Identification of new Galactic symbiotic stars with SALT. I. Initial discoveries and other emission line objects

Brent Miszalski¹,²† and Joanna Mikołajewska³

¹South African Astronomical Observatory, PO Box 9, Observatory, 7935, South Africa
²Southern African Large Telescope Foundation, PO Box 9, Observatory, 7935, South Africa
³Nicolaus Copernicus Astronomical Centre, Bartycka 18, 00716 Warsaw, Poland

ABSTRACT

We introduce the first results from an ongoing, systematic survey for new symbiotic stars selected from the AAO/UKST SuperCOSMOS Hα Survey (SHS). The survey aims to identify and characterise the fainter population of symbiotic stars underrepresented in extant catalogues. The accreting white dwarfs (WDs) in symbiotic stars, fuelled by their red giant donors with high mass loss rate winds, make them promising candidates for type Ia supernovae. Several candidates were observed spectroscopically with the Southern African Large Telescope (SALT). A total of 12 bona-fide and 3 possible symbiotic stars were identified. The most remarkable example is a rare carbon-rich symbiotic star that displays coronal [Fe X] λ6375 emission, suggesting it may be a supersoft X-ray source with a massive WD. Several other emission line objects with near-infrared colours similar to symbiotic stars are listed in an appendix, including 6 B[e] stars, 4 planetary nebulae (PNe), 2 possible Be stars, one [WC 9] Wolf-Rayet (WR) central star of a PN and one WC9 WR star. These initial discoveries will help shape and refine the candidate selection criteria that we expect will uncover several more symbiotic stars as the survey progresses.

Key words: surveys - binaries: symbiotic - planetary nebulae: general - stars: carbon - stars: emission-line, Be - stars: Wolf-Rayet

1 INTRODUCTION

Symbiotic stars are interacting binaries with the longest orbital periods. A rich variety of phenomena are created in the interplay between the high mass loss rate wind of the red giant and its hot, accreting white dwarf companion (see e.g. Mikołajewska 2012). There are less than 300 Galactic symbiotics known (e.g. Allen 1984; Kenyon 1986; Mikołajewska, Acker & Stenholm 1997; Belczyński et al. 2000; Corradi et al. 2008, 2010a; Miszalski, Mikołajewska & Udalski 2013, hereafter MMU13), considerably fewer than population estimates of $3 \times 10^3$ (Allen 1984), $3 \times 10^4$ (Kenyon et al. 1993) or $3-4 \times 10^5$ (Munari & Renzini 1992; Magrini et al. 2003). To better estimate the true size of the population and the connection with type Ia supernovae (see e.g. Di Stefano 2010; Dilday et al. 2012), we require a more representative population of symbiotic stars. New surveys must be undertaken to find and characterise the full extent of the fainter population of symbiotic stars that are underrepresented in current catalogues (e.g. Belczyński et al. 2000).

The strong Hα emission of symbiotic stars ensures that they stand out in large Hα surveys such as the INT Photometric Hα Survey (IPHAS; Drew et al. 2005) and the AAO/UKST SuperCOSMOS Hα Survey (SHS; Parker et al. 2005). The surveys constitute a promising discovery medium for new symbiotic stars with their excellent sensitivity to faint Hα emission line stars and large sky coverage. Nineteen new symbiotic stars have so far been spectroscopically confirmed from the IPHAS survey (Corradi et al. 2008, 2010a,b, 2011; Corradi & Giammanco 2010; Corradi 2012; Rodríguez-Flores et al. in preparation). Their target selection strategy combined selections in the IPHAS colour-colour plane, to select for Hα emitters across ~35 deg² towards the Galactic Bulge and spectroscopically confirmed 20 new symbiotic stars, as well as several other possible symbiotic star candidates. These new IPHAS and SHS discover-

* Based on observations made with the Southern African Large Telescope (SALT) under programme 2013-1-RSA-POL-001.
† E-mail: brent@saao.ac.za
ies represent a typically fainter population than the known sample of symbiotic stars (see e.g. figure 16 of MMU13).

No systematic survey to increase the number of southern Galactic symbiotic stars has yet been made using the SHS catalogue photometry. The SHS contains catalogue photometry in three filters, an Hα interference filter, a Short-Red (SR) filter (5000–6900 Å) that serves as an off-band for Hα, and an I-band filter (see Parker et al. 2005 for details). Pierce (2005) investigated the position of Belczyński et al. (2000) symbiotic stars in the SHS colour–colour plane (SR − I and Hα − SR), but did not conduct a search for new symbiotic stars. Miszalski et al. (2008) demonstrated that is part of the MASH-II survey.

In this paper we introduce an ongoing, systematic survey for new southern Galactic symbiotic stars and present the first discoveries made from spectroscopic follow-up with the Southern African Large Telescope (SALT). Section 2 outlines the candidate selection from SHS and 2MASS catalogue photometry and Sect. 3 describes the SALT spectroscopy. Section 4 introduces 12 new symbiotic stars and we conclude in Sect. 5. Appendix A presents several other Hα emission line objects.

