Discovery of the first symbiotic star in NGC 6822

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ABSTRACT

We report the discovery of the first symbiotic star (V = 21.6, Ks = 15.8 mag) in the Local Group dwarf irregular galaxy NGC 6822. This star was identified during a spectral survey of Hα emission-line objects using the Southern African Large Telescope (SALT) during its performance-verification phase. The observed strong emission lines of H i and He ii suggest a high electron density and T∗ < 130 000 K for the hot companion. The infrared colours allow us to classify this object as an S-type symbiotic star, comprising a red giant losing mass to a compact companion. The red giant is an AGB carbon star, and a semi-regular variable, pulsating in the first overtone with a period of 142 days. Its bolometric magnitude is Mbol = −4.4 mag.

We review what is known about the luminosities of extragalactic symbiotic stars, showing that most, possibly all, contain AGB stars. We suggest that a much larger fraction of Galactic symbiotic stars may contain AGB stars than was previously realised.

Key words: stars: mass-loss — binaries: symbiotic — galaxies: individual: NGC 6822

1 INTRODUCTION

The galaxies of the Local Group (LG) and its immediate surroundings are of particular interest. Their proximity permits us to study many aspects of galaxy evolution in great detail, and this detailed information is in turn used to constrain studies of high-redshift galaxy formation. In particular, individual H ii regions, supergiants, planetary nebulae and emission-line stars such as symbiotic stars in the LG are available for high S/N spectrophotometry with present-day large telescopes; this information can be used to derive accurate chemical abundances. The goal is to use these abundances, together with colour-magnitude studies of stellar populations in these galaxies, to unveil the detailed chemical evolution and star formation history of the LG galaxies and to answer questions such as whether dwarf spheroidals and ellipticals are the end result of gas-rich dwarf irregulars (e.g., Grebel et al. [2003]). At the same time we should be able to obtain a more detailed understanding of stellar evolution in different environments.

We have an on-going project using several different telescopes to determine accurate chemical abundances of PNe and H ii regions in a sample of the nearest dwarf galaxies (Kniazev et al. [2005a,b, 2007, 2008a]) that we have expanded to study emission-line stars. Here we report the spectroscopic discovery of the first symbiotic star in the well studied LG dwarf galaxy, NGC 6822, which is both gas-rich and exhibits continuing star formation (see e.g., Lee et al. [2008], and references therein). We will call this star NGC6822 SySt–1 following the naming pattern that was suggested by Gonçalves et al. [2008] for the first symbiotic star found in the LG galaxy IC 10.

Symbiotic stars are interacting binaries, in which an evolved giant transfers material to a much hotter, compact companion, usually a white dwarf, more rarely a neutron star or a main-sequence star. Mass-transfer is often via an
der of 0.1 or 0.2 mag will not affect any of our conclusions on the LMC and NGC 6822. However, uncertainties of the ordering correction uncertainties, and any corrections that might be necessary for the difference in metallicities between dening the uncertainties, and any corrections that might be necessary for the difference in metallicities between the LMC and NGC 6822. The dashed line in the top panel outlines the area illustrated in the lower panel. The Symbiotic star NGC 6822 SySt–1 was identified as a strong emitter in a continuum subtracted Hα image from the SINGS 5th data release, retrieved from the NED database. The V (also from SINGS) and Hα finding charts are presented in Fig. 1. The field of view covers 80×80 square arcsec and shows stars as well as compact and extended Hα emission around the target.

