Contrib. Astron. Obs. Skalnaté Pleso **54/2**, 75 – 84, (2024)
https://doi.org/10.31577/caosp.2024.54.2.75

Accreting-only symbiotic stars in the era of large Galactic Archeology spectroscopic surveys

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Received: October 18, 2023; Accepted: January 3, 2024

Abstract. Symbiotic stars are interacting binary systems consisting of a primary star, usually a red giant, and a companion star, usually a white dwarf. In general, there are two phases of symbiotic stars: a burning phase characterized by a rich emission line spectrum and an accreting-only phase in which the optical spectrum is dominated by the red giant, making them difficult to detect as a symbiotic star. The characterization and quantification of the entire population of symbiotic stars can provide crucial insights into the evolution and properties of our Galaxy. Our research is based on the GALAH spectroscopic survey, where we aim to identify symbiotic stars with the lowest accretion rates through spectral emission lines such as Hα and Hβ. In the search for new accreting-only symbiotic star candidates, we focus on spectroscopic and photometric properties that distinguish these systems from single giants.

Key words: symbiotic stars – outbursts – photometry – spectroscopy

1. Symbiotic stars

Symbiotic stars are close binary systems consisting of a cool giant (either a red giant branch, RGB, or an asymptotic giant branch, AGB giant) and a degenerate companion, typically a white dwarf (see Munari (2019)). In symbiotic binary systems, the separation between two stars is relatively large, and the mass is transferred from red giant onto the surface of the white dwarf mostly in the form of a stellar wind emitted by the giant (Mürset & Schmid, 1999). The accretion leads to a buildup of material on the white dwarf, eventually resulting in the nuclear burning of the accreted shell. This process can happen either explosively, which can be observed as a nova eruption, or in thermal equilibrium, depending on the degree of degeneracy and mixing (Shen & Bildsten, 2007). Symbiotic stars have been known to have long orbital periods ranging from a few hundred days to more than a few hundred years (Zamanov et al., 2021).

In symbiotic systems, the white dwarf is accreting material onto its surface. When it accretes enough material, the nuclear burning of accreted material begins. If the accreted matter is electron degenerate, the burning process can be explosive. However, if the accreted matter is not electron degenerate, the nuclear burning is slow and in thermal equilibrium. It can take a few years to reach maximum brightness and a few decades to burn the accreted envelope and return to the quiet phase. Therefore, symbiotic stars can be broadly divided into two distinct phases: an accreting-only and a burning-type star. There are several hundred known symbiotic systems (see recent catalogs by Merc et al. (2019a) and Akras et al. (2019a)), most of which are the burning-type stars, but we believe that this is due to an observational bias (Munari et al., 2021a). In the burning-type case, we observe a strong nebular continuum and a rich emission line spectrum, so systems in this phase can be easily detected at the optical part of the spectrum throughout the Galaxy and beyond, with about 400 systems known so far (Zamanov et al., 2021; Mukai et al., 2016). In the case of accreting-only symbiotic systems, the optical part of the spectrum is dominated by the red giant. There are generally none or only very weak emission lines present in the spectrum, and only a few tens of systems were discovered until recently (Merc et al., 2019b; Munari et al., 2021a).

In accreting-only symbiotic star systems, the accreted material from the red giant slowly accumulates on the surface of the white dwarf. This is a very slow process in comparison with the nuclear burning of the material. The latter can last several decades or even centuries, as also observed thus far (Munari et al., 2021a), while the accretion time is supposedly several orders of magnitude longer, which is why we assume that most of the symbiotic stars belong to the accreting-only type. This is in stark contrast to previously stated numbers of observed systems where the burning-type symbiotic stars dominate, and we aim to statistically evaluate this observational bias. This can further lead to determining the significance of symbiotic stars in the Galaxy, for which we need to characterize and quantify the entire population, not just the easily observed burning-type systems (Munari et al., 2021a).

Symbiotic stars are important for a better understanding of the evolution and properties of our Galaxy. They are considered one of the candidates responsible for the enrichment of the interstellar medium with lithium and other elements due to their nova outbursts. Furthermore, in the case of a white dwarf reaching critical mass, the subsequent accretion process may result in an explosion, making them promising Type Ia supernova progenitors, as initially proposed by Munari & Renzini (1992) (see also Hachisu et al. (1999)). For these reasons, obtaining better knowledge about the properties of accreting-only symbiotic stars and quantifying their total number in the Galaxy is essential.