2 CANDIDATE SELECTION

During the first phase of this project relatively loose criteria were chosen to allow for several types of Hα emission line stars to be observed. These early non-symbiotic contaminants will inform stricter selection criteria and will help determine the completeness of the survey during later phases. We therefore postpone a full discussion of the symbiotic star candidate selection criteria until the spectroscopic follow-up of candidates is more advanced. Nevertheless, we can outline here the candidate selection process during the first exploratory phase. Catalogue photometry was retrieved from the SHS website for Hα ≤ 15 mag and SHS field centres with RA ≥ 14 h. A variety of colour–colour and magnitude cuts were applied to the catalogue photometry using the STILTS package of command-line tools for processing table data (Taylor 2006, 2011). The cuts were designed to incorporate the colours and magnitudes of MMU13 symbiotic stars that we have assumed to be representative of the relatively faint and reddenened symbiotic star population that awaits discovery elsewhere in the SHS. The resultant candidates were then cross-matched against 2MASS using the Centre de Données astronomiques de Strasbourg (CDS) cross-match service. Further constraints were applied to the 2MASS photometry and duplicates were removed using the 2MASS ID as the unique name for each object. Candidates were then visually inspected using colour-composite images as described in Miszalski et al. (2008), with promising candidates selected based on their similar appearance to MMU13 symbiotic stars.

3 SALT RSS SPECTROSCOPY

We observed several candidates spectroscopically with the Robert Stobie Spectrograph (RSS; Burgh et al. 2003; Kobulnicky et al. 2003) on the queue-scheduled Southern African Large Telescope (SALT; Buckley, Swart & Meiring 2006; O’Donoghue et al. 2006) under programme 2013-1-RSA_POL-001 (PI: Miszalski). A single RSS configuration was adopted with the PG900 grating and a 1.5 arcsec wide slit at a position angle of 0° to give wavelength coverage from ∼4340–7420 Å at a resolution of 6.2 Å (full-width at half maximum, FWHM) and a reciprocal dispersion of 0.97 Å pixel⁻¹. Two CCD chip gaps are present in RSS spectra, approximately covering 5355–5415 Å and 6400–6460 Å, with the exact coverage and wavelengths depending on spectrograph flexure at the time of observation. Table 1 records the 2MASS point source catalogue designation, date and exposure time of the observations presented in this paper. The exposure time given corresponds to the long exposure that is taken after a short 30 or 60 s exposure to measure Hα unsaturated. A xenon arc lamp reference spectrum is taken after the long exposure, while no flat-field frames are taken. Other candidates were also observed, but these will be included in future papers to help define the candidate selection criteria. Relatively long exposure times were selected for most candidates to correspond with the relaxed observing conditions of the programme, namely any lunar phase, thin cloud and seeing up to 3.0–3.5 arcsec. The observations were therefore taken under a wide range of conditions and sometimes in considerably better seeing. Three objects were observed during October when SALT visibility windows were rapidly shrinking, necessitating very short exposure times. This meant two objects were observed well before astronomical twilight, namely 2MASS J17422035–2401162 and 2MASS J18272892–1555547, observed 25 and 33 minutes before twilight, respectively.

A higher priority weighting was given to objects with redder 2MASS colours in an effort to address the difficulties in discovering D-type symbiotic stars (Corradi et al. 2008, 2010a; MMU13). In D-type (dusty) symbiotic stars the red giant is a Mira variable (Whiteoak 1987) that is often completely obscured by dust at optical wavelengths. To confirm a symbiotic star the red giant must be observed and in D-types the high extinction makes this task consistently difficult when only optical spectroscopy is available.

Basic reductions were applied using the PYSLT package (Crawford et al. 2010) and cosmic ray events were cleaned using the LACOSMIC package (van Dokkum 2001). Wavelength calibration was performed using the standard IRAF tasks IDENTIFY, REIDENTIFY, FITCOORDS and TRANSFORM, and one-dimensional spectra were extracted using the IRAF task APALL. A relative flux calibration was applied to the extracted spectra using a spectrum of the spectrophotometric standard star LTT 6248 (Hamuy et al. 1994). As the moving pupil design of SALT does not allow for an accurate absolute flux scale, we have normalised the spectra by the average continuum value measured in the region 6200–
New Galactic symbiotic stars with SALT

4 NEW SYMBIOTIC STARS

We have identified 12 bona-fide and three possible symbiotic stars following the classification criteria for symbiotic stars in Belczyński et al. (2000) and MMU13. Their basic properties are presented in Table 1 and their spectra in Figures 1 and 2. The bona-fide sample consists of 11 S-types and 1 D-type, all of which have multiple necessary features to be classified as symbiotic stars. Strong and broad He emission and He I emission lines are found in all objects. The cool components are present in all S-types and their spectral types in Table 1 were mostly determined as in MMU13, using the indices of Kenyon & Fernandez-Castro (1987), except for 2MASS J16003761−4835228 in which case we used the Barnbaum, Stone & Keenan (1996) atlas of carbon stars. The Barnbaum et al. (1996) atlas is based on the revised MK classification of red carbon stars (Keenan 1993). Spectral types of red giants with under-exposed stellar continua are less certain and are marked with an additional ‘:’. The red giant in the D-type 2MASS J16422739−4133105 was not detected and is likely too obscured by dust to be visible at optical wavelengths. Hot components are readily detected via key emission lines including He II λ4686 (all objects), the Raman-scattered O VI emission lines (Schmid 1989) that are a telltale diagnostic feature of symbiotic stars (8 out of 11 S-types and 1 D-type), and [Fe VII] λλ5721, 6089 (7 out of 11 S-types and 1 D-type). The weakest He II λ4686 emission is found in 2MASS J17347287−2719266, while it is exceptionally strong in 2MASS J18300636−1940315. The highest ionization emission line detected is coronal [Fe X] λ6375 in the carbon-rich 2MASS J16003761−4835228, strongly suggesting it may be a supersoft x-ray source (see Sect. 4.1).