Spectral observations of selected Hα emission sources in NGC 6822 were taken at the prime focus of the newly available 10-m class Southern African Large Telescope (SALT; Buckley, Swart & Meiring 2003; O’Donoghue et al. 2006) during its performance-verification stage while commissioning the multi-object spectroscopic mode of the Robert Stobie Spectrograph (RSS; Burgh et al. 2003; Kobulnicky et al. 2004). Data for the field with NGC 6822 SySt–1 were obtained on 2006 October 20. Two exposures, of 1150 s and 960 s length respectively, fitting within a single SALT visibility track, were taken in seeing conditions of approximately 1 arcsec. The field of view is 0′′129 and the effective field of view 8′×8′ in diameter. We utilized a binning factor of 2, to give a final spatial sampling of 0′′258 pixel−1. The Volume Phase Holographic (VPH) grating GR900 was used to cover the spectral range 4000–7000 Å with a final reciprocal dispersion of ∼0.95 Å pixel−1 and a spectral resolution FWHM of 5–6 Å. Spectra of ThAr comparison arcs were obtained to calibrate the wavelength scale. The spectrophotometric standard stars G 93-48 and Hiltner 600 were observed for relative flux calibration. Data reduction was carried out in the standard manner described in Kniazev et al. (2008b). Since SALT has a variable pupil size, an absolute flux calibration is not possible using spectrophotometric standard stars. To calibrate absolute fluxes we used objects visible in our target field and the corresponding PN fluxes from Leisy et al. (2003) and Hα fluxes taken from images of the 'Survey of Local Group Galaxies Currently Forming Stars' (Massey et al. 2004, 2007). The resulting reduced, extracted and flux calibrated spectrum of NGC 6822 SySt–1 is shown in Fig. 2. All emission lines in the SALT spectrum were measured applying procedures described in detail in Kniazev et al. (2004). All the detected emission lines, their equivalent widths and relative strengths compared to the measured flux of the Hβ emission line, are presented in Table 1.

### Table 1. Line intensities of NGC 6822 SySt–1

| λ0(Å) | F(λ)/F(Hβ) | EW(Å) |
|-------|-------------|-------|
| 4101  | 0.25±0.07   | 45±11 |
| 4340  | 0.40±0.05   | 42±6  |
| 4686  | 0.36±0.05   | 60±8  |
| 4861  | 1.00±0.09   | 210±18|
| 5876  | 0.13±0.04   | 11±4  |
| 6563  | 7.52±0.55   | 753±50|
| 6678  | 0.05±0.04   | 43±3  |
| 6830  | 0.23±0.06   | 12±4  |

*F(Hβ)*a in units of 10−16 ergs s⁻¹cm⁻².

2 OBSERVATIONS AND DATA REDUCTION

2.1 Spectroscopy

NGC 6822 SySt–1 was identified as a strong emitter in a continuum subtracted Hα image from the SINGS 5th data release (Kennicutt et al. 2002), retrieved from the NED database. The V (also from SINGS) and Hα finding charts are presented in Fig. 1. The field of view covers 80×80 square arcsec and shows stars as well as compact and extended Hα emission around the target.

accretion disk. High excitation emission lines are produced in the surrounding nebulosity, excited by the hot source. Symbiotics are of interest among other things as possible progenitors of type Ia supernovae (e.g., Munari & Renzini 1992).

We have adopted a distance modulus of (m − M)₀ = 23.31 mag for NGC 6822 which is based on classical Cepheids (Gieren et al. 2006). There is some remaining uncertainty in this value resulting from uncertainty in the adopted LMC distance (Gieren et al. assume (m − M)₀ = 18.5 mag), reddening correction uncertainties, and any corrections that might be necessary for the difference in metallicities between the LMC and NGC 6822. However, uncertainties of the order of 0.1 or 0.2 mag will not affect any of our conclusions regarding the nature of the stars discussed.

Figure 1. Continuum subtracted Hα (top) and V-band (bottom) images (Kennicutt et al. 2003) of the area of interest in NGC 6822. The dashed line in the top panel outlines the area illustrated in the lower panel. The Symbiotic star NGC 6822 SySt–1 (α2000.0 = 19:44:53.88, δ2000.0 = −14:51:46.8) is located at the center of each image. For the Hα image the contrast is adjusted to highlight both bright and faint Hα emission. Black objects on the image indicate bright sources.
Camera, which has a field of view of about 7 arcminutes and a plate scale of 0.45 arcsec/pixel. The data were extracted from the database. The putative symbiotic and its close neighbour have been identified in common in the field containing the symbiotic. No colour equations were used. This photometry is listed in Table 2.