This research aims to uncover the hidden population of symbiotic stars by examining their spectral and photometric characteristics and quantifying their total number in the Galaxy, ultimately shedding light on their significance in the evolution of our Galaxy.

In this contribution are presented two (and three additional) of the validation criteria for confirming the symbiotic star candidates by analysing their spectral and photometric properties using primarily spectroscopic data from the GALAH survey, complemented with follow-up spectroscopic and photometric observations from Asiago, and archival data from large photometric surveys, such as Gaia, 2MASS and ASAS-SN.

2. Properties of symbiotic stars

Symbiotic stars have unique properties that allow us to distinguish them from single red giants and can be broadly divided into two categories: the ones related to their stellar spectrum and the ones related to their photometric nature.

The optical spectrum of accreting-only symbiotic stars is dominated by a red giant, where we can observe distinct absorption features, including molecular absorption bands, and generally weak emission lines forming presumably in the accretion disk and showing both irregular and periodic variability (Chen et al., 2019).

In symbiotic systems, we can detect excess light, which serves as another indication of the presence of a white dwarf in these systems, and such excess light can be observed across different wavelengths:

- *Ultraviolet excess*

  The UV excess is a direct manifestation of the presence of an accretion disk, with direct emission from the central white dwarf (Luna et al., 2013). A higher accretion rate causes a brightening of the accretion disk around the white dwarf, manifesting as an excess in near-UV luminosity and detectable emission lines.

- *X-ray excess*

  The X-rays are emitted from regions of the accretion disk positioned closer to the white dwarf than the UV-dominated regions. The hardness of the X-ray spectrum also depends on the strength of the gravitational potential well, signifying that more massive white dwarfs yield harder X-ray spectra. In the case of white dwarfs with a mass exceeding $0.6 M_{\odot}$, these systems may experience recurrent nova outbursts or produce strong X-ray emission. The X-ray production also depends on the accretion rate (Luna et al., 2013),

- *Infrared excess*

  The IR radiation of symbiotic stars is caused by either stellar photosphere of the giant, free-free/free-bound emission from the ionized portion of the wind and from the outer portions of the accretion disk (Chen et al., 2019).

Two spectra of a symbiotic star SU Lyn taken with the Asiago telescope are shown in Figure 1, illustrating the differences between very low (black) and moderately high (red) accretion rates (Munari et al., 2021a). At low rates, the spectrum is dominated by a red giant and resembles a typical spectrum of a single giant. This presents a difficulty in the search for symbiotic stars with the lowest accretion rates. A higher rate causes a brightening of the accretion disk around the white dwarf, which manifests as an excess near-UV brightness and detectable emission lines.

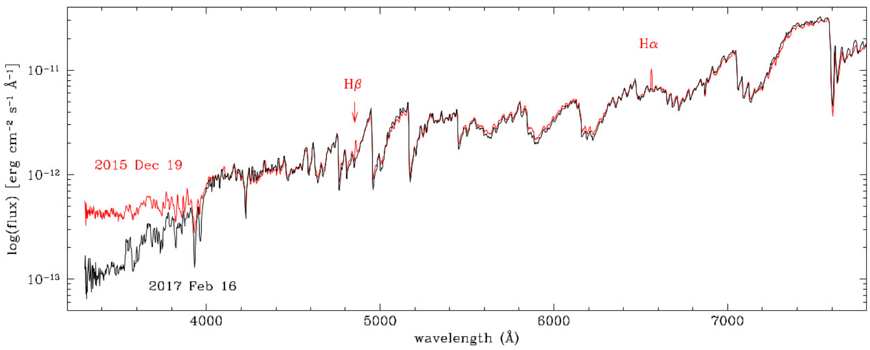

Figure 1. There are two spectra of an accreting-only symbiotic star SU Lyn presented: one at low (black) and one at high (red) accretion rates, the latter showing an excess in the near-UV regions and detectable emission lines (Munari et al., 2021a).

