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A Mini Atlas of H-Band Spectra of Southern Symbiotic Stars

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Abstract: Symbiotic stars are interacting binary systems composed of an evolved star (generally a late-type red giant) and a degenerate or dwarf companion in orbit close enough for mass transfer to occur. Understanding the status of the late-type star is important for developing binary models for the symbiotic systems as it affects the transfer of matter needed to activate the hot component. Infrared observations have been very useful in probing the nature of late-type stars in symbiotic systems. This work presents a set of symbiotic stars observed with SOAR/OSIRIS ($R\sim3000$) in the H-band. We aimed to search for possible molecular circumstellar emission, to characterize the cool companion in these systems, and to confront the new findings with those obtained from the previous K-band classifications. We detected molecular emission from just one object, BI Cru, which displays the second-overtone CO-bands. To fit the observed photospheric CO absorption bands, we used the MARCS atmosphere models. We present our results as a mini atlas of symbiotic stars in the near-infrared region to facilitate the comparison among different observed symbiotic systems.

Keywords: techniques: spectroscopic; stars: symbiotic, binaries; stars: infrared

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1. Introduction

Symbiotic stars display a combined spectrum that shows high excitation emission lines superposed on the absorption lines of two stellar components: a late-type giant and a hot compact star. This characteristic led to defining symbiotic stars as strongly interacting binaries consisting of a cool giant of spectral type M (sometimes K- or G-type giant) as a donor, which transfers material to an accretor compact star, most commonly a hot white dwarf (or, in some systems, a neutron star). Such a binary system is surrounded by a circumstellar nebula enriched by the material lost from both components [1,2]. In addition, there are other contributions to the spectral energy distribution (SED) of a symbiotic star, such as emission from heated dust and jets or collimated bipolar outflows. Therefore, the entire SED of symbiotic systems is a superposition of all these contributions, which dominate the emission spectrum in different wavelength regions. With additional processes such as mass loss, accretion, and ionization, the spectrum of each symbiotic object is unique, and as a group, they appear rather heterogeneous. In this sense, Reference [3] proposed a physical definition where "*a symbiotic system is a binary in which a red giant transfers enough material to a compact companion to produce an observable signal at any wavelength*".

Regarding the near-infrared region, symbiotic stars have been divided into two types [4]. If they display an infrared (IR) excess emission that results from dust, they are called D-type (dust). In these systems, the cool giant is a very evolved Mira variable surrounded by warm dust. If they display an IR continuum emission from the cool companion, the symbiotics belong to the S-type (stellar), in which the cool star is a regular red giant, often filling its Roche lobe. The orbital periods of S-type symbiotics are about 2–3 years, while those of the D-types are at least an order of magnitude longer [5]. There is a third type of symbiotic system introduced by Allen et al. [6]: D′-type systems, which are a sub-type of the classical D-types. In these symbiotics, a significantly hotter star of spectral types F and G constitutes the cool component. Furthermore, like D-type symbiotics, D′-type systems also exhibit IR dust emission. However, their SEDs reveal distinct characteristics, with a nearly flat profile indicative of a cool companion and a dusty shell. This is in contrast to D- and S-types, which exhibit intensity peaks at wavelengths between 2 and 4 μm and between 0.8 and 1.7 μm, respectively [7].

As previously mentioned, the accretion object for most symbiotic stars is a white dwarf. However, in a small number of systems, it is believed to be a neutron star. These symbiotic X-ray binaries (SyXBs) represent a special class of symbiotic binaries that have garnered significant interest among astronomers. One notable example is IGR J16194-2810, which was observed in the low/hard state using the Suzaku X-ray satellite. This particular SyXB has been classified as a low-mass X-ray binary [8,9] since the system is composed of an M-type giant and probably a neutron star [10].

Symbiotic systems show a complex emission spectrum with plenty of lines of different ionization degrees and forbidden transitions and also show a different phenomenology, including stellar pulsations (semi-regular and Mira variables), orbital variations, and slow changes due to dust. These systems are interesting objects to study the formation and evolution of gaseous and dusty circumstellar or circumbinary environments, providing clues to investigate other related objects, such as those showing the B[e] phenomenon. Symbiotic stars may also help to solve one of the timeliest problems in modern astrophysics, the missing progenitors of Type Ia supernovae (SNe Ia).

