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# SS 383: A NEW S-TYPE YELLOW SYMBIOTIC STAR?

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## ABSTRACT

Symbiotic stars are key objects in understanding the formation and evolution of interacting binary systems, and are probably the progenitors of Type Ia supernovae. However, the number of known symbiotic stars is much lower than predicted. We aim to search for new symbiotic stars, with particular emphasis on the S-type yellow symbiotic stars, in order to determine their total population, evolutionary timescales, and physical properties. The Two Micron All Sky Survey (2MASS) $(J - H)$ versus $(H - K_s)$ color–color diagram has been previously used to identify new symbiotic star candidates and show that yellow symbiotics are located in a particular region of that diagram. Candidate symbiotic stars are selected on the basis of their locus in the 2MASS $(J - H)$ versus $(H - K_s)$ diagram and the presence of H$\alpha$ line emission in the Stephenson & Sanduleak H$\alpha$ survey. This diagram separates S-type yellow symbiotic stars from the rest of the S-type symbiotic stars, allowing us to select candidate yellow symbiotics. To establish the true nature of the candidates, intermediate-resolution spectroscopy is obtained. We have identified the H$\alpha$ emission line source SS 383 as an S-type yellow symbiotic candidate by its position in the 2MASS color–color diagram. The optical spectrum of SS 383 shows Balmer, He I, He II, and [O III] emission lines, in combination with TiO absorption bands that confirm its symbiotic nature. The derived electron density ($\simeq 10^{8-9}$ cm$^{-3}$), He I emission line intensity ratios, and position in the [O III] $\lambda 5007/\mathrm{H}\beta$ versus [O III] $\lambda 4363/\mathrm{H}\gamma$ diagram indicate that SS 383 is an S-type symbiotic star, with a probable spectral type of K7-M0 deduced for its cool component based on TiO indices. The spectral type and the position of SS 383 (corrected for reddening) in the 2MASS color–color diagram strongly suggest that SS 383 is an S-type yellow symbiotic. Our result points out that the 2MASS color–color diagram is a powerful tool in identifying new S-type yellow symbiotics.

*Key words:* binaries: symbiotic – stars: fundamental parameters – stars: individual (SS 383)

*Online-only material:* color figures

## 1. INTRODUCTION

Symbiotic stars are interacting binaries formed by a red giant and a hot source (for example, a white dwarf) that ionizes the wind of the cool component. There exist, however, some cases in which the hot source is a neutron star (see, e.g., Table 1 of Lü et al. 2012). In the optical, the spectra of symbiotic stars are dominated by both emission lines originating from the ionized nebula and the continuum of the red giant, which is characterized by strong TiO absorption features. Symbiotic stars are divided into two groups: those with an excess of IR emission between 1.0 $\mu$m and 5.0 $\mu$m and those with a pure stellar continuum in the same spectral range. The former are classified as D type, since the IR emission is attributed to dust that emits radiation at $T \approx 800$–1000 K (Belczyński et al. 2000), while the latter are classified as S type. A third group is considered, D′-type symbiotic stars, that is characterized by cool components, earlier $(F - K)$ spectral types, and IR dust emission, but with typically lower temperatures than those observed in D types. The majority of symbiotic stars belong to the S type. They comprise $\simeq$80% of the total number of known symbiotics (Belczyński et al. 2000) and have a normal M-giant star as the cool component of the binary system. However, there is a small subsample of S-type symbiotic stars where the cool component is warmer, with typically mid-*K* spectral types (Mürset & Schmid 1999). These are called S-type yellow symbiotic stars. Up to now, there are 12 Galactic S-type yellow symbiotic stars known, although only 7 have already been investigated by means of high-resolution spectroscopy: AG Dra (Smith et al. 1996), BD-21 3873 (Smith et al. 1997; Pereira & Porto de Mello 1997), Hen 2-467 (Pereira et al. 1998b), and four symbiotics analyzed by Pereira & Roig (2009; CD–43°14304, Hen 3-1213, Hen 3-863, and StH$\alpha$ 176). There are still five Galactic S-type yellow symbiotic stars to be investigated with high-resolution spectroscopy.

