A Survey of the Local Group of Galaxies for Symbiotic Binary Stars. I. First detection of symbiotic stars in M33

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ABSTRACT

We present and discuss initial selection criteria and first results in M33 from a systematic search for extragalactic symbiotic stars. We show that the presence of diffuse interstellar gas emission can significantly contaminate the spectra of symbiotic star candidates. This important effect forces upon us a more stringent working definition of an extragalactic symbiotic star. We report the first detections and spectroscopic characterisation of 12 symbiotic binaries in M33. We found that four of our systems contain carbon-rich giants. In another two of them the giant seems to be a Zr-enhanced MS star, while the remaining six objects host M-type giants. The high number ratio of C to M giants in these binaries is consistent with the low metallicity of M33. The spatial and radial velocity distributions of these new symbiotic binaries are consistent with a wide range of progenitor star ages.

Key words: surveys – binaries: symbiotic – stars: general – M33

1 INTRODUCTION

Symbiotic stars (SySt) are interacting binaries, in which an evolved giant (either a normal red giant (RG) in S-type, or a Mira surrounded by an opaque dust shell in D-type SySt) transfers mass to a hot, luminous and compact companion which is usually a white dwarf (WD). The interacting stars are embedded in rich and complex surroundings, including both ionized and neutral regions, accretion/excretion disks, interacting winds, and jets. SySt are important and luminous tracers of the late evolutionary phases of low- and medium-mass binary stars, and excellent laboratories to test models of close binary star evolution. They should be detectable throughout the Milky Way. Moreover, the rapid mass transfer in these WD + giant binaries suggests that some of them might be single-degenerate (SD) progenitors of type Ia supernovae (SNIa). Many SySt will evolve to become double WDs, and mergers of such objects are another pathway to SNIa. The most recent extensive review of SySt is in Mikołajewska (2012).

While about 300 Galactic symbiotics are known (e.g. Belczyński et al. 2000, Miszalski et al. 2014, and references therein), and a few dozen are relatively well studied, their distances (and hence their luminosities and other distance-related physical parameters) are poorly determined. This makes confrontation of theoretical models of SySt with the observed parameters of real stars, to test theories of their interactions and evolution, very challenging.

Fortunately, a few dozen bright SySt have been detected in the Magellanic Clouds (Belczyński et al. 2000, Miszalski et al. 2014, and references therein) and recently even in members of the Local Group of galaxies (Goncalves et al. 2008, Kniazev et al. 2009, Mikołajewska et al. 2014 hereafter MCS14). These discoveries have been, however, in almost all cases, serendipitous. A systematic search for SySt in multiple galaxies is essential to provide samples that are large enough to be suitable for statistical analyses and tests of binary evolution theory.

The motivation and the basic concepts for this survey have already been presented by MCS14. In essence, our goal is to obtain large, complete, luminosity-limited samples of extragalactic SySt to determine their total numbers and their spatial distributions in galaxies of different types. These are strong constraints on binary stellar evolution and the progenitor masses. Large samples, all at the same distance, will enable us to determine the values and distributions of these stars’ luminosity-related physical parameters.

This paper focuses on our initial selection criteria and results in M33. Our most important result is that while extragalactic SySt candidates can be easier to select than their Galactic counterparts, there is an isidious systematic effect at work that must be understood and accounted for before their confirmation and characterization is valid. This effect - the superposition of diffuse interstellar...
gas (DIG) in extragalactic SySt spectra - is so ubiquitous and important that we devote part of this first paper to demonstrating its importance for all future studies of extragalactic SySt. The working definition of an extragalactic symbiotic star must take into account the possible presence of DIG emission if we are to produce samples uncontaminated by imposters that are not really SySt. In this paper we present the first 12 symbiotic stars to be detected in M33, and in the subsequent paper in this series we will report on over 100 new detections in M31. As expected, the spatial distributions of these stars offer important clues to their progenitor masses and ages.

In Section 2 we describe the selection method, and the data and their reductions for our initial M33 survey. The coordinates, observed and dereddened spectra, and classification of the new stars we observed are presented in Section 3. We characterize our new SySt in Section 4 and briefly summarize our results in Section 5.