Observations in the IR are particularly important for those systems in which the cold companion is hidden in the optical spectral range. For example, the water vapor and carbon monoxide absorption bands observed in the 1–4 μm spectral range allow us to describe the characteristics of the late-type stars in these systems. It is interesting to note that, in systems with extremely dense environments, the CO-bands might turn into emissions. So far, BI Cru has been known for a long time to show intense CO-bands in emission [11]. Furthermore, H 1-25 (Hen 2-251) and RX Pup were reported by Schmidt and Mikołajewska [12] as symbiotic stars whose spectra show evidence of weak CO emission instead of absorption.

In a previous work, the medium-resolution K-band spectra of a sample of eight symbiotic objects were presented [13]. These observations were used to characterize the cool companions based on their CO first-overtone absorption bands along with measured equivalent widths of Na I and Brγ. Now, in order to obtain a more complete picture of each source, we present the H-band spectra of the same objects and follow a different approach. We derived the effective temperature of the late-type components using synthetic spectra computed with the MARCS atmosphere model' code [14]. However, considering the significant deviation of effective temperatures in red giant stars from temperatures derived using blackbody models, we propose to implement the correction recommended by Akras et al. [7], thereby obtaining what we will refer to as an equivalent temperature $T_{\rm E}$. These results were used to estimate a more solid spectral type determination of the red giant.

The paper is structured as follows: Section 2 provides a description of the observations and data reduction process. Section 3 presents the fitting with the MARCS model spectra, the determination of the equivalent temperature T_E, the estimation of the spectral type for each symbiotic object, along with a concise overview of each object. In Section 4, we analyze the advantages and disadvantages of the spectral classification in different spectral bands. Finally, Section 5 ends the paper with our conclusions.

2. Observations and Data Reduction

On 8 June 2014, a selection of nine southern symbiotic stars was observed with the Ohio State InfraRed Imager/Spectrometer (OSIRIS), coupled to the 4.1 m telescope of the

Southern Observatory for Astrophysical Research (SOAR, Cerro Pachón, Chile) under the proposal ID: SO2014A-009. The selected instrumental configuration consisted of a single-order long-slit spectrometer and the camera f/7 to obtain medium-resolution ($R\sim3000$) spectra in the H- and K-bands. The spectral coverage reached $\lambda\lambda$ 1.50–1.77 µm and $\lambda\lambda$ 2.0–2.4 µm for the H- and K-bands, respectively. The data of eight symbiotic stars obtained in the K-band were published by Marchiano et al. [13].

During all observations, several offset patterns following an ABBA cycle were taken, and the AB pairs were subtracted to remove the sky emission. Each spectrum was flat-fielded, telluric-corrected, and wavelength-calibrated. The reduction process was carried out with the IRAF [1] software package.

Relevant information on the observed targets is given in Table 1. There, we list the star names, the stellar coordinates, the H and K magnitudes, and the IR classification type (D or S) [7,15], and in the last six columns, we show the spectral type of the cool component determined from near-IR spectra (using wavelengths between 7000 and 10,000 Å), the effective temperature T_{cool}, the references where we obtained these data, the spectral type of the cool component derived from the CO-bands at 2.3 µm by Marchiano et al. [13], the spectral type of the cool component obtained in this work, and the equivalent temperature T_E, which we will explain in the next section.

Table 1. Stellar sample data with literature classifications.

Object	**α (h:m:s)**	**δ (° ′ ″)**	**H (mag)**	**K (mag)**	**Type**	**Sp.T.**	**T_{cool} (K)**	**Ref.**	**Sp.T. Ref. [13]**	**Sp.T. this work**	**T_E (K)**
BI Cru	12:23:26	−62:38:16	6.187	5.064	D	M0–M1	-	1	-	-	-
RS Oph	17:50:13	−06:42:28	6.858	6.5	S	M2	4100	3, 4	K1–K2	G8	4760
Hen 3-1341	18:08:37	−17:26:39	7.892	7.479	S	M4	3500	2, 3	K3	K3	4170
CL Sco	16 54 51	−30 37 18	-	7.86	S	M5	3400	3	M0	M5	3430
SY Mus	11:32:10	−65:25:11	8.14	4.593	S	M4.5	3400	2, 3	K4–K5	M4	3490
RT Cru	12:25:56	−61:30:28	5.583	5.185	D	M6	-	5	M3.5	M3	3660
V347 Nor	16:14:01	−56:59:28	5.811	4.943	D	M7–M8.5	-	2	M2.5–M3.5	M0	3970
KX TrA	16:44:35	−62:37:14	6.409	5.979	S	M6	3300	2, 3	M2	M3	3600
V694 Mon	07:25:51	−07:44:08	5.471	5.069	S	M6	3300	2, 3	-	M2	3720

References: 1. Schulte-Ladbeck ([16]), 2. Mürset and Schmidt ([17]), 3. Gałan et al. ([18]), 4. Zamanov et al. ([19]), 5. Pujol et al. ([20]).