### Table 2. Infrared photometry for NGC 6822 SySt–1.

| JD–2450000  |  $J$  |  $H$  |  $K_S$  |
|-------------|------|------|--------|
| (day)       | (mag)| (mag)| (mag) |
| 2353.49644  | 17.261±0.028 | 16.300±0.019 | 15.750±0.025 |
| 2436.50394  | 17.362±0.057 | 16.402±0.039 | 15.974±0.052 |
| 2441.50423  | 17.529±0.043 | 16.450±0.028 | 15.892±0.039 |
| 2442.50430  | 17.535±0.059 | 16.540±0.041 | 15.965±0.052 |
| 2507.34437  | 17.064±0.030 | 16.182±0.024 | 15.675±0.030 |
| 2809.42608  | 17.099±0.030 | 16.237±0.025 | 15.727±0.025 |
| 2529.29629  | 17.154±0.025 | 16.225±0.019 | 15.719±0.021 |
| 2882.39648  | 17.486±0.035 | 16.443±0.025 | 15.684±0.030 |
| 3173.48911  | 17.583±0.039 | 16.621±0.024 | 15.935±0.023 |
| 3243.39302  | 17.349±0.027 | 16.363±0.018 | 15.770±0.017 |
| 3259.30017  | 17.376±0.024 | 16.351±0.017 | 15.836±0.020 |
| 3260.30002  | 17.366±0.021 | 16.360±0.016 | 15.840±0.019 |
| 3293.32443  | 17.366±0.021 | 16.360±0.016 | 15.840±0.019 |
| 3531.58399  | 17.270±0.026 | 16.320±0.019 | 15.748±0.018 |
| 3533.44826  | 17.336±0.027 | 16.310±0.018 | 15.779±0.019 |
| 3612.35759  | 17.476±0.020 | 16.464±0.014 | 15.888±0.019 |

### 2.2 Infrared Imaging

Fifteen observations of NGC 6822 have been obtained over a period of almost 3.5 years as part of a survey of AGB stars in Local Group galaxies (Feast, Whitelock, Menzies, in preparation). This programme uses the Japanese-South African 1.4-m Infrared Survey Facility (IRSF) at Sutherland. Simultaneous $J$, $H$, and $K_S$ images are obtained with the SIRIUS camera, which has a field of view of about 7.5 × 7.5 square arcminutes and a plate scale of 0.45 arcsec/pixel. The data for the putative symbiotic and its close neighbour have been extracted from the database. The $JHK_S$ photometry was put on the 2MASS system with reference to about 70 stars in common in the field containing the symbiotic. No colour equations were used. This photometry is listed in Table 2.

### 3 RESULTS AND DISCUSSION

#### 3.1 Astrometry and photometry

The images from Kennicutt et al. (2003) are astrometrically calibrated, and we derived the position $\alpha_{2000.0} = 19:44:53.88$ and $\delta_{2000.0} = -14:51:46.8$ with an error smaller than 1 arcsec for NGC 6822 SySt–1.

From the calibrated SALT spectrum, using methods described in Kniazev et al. (2005a), we calculated the $V$-band magnitude of this star, $V = 21.65 \pm 0.25$ mag, which translates to $M_V \sim -2$ mag at our assumed distance modulus of 23.3 mag. With the 1.4-m telescope of Cerro Tololo Inter-American Observatory Massey et al. (2007) obtained photometric data for the resolved stellar population of several dwarf galaxies with active star formation. We identify NGC 6822 SySt–1 as their emission-line star J194453.88-145146.6, which has $V = 21.62$ mag ($(B - V) = 1.20$ mag and $(U - V) = -0.18$ mag). Given that this is a symbiotic star we would expect $V$ to vary; nevertheless our derived $V$ mag agrees well with the published value.

A Fourier analysis of the 15 $H$ and 14 $J$ and $K_S$ observations yields a clear period of 142 ± 3 days. The $K$ light-curve, folded on this period is shown in Fig. 3, and the Fourier mean magnitudes and peak-to-peak amplitudes are listed in the first two lines of Table 3. The period and amplitudes suggest a semi-regular (SR) variable and in order to make a comparison with published data we put our data onto the SAAO system, following Carpenter’s (2001) prescription as given in the updated web page. The transformed magnitudes are given in the third line of Table 3 while the fourth lists the values after correction for extinction (see section 3.2) according to the reddening law given by Glas (1999).