Three possible symbiotic stars were identified that almost meet the classification criteria. In the case of the possible D-types 2MASS J16503229−4742288 and 2MASS J17145509−3933117, a PN-like spectrum is observed to coincide with red 2MASS colours typical of D-type symbiotic stars (J − H and H − Ks are both ≥2.0), however a red giant is not seen in the optical spectra and further NIR observations are required to determine if one is present. If a significant amount of the reddening towards 2MASS J16503229−4742288, 2MASS J16422739−4133105 and 2MASS J17145509−3933117 is circumstellar, then their Mira components would not be visible in the optical spectrum. In known D-type symbiotic stars, an average intrinsic colour for unobscured symbiotic Miras of (J − Ks) = 1.5 mag can be adopted from the period-colour relation (Gromadzki et al. 2009). Our new D-type systems have observed J − Ks colours of 2.67, 4.51 and 4.05 mag for 2MASS J16422739−4133105, 2MASS J16503229−4742288 and 2MASS J17145509−3933117, respectively, corresponding to AK ∼ 0.8, ∼2.0 and ∼1.8 mag (Cardelli et al. 1989). Assuming Case B conditions, we measure the reddening from the nebular Balmer decrements to be AV = 6.0, 8.0 and 7.1 mag, respectively, corresponding to AK = 0.69, 0.91 and 0.81 (Cardelli et al. 1989). The reddening calculated in this way is a upper limit and may be smaller due to optical depth effects. As these values are less than the expected AK values, a significant amount of the reddening should indeed be circumstellar, explaining the absence of the cool components in our spectra. Similar outcomes appear in many other D-type symbiotics (Mikołajewska et al. 1999; MMU13). Another alternative explanation for the two possible D-types might be a PN with a dusty Wolf-Rayet central star (e.g. Sect. 4.2), but these typically have temperatures of ∼30 kK and are unable to ionise the [Ar IV] and [Ar V] emission lines observed. These lines are more common in D-type symbiotic stars than in PNe and are evident in several objects in MMU13.

4.1 Notes on some individual objects

We searched for matches to all new and possible symbiotic stars in SIMBAD and VizieR. Most objects are either not catalogued or have minimal associated information. As would be expected, the only IRAS detections in our sample are found in the D-type 2MASS J16422739−4133105 (IRAS 16389−4737) and possible D-types 2MASS J16503229−4742288 (IRAS 16468−4737) and 2MASS J17145509−3933117 (IRAS 17114−3929). In the fol-

---

Table 1. Log of SALT RSS observations. Only the long exposure time is given (see text).

| Name (2MASS J) | Date (dd/mm/yy) | Exposure (s) |
|----------------|-----------------|--------------|
| 14031865−5809349 | 18/06/13 | 1500 |
| 14135896−6709206 | 25/05/13 | 1800 |
| 15431767−5857221 | 20/05/13 | 1200 |
| 15460752−6258042 | 11/05/13 | 1500 |
| 16003761−4835228 | 14/05/13 | 1200 |
| 16092019−5536100 | 29/04/13 | 1800 |
| 16141537−5146036 | 13/05/13 | 1800 |
| 16293215−5215338 | 12/06/13 | 1800 |
| 16422739−4133105 | 02/05/13 | 1200 |
| 16490162−3827431 | 13/07/13 | 1800 |
| 16503229−4742288 | 23/05/13 | 1680 |
| 17050868−4849122 | 18/09/13 | 900 |
| 17060193−3848359 | 29/05/13 | 1500 |
| 17145509−3933117 | 17/06/13 | 1500 |
| 17334728−2192606 | 10/09/13 | 600 |
| 17391715−3546593 | 12/07/13 | 1500 |
| 17400382−4019271 | 21/07/13 | 1209 |
| 17422035−2401162 | 16/10/13 | 297 |
| 17460199−3303085 | 21/09/13 | 1200 |
| 17463311−2419558 | 18/10/13 | 500 |
| 18114984−2015713 | 24/07/13 | 1500 |
| 18131474−1007218 | 22/07/13 | 1250 |
| 18143298−1825148 | 22/07/13 | 1200 |
| 18144673−2035178 | 25/07/13 | 1800 |
| 18272892−1555547 | 22/10/13 | 670 |
| 18285604−2432017 | 25/07/13 | 1500 |
| 18300636−1940315 | 21/09/13 | 1050 |
| 18332967−0333531 | 23/04/13 | 1800 |
| 18343000−1132321 | 20/06/13 | 1800 |
| 184818924+0140366 | 27/04/13 | 1500 |
| 18482874−1237434 | 13/07/13 | 1800 |
| 18500902−0515041 | 25/04/13 | 1500 |
| 19003482−0211579 | 29/04/13 | 1800 |

6300 Å. The spectra are presented in subsequent sections of the paper and have not been reddened. The relatively short exposures of 2MASS J17463311−2419558 and 2MASS J17422035−2401162 that we present later have been lightly smoothed with a boxcar filter.