The number of known symbiotic stars ($\simeq$180) is much smaller than the predicted number, $\simeq 3 \times 10^4$ (Kenyon et al. 1993). Other authors provide different estimates for the predicted number, for instance, $3 \times 10^5$ (Munari & Renzini 1992) and $4 \times 10^5$ (Magrini et al. 2003). The discovery of new S-type symbiotic stars, particularly of the yellow ones, is important because of their special spectroscopic characteristics. For example, the absorption spectra of these symbiotics stars are free from the strong opacity due to the TiO molecule absorption feature, which is always observed in the majority of S-type symbiotics and complicates the measurement of some atomic lines. Another observational characteristic is the high electron density observed in these objects. This property makes it possible to measure the absorption lines in an easier way (once they are not crowded by several emission lines). Moreover, symbiotic stars are now considered potential candidate progenitors of Type Ia supernovae (SNeIa; Munari & Renzini 1992), although evidence is restricted to a few cases yet. For example, RS Oph is a symbiotic recurrent nova (Kenyon 1986) with a white dwarf close to the Chandrasekhar limit (Dobrzycka & Kenyon 1994; Brandi et al. 2009). For this reason, RS Oph has been proposed as a strong candidate progenitor of SNIa (Hachisu & Kato 2000, 2001). In addition, S-type yellow symbiotic stars are very useful objects for determining whether mass transfer has happened in

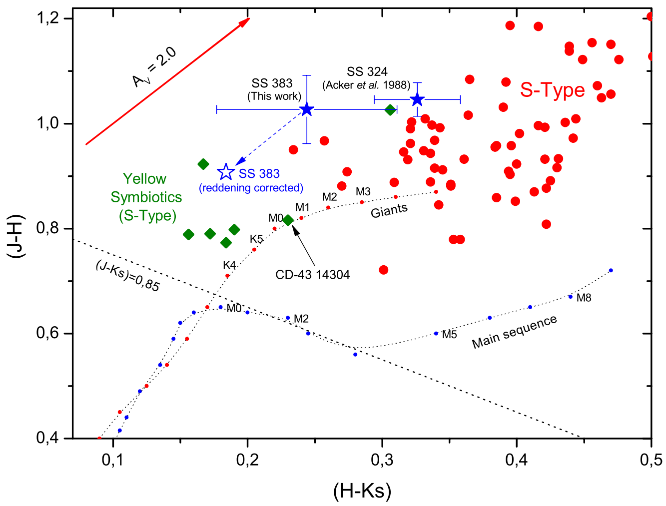


**Figure 1.** SS 383 and SS 324 (blue stars) in the 2MASS color–color diagram (error bars are shown for each object). The seven S-type yellow symbiotic stars (green diamonds) confirmed using high-resolution spectroscopy are distinguished from the rest of the S-type symbiotic stars (red circles). They are located along the line of giant stars. The positions of the objects, except for SS 383, are not corrected for reddening, which is indicated by an arrow (top left). The dashed line at $(J - K_s) = 0.85$ indicates an effective temperature of ∼4000 K. The locus of main-sequence and RGB stars is marked by the dotted lines (Straizys & Lazauskaite 2009).

these binary systems in the past. For example, measuring the abundance of elements created by the slow neutron-capture reactions (*s*-process), one may probe their overabundances (Smith et al. 1996, 1997; Pereira et al. 1998a; Pereira & Roig 2009). Since these symbiotics are not luminous enough to have undergone the third dredge-up on the asymptotic giant branch (AGB) phase, the overabundances of the *s*-process elements have been attributed to the mass transfer in the binary system from a former AGB star (now the hot component in the symbiotic system). These comments and the low number of known S-type symbiotics point to the need for new identifications.