2 SELECTION METHOD AND FOLLOW-UP SPECTROSCOPY

We selected candidates on the basis of photometric measurements from the publicly available Local Group Galaxy Survey (LGGS) images (Massey et al. 2007). First, we downloaded images of M33 from the Lowell Observatory’s website, and rereduced them using the aperture photometry routines in DAOPHOT (Stetson 2011). We then created catalogs of SySt candidates with the following criteria: (i) each star must be detected in the VRI and Hα filter images; (ii) each candidate must be red, i.e. $V - I \gtrsim 1$, and (iii) each candidate must display Balmer emission, so that $H\alpha - R \gtrsim 0$. The resulting catalogs contained over 20,000 objects in M33.

The rationale for our criteria are, of course, that SySt are simultaneously red from the presence of a cool giant and show strong emission lines from the nebula that is ionized by the hot WD. For our first observing run (September 2014 - see below) we selected those candidates with $V - I \gtrsim 1$, $U - B \lesssim 0$, and $-1 \gtrsim H\alpha - R \gtrsim -4$, motivated by the $UBVIH\alpha$ magnitudes of SySt from MCS14. These criteria yielded ~3700 candidates in M33.

The frames were first de-biased and flat fielded. Individual spectra were then extracted and wavelength calibrated. Sky subtraction is achieved with Hectospec by averaging spectra from "blank sky" fibers from the same exposures or by offsetting the telescope by a few arcseconds. Standard star spectra obtained intermittently were used for flux calibration and instrumental response. These relative flux corrections were carefully applied to ensure that the relative line flux ratios would be accurate. The total exposure time was 5400 s for all spectra.

Whereas practically all objects revealed at least some Hα...
emission, only 64 of them revealed the presence of a RG. Thus for the future observing runs we selected only very red candidates with \( V - I \gtrsim 2 \). We also abandoned attempts to observe objects with \( I \gtrsim 21 \) (which corresponds to the faintest SySt detected in M31 by MCS14). That left \( \sim 700 \) SySt candidates, of which 283 were observed during our second observing run with Hectospec on the nights 16, 17, 19 and 26 November 2014. During this run, we also repeated observations of 17 objects (SySt and a few other interesting objects).

### 3 IDENTIFICATION AND CLASSIFICATION OF SySt IN M33

To classify an object as a SySt, most authors adopt Kenyon’s (1986) definition, which, in addition to the presence of absorption features of a late-type giant, requires strong H\(_\alpha\) and He\(_\text{i}\) emission lines, and additional lines with an ionizational potential of at least 30 eV (e.g. [O\(_\text{iii}\)] and an equivalent width > 1 Å. This is entirely appropriate for Galactic SySt, as contamination from interstellar emission lines is not observed.

The spectra of \( \sim 40\% \) of the observed SySt candidates in M33 revealed the presence of a RG and strong emission lines satisfying the above definition (Fig. 1). However, in most of those stars, the highest IP lines are those from [O\(_\text{iii}\)] \( \lambda \lambda 4959, 5007 \) lines. Moreover, the forbidden [O\(_\text{ii}\)], [O\(_\text{iii}\)], [N\(_\text{ii}\)] and [S\(_\text{ii}\)] line ratios are consistent with low-density \( (n_e \sim 100 \text{ cm}^{-3} \) or less) formation regions, and these lines presumably originate in diffuse ionized gas (DIG) in M33 rather than in the much denser symbiotic nebula. Such DIG is present in all Local Group Galaxy disks, and is particularly abundant in star forming regions (e.g. Hoopes & Walterbos 2003), and it may significantly pollute the SySt candidate spectra. This is because in extragalactic systems our spectrographs capture the light of large volumes of space containing large quantities of line emitting, hot gas that surrounds RGs that are not part of symbiotic binaries. Fig. 1 show an exemplary spectrum of a true SySt in M33, as well as that of a SySt impostor – a RG with strong, superposed DIG lines. The SySt, M33SyS J013303.27+303528.3, is clearly visible as a strong, point-like source in the H\(_\alpha\) image whereas the impostor, M33 J013300.51+303105.9, is embedded in strong extended DIG emission (Fig. 2).

A map of all of our candidates which displayed RG with emission lines is shown in Fig. 3.