---

Log of SALT RSS observations. Only the long exposure time is given (see text).
Figure 1. SALT RSS spectra of new S-type symbiotic stars.
Figure 2. SALT RSS spectra of new S-type symbiotic stars (continued).
Table 2. Basic properties of the new and possible symbiotic stars.

| Name (2MASS J)          | ℓ (°) | b (°) | IR type | Spectral type | J   | J – H | H – K_s | Hα | Hα – SR | SR – I |
|-------------------------|-------|-------|---------|---------------|-----|-------|---------|----|---------|--------|
| 14031865–5809349        | 312.3148 | 3.3967 | S       | M4            | 10.42 | 1.10  | 0.38    | 12.10 | -1.60   | 1.44   |
| 15431767–5857221        | 323.5413 | -3.1423 | S       | M2.5          | 11.22 | 1.09  | 0.41    | 12.43 | -1.40   | 0.34   |
| 16003761–4835228        | 332.0679 | 3.2823 | S       | C-N5 C2.4.5   | 10.80 | 1.33  | 0.58    | 13.22 | -1.75   | 1.89   |
| 16422739–4133105        | 342.2640 | 3.0318 | D       | -             | 10.33 | 1.37  | 1.30    | 10.71 | -3.30   | -1.21  |
| 17050868–4849122        | 339.1468 | -4.6492 | S       | M4            | 10.04 | 1.09  | 0.38    | 11.81 | -2.07   | 2.28   |
| 17334728–2719266        | 359.9791 | 3.0663 | S       | M2            | 9.32  | 1.41  | 0.65    | 11.23 | -1.79   | -0.58  |
| 17391715–3546590        | 353.4730 | -2.4679 | S       | M1.5          | 9.81  | 1.37  | 0.81    | 12.93 | -2.60   | 0.86   |
| 17422035–2401162        | 3.8062  | 3.1975 | S       | M2:           | 10.20 | 1.21  | 0.56    | 12.70 | -1.98   | 1.05   |
| 17463311–2419558        | 4.0423  | 2.2155 | S       | M4:           | 9.86  | 1.35  | 0.60    | 11.46 | -2.28   | -0.86  |
| 18131474–1007218        | 19.5540 | 3.7375 | S       | M0            | 10.94 | 1.30  | 0.46    | 13.75 | -1.51   | 1.16   |
| 18272892–1555547        | 16.0601 | -2.0558 | S       | M1            | 9.16  | 1.36  | 0.62    | 11.14 | -2.95   | 3.67   |
| 18300636–1940315        | 13.0226 | -4.3378 | S       | M3.5          | 11.07 | 1.11  | 0.41    | 12.56 | -2.21   | 1.23   |
| 16503229–4742888        | 338.5095 | -2.0533 | D?      | -             | 13.99 | 2.44  | 2.07    | 14.54 | -2.78   | -0.73  |
| 17145599–3933117        | 347.6561 | -0.5638 | D?      | -             | 11.92 | 2.30  | 1.75    | 13.21 | -2.10   | -0.14  |
| 17460199–3303085        | 356.5301 | -2.2173 | S?      | K5-M0         | 9.86  | 1.16  | 0.53    | 9.50  | -2.34   | 0.81   |

Figure 3. SALT RSS spectra of the new symbiotic stars 2MASS J18300636–1940315 (S-type) and 2MASS J16422739–4133105 (D-type).

Following we provide some information on some noteworthy individual objects.

4.1.1 2MASS J14031865–5809349

Skiff (2013) lists this object as emission line object Wray 15-1167, referenced in Stephenson & Sanduleak (1977b), but it does not appear in Stephenson & Sanduleak (1977a). A marginal detection of [Fe VII] emission lines may also be
present in the spectrum, however the strong He II $\lambda$4686 leaves no doubt that the hot component is present.

### 4.1.2 2MASS J16003761−4835228 - a carbon-rich supersoft X-ray source candidate

The new S-type 2MASS J16003761−4835228 is remarkable because of its C-N5 C$_2$4.5 carbon star in the Barnbaum et al. (1996) scheme, making it the latest in a list of rare carbon-rich Galactic symbiotic stars after IPHAS J205836.43+503307.2 (Corradi et al. 2011) and H1-45 (MMU13). A total of five are now known, including SS 38 and AS 210 (Gromadzki et al. 2009). These discoveries seem to appear with greater frequency in the relatively fainter H$\alpha$ selected candidates from which they were found compared to those in Belczyskii et al. (2000). It may be explained by the more representative nature of the reddened or more distant sample.