3. Results

The H-band spectral observation of each symbiotic system listed in Table 1 is presented in Figure 1. This figure shows the complete set of spectra, which were normalized and vertically shifted to ease inspection and comparison. The spectra are first displayed according to the presence of CO-bands in emission and then according to the strength of the atomic absorption lines.

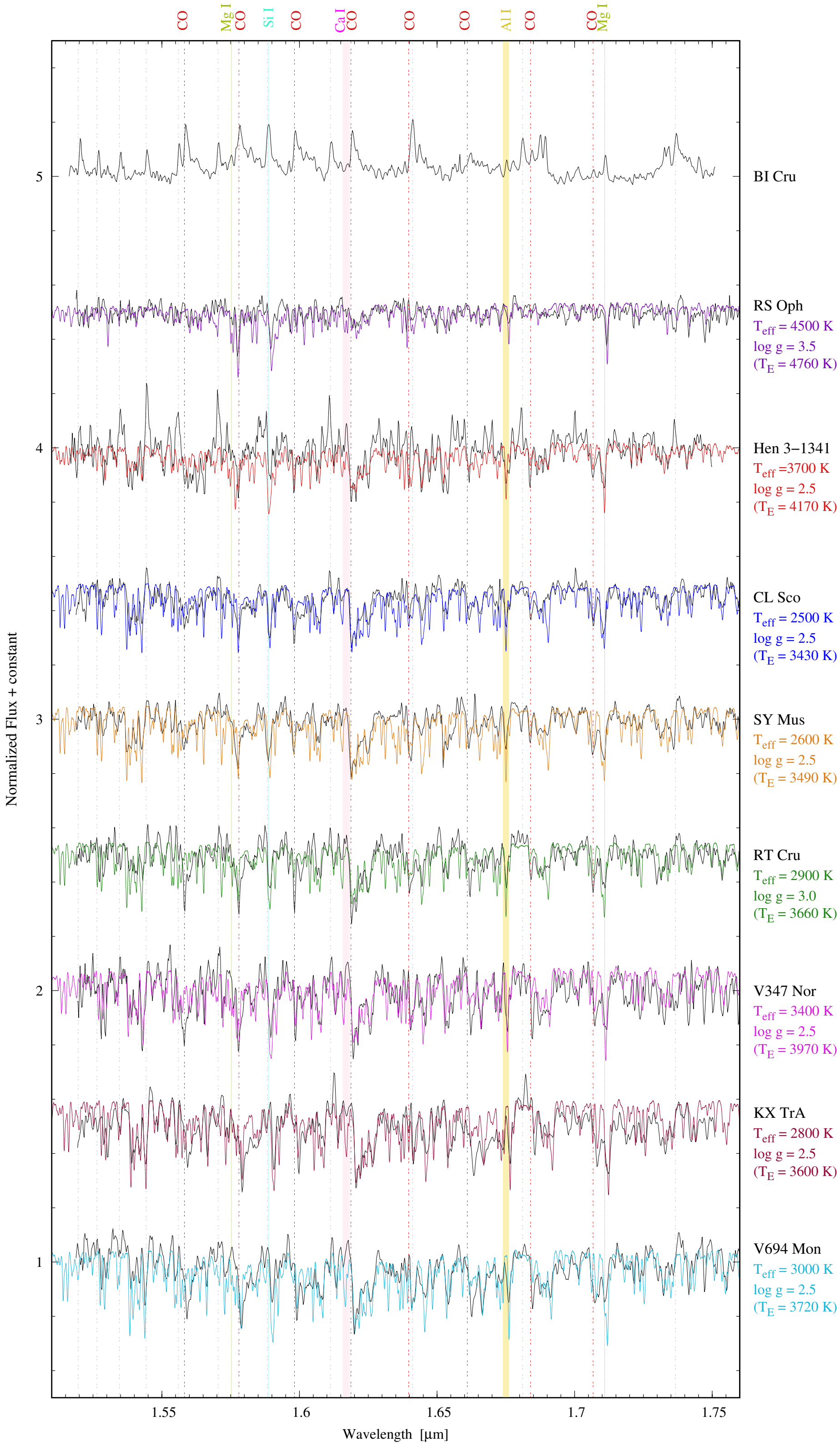

Figure 1. Comparison between the H-band spectra of our sample stars observed with SOAR/OSIRIS (black) and the best synthetic spectra computed with the MARCS model atmospheres (in different colors). Brackett series are indicated in gray, emission/absorption of CO in red, Mg I in green, and Si I in light blue. Ca I lines (1.6150 µm, 1.6157 µm, and 1.6197 µm) are indicated with a pink band and Al I lines (1.67504 µm, 1.67505 µm, 1.67189 µm and 1.67633 µm) with a yellow band. The stellar parameters of each model are also provided.

Our observations showed that all lines in BI Cru were in emission, and the remaining objects all showed CO-bands in absorption. More accurately, carbon monoxide molecules were observed in strong absorption in all stars, confirming the typical atmosphere of cool giants [21].

As a special case, the same as what was seen in the K-band [13], was RS Oph, which showed a weaker CO-band intensity than expected for the spectral type of the cool component. This weakening might be a consequence of the presence of dust with a temperature of ∼1000 K. Such a warm, dusty envelope veils the stellar photospheres and contributes to the total SED with emission of the absorbed and scattered stellar light at wavelengths longer than 2 µm [22].

Brackett series emission was significant in the spectra of BI Cru and Hen 3-1341. In addition to the lines of the hydrogen series, we also identified lines from Mg I, Ca I, Si I, and Al I. The Mg I line at λ 1.7109 µm was present in eight of the nine stars of our sample in absorption and in emission only in BI Cru. Note that the Si I line at λ 1.5888 µm was blended with a line of the Brackett series; it is important to take this into account in future observations with higher resolution to better distinguish the contributions of each line.