In light of the discussion above, we propose that stronger criteria must be adopted to accept an extragalactic star as a SySt. In addition to RG features and strong H\(_\alpha\) lines, the presence of He\(_\text{ii}\) 4686 and higher ionization emission lines excited by a source with \( T \gtrsim 10^5 \text{ K} \) must be present. This is the definition originally proposed by Allen (1984). These much stronger criteria leave us with only a dozen SySt in M33, which are presented in this paper.
Table 1. List of new symbiotic stars with accurate coordinates, their other cross identifiers, and the reference to the number of figure presenting the spectrum.

| No. | M33SyS J | RA(2000) | DEC(2000) | Cross IDs | Spectrum |
|-----|-----------|----------|-----------|-----------|----------|
| 1   | 013219.75+303731.7 | 01:32:19.75 | 30:37:31.7 | LGGS J013219.75+303731.7 | Fig. 10 |
|     |           |          |           | [HBS2006]260101 |         |
|     |           |          |           | SDSS9 J013219.72+30:37:31.5 |         |
|     |           |          |           | SST3M307 J013219.72+30:37:31.5 |         |
| 2   | 013239.11+303836.5 | 01:32:39.11 | 30:38:36.5 | LGGS J013303.27+303528.3 | Fig. 7 |
|     |           |          |           | [HBS2006] |         |
| 3   | 013303.27+303528.3 | 01:33:03.27 | 30:35:28.3 | SST3M307 J013303.24+303528.0 | Fig. 8 |
| 4   | 013311.10+301528.2 | 01:33:11.10 | 30:15:28.2 | SDSS9 J013311.03+301527.7 |         |
|     |           |          |           | SST3M307 J013311.04+301527.6 |         |
| 5   | 013327.01+304045.8 | 01:33:27.01 | 30:40:45.8 | [HBS2006]151442 | Fig. 9 |
| 6   | 013334.95+305108.3 | 01:33:34.95 | 30:51:08.3 | [HBS2006]30376 | Fig. 8 |
| 7   | 013417.72+304119.5 | 01:34:17.72 | 30:41:19.5 | [HBS2006]330166 | Fig. 8 |
| 8   | 013400.44+303460.0 | 01:34:30.14 | 30:33:46.0 | SST3M307 J013303.12+303345.8 |         |
| 9   | 013435.17+303409.4 | 01:34:35.17 | 30:34:09.4 | M33 V0479 | Fig. 7 |
| 10  | 013449.50+304736.9 | 01:34:49.50 | 30:47:36.9 | [HBS2006]222817 | Fig. 7 |
| 11  | 013457.79+310054.2 | 01:34:57.79 | 31:00:54.2 | [HBS2006]30376 | Fig. 8 |
| 12  | 013510.81+305146.8 | 01:35:10.81 | 30:51:46.8 | [HBS2006]110047 | Fig. 8 |

LGGS... - identifier in Massey et al. (2007)
[HBS2006] XXXXXX - number in Hartman et al. (2006)
SDSS9... - identifier in The SDSS Photometric Catalog Release 9 (Ahn et al. 2012)
SSTM3307... - identifier in McQuinn et al. (2007)
M33 V.... - identifier in General Catalogue of Variable Stars (Samus et al. 2007-2013)

Table 2. Photometric data of new SySt.