The 2MASS $(J - H)$ versus $(H - K_s)$ color–color diagram has been previously used to identify new symbiotic star candidates and show that yellow symbiotics are located in a particular region of that diagram (Corradi et al. 2008, 2010). Recently, Baella (2012) used the 2MASS $(J - H)$ versus $(H - K_s)$ diagram, in combination with the Stephenson & Sanduleak (1977, hereafter SS77) H$\alpha$ survey, to identify new S-type yellow symbiotic stars. H$\alpha$ emission line stars in the SS77 catalog located in that particular region of the 2MASS two-color diagram are candidate S-type yellow symbiotic stars. We have identified SS 383 as one of these candidates and we present in this paper spectroscopic observations with the aim of studying the nature of this object.

## 2. TARGET SELECTION

We use the 2MASS color–color diagram to analyze the possibility of distinguishing new S-type yellow symbiotic stars among the H$\alpha$ emission line objects from the SS77 catalog. Figure 1 presents the 2MASS color–color diagram in which S-type symbiotic stars from the Belczyński catalog (2002) are shown (red circles) and they are distinguished from the seven objects confirmed to be S-type yellow symbiotic stars using high-resolution spectroscopy (green diamonds). In order to show the locus of S-type yellow symbiotic stars, only symbiotic stars with color indexes between $0.1 < (H - K_s) < 0.5$ and $0.4 < (J - H) < 1.2$ are plotted in this diagram. The positions of the symbiotic stars in the diagram are determined by the cool component of the symbiotic system and the diagram effectively separates the yellow symbiotics toward smaller values of the $(H - K_s)$ color. In fact, the S-type yellow symbiotics are located at approximately around $(H - K_s) \simeq 0.2$ and $(J - H) \simeq 0.8$. The yellow symbiotic Hen 3-1213 (next to SS 324, see below) is far from that region, probably due to high reddening caused by its proximity to the Galactic plane ($b = -2\overset{\circ}{.}8$). With this result, the method to select S-type yellow symbiotic candidates consists of placing H$\alpha$ emission line objects from the SS77 catalog in the 2MASS color–color diagram. Objects located in or close to the region of S-type yellow symbiotics can be considered potential candidates for this type of object.

Figure 1 also shows the position in the 2MASS color–color diagram of two H$\alpha$ emission line objects from the SS77 catalog: SS 383 and SS 324 (blue stars). These two objects are located close to the boundary region between the S-type symbiotic stars (red circles) and S-type yellow symbiotic stars (green diamonds). SS 324 is a known S-type symbiotic star (Acker et al. 1988) from the SS77 catalog. SS 383 is close to the locus of the S-type yellow symbiotics, and, therefore, it is a good candidate for a symbiotic star and, in particular, for the yellow type.

## 3. OBSERVATIONS AND REDUCTION

Spectroscopic observations of SS 383 were performed on 2012 June 9 with the Cassegrain Twin Spectrograph (TWIN) attached to the 3.5 m telescope of the Calar Alto Observatory (Almeria, Spain). TWIN includes two separate spectroscopic channels (blue and red) behind the common entrance slit aperture. The detectors were a SITe CCD 22b in the blue channel and a SITe CCD 20b in the red channel, in both cases with 2000 pixels in the spectral direction. The observations were done using gratings T08 (blue) and T04 (red) to cover the spectral ranges 3200–5800 Å and 5500–7600 Å, respectively, at a spectral resolution of 1.08 Å pixel$^{-1}$ in both channels. This resolution is enough to separate the [O III] $\lambda$4363 and the H$\gamma$ emission lines. The slit was oriented east–west and its width was 2″. Two exposures were obtained for each grating: one of 180 s, in order to avoid possible saturation of strong emission lines, and the other of 900 s in order to register faint emission lines and the absorption spectrum of the star.

The spectra were reduced using standard IRAF tasks, from bias subtraction and flat-field correction, through spectral extraction and wavelength and flux calibration. Spectrophotometric standards from Massey et al. (1988) were also observed with the same instrumental configuration before and after the object for flux calibration.