The most exceptional property of 2MASS J16003761−4835228, however, is the presence of the weak [Fe X] $\lambda$6375 Å emission line, that combined with the fairly strong Raman scattered O VI emission band, places 2MASS J16003761−4835228 amongst those symbiotic stars showing the highest degree of ionization. The coronal [Fe X] A6375 line appears in classical novae (e.g. McLaughlin 1953), symbiotic novae (e.g. PU Vul, Andrillat & Houziaux 1994), and symbiotic recurrent novae (Williams et al. 1991) during their nebular phase, however it is exceedingly rare in classical symbiotic stars. In principle, the presence of [Fe X] is well-documented only in SMC 3, which is also the brightest supersoft X-ray source (SSXS) associated with a symbiotic binary (e.g. Jordan et al. 1996; Orio et al. 2007). Kato et al. (2013) argued that in SMC 3 both the soft X-rays and the coronal [Fe X] line originate from a hot and dense ($n_e \sim 10^9 - 10^{10} \text{ cm}^{-3}$) nebula around the nuclear-burning massive white dwarf which scatters X-rays from the white dwarf.

There are only a handful SSXS (with all photons detected below 1.0 keV) among known symbiotic stars (Miüset et al. 1997; Luna et al. 2013), however [Fe X] has not been reported for any of them except SMC 3 (although we cannot exclude that a weak line could be overlooked). All of them have been found in metal-poor populations, either at high Galactic latitudes (e.g. AG Dra and StHa32), or in the
SMC (SMC 3 and Lin 358). The most likely origin of the soft X-rays in these systems is quasi-steady H-shell burning on the white dwarf (e.g. Mikołajewska et al. 1995; Orio et al. 2007). On the other hand, most of the known symbiotic stars contain such thermonuclear shell-burning white dwarfs and the scarcity of SSXS among them indicates that there must be efficient ways to quench X-ray emission. One obvious way to suppress this emission is interstellar extinction which affects practically all known Galactic systems. However, even unreddened symbiotic white dwarfs are embedded in the wind of their cool giant companion and they may also emit their own wind. Nielsen et al. (2013) showed that soft X-ray emission from steadily accreting and nuclear-burning white dwarfs can be very efficiently attenuated even for modest circumbinary mass loss rates. The final effect will also depend strongly on the metallicity as it determines the neutral and ionized gas opacity (Nielsen et al. 2013).

The presence of a cool, carbon-rich and possibly metal-poor giant in 2MASS J16003761−4835228, together with the very high degree of ionization indicated by [Fe X], makes it a very appealing candidate for a SSXS. However, detecting soft X-rays in 2MASS J16003761−4835228 may be severely hindered or blocked entirely by neutral gas and dust (to a lesser extent) in the Galactic plane at the b = 3.03° latitude of 2MASS J16003761−4835228. The high reddening towards 2MASS J16003761−4835228 is evident in the high E(B − V) ~ 1.6 mag from the Galactic extinction map of Schlafly & Finkbeiner (2011).

### 4.1.3 2MASS J17334798−2119266

The S-type is included in Terzan & Gosset (1991) as variable star V 2513 that reached R = 8.0 mag, however the authors note this upper limit to be uncertain. This is an increase of up to 5.0 mag over the SHS SR magnitude (Tab. 2), which could be explained either by a Z-And outburst (typically 1–3 mag, Mikołajewska 2003) or a symbiotic nova outburst (several magnitudes).

### 4.1.4 2MASS J17391715−3546593

The S-type was discovered first as PN K 5-8 (Kohoutek 1994), with the remark of ‘stellar (low excitation)’, Escudero & Costa (2001) later remarked that the spectrum of K 5-8 does not seem to be that of a PN and it was therefore not included in their analysis.

### 4.1.5 2MASS J17422035−2401162

The S-type is classified as a semi-regular variable in the OGLE-III Galactic bulge long period variable (LPV) catalogue with a primary period of 1056 d (Soszyński et al. 2013). Figure 4 reproduces the I-band light curve where we have used an ephemeris at light curve minimum of 2676.4 d (JD−2450000 + 1056E). The light curve is consistent with those of other S-type symbiotic stars where the orbital period is modulated by pulsations from the red giant (e.g. MMU13; Gromadzki, Mikołajewska & Soszyński 2013). The average I-band magnitude is 13.45 mag, while we determine a less certain average V-band magnitude of 17.40±0.25 mag from only three OGLE-III V-band measurements.

### 4.1.6 2MASS J17460199−3303085

The possible S-type was catalogued as KW 055 in the Hα emission star catalogue of Kohoutek & Wehmeyer (2003). The spectrum resembles an S-type symbiotic, but we lack the crucial features needed to confirm the presence of a hot component. Features such as He II λ4686 may be suppressed below the noise level of the spectrum due to the high reddening towards the object. Additional spectra may reveal these features at a different orbital phase, as observed in 002.86–01.88 with O VI emission only appearing in one out of two spectra (MMU13).

### 5 CONCLUSIONS

We have presented the first results from an ongoing survey for new symbiotic stars in the southern Galactic plane. Candidates were selected from SHS and 2MASS photometry catalogues with relatively loose selection criteria based on the observed properties of MMU13 symbiotic stars. Several new symbiotic stars were confirmed spectroscopically with SALT, in addition to many other Hα emission line objects that will refine our selection criteria as the survey progresses. We expect to discover many more symbiotic stars in the near future, as we observe candidates selected from all SHS fields, most of which will be found towards the Galactic bulge.