Note that the $JHK_S$ mags given in the first line of Table 3 differ significantly from the values published in the 2MASS catalogue, $J = 16.91$ mag, $H = 15.78$ mag and $K_S = 15.29$ mag (the 2MASS quality flags are UBU for this measurement). While this must be partially a consequence of variability it is more important that 2MASS does not resolve two stars, ~2 arcsec from each other at the location of the target, into separate sources. Our IRSF data show the nearby star ($\alpha_{2000.0} = 19:44:53.76$, $\delta_{2000.0} = -14:51:46.2$) to be of similar brightness and its magnitudes are listed in

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1 www.astro.caltech.edu/~jmc/2mass/v3/transformation/
Table 3. Mean Infrared photometry for stars of interest.

|       | J        | H        | $K_S/K$ | Description       |
|-------|----------|----------|---------|-------------------|
| NGC6822 SySt–1 |          |          |         |                   |
| 17.34 | 16.37    | 15.82    |         | Fourier mean      |
| 0.48  | 0.35     | 0.27     |         | amplitudes $\Delta J \Delta H \Delta K_S$ |
| 17.43 | 16.35    | 15.82    |         | SAAO system       |
| 17.21 | 16.22    | 15.74    |         | corrected for $E_B-V = 0.27$ |

LDBK398: neighbour to NGC6822 SySt–1

|       | J        | H        | $K_S/K$ | Description       |
|-------|----------|----------|---------|-------------------|
| 17.27 | 16.25    | 15.63    | ±0.02   | mag; mean         |
| 17.38 | 16.25    | 15.64    |         | SAAO system       |
| 17.17 | 16.13    | 15.56    |         | corrected for $E_B-V = 0.27$ |

Table 3. Interestingly, this nearby star was identified as a carbon star by Letarte et al. (2002) using filters sensitive to absorption in the TiO and CN bands; it is star number 398 in their list and identified as LDBK398 in our Table 3.

3.2 Spectrum

The spectrum of NGC6822 SySt–1 presented in Fig. 2 is that of a symbiotic star (see, e.g., the atlas in Munari & Zwitter (2002)). NGC6822 SySt–1 shows both strong emission lines of H i and He ii (e.g., Belczyński et al. 2000) and a broad emission feature at 6830 Å. Only symbiotic stars are known to show the latter feature, which is due to Raman scattering of the O iV IV 1032, 1038 resonance lines by neutral hydrogen (Schmid 1989). The absence of forbidden lines in the spectrum of NGC6822 SySt–1 must be due to collisional de-excitation, suggesting very high electron densities for the gas surrounding the binary system, up to about $N_e = 10^9$ cm$^{-3}$ (e.g., Mikolajewska, Acker & Stenholm 1997). The high densities (Gutiérrez-Moreno, Moreno & Cortés 1995; Proga et al. 1996) are consistent with the S-type symbiotic star classification assigned below. The hot component of the binary is most probably a white dwarf, but it is difficult to be certain of this without ultraviolet data.

Balmer line ratios in many symbiotic nebulae indicate self-absorption effects (because of high densities), making the application of standard methods to estimate reddening difficult. Fortunately, we observed the spectra of many H ii regions (which are visible on Fig. 1 as dark regions) around NGC6822 SySt–1. Using these data, we measured an average $E(B-V) = 0.27 \pm 0.04$ for the region. Reddening estimates for NGC6822 range between $E(B-V) = 0.20$ and 0.36 (e.g., de Vaucouleur 1978; Gallart, Aparicio & Vilchez 1999; Massey et al. 2007; Gieren et al. 2006) and it is obviously variable across the galaxy. To estimate the temperature of the ionizing source (hot component) we used the ratio $\text{He} i \ 6678/\text{H} i \ 6563$ (Hiirnka 1982), which gives us an upper limit of $T^* \sim 130,000$ K since significant optical depth effects could exist in the Balmer lines. This calculated $T^*$ is close to typical values, $T^* \sim 100,000$ K, for the hot components of symbiotic stars (Mziet et al. 1991).

