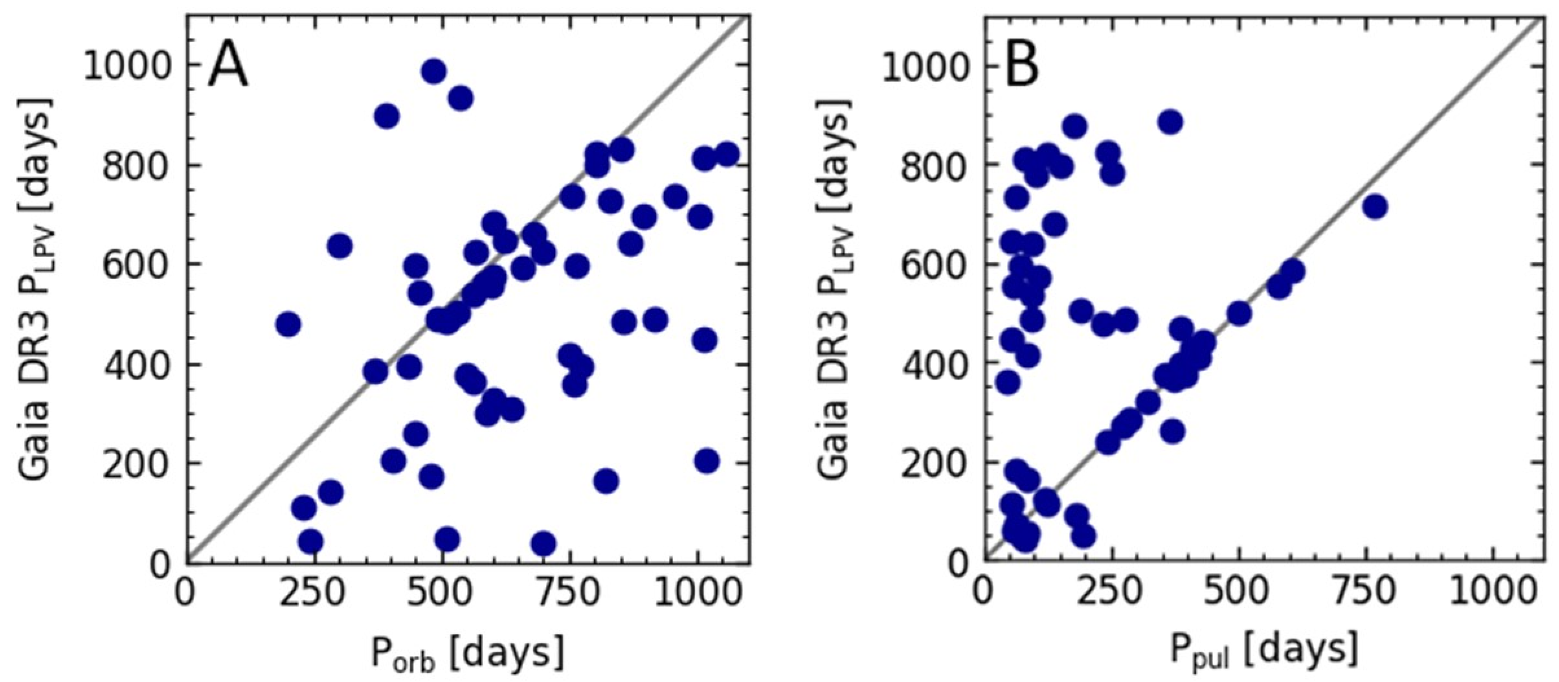
Gaia DR3 includes the **astrophysical parameters of the sources** [9]. While we found out that, e.g., the detailed chemical abundances are **not available for the majority** of the symbiotic systems, T_{eff} obtained using both BP/RP and RVS spectra are inferred for a large sample of symbiotic stars.