The main conclusions are as follows:

- Twelve new symbiotic stars were identified across a range of Galactic longitudes. The sample consists of 11 S-types and 1 D-type, of which 8 objects show the telltale Raman scattered O VI emission band (Schmid 1989).
- Most remarkable in the sample is 2MASS J16003761−4835228, a carbon-rich symbiotic star that exhibits a weak coronal [Fe X] λ6375 emission line. This suggests 2MASS J16003761−4835228 may be a supersoft X-ray source, produced by quasi-steady H-shell burning onto the WD (e.g. Mikołajewska et al. 1995; Orio et al. 2007). Such systems are prime candidates to identify massive accreting WDs that form promising type Ia supernovae (e.g. Kato et al. 2013). If the supersoft X-rays are not entirely attenuated (e.g. Nielsen et al. 2013), their detection may prove very challenging due to the high interstellar absorption towards 2MASS J16003761−4835228. The C-N5 C24.5 carbon star component makes it the fifth known carbon-rich Galactic symbiotic star known, following other recent carbon-rich discoveries by Corradi et al. (2011) and MMU13. There may be a propensity for fainter symbiotic star populations to exhibit a greater frequency of carbon-rich symbiotic stars. We speculate that this may be explained by more reddened or more distant symbiotic stars included in our sample and further survey work is required to test this hypothesis.
- The discovery of D-type symbiotic stars proved unexpectedly more difficult than in MMU13. Despite efforts to bias the spectroscopic follow-up towards objects with dusty NIR colours, only one D-type and two possible D-types were identified. The most numerous contaminating objects included six B[e] stars and reddened PNe. Dusty [WC] Wolf-Rayet central stars of PNe also occupy this parameter space, as evidenced by the discovery of a [WC9] nucleus in K3-18.
previously suspected of being a symbiotic star (Giammanco et al. 2011). A dusty [WC] central star can be excluded if [Ar IV] and [Ar V] emission lines are present, since many cool [WC] central stars do not ionise [O III] which has a lower ionisation potential.

6 ACKNOWLEDGEMENTS
All of the observations reported in this paper were obtained with the Southern African Large Telescope (SALT) and we would like to thank the Polish SALT time allocation committee for their generous award of SALT time. JM is supported by the Polish National Science Center grant number DEC-2011/01/B/ST9/06145. This research made use of the cross-match service, the SIMBAD database and the VizieR catalogue access tool, all provided by CDS, Strasbourg, France. This research has made use of SAOImage DS9, developed by Smithsonian Astrophysical Observatory, and we would also like to thank Mark Taylor for developing and maintaining the stilts and topcat software packages used heavily in this work. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

REFERENCES
Acker, A., & Neiner, C. 2003, A&A, 403, 659
Allen, D. A. 1984, PASA, 5, 369
Andrillat, Y., & Houziaux, L. 1994, MNRAS, 271, 875
Barnbaum C., Stone R. P. S., Keenan P. C., 1996, ApJS, 105, 419
Belczyński, K., Mikołajewska, J., Munari, U., Ivison, R. J., & Friedjung, M. 2000, A&AS, 146, 407
Benjamin, R. A., Churchwell, E., Babler, B. L., et al. 2003, PASP, 115, 953
Bessell, M. S., & Brett, J. M. 1988, PASP, 100, 1134
Buckley, D. A. H., Swart, G. P., & Meiring, J. G. 2006, SPIE, 6267, 32
Burgh, E. B., Nordsieck, K. H., Kobulnicky, H. A., et al. 2003, SPIE, 4841, 1463
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Carpenter, J. M. 2001, AJ, 121, 2851
Churchwell, E., Babler, B. L., Meade, M. R., et al. 2009, PASP, 121, 213
Cohen, M., & Kuhi, L. V. 1979, ApJS, 41, 743
Cohen, M., Parker, Q. A., Green, A. J., et al. 2011, MNRAS, 413, 514
Condon, J. J., Cotton, W. D., Greisen, E. W., et al. 1998, AJ, 115, 1693
Corradi, R. L. M., Rodríguez-Flores, E. R., Mampaso, A., et al. 2008, A&A, 480, 409
Corradi, R. L. M., & Giammanco, C. 2010, A&A, 520, A99
Corradi, R. L. M., Valentini, M., Munari, U., et al. 2010a, A&A, 509, A41
Corradi, R. L. M., Munari, U., Greimel, R., et al. 2010b, A&A, 509, L9
Corradi, R. L. M., Sabin, L., Munari, U., et al. 2011, A&A, 529, A56
Corradi, R. L. M. 2012, Baltic Astronomy, 21, 32
Costa, V. M., Gameiro, J. F., & Lago, M. T. V. T. 1999, MNRAS, 307, L23
Crawford, S. M., Still, M., Schellart, P., et al. 2010, Proc. SPIE, 7737E, 54
Crowther, P. A., De Marco, O., & Barlow, M. J. 1998, MNRAS, 296, 367
Dilday, B., Howell, D. A., Cenko, S. B., et al. 2012, Science, 337, 942
Di Stefano, R. 2010, ApJ, 719, 474
Depew, K., Parker, Q. A., Miszalski, B., et al. 2011, MNRAS, 414, 2812
Drew, J. E., Greimel, R., Irwin, M. J., et al. 2005, MNRAS, 362, 753
Escudero A. V., Costa R. D. D., 2001, A&A, 380, 300
Giammanco, C., Sale, S. E., Corradi, R. L. M., et al. 2011, A&A, 525, A58
Górny, S. K., Stasińska, G., Escudero, A. V., & Costa, R. D. D. 2004, A&A, 427, 231
Górny, S. K., Chiappini, C., Stasińska, G., & Cuisinier, F. 2009, A&A, 500, 1089
Graus, A. S., Lamb, J. B., & Oey, M. S. 2012, ApJ, 759, 10
Gromadzki, M., Mikołajewska, J., Whitelock, P., & Marang, F. 2009, Acta Astron., 59, 169
Gromadzki, M., Mikołajewska, J., & Soszyński, I. 2013,