The flux of the detected emission lines was measured by the conventional method, adjusting a Gaussian function to the line profile, thereby obtaining the intensity and the central wavelength. Uncertainties in the line fluxes come mainly from the position of the underlying continuum. We estimate the flux error to be about 20% for the weak lines (line fluxes ≈10 on the scale of $F(\mathrm{H}\beta) = 100$) and about 10% for stronger lines.

## 4. RESULTS AND DISCUSSION

### *4.1. The Spectrum of SS 383*

Figure 2 shows the spectrum of SS 383 and Table 1 provides the observed line flux of the identified emission lines. The emission spectrum exhibits the Balmer lines, the major He I emission lines, the He II $\lambda$4686 emission line, and the [O III]

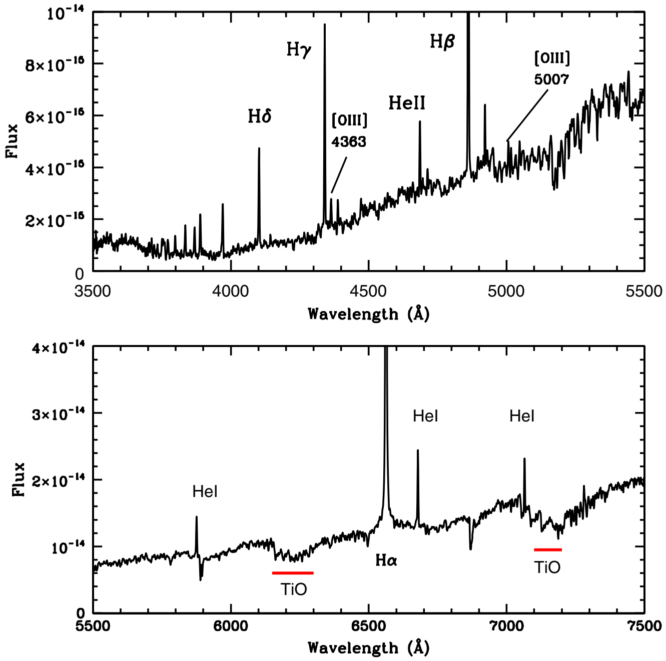


**Figure 2.** Flux calibrated spectrum of SS 383. The flux is in units of erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$. Some emission lines and TiO absorption bands are indicated.
(A color version of this figure is available in the online journal.)

emission lines at 4363 Å and 5007 Å. [O III] λ4959 is probably present but at a very low intensity level and cannot be measured. In addition, the TiO absorption bands at 6200 Å, 7125 Å, and 7160 Å can be identified in the spectrum of SS 383. Around 5890 Å, Na I is seen in absorption. The combination of an emission-line spectrum with a stellar late-K/early-M continuum and also with TiO bands confirms that SS 383 is a symbiotic star.

To obtain information about the most probable spectral type of SS 383, we followed two basic procedures.

1. We first compared the spectrum of SS 383 with the spectra available in the spectrophotometric atlas of symbiotic stars of Munari & Zwitter (2002). We found remarkable similarities between SS 383 and the S-type yellow symbiotic star CD-43°14304 (Pereira & Roig 2009) in the spectral range of 3700 and 7500 Å. CD-43°14304 has a K7 spectral type (Mürset & Schmid 1999) and, therefore, SS 383 should have a very similar spectral type. To illustrate the similarities between these two stars, we show in Figure 3 the spectra of CD-43°14304 and SS 383 in the 3700–5100 Å spectral range. The spectrum of CD-43°14304 was obtained in 1998 July 15, with an exposure time of 600 s and a slit width of 4″, at the Boller & Chivens spectrograph at the 1.52 m telescope at La Silla (Chile), in the framework of the analysis of the Bowen emission lines in D-type symbiotic stars (Pereira et al. 1999). In that observing run, several other S-type symbiotic stars with the He II λ4686 emission line were also observed for the study of the Bowen fluorescence process. In that study, the authors obtained spectra of symbiotic stars in two spectral regions, one from 3100 to 4100 Å and another from 3700 to 5700 Å. Interestingly, the dispersion of the TWIN blue spectrum of SS 383 is 1.08 Å pixel$^{-1}$,