| M33SyS J | I | V–I | B–V | U–B | R–I | Ha–R | SDSS/CFHT | 2MASS |
|----------|---|-----|-----|-----|-----|------|-----------|-------|
| 013219.75+303731.7 | 19.64 | 1.48 | 0.45 | -0.64 | 0.65 | -1.29 | 20.09 | 0.73 | 0.34 | 20.89 | 0.87 | 0.25 |
| 013239.11+303836.5 | 20.74 | 2.13 | 0.73 | 0.04 | 0.85 | -1.08 | 20.22 | 1.66 | 0.67 | 20.83 | 1.51 | 1.11 | 18.73 | 17.79 | 17.48 |
| 013303.27+303528.3 | 19.58 | 2.54 | 1.67 | -0.27 | 1.16 | -1.24 | 20.09 | 0.73 | 0.34 | 20.89 | 0.87 | 0.25 |
| 013111.10+301528.2 | 20.32 | 2.93 | 1.21 | -1.60 | 21.05 | 1.39 | 1.02 | 18.73 | 17.79 | 17.48 |
| 013327.01+304045.8 | 20.59 | 2.72 | 1.54 | -1.06 | 21.12 | 1.08 | 1.78 | 20.83 | 1.51 |
| 013334.95+305108.3 | 20.44 | 3.05 | 1.24 | -1.24 | 21.12 | 1.08 | 1.78 | 20.83 |
| 013417.72+304119.5 | 20.33 | 2.84 | 1.24 | -1.20 | 21.12 | 1.08 | 1.78 | 20.83 |
| 013430.44+303460.0 | 20.17 | 2.48 | 0.48 | -0.65 | 1.15 | -1.31 | 21.12 | 1.08 | 1.78 | 20.83 |
| 013435.17+303409.4 | 20.59 | 3.20 | 1.55 | 0: | 20.55 | 1.72 | 0.83 | 17.97 | 17.02 | 16.74 |
| 013449.50+304736.9 | 19.46 | 2.02 | 1.71 | -0.33 | 0.84 | -1.09 | 20.02 | 1.61 | 0.53 | 20.93 | 1.24 | 0.97 | 18.90 | 17.96 | 17.92 |
| 013457.79+310054.2 | 20.54 | 2.98 | 1.41 | -1.06 | 20.93 | 1.24 | 0.97 | 18.90 |
| 013510.81+305146.8 | 20.29 | 2.18 | 0.82 | -0.63 | 0.85 | -1.51 | 20.98 | 1.30 | 0.79 | 21.28 | 1.91 | 0.61 |

1 Our measurements on the LGGS images
2 The average values from the CFHT photometry [Hartman et al. 2006]
3 SDSS photometry on JD 2455123
4 SDSS photometry on JD 2454861
5 Cioni et al. 2008
Symbiotic stars in M33

The point, of course, is to NOT accept as a SySt any RG that displays emission lines from DIG. Such objects are SySt imposters. Counting them as real SySt will greatly inflate our SySt population statistics, and skew our perception of true SySt spatial distributions towards star regions rich in ionized hydrogen.

We emphasize that many well-known Galactic SySt do NOT show a detectable optical He ii 4686 emission line. To quantify this issue, we estimated the He ii/He i intensity ratio from the 146 spectra of 110 SySt collected by Munari & Zwitter (2002). Adopting an optimistic detection limit for our survey, He ii/He i ≥ 0.1, we find that 46 out of the 146 spectra of known SySt - about 1/3 - would not satisfy Allen’s SySt definition. A more conservative detection limit, namely He ii/He i ≥ 0.3 will detect only about half of known Galactic SySt. Moreover, in the case of a SySt with a C-rich giant, a weak He ii line can be also easily buried in the C ii 4737 band. This effect is clearly visible in the spectra of the known SySt LMC S63 taken near the hot component eclipse (Ilkiewicz et al. 2015). We maintain, however, that this is a price that the SySt community must be willing to pay to prevent wholesale contamination of extragalactic SySt catalogs with imposters that have nothing to do with SySt.

We note that with high enough S/N spectra, additional crite-

Figure 4. LGGS R, Ha and I images of the new SySt in M33. The FoV is 16×18 arcsec. The red circles have 2 arcsec diameter, and they are centered at the coordinates adopted for our Hectospec observations.

Figure 5. LGGS R, Ha and I images of M33 SyS J013435.17+303409.4. The star does not show up as an Ha-bright object.

Figure 6. LGGS R, Ha and I images of the new SySt in M33 with strong DIG component. They appear point-like in the Ha filter but the strong extended DIG emission is also visible (see text).

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ria can be applied to differentiate SySt from DIG-dominated RG. These e.g. involve the [O iii] and He i diagnostic diagrams, which cleanly distinguish between dense SySt nebulae and lower density planetary nebulae and H ii regions (for details see MCS14, and references therein). Additionally, RG with broad Hα (FW 500 km s^{-1}) and without the low-density DIG ([S ii], [N ii] and [O ii]) are very likely low IP SySt, similar to the known Galactic SySt CH Cyg and the quiescent symbiotic recurrent nova T CrB and RS Oph which show only Balmer emission most of the time. However, in this study we concentrate only on those unambiguous SySt with detectable He ii.