Figure 5. The OGLE-III I-band light curve of the new S-type symbiotic star 2MASS J17422035−2401162 (Soszyński et al. 2013).
D-type symbiotics, which have proven difficult to find (Corradi et al. 2008, 2010a; MMU13), but this was complicated by several object types sharing Hα emission and hot dust.

A search of SIMBAD and Vizier of the six B[e] stars showed that some were misclassified as PNe. Stenholm & Acker (1987) commented that only Hα was visible in their spectra for 2MASS J18285064−2432017 (H 2-47) and 2MASS J18500902−0515041 (THA 14-39, The 1962). The B[e] star 2MASS J16092019−5356100 was originally catalogued as a possible new PN in the IRAS catalogue (IRAS 16053-5528; PM 1-106, Preite-Martinez et al. 1988). Later, it appeared in Suárez et al. (2006) catalogue where it is classified as a low excitation class PN. Mottram et al. (2011) remarked that 2MASS J16141537−5146036 (IRAS 16103-5138) is more likely a young or old star, rather than an HII region or PN.

Finally, 2MASS J14135896−6709206, listed as the Hα emission line star SS 255 (Stephenson & Sanduleak 1977a), strongly resembles the B[e] stars, however the 2MASS colours do not show evidence for hot dust and the [Ni II] emission lines are absent. Similar objects were studied by Pereira et al. (2003, 2008) and their classification is particularly difficult. We suggest a Be star (Porter & Rivinius 2003) classification for 2MASS J14135896−6709206, based on the similar appearance to SSS 24 (Pereira et al. 2003). Given the strong similarity between the spectra of 2MASS J14135896−6709206 and 2MASS J18332967−033531, we suggest that 2MASS J18332967−033531 is a reddened Be star. Other possible classifications for these two objects include a B[e] star with no hot dust (e.g. Graus, Lamb & Oey 2012) or a pre-PN (Pereira et al. 2008), but it is beyond the scope of this work to speculate further on this point.

APPENDIX A: OTHER EMISSION LINE OBJECTS

Included in Tab. A1 are different Hα emission line stars or nebulae of various kinds. As previous studies have found (e.g. Corradi et al. 2008, 2010a; MMU13), their NIR colours often overlap D-type symbiotics, and to a lesser extent, S-type symbiotics. Table A1 collates their basic properties and we display the Galactic distribution of the entire sample in Fig. A2. Classifications were made based on features in the SALT RSS spectra and their positions in the 2MASS colour-colour diagram (Fig. A2) that provides additional diagnostic power (e.g. Schmeja & Kimeswenger 2001; Mikolajewska 2004; Corradi et al. 2008).

A1 B[e] and possible Be stars

The most numerous in Tab. A1 are six B[e] stars whose spectra are displayed in Figures A3 and A4. Their spectra are similar to two B[e] stars found by Corradi et al. (2010a) and one by MMU13. They are classified according to the criteria given by Lamers et al. (1998), namely the presence of strong Balmer emission lines, low excitation permitted emission lines (e.g. Fe II), forbidden emission lines of [Fe II] and [O I], and a strong NIR excess due to hot dust. The last property is evident in Fig. A2 where the B[e] stars cluster around J−H ∼ 1.6 and H−Ks ∼ 1.7, except for 2MASS J18285064−2432017 which has redder colours. All six show fluorescent [Ni II] emission lines λλ6667, 7378 and 7412 Å (Lucy 1995; Corradi et al. 2010a). The relatively high number of B[e] stars found can be explained by the higher priority we gave to dusty D-type candidates in the SALT queue. This was done in order to improve the chances of finding 4 The bright C II λ7235 emission line is a scaled replacement from the short exposure where the line core was unsaturated.
Table A1. Basic properties of other emission line objects.