We have therefore compared the **temperatures from *Gaia*** with the effective temperatures of symbiotic giants (which dominate the observed spectral region) estimated from their spectral types. Unfortunately, it seems that there is a **rather large scatter** in the *Gaia* temperatures that, in many cases, differ from the ones estimated from the spectral types of the giants by a few thousand K. This difference might be caused by several factors, e.g., by the fact that the measured flux in the *Gaia* filters is not solely given by the flux of the red giant, but also the nebula can contribute significantly to it or by the **imprecise extinction**, as the reddening in symbiotic binaries is often caused not only by the interstellar dust but also by the matter surrounding the binary.

It is still an **open question** if symbiotic giants belong to a **metal-rich population,** or if their metallicity is **sub-solar** [10, 11]. Only a few symbiotic stars have metallicity estimates obtained from the RVS spectra, while for most of them, only the values inferred from the BP/RP spectra are available. In general, both samples suggest **slightly sub-solar metallicities** for known symbiotic stars. On the other hand, it is clear from the comparison of the metallicities of known symbiotic stars collected in the New Online Database of Symbiotic Variables from literature with the values estimated from the *Gaia* data that the **latter values differ significantly** from the values obtained typically using the high-resolution IR spectra. Therefore, **one needs to be careful** when interpreting *Gaia* metallicities of symbiotic stars.



Astrophysical parameters of symbiotic stars in *Gaia* DR3.
A: Comparison of temperatures presented for known symbiotic stars in *Gaia* DR3 with those obtained from the spectral types of the giant. Temperatures obtained from the mean BP/RP spectra and from the fitting of RVS spectra are shown as dark blue dots and light blue squares, respectively. **B:** Comparison of metallicities from literature and *Gaia* DR3.



Variability of *Gaia* DR3 long-period variables.
A: Comparison of the orbital periods of known symbiotic stars classified as long-period variables in *Gaia* DR3 with the values obtained from the *Gaia* data. **B:** Same as panel A, but for pulsation periods collected in our Database.

Variability of symbiotic sources in Gaia DR3

For a subset of sources in *Gaia* DR3, **photometric time series** are available. In addition, Eyer et al. [12], classified the **variable sources into 35 variability types** (subtypes), including symbiotic stars.

Some of the groups of variable stars have been studied in more detail, including **long-period variables** (LPV; [13]). For these objects, additional parameters, such as the **observed periods and the amplitudes**, have been published. Among the objects classified as LPV in *Gaia* DR3, one can find 242 confirmed symbiotic stars. We compared the periods published in *Gaia* DR3 LPV sub-catalog with the known orbital and pulsation periods of particular symbiotic stars, respectively. The inferred *Gaia* periods are, in some cases, consistent with **pulsation** and, in others, with **orbital periods** of known symbiotic systems.

More careful analysis of the time series would be needed to **disentangle the effects** in the multi-color light curves. In any case, this result proves that the observations of the *Gaia* satellite could serve as a **great resource for the analysis of the periodicities** observed in symbiotic binaries, especially when a longer time base is available. The current data release is based only on 34 months of data (slightly more than 1000 days), while typical S-type symbiotic stars have orbital periods in the range of 500 - 600 days [14,15].