Table 1 lists the names and coordinates of the new SySt. Their locations in M33 are shown on the map in Fig. 3 and their finder charts in Figs. 2–6. As in MCS14, each object’s name was built from its position, which resulted in the format M33SyS JHHMMSS.ss+DDMMSS.s where the acronym M33SyS indicates that they are also SySt. We used VizieR[1] to search for matches to our new SySt in all catalogs available in the CDS database. The resulting matches within 0.5 arcsec radius are listed in Table 1. In particular, only two of our new SySt were included in the LGGS catalogue (Massey et al. 2006, Massey et al. 2007).

The UBVRI Hα mag measured on the LGGS images, and the JHK and gri (Sloan filters) photometry collected from the literature are given in Table 2. Table 1 also provides the reference number of the figure presenting the spectrum normalized to I magnitudes. The accuracy of the flux calibration depends on the variability of our objects which is discussed in Section 4.1. The emission line fluxes and other measurements from the spectra are listed in Tables 3–4.

The absorption features of a cool component are present in all dozen spectrographically confirmed SySt in our sample.

1 http://vizier.u-strasbg.fr/viz-bin/VizieR
In particular, four SySt show strong CN bands, and three of them also strong C\textsubscript{2} bands, indicating carbon rich (C) red giants (Fig. 9 and Fig. 7). All of them are N-type carbon stars except M33SyS J013239.11+303836.5 which is of CH type as indicated by the presence of a strong G-band of CH at 4300 Å. The spectrum of M33SyS J013435.17+303409.4, in addition to strong CN bands, also shows strong Ba\textsubscript{ii} 6495 line, and it is very similar to the symbiotic C-rich Mira H1-45 (Miszalski et al. 2013). It is also the coolest objects in our sample, and its light curve (Section 4.1) suggests that it is indeed a Mira variable. In the remaining objects the TiO bands are present, indicative of M-type giants (Fig. 8 – 11). Additionally, M33SyS J013510.81+305146.8 and M33SyS J013430.14+303346.0 show clearly detectable ZrO bands which indicates some s-process enrichment; we note this by classifying their red components as ‘MxS’.

All of our new SySt sample show the He\textsubscript{ii} \lambda 4686 emission line and five of them also show the Raman-scattered O\textsubscript{vi} lines. The [Fe \textit{vi}i] \lambda 6086 line is visible in only 2 of our SySt, M33SyS J013457.79+310054.2 and M33SyS J013303.27+303528.3, which are also the hottest as indicated by their very high ratio of He\textsubscript{ii} \lambda 4686/H\beta (Table 3).

The C-rich M33SyS J013435.17+303409.4 shows the faintest emission lines (Table 3 Fig. 7), and it does not show up as an H\alpha-bright object in the LGGS images (Fig. 5). Thus, it should not have been selected according to our criteria, and the colour remeasured for this paper is H\alpha – R \sim 0 (Table 5). We suspect that there must be some error in our first measurement which gave H\alpha – R \sim –3.7!

Finally, we note that three of our objects, M33SyS J013327.01+304045.8, M33SyS J013334.95+305146.8, and M33SyS J013430.14+303346.0, show relatively strong lines from the [O \textit{ii}], [N \textit{ii}] and [S \textit{ii}] lines (Fig. 7) which might suggest DIG origin. Although the low-density forbidden lines of [N \textit{ii}] and [O \textit{ii}] can be very strong in some SySt, especially those with a Mira-type giant (a very good example is Hen 2–147, see figure 43 in Munari & Zwitter 2002, and symbiotic novae, they usually do not show strong [S \textit{ii}] \lambda 6717,6731 lines. The [N \textit{ii}]/H\alpha, [S \textit{ii}]/H\alpha and [S \textit{ii}]\lambda 6717/6731 ratios locate these three objects near the borderline between H\alpha regions and shock-dominated nebulae (e.g. Canto 1981, Phillips & Cuesta 1999). Strong [S \textit{ii}] \lambda 6717, 6731 lines were found in extended nebulae of Sanduleak’s star, the jet–dominated LMC SySt (Angeloni et al. 2013).
classified as a Cepheid in Hartman et al. (2006). Moreover, the position of all three strong, while in the remaining two objects the line is relatively weak but detectable (Fig. 9). Figure 12. The CFHT light curve of M33SyS J013219.75+303731.7 misclassified as a cepheid in Hartman et al. (2006).