The single-peaked Hα profile, with a shoulder on the short wavelength-side, is similar to those of well known symbiotic stars like AG Draconis (Tomova & Tomov 1996; Leedjärv et al. 2004). The observed profile of the Hα line is shown in Fig. 4, where we also plot the result of Gaussian two-component fitting. As can be seen from Fig. 4 the Hα line has extended low intensity wings which practically reach the continuum level at about 750 km s$^{-1}$ (1000 km s$^{-1}$ in the case of AG Draconis). Tomova & Tomov (1996) suggested that the observed asymmetry of the Hα profile of AG Draconis is a sign of self-absorption and the velocity in the wings should be close to that of the mass centre of the system. In the case of NGC6822 SySt–1 the heliocentric radial velocity of the wings is $-40 \pm 10$ km s$^{-1}$ and identical to that of the other Balmer lines within the range of error. Comparison of NGC6822 SySt–1’s position and its optical radial velocity with the 2D H i velocity distribution (Figs. 2 and 3 from Winkel, de Block & Walter (2003)) shows agreement to within the uncertainties of our velocity measurements.

3.3 Classification

We can compare the IR colours with those of Galactic symbiotics in Whitelock & Munari (1992) and Gallart, Aparicio & Vilchez (1999). The IR colours are similar to those of Galactic Miras and we therefore classify this system as an S-type symbiotic. On the other hand the colours are somewhat redder than most of the Galactic S-types, particularly in $(H-K)$. This can be understood if the red-giant in NGC6822 SySt–1 is a carbon star. Indeed, the colours are not very different from those of its neighbour which has been classified as a...
C star (see section 3.1). Most of the Galactic systems have O-rich giants.

Ita et al. (2004) discussed $JHK$ photometry for red variables in the LMC obtained with the IRSF. Assuming that the difference in distance moduli between the LMC and NGC 6822 is 4.81 mag, then $K_0 = 10.93$ mag at the LMC distance. This is in fact reasonably close to the value of $K_0$(LMC) = 10.78 mag, determined for the LMC from the mid-range of stars with $P=142$ days and $(J-K) > 1.4$ on sequence $C'$ (according to Ita et al. Table 3 and assuming $A_K = 0.02$ for the LMC). This would suggest that the red giant in NGC 6822 SySt–1 is pulsating in the first overtone. It is about 1.2 mag brighter than the tip of the giant branch (which is at $K = 12.1$ mag in the LMC) and therefore clearly on the asymptotic giant branch (AGB).

The colours of this star are very similar to those of C-rich variables in the Galaxy as discussed by White et al. (2006). Although it has a somewhat shorter period and is bluer than most of the stars from White et al. (2006), it does fall very close to the $(J-H)/\alpha$ relation illustrated in Fig. 8 of that paper. NGC 6822 is known to contain a large number of carbon stars (Letarte et al. 2002; Kang et al. 2006) and, indeed, given its low metallicity, we would expect most of its upper AGB stars to be C-rich. This is because stars become C-rich when a sufficiently large number of carbon atoms have been dredged-up to outnumber the oxygen atoms. Stars with lower metallicity (or more strictly lower abundances of α-elements) have less oxygen to start with and therefore become C-rich soon after third dredge-up starts. Using the $(J-K)$ dependent bolometric correction from White et al. (2006) we find that $m_{bol} = 18.9$ (if the star were O-rich it would not be significantly different) or $M_{bol} = -4.4$ mag and $M_K = -7.8$ mag.

It is perhaps surprising that we do not see in the spectrum any stellar features that might be attributed to the late-type giant, although this may simply be a consequence of the low-level signal of the detected continuum. Carbon star SR variables typically have $5 < (V-K) < 8$, and possibly this one is at the red end of this distribution as nothing is evident even at $\lambda > 6500\AA$.

3.4 Symbiotic stars in the other galaxies

Belczyński et al. (2000) list the coordinates of the Magellanic Cloud symbiotics, which have been discussed by McNeil, Schild & Vogel (1996) and Mikolajewska (2004), who noted that most of the cool components were AGB stars, and by Phillips (2007), who discusses their 2MASS colours. The LMC contains three D-types (excluding Sanduleak’s star whose status is unclear), two of which contain C stars, and four S-type, two of which contain C stars. The 2MASS $K$-mags for the S-types are: 11.3, 11.5, 11.5 and 11.8 (the most luminous 2 are the C stars). The tip of the giant branch (TRGB) in the LMC is at $K = 12.1$ mag (e.g., Ita et al. 2004), so, as Mikolajewska pointed out, all the LMC symbiotics contain AGB stars.