We fit the observations with the MARCS model spectra [14] to obtain the effective temperature ($T_{\rm eff}$). A grid was computed for M giant stars, covering the temperature range 2500 K $\leq T_{\rm eff} \leq$ 4600 K, with a step of 100 K. Models were generated with a power resolution of $R = 3000$, solar metallicity $[M/H] = 0$, $v \sin i = 8$ km s^{-1}, and 30 km s^{-1} and $\log g = 3.0$, 2.5, and 2.0. For temperatures lower than 3500 K, the microturbulence was taken with a value of 4 km s^{-1} and the macroturbulence equal to 8 km s^{-1}. For a hotter grid (temperatures higher than 3500 K), lower values for microturbulence (1 km s^{-1}) and macroturbulence (3 km s^{-1}) were considered, based on typical values adopted by studies of red giants and symbiotic stars [23,24]. On the one hand, it is important to note that the projected rotational velocity $v \sin i = 8$ km s^{-1}, or 30 km s^{-1}, taken as a fixed parameter, does not represent the majority of late-type giants in a symbiotic binary system ([25–27]). On the other hand, due to the instrument's spectral resolution used, the minimum detectable velocity would be approximately 100 km s^{-1}. Therefore, this particular instrument would not resolve any velocity change below 100 km s^{-1}.

In order to achieve a more accurate fit, we took into account not only the intensity of the CO absorptions, but also the relative relationships between these lines and other absorptions observed in each spectrum. The estimated values of $T_{\rm eff}$ and $\log g$ of each symbiotic star are shown on the right side of Figure 1. The error of $T_{\rm eff}$ was estimated to be around 100–200 K. Temperatures $T_{\rm E}$ between parentheses refer to the correction made to the effective temperature of red giant stars with $T_{\rm eff} < 4000$ K according to the polynomial functions applied in the work of Akras et al. [7] and van Belle et al. [28]. We used this correction to the $T_{\rm eff}$ values derived from the MARCS model to enable their comparison or equivalence with temperatures calculated via the blackbody approximation. Once this correction is obtained, which we refer to as the equivalent temperature $T_{\rm E}$ for convenience, we applied the empirical relationships for red giants from the work of van Belle et al. [28] to determine the corresponding spectral type.

A brief summary of each individual symbiotic system is provided below with a description of the emission and absorption characteristics observed in this sample. It is worth clarifying that all systems belong to the catalog of symbiotic stars published by Belczynski et al. [15], which was used for the selection of the nine observed objects. Furthermore, there exist more recent catalogs of symbiotic stars, such as those compiled by Akras et al. [7] and Merc et al. [29].