Among the most important photometric properties of symbiotic stars is the presence of flickering. Flickering is a rapid, non-periodic change in magnitude resulting from chaotic processes, such as density fluctuations within the accretion stream flowing from the primary to the accreting star. It develops on timescales of a few minutes, significantly shorter than the timescales associated with other sources of variability (Zamanov et al., 2022), typical for active accretion disks (Zamanov et al., 2021). Moreover, the photometric data provides information on the detection of excess light in the UV and X-ray regions.

Photometric data analysis also allows the opportunity to explore the presence of IR excess caused by either the stellar photosphere of the giant, free-free/bound-free emission emanating from the wind of the giant, or by the thermal dust emission surrounding the binary system (Chen et al., 2019; Akras et al., 2019c).

3. Observational data and sample selection

Our research includes the analysis of both spectroscopic and photometric datasets. In addition to the publicly available data from the spectroscopic and photometric surveys, we are conducting follow-up observations of a selected sample of symbiotic star candidates using the Copernico 1.82m telescope with a high-resolution Echelle spectrograph in Asiago. Simultaneously, we are executing photometric observations using the Schmidt 67/92cm telescope in Asiago.

3.1. Spectroscopic data

The selection of our large primary sample of red giant stars was based on spectroscopic observations from the GALactic Archaeology with HERMES (GALAH) survey (Buder et al., 2021) using the HERMES instrument with the Anglo-Australian 4m telescope. The focus of our research is giants of spectral type M, which appear to be the most common among the known symbiotic stars (Akras et al., 2019b), selected and described in detail in the paper of Munari et al. (2021a). The identification of potential symbiotic star candidates within the sample was achieved by examining characteristic features that can be used to distinguish a symbiotic star from a single giant; more specifically, we were looking for emission in the Hα and Hβ spectral lines. For these selected candidates, the data set is complemented by high-resolution spectra obtained with the Copernico telescope and the Echelle spectrograph in Asiago. The repeated observations enable us to monitor any temporal changes in emission lines.

3.2. Photometric data

To isolate the cool giants from the other objects in our primary sample, we first apply selection criteria based on their color. The photometric data was used from the Gaia and the Two Micron All-Sky (2MASS) surveys. In addition, the light curves of the selected candidates were obtained from the All Sky Automated Survey for SuperNovae (ASAS-SN) and used to exclude false positives due to pulsating stars. Photometric follow-up observations of our symbiotic star candidates are carried out with the Schmidt telescope in Asiago.

4. Validation criteria for symbiotic star candidates

The search for symbiotic stars has only recently begun. The theoretical models predict that many more accreting-only symbiotic stars can be found. Now, through the confirmation of the accreting-only symbiotic stars, we continue the search for the hidden population. Among the selected candidates, we are focusing on the variability in Hα and Hβ emission lines and searching for the presence of flickering.

4.1. Emission line variability

Our research involves the search for characteristic signatures that indicate the presence of the accretion process within the binary star system. The main focus is on the study of emission lines present in the spectrum, such as Hα and Hβ, both originating from the area of the accretion disk or from the wind of the giant in the vicinity of the disk and ionized by it. The presence of strong emission lines can serve as a potential indicator of a symbiotic nature. However, it is crucial to investigate other properties of symbiotic stars, as such emission lines may also be the result of other processes.

In the spectra of our symbiotic star candidates, we are searching for the variability in emission lines. An example of such variability in the Hα emission line is shown in Figure 2. The figure shows eight low-resolution spectra of the symbiotic star 2SXPS taken with the 0.84m telescope in Varese, Italy, under the direction of the collaboration. Over a four-month period, an apparent change in the profile and intensity of the Hα emission line can be seen, indicating the degree of accretion and the state of the accretion disk around a white dwarf (Munari et al., 2021b).