**Table 1**
Observed and Reddening-corrected Emission Line Fluxes Relative to $F(\mathrm{H}\beta) = 100$

| Wavelength (Å) | Identification | $F(\lambda)$ (Observed) | $F(\lambda)$ (Corrected) |
|---|---|---|---|
| 3798 | H 10 | 3.3 | 4.3 |
| 3835 | H 9 | 6.0 | 7.8 |
| 3869 | [Ne III] | 4.6 | 5.9 |
| 3889 | He I | 6.1 | 7.8 |
| 3970 | Hϵ | 9.6 | 12.1 |
| 4101 | Hδ | 14.1 | 17.2 |
| 4340 | Hγ | 32.2 | 37.3 |
| 4363 | [O III] | 6.8 | 7.8 |
| 4388 | He I | 6.0 | 6.9 |
| 4471 | He I | 5.6 | 6.2 |
| 4686 | He II | 13.8 | 14.5 |
| 4713 | He I | 5.0 | 5.2 |
| 4861 | Hβ | 100.0 | 100.0 |
| 4922 | He I | 10.6 | 10.5 |
| 5007 | [O III] | 8.1 | 7.8 |
| 5015 | He I | 5.8 | 5.6 |
| 5047 | He I | 8.3 | 7.9 |
| 5876 | He I | 27.5 | 21.6 |
| 6563 | Hα | 655.3 | 455.9 |
| 6678 | He I | 51.0 | 35.0 |
| 7065 | He I | 36.4 | 23.7 |
| 7281 | He I | 29.1 | 18.5 |
| $F(\mathrm{H}\beta)$ erg cm$^{-2}$ s$^{-1}$ | $1.03 \times 10^{-13}$ | | |

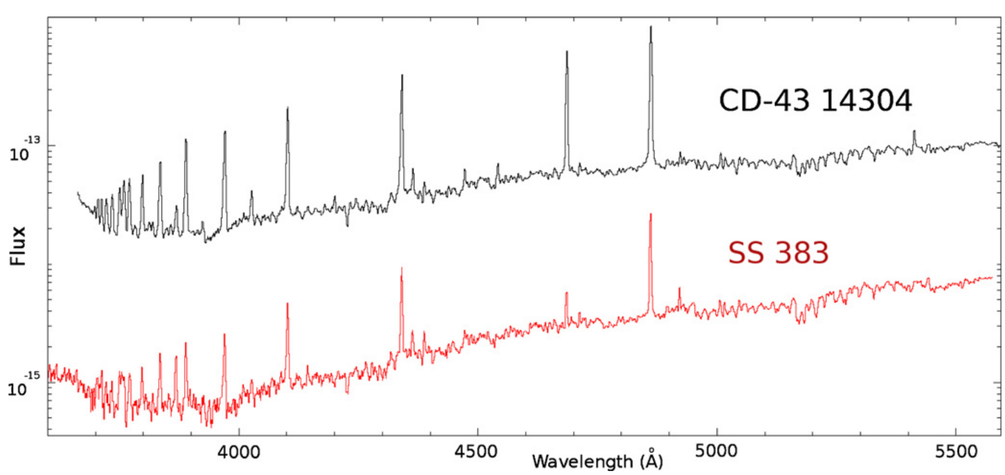


**Figure 3.** Flux calibrated spectra of CD-43°14304 and SS 383. The flux is in units of erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$.
(A color version of this figure is available in the online journal.)

**Table 2**
Physical Parameters of SS 383

| Parameter | Value |
|---|---|
| $E(B-V)$ | $0.33 \pm 0.05$ |
| $A_V$ | $1.03 \pm 0.15$[a] |
| $\tau_{H\alpha}$ | $2.4 \pm 0.1$ |
| $\log(N_e)$[b] ($cm^{-3}$) | 8–9 |
| He I λ6678/λ5876 | 1.6 |

**Notes.**
[a] Using $R = 3.1$.
[b] From the [O III] emission lines and $T_e = 10{,}000$–12,000 K.

virtually identical to the dispersion of 1.0 Å $pixel^{-1}$ of the spectrum of CD-43°1430 taken with the Boller & Chivens spectrograph, which allow us a detailed comparison. Figure 3 shows the remarkable similarity between these two spectra. From this comparison, we conclude that SS 383 likely has a spectral type of late K and is a new S-type yellow symbiotic star.