In M33SyS J013327.01+304045.8 the He II λ4686 is relatively strong, while in the remaining two objects the line is relatively weak but detectable (Fig. 9). Moreover, the position of all three in the [O III] diagnostic diagram (Gutierrez-Moreno et al. 1995, see also MCS14) indicate that they are SySt. Thus we maintain that they are likely SySt with some component of shock excitation and/or polluted by DIG which is very abundant in M33.

4 CHARACTERIZATION OF THE NEW SySt in M33

4.1 Variability

Light curves for 8 objects are available in the variability survey of M33 conducted with the 3.6-m Canada-France-Hawaii Telescope (CFHT) by Hartman et al. (2006). The data were obtained in gri (Sloan filters), and the observations were made for 27 nights spanning 17 months.

Hartman et al. (2006) have classified all these objects as long-period variables, except for M33SyS J013219.75+303731.7 which was classified as a Cepheid with a 23.11 day period. However, both the light curves of M33SyS J013219.75+303731.7 phased with this period in Hartman et al. (2006) as well as its symbiotic spectrum (Fig. 10) are totally incompatible with such a classification. Thus, we retrieved the original measurements, and the resulting light curves shown in Fig. [12] are similar to those observed for the seven remaining SySt (Figs. 13–15). The reason for this misclassification seems to be that Hartman et al. (2006) based their classification on magnitude-colour diagrams (their figure 7) which separate the Cepheid region from other classes of variable stars. Although the relatively blue g−r and r−i colours of M33SyS J013219.75+303731.7 are indeed consistent with a Cepheid, SySt with their composite spectra can easily mimic early spectral types. A very good example is the well-studied Galactic SySt AR Pav which shows the red giant colours only during eclipses. Outside the eclipse, its V ∼ 10.6, (V − RC) ∼ 0.7 and (V − Ic) ∼ 1.4 (Menzies et al. 1982) which roughly correspond to r ∼ 21.4, g−r ∼ 0.4 and r−i ∼ 0.5 (adopting the relations from Fukugita et al. 1996) will locate AR Pav in the Cepheid region rather than that occupied by M giants.

Similarly, M33SyS J013430.14+303346.0 was classified as a W Vir star with P=29.12 by Kinman et al. (1987) who published only the phased light curve. Fortunately, we managed to recover the original light curve using the dates of observations (table I in Kinman et al. 1987), and the resulting light curve is shown in Fig. 12. It is clear that the average gaps between the observations are comparable to the period found by Kinman et al. (1987), and the light curve is dominated by long-term changes. The B − RC ∼ 1.7 measured for M33SyS J013430.14+303346.0 is similar to those of other W Vir variables (table IV in Kinman et al. 1987), however it is also significantly redder than the out-of-eclipse B − RC ∼ 1.3 in AR Pav (Menzies et al. 1982). Similarly, the out-of-eclipse B − RC ∼ 1.3 in AR Pav is also bluer than B − RC ∼ 1.7 measured for M33SyS J013430.14+303346.0 by Kinman et al. (1987).

The light curves of all our SySt (Figs. 12–15) are similar to those observed for the Galactic and Magellanic SySt (Gromadzki et al. 2009; Gromadzki et al. 2013; Angeloni et al. 2014). Unfortunately, it is not easy to distinguish between the red giant pulsation and orbitally related variations because both become redder in gri bands at minimum light. However, the colour changes are larger for larger amplitudes and longer pulsation periods (Mira or LPV variables), and often negligible in low-amplitude semiregular (SR) variables. The orbital variability can be detected only in S-type SySt where the red giant is nonvariable or an SR variable (Gromadzki et al. 2013; Ilkiewicz et al. 2015). In these SySt, the orbital modulation is best visible in the visual and blue bands while the low amplitude SR pulsations in these SySt dominate in the red bands (in SySt with strong emission lines the SR pulsations are visible only during the orbital minimum). In fact, the light curve and colour behaviour of M33SyS J013219.75+303731.7 is similar to orbitally related changes in S-type SySt, and rather does resemble the red giant pulsations. The case of M33SyS J013430.14+303346.0 is less clear because there is no information about the colour changes.