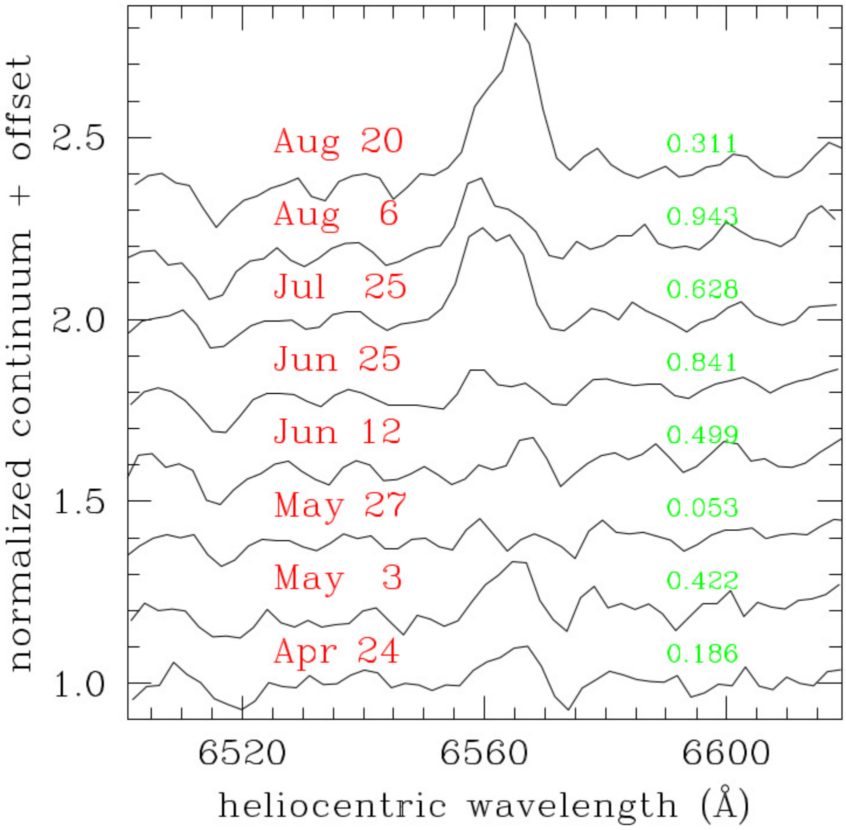

Figure 2. Low-resolution spectra of a symbiotic star 2SXPS were obtained on eight separate nights in 2020. They illustrate the temporal evolution of the Hα emission line over a four-month interval, indicating the presence of the accretion disk. The observational dates (red) and equivalent width of Hα line (green) are provided above each spectrum (Munari et al., 2021b).

4.2. Optical flickering

Symbiotic stars exhibit a significant photometric feature known as flickering. Detecting this rapid change in magnitude could confirm the presence and nature of a compact object.

The left panels of Figure 3 show two examples of the B-band time series for two distinct symbiotic star candidates in the search for evidence of ickering emanating from the accretion disk. The measurements of each symbiotic star are presented in blue dots, along with the nearby eld stars of similar brightness and photometric color shown in different colors. Beneath the measurements for each object is provided the dispersion around the median of the B-band data. The accompanying plots in the right panels of Figure 3 show the relationship between dispersion and B-band magnitude, with the symbiotic star indicated by a red star and the nearby field stars represented as black circles. As evident in the visual representation, the top panels demonstrate that the symbiotic star candidate exhibits flickering well over the noise levels observed in the comparison stars, despite it being less apparent in the left panels. On the other hand, the symbiotic star candidate in the bottom panel remains stable, showing a noise level equivalent to that of the field stars.

4.3. Additional validation criteria

Establishing validation criteria describes a fundamental aspect of confirming the symbiotic nature within binary systems, and the criteria described above only serve as two of the indicators. Beyond the initial confirmation of Hα variability and the presence of flickering, candidates must satisfy additional criteria, some of them being:

– *Long-term photometric variability*

  The observation of long-term photometric variability can be helpful in separating the radial pulsators, such as Mira variables, from symbiotic stars. The lightcurves are usually reconstructed from multi-band photometric campaigns such as ASAS-SN. Radial pulsators can be identified by the characteristics of their lightcurves, which typically exhibit regular, long periods and sinusoid-like variations with large amplitudes, often exceeding ten magnitudes. Symbiotic stars also show significant variability in magnitude, but their lightcurves lack a large amplitude and regular period (Munari et al., 2021a).