2. We also used the quantitative TiO indices as defined by Kenyon & Fernandez-Castro (1987b) in order to better constrain the spectral type of SS 383. In Figure 4, we show the position of SS 383 (red star) among the sample of S- and D-type symbiotic stars and among a small sample of the S-type yellow symbiotic stars also analyzed by those authors, namely, AG Dra, RS Oph, and TX CVn. As can be seen in Figure 4, SS 383 lies very close to TX CVn. Finally, with the help of the TiO indices and using the dependence of these indices with the spectral types for K and M giants seen in Figures 2 and 3 of Kenyon & Fernandez-Castro (1987b), the most probable spectral type of SS 383 is K7-M0.

### 4.2. *Physical Parameters*

Several physical parameters of SS 383 can be derived from the spectrum, such as reddening $E(B-V)$, optical depth in Hα ($\tau_{H\alpha}$), and electron density ($N_e$). Table 2 summarizes the results. We note that symbiotic nebulae have electron densities high enough to invalidate the assumption that the hydrogen Balmer ratios ($H\beta/H\gamma$ and $H\alpha/H\beta$) can be used to derive the interstellar reddening by comparing their observed values with those expected for case B recombination. Therefore, we used the analytical procedure described by Gutiérrez-Moreno & Moreno (1996) to obtain $E(B-V)$ and $\tau_{H\alpha}$. Using the observed $H\gamma/H\beta$ and $H\delta/H\beta$ line intensity ratios, the interstellar extinction curve by Fitzpatrick & Massa (2007), and the analytical expressions of Gutiérrez-Moreno & Moreno (1996), we obtain $E(B-V) \simeq 0.33$ and $\tau_{H\alpha} \simeq 2.4$. In Table 1, we also list the emission-line intensities reddening-corrected with the obtained value of $E(B-V)$.

Using the [O III] lines at 5007 Å and 4363 Å corrected for reddening and considering $I$([O III] λ4959) $\simeq 1/3 \times I$([O III] λ5007) for $T_e = 10{,}000$–12,000 K (Nussbaumer et al. 1988), we obtain $N_e \simeq 10^8$–$10^9$ $cm^{-3}$. This electron density is higher than that observed in D-type symbiotic stars ($N_e \approx 10^{6-7}$ $cm^{-3}$; Schmid & Schild 1990; de Freitas Pacheco & Costa 1992; Gutiérrez-Moreno & Moreno 1996; Pereira et al. 1998a) but compatible with that observed in S-type symbiotic stars ($N_e \approx 10^{8-10}$ $cm^{-3}$; Kenyon & Fernandez-Castro 1987a; Mikolajewska & Kenyon 1992; Gutiérrez-Moreno et al. 1997, 1999). Moreover, Proga et al. (1994) demonstrated that He I emission line intensity ratios can be used to distinguish between S-type and D-type symbiotic stars, besides their IR colors. In particular, given the large