| Name (2MASS J) | ℓ (°) | b (°) | Type | J | J − H | H − Ks | Hα | Hα − SR | SR − I |
|----------------|-------|------|------|---|-------|--------|-----|---------|-------|
| 16092019−5536100 | 328.3956 | −2.8404 | Be? | 14.26 | 1.52 | 1.68 | 12.50 | −2.53 | −0.63 |
| 16490162−3827431 | 345.4383 | −4.0800 | PN | 14.02 | 1.55 | 1.29 | 14.31 | −2.26 | −0.54 |
| 17060193−3848359 | 347.2329 | 1.2633 | PN | 14.06 | 0.55 | 1.90 | 12.30 | −3.19 | −1.57 |
| 18144673−2035178 | 10.5302 | −1.5843 | PN | 14.24 | 1.30 | 1.47 | 14.02 | −2.50 | 1.11 |
| 18482874−1237434 | 21.3298 | −5.0762 | HDC PN | 14.28 | 0.97 | 1.49 | 12.11 | −2.23 | −1.52 |
| 16293215−5215338 | 322.8628 | −2.5470 | PN? | 14.50 | 0.85 | 0.89 | 13.86 | −2.27 | 0.09 |
| 16490162−3827431 | 345.4383 | −4.0800 | PN | 14.02 | 1.55 | 1.29 | 14.31 | −2.26 | −0.54 |
| 17060193−3848359 | 347.2329 | 1.2633 | PN | 14.06 | 0.55 | 1.90 | 12.30 | −3.19 | −1.57 |
| 18144673−2035178 | 10.5302 | −1.5843 | PN | 14.24 | 1.30 | 1.47 | 14.02 | −2.50 | 1.11 |
| 18482874−1237434 | 21.3298 | −5.0762 | HDC PN | 14.28 | 0.97 | 1.49 | 12.11 | −2.23 | −1.52 |

Figure A1. Galactic distribution of our sample. Small dots show symbiotic stars from Belczyński et al. (2000), MMU13 and IPHAS (Corradi 2012 and ref. therein). Survey footprints of SHS and IPHAS are indicated by the grey shaded region and solid lines, respectively.

lines from carbon species, typical of low mass WR central stars of PNe (Crowther et al. 1998; Górnay et al. 2004, 2009; Acker & Neiner 2003; DePew et al. 2011; Miszalski et al. 2011c; MMU13). To classify the central star we again use the scheme of Crowther et al. (1998). In the C III λ5696 line we measure a FWHM=10.2 ± 0.1 Å and an equivalent width $W_{\lambda}=−75 ± 5$ Å. The C IV λ5801,5812 lines are resolved with equivalent widths of approximately −7 and −13 Å, respectively. If we take the log $W_{\lambda}$ ratio of both C IV lines to C III λ5696 we get −0.55, which falls inside the −0.7 to −0.3 range for the WC9 subtype (Crowther et al. 1998). As this is the primary classification criterion, we adopt a [WC9] classification for the central star, where the square brackets distinguish WR central stars of PNe apart from massive WR stars.

A3 Planetary Nebulae

Reddened PNe may also be found near D-type symbiotic stars in Fig. A2. Figure A3 displays SALT RSS spectra of objects suspected to be reddened PNe in our sample. It can be difficult, however, to distinguish them from reddened compact or ultra-compact HII regions (e.g. Cohen et al. 2011). A useful diagnostic in this respect is the MIR/radio flux ratio (Cohen et al. 2011). Low values of the ratio are common amongst bona-fide PNe, whereas high values are more common amongst HII regions. Taking the AKARI 9 μm (Ishihara et al. 2010) and NVSS 1.4 GHz (Condon et al. 1998) fluxes for 2MASS J17060193−3848359, we derive a ratio of 6.32. This low ratio, combined with the relatively strong ([N II]λ6548+[N II]λ6583)/Hα ratio of 1.64, suggests a firm PN classification, contrary to the candidate YSO classification given by Mottram et al. (2007). The situation is less clear for 2MASS J18144673−2035178 which has a rela-
Figure A3. SALT RSS spectra of B[e] stars.
A4 Young stellar objects

Some emission line stars can prove challenging to classify in symbiotic star surveys. Young stellar objects, in particular those few examples showing He II λ4686 emission (e.g. Costa et al. 1999), can appear very similar to symbiotic star spectra. Figure A7 shows three examples of young stellar objects identified, two T Tauri stars (2MASS J15460752−6258042 and 2MASS J18481892+0143066) and one Herbig Ae/Be star (2MASS J18114984−2017513). Both of the T Tauri stars have clearly identifiable CaH λλ 6382, 6389 Å absorption bands that are found in T Tauri stars and never in red giants (e.g. Cohen & Kuhi 1979). This is an additional useful diagnostic to the NIR colours that also indicate a reddened luminosity class V-IV star, rather than a giant star (see Fig. A2). While the emission line spectrum of 2MASS J15460752−6258042 does show weak HeII 4686 emission, no other high excitation lines are present. The
Figure A5. SALT RSS spectrum of the massive WC9 star 2MASS J18143298−1825148 and the PN K3-18 (2MASS J19003482−0211579) revealing its [WC9] central star.

presence of Na I D lines in emission is common in T Tauri stars, but relatively rare in symbiotic stars (an exception is RX Pup, Mikolajewska et al. 1999). We have also identified 2MASS J18114984−2017513 as a Herbig Ae/Be star using the online atlas of R.O. Gray. This object demonstrates more reddened NIR colours, consistent with it being embedded in more dust. All these factors, combined with those discussed by Corradi et al. (2010a), serve as useful diagnostics to distinguish some young stellar objects from symbiotic stars.

5 http://ned.ipac.caltech.edu/level5/Gray/Gray16.html
Figure A6. SALT RSS spectra of PNe or PN-like objects.
Figure A7. SALT RSS spectra of young stellar objects.