BI Cru (= Hen 3-782 = WRAY 15-967):

BI Cru is a D-type symbiotic object. It is one out of three currently known symbiotic stars in which CO molecular emission was detected in the near-infrared at 2.3 µm [30], which seems to be stable over long time intervals. From the modeling of the CO-band emission detected in a high-resolution (R∼45,000) K-band spectrum, Marchiano et al. [31] derived the kinematics and the physical properties of the molecular circumstellar medium.

This CO emission is associated with a dense disk, which would form after one or more episodes of intense mass loss from the red giant.

McCollum et al. [32] reported an IR shell of BI Cru more than five-times larger in arc size than the star's optical lobe. The temperature of this IR dust emission associated with our object was estimated to be 1300 K [33,34].

RS Oph (= HD 162214 = MWC 414):

RS Ophiuchi is a symbiotic recurrent nova consisting of a white dwarf with a mass near the Chandrasekhar limit that orbits inside the outer wind of a red giant. The system has had numerous outbursts recorded in 1898, 1933, 1958, 1967, 1985, and 2006, and more recently, in August 2021, it underwent its seventh optical eruption. Brandi et al. [35] re-determined the spectroscopic orbit of this star based on the optical spectra over the decade of 1998–2008.

The spectral type of the red giant and its temperature were estimated by Ribeiro et al. [36] and Pavlenko et al. [37]. In Table 1, we mark the reference of Zamanov et al. [19] because these authors applied a more precise method to classify the star. However, the spectral types obtained both by Marchiano et al. [13] and through this work (see Table 1) indicated an earlier spectral type than Zamanov et al. [19].

Hen 3-1341 (= V2523 Oph = SS73 75):

Hen 3-1341 is one of about ten symbiotics that shows hints of jets. According to Stute et al. [38], its optical and ultraviolet spectra show strong emissions in the Balmer continuum from N V, [Fe VII], and He II and the band at 6830 Å due to Raman scattering by neutral hydrogen. Furthermore, the object's infrared colors are appropriate for a cool giant (Spectral Type M4) without circumstellar dust. In quiescence, Hen 3-1341 resembles Z And, the prototype of symbiotic stars [39].

So far, no H-band observations have been reported. Our K-band observations [13] revealed an earlier spectral type for the red giant of this symbiotic star (see Table 1). From our fitting of the spectral features in the H-band, we found $T_{\rm eff} = 3700$ K and $T_{\rm E} = 4170$ K if we applied the temperature scale correction [7,28]. With this correction, we obtained the same spectral type found in the K-band. It is important to note that CO-bands in the spectrum of this star (see Figure 1) could be contaminated with emission lines. Furthermore, Hen 3-1341 presents emission lines that resemble those of BI Cru. New observations of this star in this band will be necessary to better confine its temperature.

CL Sco (= Hen 3-1286):

Infrared radial velocities were used by Fekel et al. [40] to compute the orbital parameters of this star. They obtained physical parameters adopting a period $P = 625$ days for a circular solution, which agrees with Kenyon and Webbink [41]. Besides, the orbital solution for both components was presented by Montané et al. [42].

In the near-IR, Gałan et al. [18] measured the photospheric chemical abundances of this object from high-resolution ($R \sim 50{,}000$) spectra. They presented the observed K- and H-band spectra of CL Sco together with synthetic spectra calculated using their own abundance estimates. According to our fitting in the H-band, the obtained $T_{\rm E}$ value would indicate a later spectral type than that obtained by Marchiano et al. [13] from the analysis of the K-band; however, this coincides with that obtained by Gałan et al. [18].

SY Mus (= HD 100336 = Hen 3-667):

Dumm et al. [43] obtained the orbital parameters of the M star in this eclipsing symbiotic system and observed an asymmetry in the UV continuum light curve, which they explained as being caused by an asymmetric distribution of the wind from the cool component.

SY Mus was observed at high resolution ($R \sim 50{,}000$) in the HA-, K-, and $K_{\rm r}$-bands using the Phoenix cryogenic echelle spectrometer on the Gemini South telescope by Mikołajewska et al. [23]. All the spectra cover a narrow spectral range of $\sim$100 Å. Spectrum synthesis employing standard local thermal equilibrium analysis and atmosphere models was used to perform an analysis of the photospheric abundance of CNO for the red giant component. They obtained an isotopic ratio of $^{12}C/^{13}C \sim 6-10$, which indicates that the giant has experienced the first dredge-up.