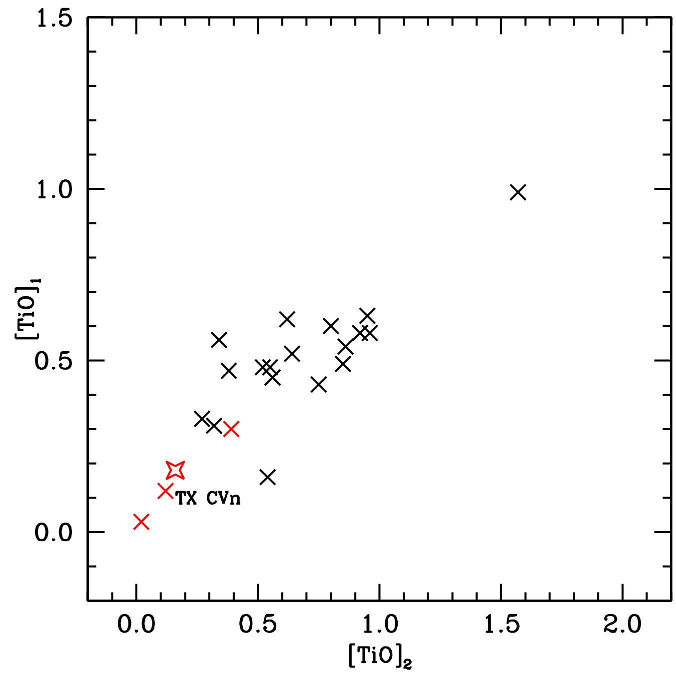


**Figure 4.** Position of SS 383 (red star) in the $[TiO]_1$ vs. $[TiO]_2$ diagram for a sample of symbiotic stars analyzed by Kenyon & Fernandez-Castro (1987b). The black crosses represent the S- and D-type symbiotics with spectral types later than M0. The smaller sample of S-type symbiotics with spectral types not later than K9 ("the yellow symbiotics"), AG Dra, RS Oph, and TX CVn, also analyzed by Kenyon & Fernandez-Castro (1987b), are represented in this diagram by red crosses. Notice that the position of SS 383 is similar to other S-type yellow symbiotic stars.

difference in electron density of both types of symbiotics, the $I$(He I λ6678)/$I$(He I λ5876) ratio distinguishes the two types. Those with $I$(He I λ6678)/$I$(He I λ5876) ≈ 0.25 are D-type symbiotics and those with $I$(He I λ6678)/$I$(He I λ5876) ⩾ 0.50 are S-type symbiotics. In the case of SS 383, the $I$(He I λ6678)/ $I$(He I λ5876) corrected for reddening is ≃1.6 (see Table 1), in agreement with the S-type classification derived above.

We note that the position (corrected for reddening, using $A_V = 1.03$; see Table 2) of SS 383 in the 2MASS color–color diagram (Figure 1) is compatible with the region of S-type yellow symbiotic stars and the region of late-K–early-M spectral type stars. In addition, the position of SS 383 is close to the position of CD-43°14304 in this diagram. It is important to note that the position of the well-known S-type yellow symbiotic CD-43°14304 in Figure 1 is compatible with the region of late-K–early-M spectral type stars. This result and (1) the similarity between the spectra of SS 383 and CD-43°14304 and (2) the position in the $[TiO]_1$ versus $[TiO]_2$ diagram suggest that SS 383 is an S-type yellow symbiotic star. Our result supports the use of the 2MASS color–color diagram to identify these kinds of symbiotic stars.

### 4.3. *SS 383 in the Diagnostic Diagram*

An interesting aspect of the spectrum of SS 383 is the relative intensity of [O III] λ5007 to Hβ (≃0.08; Table 1). This very low line intensity ratio is usually seen in S-type symbiotic stars with high electron densities (Gutiérrez-Moreno et al. 1995). In fact, for electron densities higher than $N_e = 10^5$ $cm^{-3}$, which is the case for all symbiotics (Gutiérrez-Moreno et al. 1995), collisional de-excitation becomes important and thus contributes more strongly to the weakening of the [O III] λ5007 with respect to the [O III] λ4363 emission line. For instance, the critical