– *Radial velocity variability*

  Monitoring the radial velocity variability is another feature that provides insights into the nature of the variable object. Symbiotic stars exhibit irregular and complex velocity changes resulting from dynamic interactions within the binary system, such as accretion and mass transfer, which can often obscure clearly defined orbital periods, making it difficult to decipher the underlying

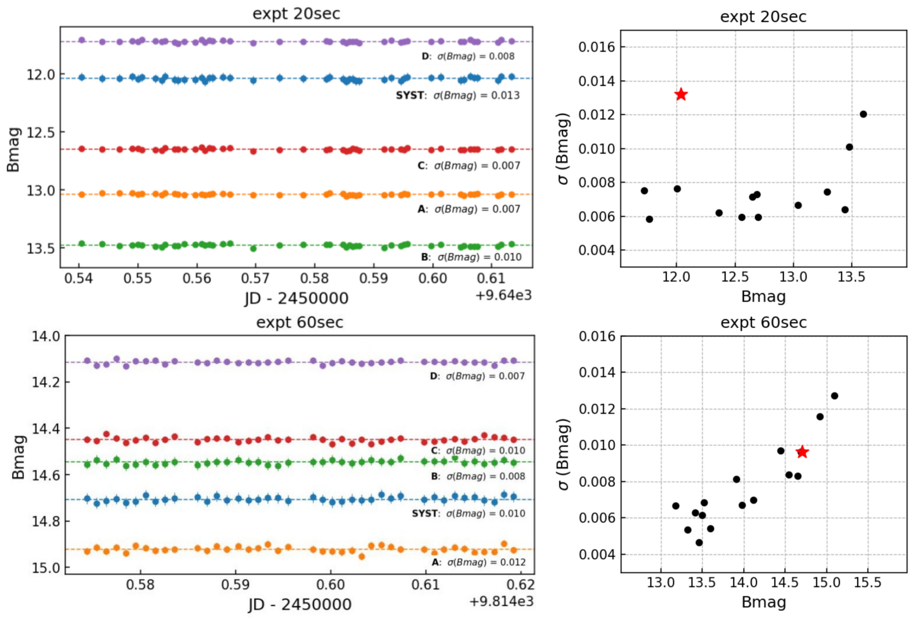

Figure 3. Examples of two symbiotic star candidates, one showing flickering (top panels) and one not showing flickering (bottom panels). Left panels display B-band time series data, aiming to detect flickering from the accretion disk. Periodic gaps represent V-band frame acquisitions for data transformation to the Landolt system. The measurements of the symbiotic star candidate (in blue) and field stars (in various colors) are accompanied by dispersion values around the median written beneath, denoted as "$SYST$" for the symbiotic star and "A, B, C, and D" for comparison stars. The right panels illustrate the relationship between the dispersion and B-band magnitude, contrasting the symbiotic star (marked by a red star) and the nearby field stars (represented as black circles). As evident from the right panels, the symbiotic star clearly shows the presence (upper panels) and the absence of flickering (bottom panels).

orbital dynamics. In contrast, when we examine the orbital motion in other long-period variables, e.g. Mira pulsators, they show regular and sinusoidal-like radial velocity variations driven by their intrinsic pulsation mechanisms, leading to well-defined orbital periods (Munari et al., 2021a).

– *Detectable emission excess in UV and X-ray part of the spectrum*

  Yet another criterion for confirming symbiotic stars is the detection of excess light at wavelengths shorter than 4000 $\AA$. This excess emission, particularly in the UV and X-ray regions, indicates a higher accretion rate, which causes the brightening of an accretion disk around a white dwarf (Luna et al., 2014).

5. Conclusion

Symbiotic stars provide important insights into the evolution and properties of our Galaxy. The accretion of stellar wind from the red giant onto the surface of the white dwarf makes symbiotic stars a promising Type Ia supernova progenitor. They are also considered to be one of the candidates responsible for the enrichment of the interstellar medium with lithium and other elements because of their novae outbursts.

The spectroscopic analysis of symbiotic stars offers valuable insights into their physical properties, enabling the determination of mass accretion rates and providing an indication of the origin of the mechanism governing mass transfer, shedding light on their evolutionary state. On the other hand, photometric analysis can reveal the variability behavior of symbiotic stars, focusing on the search for flickering and looking for the presence of UV, X-ray, and IR excess.

Examining these characteristics will contribute to a better understanding of symbiotic stars, allowing us to identify and characterize accreting-only symbiotic stars within large-scale spectroscopic surveys such as GALAH, Gaia-ESO, and in the future 4MOST and WEAVE.

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