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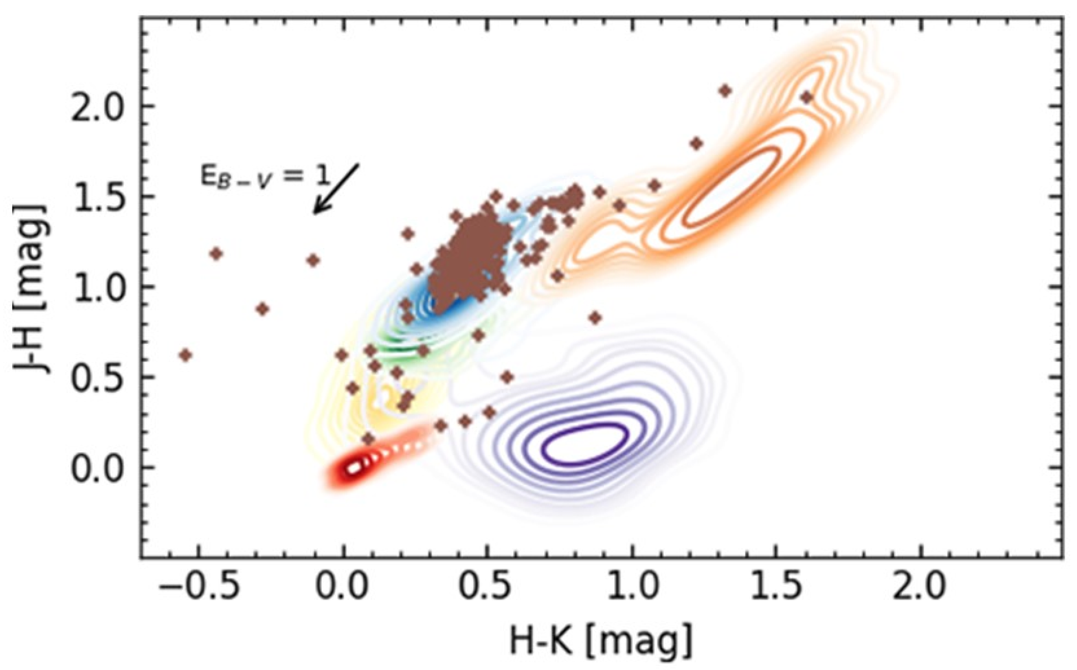
Gaia DR3 symbiotic candidates

The variable sources in *Gaia* DR3 have been classified into several categories, including symbiotic stars. Out of 360 confirmed symbiotic stars in the New Online Database of Symbiotic Variables, 247 are **correctly classified as symbiotic stars** in *Gaia* DR3. Also, 61 candidates and 2 misclassified objects from our Database are marked as symbiotic stars in the *Gaia* catalog. However, one should mention that many of these sources have been classified as symbiotic stars **apriori as a training sample** for the machine-learning algorithms. In addition to 310 sources that have been previously confirmed or suspected of a symbiotic nature and are included in the New Online Database of Symbiotic Variables, another **339 objects are classified as symbiotic binaries in *Gaia* DR3 for the first time** [16].

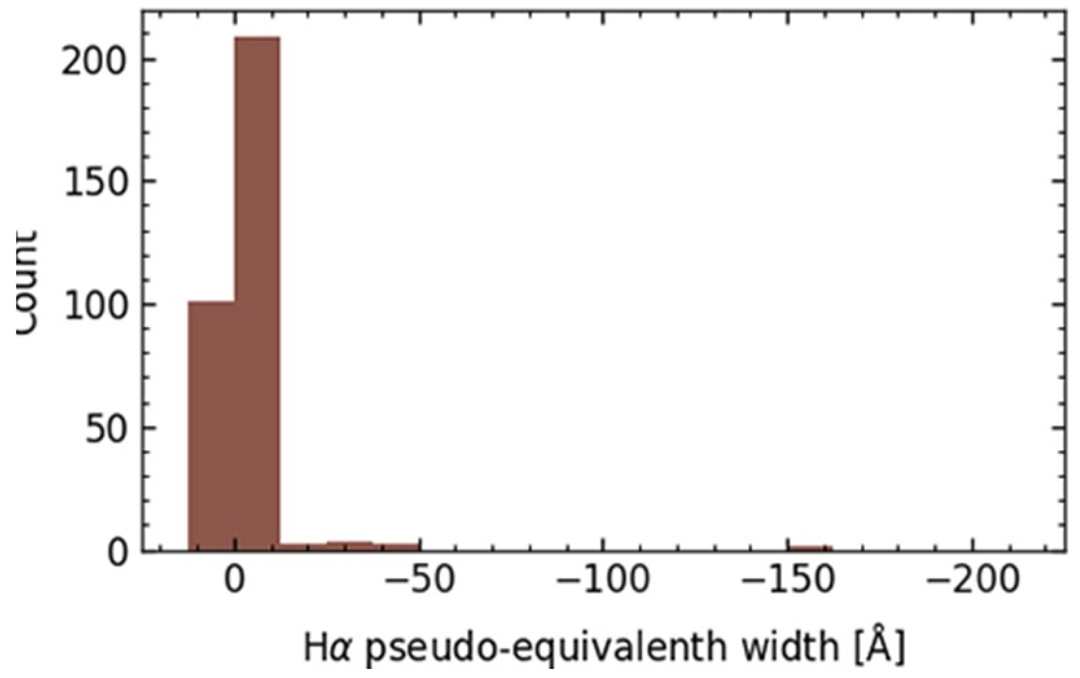
The classification of the sources as symbiotic stars in *Gaia* DR3 is based on the astrometric parameters of the objects, RP spectra, and especially their light curves in G, G_{BP}, and G_{RP} bands. Such an approach could produce a **number of contaminants** in the case of symbiotic stars. One should especially keep in mind that the **light curves** of symbiotic binaries are **very complex** (e.g., the variations are caused by the orbital motion, pulsations, and outbursts). For this reason, it is hard to find a set of statistical parameters to describe the general photometric behavior of a prototypical symbiotic star. Another major concern comes from the fact that a **single pulsating red giant** (semiregular or Mira variable) can have exactly the same light curve as a quiescent symbiotic binary.