The CFHT light curves for the remaining O-rich SySt are shown in Fig. 14. Among these, only M33SyS J013510.81+305146.8 shows clear indication that its variability, especially in the g, r bands is presumably due to an orbital motion with low-amplitude SR pulsation of the red giant dominating in the i

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band. The light curves of M33SyS J013311.10+301528.2 and M33SyS J013327.01+304045.8 seem to be dominated by the red giant pulsations. The case of M33SyS J013457.79+310054.2 is less obvious, however, if the prominent light modulation is due to Mira-type pulsations, the period should be relatively long, $\gtrsim 300^d$. However, its observed $K$ (Table 2) corresponds to the absolute magnitude $M_K \sim -6.7$ at the distance of M33 (see Section 4.2), which is too faint for a Mira. In fact, all Galactic symbiotic Miras with similar periods have $M_K \lesssim -7.8$ (Gromadzki et al. 2009). Thus we think that the variability of this SySt is due to orbital motion.

The CFHT light curves of our C-rich SySt are shown in Fig. 15. M33SyS J013435.17+303409.4 is definitely a Mira variable with a period of $\sim 300^d$. The observed $K$ magnitude (Table 2) corresponds to the absolute magnitude $M_K \sim -7.9$, which is also consistent with a Mira variable and $P \sim 300^d$ (Gromadzki et al. 2009). Its spectrum (Fig. 7) is very similar to the symbiotic C-rich Mira H1–45 (Miszalski et al. 2013). It is also the coolest SySt in our sample, as indicated by its optical and $JHK$ magnitudes and colours. However its $JHK$ magnitudes and colours do not show any evidence for an optically thick dust found in the majority of Galactic symbiotic Miras.

The light curves of M33SyS J013303.27+303528.3 also seem to be dominated by the red giant pulsation, however, with a significantly lower amplitude and a shorter period ($\sim 100^d$). Finally, in M33SyS J013449.50+304736.9, the $g-i$ colour is redder when the star became brighter (mean $I$ magnitude is lower), and the oscillations disappear. Thus, its light curve can be a combination of the low-amplitude SR pulsations of the giant and orbitally related changes with a longer ($\gtrsim 500^d$) period. Similar behaviour is observed in the C-rich SySt LMC S63 (Iłkiewicz et al. 2015).

Figure 14. The CFHT light curves of SySt in M33 with M/MS giants.
The physical parameters of our symbiotic sample are presented in Table 4. The hot component temperature, \( T_h \), was estimated in the same way as by MCS14. In particular, the lower limit was set by the highest ionization stage, \( I_{\text{max}} \), using the formula \( T_h = 1000 k \times I_{\text{max}} \) \([\text{eV}]\) (Mürset & Nussbaumer 1992). The upper limit for \( T_h \) was set by the HeII\( \lambda 4686 \), HeI\( \lambda 5876 \), and H\( \alpha \) line ratios assuming case B recombination and cosmic He/H (Hijmans 1981).

The foreground extinction towards M33 is very low, \( E(B-V) \approx 0.03 \) (Schlafly & Finkbeiner 2011), and the Balmer line ratios H\( \alpha \)/H\( \beta \)/H\( \gamma \) are not very useful for reddening estimates in SySt because of their significant departures from case B conditions, presumably due to self absorption effects (e.g. Proga et al. 1996 and discussion in MCS14). Thus, the absolute \( I \) magnitudes, \( M_I \), and the total \( H \alpha \) luminosities, \( L(H\alpha) \), were calculated assuming \( E(B-V) \approx 0 \), and adopting the the true distance modulus \( m-M=24.62 \) \((d=835 \text{ kpc})\) (Gieren et al. 2013). The comparison of the \( H \alpha \) fluxes measured on our spectra with those derived from the \( H \alpha \) magnitudes, and listed in Table 3 shows that they agree within a factor of \( \sim 2 \), and such a discrepancy can be easily accounted for by their intrinsic variability (e.g. Iłkiewicz et al. 2015 see also Section 4.1). To calculate \( L(H\alpha) \) we used the \( H \alpha \) fluxes derived from spectra; they are accurate within a factor of \( \sim 2 \).