In this work, we found that SY Mus has an effective temperature $T_{\rm eff} = 2600$ K. Applying the temperature scale correction, we obtained $T_{\rm E} = 3490$ K. This result is close to that published by Mürset and Schmid [17] and Gałan et al. [18], who indicated that the cold companion has a spectral type M4.5. However, this differs from what was obtained by Marchiano et al. [13], who found an earlier spectral type (see Table 1).

RT Cru (= HV 1245):

RT Crucis was classified as a symbiotic star by Cieslinski et al. [44], and the same authors reported the presence of rapid variations in its brightness. Gromadzki et al. [45] using optical and IR observations, detected two periodicities in the light curves: $P_o = 325 \pm 9$ days and $P_p = 63 \pm 1$ days, which corresponded to the orbital and pulsation periods of the red giant, respectively.

RT Cru also attracted attention due to the discovery of hard X-ray emission detected in 2003–2004 with INTEGRAL/IBIS, which promoted the study of how accumulated material advances through a disk and reaches the surface of the white dwarf [46].

Using the first-overtone band of CO in the K-band, Marchiano et al. [13] found that the spectral type of the red giant companion was earlier than the one published by Pujol et al. [20]. A result in agreement with Marchiano et al. [13] was obtained in this work using synthetic spectra computed by MARCS model atmospheres in the H-band, as can be seen with the best fit in Figure 1 and in Table 1.

V347 Nor (= Hen 2-147 = WRAY 16-208):

This is a symbiotic Mira star. It has a pulsation period of 373 days and lacks the obscuration events typical of many other D-type symbiotics [47]. Its extended nebula was first modeled as an expanding ring inclined with respect to the plane of the sky by Corradi et al. [48]. Utilizing Doppler shift measurements from VLT integral-field spectroscopy in combination with the HST images, Santander-García et al. [47] demonstrated that the intrinsic geometry of the nebula is indeed that of a circular, knotty ring of ionized gas. This ring was found to be inclined by 68 degrees with respect to the line of sight and to expand with a velocity of $\sim$90 km s^{-1}.

We present here the first H-band spectrum for this symbiotic system. Figure 1 also shows that the best-fitting spectrum gave a spectral type not only earlier than the one found by Mürset and Schmid [17], but also earlier than the one found by Marchiano et al. [13] (see Table 1).

KX TrA (= Hen 3-1242):

KX TrA is a high-excitation S-type symbiotic binary. Its optical and near-IR spectra were studied by Ferrer et al. [49] and Marchiano et al. [50]. With observations taken between 1995 and 2007, they determined an orbital solution to the absorption lines of the red giant through the radial velocity curve. Since 2004, the system has entered into a period of activity.

Gałan et al. [18,51] presented high-resolution ($R\sim$50,000) near-IR spectra for a sample of symbiotic systems. They employed stellar atmosphere models using a standard local thermal equilibrium analysis and derived the chemical abundance of several systems including KX TrA. Adopting the spectral type shown in the seventh column in Table 1, their analysis revealed a slightly subsolar metallicity ([Fe/H] ~ -0.3) for KX TrA. Based on our analysis (see Figure 1 and Table 1), the spectral type was slightly later than the spectral type reported by Marchiano et al. [13] and was earlier than the one adopted by Gałan et al. [51] cited above.

V694 Mon (= MWC 560):

The most-spectacular features in the optical spectrum of V694 Mon are the broad absorption lines, most prominently at the Balmer transitions. V694 Mon is a symbiotic star in which the accretion disk drives a powerful high-velocity jet during outbursts, producing broad, blue-shifted, variable absorption lines from atomic transitions that extend up to thousands of km s^{-1}, not only in the optical range, but also in the IR, near-ultraviolet, and far-ultraviolet [52,53].

By fitting the observations of the donor star, we derived for the first time its effective temperature of $T_{\rm eff} = 3000$ K (see Figure 1). We also obtained, through the black body approximation, the $T_{\rm E}$ value, which allowed us to estimate the spectral type of the cool companion (see Table 1).