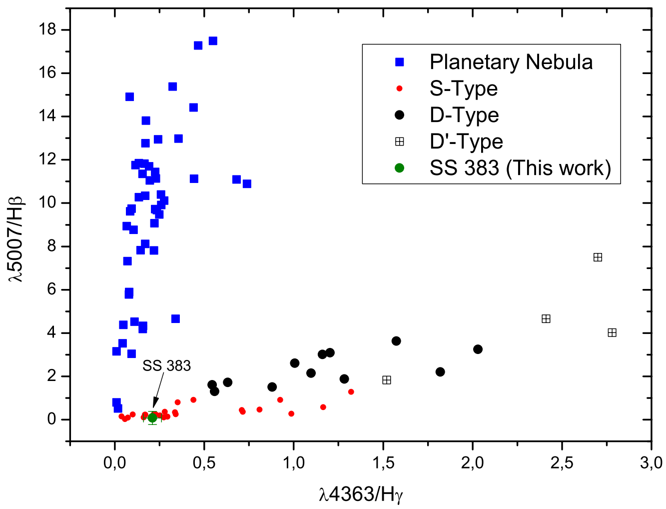


**Figure 5.** Position of SS 383 (error bars shown), planetary nebulae, and symbiotic stars in the [O III] $\lambda5007/\mathrm{H}\beta$ vs. [O III] $\lambda4363/\mathrm{H}\gamma$ diagram. Data for PNe are from Kingsburgh & Barlow (1994), S-type symbiotic stars from Gutiérrez-Moreno et al. (1999), and D- and D′-type symbiotic stars from Schmid & Schild (1990), Pereira et al. (1998a), Schmid & Nussbaumer (1993), and Gutiérrez-Moreno & Moreno (1996).

electron density for the [O III] λ5007 emission line is $\simeq 6.8 \times 10^5$ cm$^{-3}$ (Osterbrock & Ferland 2006, Table 3.15). Therefore, in the case of S-type symbiotic stars, the [O III] λ5007 emission line should have a very low intensity because it is emitted within a nebula with an electron density well above the critical density. As a consequence, line intensity ratios involving the [O III] lines are very useful in distinguishing between symbiotic stars and planetary nebulae that, in general, do not present electron densities higher than $10^5$ cm$^{-3}$. Figure 5 presents the [O III] $\lambda5007/\mathrm{H}\beta$ versus [O III] $\lambda4363/\mathrm{H}\gamma$ diagnostic diagram by Gutiérrez-Moreno et al. (1995). The measured line intensities (Table 1) place SS 383 in the same region as the S-type symbiotics and further strengthen our previous identification. It should be noted that some peculiar objects are located in this diagram at intermediate positions between symbiotic stars and planetary nebulae (see Gutiérrez-Moreno et al. 1995), which makes it difficult to determine their nature. However, this is not the case for SS 383.

## 5. CONCLUSIONS

We have presented intermediate-resolution optical spectroscopy of the Hα emission line source SS 383, which has been identified as an S-type yellow symbiotic candidate on the basis of its location in the 2MASS color–color diagram. The spectrum shows Balmer, neutral and ionized helium, and forbidden emission lines ([O III]), in combination with a stellar continuum dominated by TiO bands, that allows us to conclude that SS 383 is a symbiotic star. The high electron density ($\sim 10^{8-9}$ cm$^{-3}$) derived from the [O III] emission lines, He I line intensity ratios, and the position in the [O III] $\lambda5007/\mathrm{H}\beta$ versus [O III] $\lambda4363/\mathrm{H}\gamma$ diagram allow us to conclude that SS 383 is a new S-type symbiotic star.

The spectrum of SS 383 is remarkably similar to the spectrum of CD-43°14304, a true S-type yellow symbiotic with a K7 spectral type. Its position in the $[\mathrm{TiO}]_1$ versus $[\mathrm{TiO}]_2$ diagram also suggests a spectral type not later than M0. The position of SS 383, corrected for reddening, in the 2MASS color–color diagram coincides with the region where the S-type yellow symbiotics are located and is compatible with the region of late-K–early-M spectral type stars. Taken together, this further supports that SS 383 is in fact a new S-type yellow symbiotic star. Future high-resolution spectroscopic observations will be needed to investigate the abundance pattern of SS 383 compared with that of other known S-type yellow symbiotics. Our results further point out that the 2MASS color–color diagram is a very useful tool in identifying new S-type yellow symbiotics.

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