In the SMC there are 6 S-type symbiotics, one of which contains a carbon star. Their 2MASS $K$ mags are as follows: 10.8, 11.5, 11.5, 12.6 (C star), 12.6, 13.1. The SMC TRGB is around $K = 12.7$ mag (e.g., Ita et al. 2004), but there is a significant line of sight spread, so most, possibly all, of these symbiotics contain AGB stars.

The symbiotic star, Draco C-1, in the Draco dwarf spheroidal, shows emission lines of H$_1$, HeI and HeII that are very similar to those in NGC 6822 SySt–1, but in this case carbon star absorption features are obvious throughout the optical spectrum (Munari 1991). The infrared colours originally reported by Munari (1991b) ($J = 11.60$, $H = 11.35$, $K = 11.40$ mag) are much bluer than those of NGC 6822 SySt–1, and imply a significantly hotter star with $M_K = -8.1$ mag. However, Cioni & Habing (2003) ($J = 14.76 \pm 0.06$ $K = 13.90 \pm 0.05$ mag) and 2MASS ($JHK$, 14.38, 13.71, 13.46, mag) have very different colours which would imply $M_K \sim -6.0$ mag. The TRGB in Draco is around $K \sim 14.0$ mag (Cioni & Habing 2003), so these values still place the giant on the AGB. It is not clear why Munari’s original IR photometry is so different from the 2MASS measurements.

Gonçalves et al. (2008) have recently discovered a symbiotic star IC10 SySt-1, whose spectrum is similar to that of He2-147. The latter is a D-type symbiotic, but infrared observations are essential to distinguish the new star’s D- or S-type nature with certainty. The spectrum of the giant is oxygen rich with a spectral type of M8III. If it were identical to He2-147, with a pulsation period of 373 days (Santander-Garcia et al. 2007), it would have $M_K = -7.82$ mag (White, Feast & van Leeuwen 2008). Assuming IC 10 has a distance modulus of $(m-M)_0 = 24.4$ (Kniazev et al. 2008a; Sanna et al. 2008) and a reddening of $E_B-V = 0.78$ (Sanna et al. 2008) the apparent mean $K$ mag of the symbiotic would be $K \sim 16.8$. With 2MASS data we have estimated the $K$ is even brighter ($\sim 16.0$) and conclude that IC 10 SySt-1 also contains giant companion in AGB phase.

White & Munari (1992) pointed out that the $JHK$ colours of the S-type symbiotics were unlike those of solar neighbourhood giants (their Fig. 6) and speculated that they may be more like the metal-rich M-giants found in the Galactic bulge. However, Mikolajewska, Gromadzki & Hinkle (2003) found that abundance analyses did not support this suggestion. The colours of AGB stars above the TRGB are slightly redder than those of normal giants (this can be seen for stars in the Fornax dwarf spheroidal in Fig. 3 (in the online version only) of White et al. 2008, where the black points are AGB stars), and this is probably the explanation for the colours of the symbiotic stars.

4 CONCLUSIONS

The combination of high excitation emission, in particular HeI and the Raman scattered feature at 6830 Å, together with the strong IR flux unambiguously identifies NGC 6822 SySt–1 as a symbiotic star, the first to be found in NGC 6822. The infrared colours further identify it as an S-type symbiotic, with a carbon-rich AGB star pulsating in the first overtone with a period of 142 days.

Evidence is presented that most extra-galactic symbiotic stars contain AGB stars with luminosities greater than that of the TRGB. D-type symbiotics contain Mira variables which are close to the top of their AGBs. Most extragalactic S-types have luminosities above that of the TRGB and are therefore on the AGB. The fact that one or two have luminosities close to or below the TRGB does not prevent
them from being early AGB stars. While this high fraction of AGB stars may be partly a selection effect it seems very likely that many more of the Galactic symbiotic stars contain AGB stars than has been appreciated to date.

Our suggestion that most, if not all, Galactic and extragalactic symbiotics have AGB stars as mass donors fits well with the view that mass is transferred through the stellar winds, rather than via Roche lobe overflow, since the winds from AGB stars are stronger than from normal giants.

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