4. Discussion

Analysis of the near-infrared range in symbiotic systems is key to their study since it has been used to classify these in S- and D-type stars based on their division into color–color diagrams, (J-H) versus (H-K), and (H-K) vs. (K-L) [54]. In addition, the techniques used in this region of the electromagnetic spectrum have proven to be the most-suitable for finding the spectral type of the late-type component in these binary systems. Moreover, the near-infrared is typically not contaminated by the nebula and the emission from the hot component, which both strongly affect the spectra at optical wavelengths.

Keenan and Hynek [55] introduced the spectral classification for the cool component of symbiotic binaries using the red TiO-bands, which increase in strength with decreasing temperature. Sharpless [56] solved the spectral classification using the characteristics of the most-important molecular bands between 7500 and 8900 Å. His temperature classification was also based on the growth of the TiO- and VO-bands, but he found that the CN-bands at 7916, 7941, 7878, and 8068 Å are useful luminosity discriminators in this spectral range as well. According to Schulte-Ladbeck [16], numerous observations of symbiotic systems are subject to contamination by emission lines from the nebula. This represents a source of error because these lines weaken the absorption of molecular bands in relation to the continuum. The longer wavelength bands are expected to be less affected since the IR brightness of the red giant increases rapidly in that range.

The K-band has been widely employed in most spectroscopic studies of cool or obscured objects, due to their higher brightness in this band compared to the J- or H-bands. Moreover, for the spectral classification of cool stars, several atomic features of Mg I, Ca I, and Na I are utilized, along with the band heads of the first-overtone CO-bands, which dominate the K-band spectra. Nevertheless, observations have revealed that stars of spectral types K3-M5 also exhibit significant temperature and luminosity-sensitive features in the H-band, including the lines of Mg I, Al I, and OH, and the band heads of the CO second overtone bands [57].

The circumstellar dust in symbiotic systems (more noticeable in D-type than S-type stars) often causes a continuum emission excess in the IR, which can reach down to wavelengths of around 2 μm. If this is the case, the excess emission can significantly hinder the extraction of precise information about the photosphere of the cool component. In such systems, shorter-wavelength spectra are required to identify and characterize the underlying star.

After considering the pros and cons of performing spectral classification in different near-infrared spectral bands, we propose that the H-band can provide valuable complementary information that can help to better constrain the parameters in symbiotic systems, in particular the temperature of the red giants in dusty symbiotic systems whose K-band spectra might be contaminated by the dust emission. It is also important to clarify that the differentiation of the spectral types obtained in the H- and K-band for each symbiotic object is based on observations that have been taken with the same instrument and within the same observing run. The studies themselves, however, employed different methods. The spectral classification found from the K-band spectra is based on measurements of equivalent line widths [13], unlike in this study, where we used a more robust method. Thus, an estimate of the similarities or differences between the spectral types obtained in each band is not entirely accurate if a different methodology is used, but we are confident that the presented analysis for the H-band spectra of symbiotic objects provides more decent results regarding the classification of their cool components.

5. Conclusions

To summarize, the IR spectra of symbiotic stars are a very useful tool to perform spectral classification of the cool components of these systems [16]. They are also excellent sources of information on the physical conditions of the disks from which molecular emission (if detected) originates. On the other hand, for many years, different studies, dedicated to the near-IR spectra of symbiotic stars have utilized low-resolution data, and in general, many of those studies were restricted to a small sample of stars, some examples being Schulte-Ladbeck [16], Kenyon and Gallagher [58], Schild et al. [59]. In the last two decades, new instruments have given access to the IR spectral range and have made it possible to obtain high-quality spectra with the necessary spectral resolution to improve the understanding of these complex objects.

With the aim to enlarge the sample of symbiotic objects with near-IR classifications, we presented the medium-resolution H-band spectra of nine symbiotic systems obtained with the OSIRIS spectrograph. We summarize our results in two points:

- We observed CO emission only for BI Cru; the rest of the stars of our H-band sample showed CO absorption lines. We identified some pronounced emissions of the hydrogen Brackett series in BI Cru and Hen 3-1341; in the other seven observed stars, these lines were weaker or absent. We also identified the lines of Mg I, Si I, Al I, and Ca I.
- In the spectra with CO-bands in absorption, we fit these features with synthetic spectra obtained using MARCS atmosphere models, and we estimated the values of $T_{\rm eff}$ and $\log g$ of the cool companion of each observed symbiotic system (see the right side of Figure 1). Based on the scheme by van Belle et al. [28] and Akras et al. [7] for correcting the temperatures of red giants, we derived an approximate spectral type of the cool giant. The results are presented in the penultimate column of Table 1.

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Notes

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