Most of the new candidates occupy the **part of the HR diagram** where **confirmed symbiotic stars** can be found (but also normal single giants). This is not unexpected as the RP spectra (which would reveal the late-type star easily) and the astrometric data (which would distinguish between close red dwarfs and distant red giants) have been used for the classification.

Near IR 2MASS color-color diagram. Known S- and D-type symbiotic stars are shown in blue and orange, respectively. PNe, Be stars, T Tau stars, and CVs are shown in violet, red, green, and yellow.



The majority of the candidates **share the position** in the **NIR color-color diagram** with symbiotic stars (especially the ones of infrared S-type). Again, one should keep in mind that many single red giants can be found in the same region of the diagram. Still, this makes them reasonable symbiotic candidates.



Distribution of **pseudo-equivalent widths of Hα** line in new symbiotic candidates from *Gaia* DR3.

In contrast with the sample of known symbiotic binaries, the new candidates have the **Hα equivalent widths close to zero** (either slightly negative or slightly positive). It might be that some of these candidates are accreting-only symbiotic stars, but some might be 'just' pulsating red giants. We should note that in pulsating giants, one can sometimes find Hα in emission as well.

Search for new symbiotic stars

Comparison of the **distribution of the Hα equivalent widths** observed for new *Gaia* DR3 candidates and that of known symbiotic stars suggest the possible contamination of the symbiotic candidate *Gaia* DR3 sample by single late-type long-period variables. It might be that some of these candidates are accreting-only symbiotic stars, but some might be 'just' pulsating red giants. We should note that in pulsating giants, one can sometimes find Hα in emission as well.

As a part of the **ongoing observational campaign**, we have obtained spectroscopic data for some of the *Gaia* DR3 symbiotic candidates. Our preliminary results confirm that **only a fraction of the candidates** can be readily classified as symbiotic stars.

On the other hand, this work motivated our search for new symbiotic stars on the basis of the *Gaia* DR3 data. In particular, we have employed the **Hα measurements** in order to select the most promising symbiotic candidates, as it seems that this parameter could be a **very good indicator of the symbiotic activity** of an object and could be used to distinguish between single variable or non-variable giants and symbiotic stars. In combination with other data from *Gaia* and from other surveys, e.g., 2MASS, we were able to **identify a few tens of new symbiotic stars** in the Milky Way.

References

[16] Rimoldini et al., 2023, A&A, 674, A14

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