As in the case of SySt in M31 and the Milky Way, there is some positive correlation between \( M_I \) and \( L(H\alpha) \). The \( H \alpha \) luminosity characterizes the nebular emission which is related to the hot component temperature and luminosity while \( M_I \) characterizes the cool giant. Thus, this correlation probably reflects a relation between the hot component luminosity and that of the cool giant.

The absolute magnitudes, \( M_I \), of the M33 SySt are between \(-3.9 \) and \(-5.2 \), and they cover more or less the same range as those of SySt in M31 (MCS14). They are all close to or above the tip of the Red Giant Branch (TRGB) in the colour-magnitude diagrams of resolved galaxies. In particular, Udalski (2000) determined the TRGB \( I \)-band magnitude, \( M_I \approx -4 \), in the Magellanic Clouds. These absolute magnitudes are also consistent with the semi-regular character of CFHT light curves of most of our sample.

There is, however, a significant difference between the M33 and M31 samples in that 4 of the symbiotic giants in M33 are C-rich giants, and another 2 are MS stars whereas the M31 SySt all have O-rich, M-type giants (see table 4 in MCS14). C-rich SySt are also very rare in the Milky Way (e.g. Belczyński et al. 2000 Miszalski et al. 2014 Miszalski & Mikolajewska 2014). The ratio of C to M giants is a strong function of metallicity of the parent galaxy which is low in M33, [M/H] \( \approx -1.6 \) (Cioni et al. 2008), and roughly solar in M31. The O-rich symbiotic giants in M33 are also on the average of earlier spectral type than those in M31. The C:M ratio of non-symbiotic giants found by our survey, C:M \( \approx 0.3 \) is somewhat lower than that for SySt, however, this could be due to low number statistics. A similar effect is observed in the Magellanic SySt, where the ratio of C-rich to O-rich objects is 4:2 in the LMC, and 2:6 in the SMC, respectively, and most of the O-rich giants are of K or early M-type (Mürset et al. 1996 Miszalski et al. 2014).

Mürset et al. (1996) suggested that the Magellanic symbiotic giants are not influenced by binarity, and in particular, there is no need to account for the C abundance by a former mass transfer. However, this may not be true in the case of LMC S63 hosting a CJ-type giant (Mürset et al. 1996), and LMC N19 in which the M giant shows strong evidence for an s-process enhancement (Mikolajewska et al. 2016, in preparation). In both cases, the chemical abun-

![Figure 15. The CFHT light curves of SySt in M33 with C giants.](image-url)
Table 3. Emission line ratios (Hβ=100) measured in the spectra of the new M33 SySt. In addition, the last column gives the Hα fluxes measured on the spectra (first value) and those derived from the Hα magnitudes (second value).

| M33SySJ | [O i] | [Ne ii] | Hγ | [O iii] | He i | [Fe ii] | Hα | [N ii] | He i | [S ii] | O i | He i | F(Hα) |
|---------|-------|---------|----|--------|-----|--------|----|--------|-----|--------|-----|-----|-------|
| 013219.75+303731.7 | 38 | 8 | 61 | 13 | 22 | 503 | 16 | 2 | 16 | 41/23 |
| 013239.11+303836.5 | 51 | 10 | 88 | 66 | 445 | 3/5 | | | | | | |
| 013303.27+303528.3 | 205 | 40 | 9 | 97 | 45 | 29 | 11 | 575 | 30 | 10 | 35/25 | 35 | 24 | 16/14 |
| 013311.10+301528.2 | 100 | 26 | 72 | 26 | 523 | 17 | 25 | 10/10 |
| 013327.01+304045.8 | 536 | 40 | 17 | 40 | 147 | 25 | 336 | 76 | 67/47 |
| 013334.95+305108.3 | 365 | 21 | 52 | 27 | 10 | 12 | 335 | 65 | 6 | 77/53 |
| 013417.72+304119.5 | 865 | 81 | 41 | 13 | 21 | 193 | 322 | 167 | 186/136 |
| 013430.14+303346.0 | 37 | 25 | 24 | 76 | 19 | 12 | 480 | 16 | 10 | 29 | 12/9 |
| 013435.17+303409.4 | 43 | 25 | 24 | 76 | 19 | 12 | 480 | 16 | 10 | 29 | 12/9 |
| 013449.50+304736.9 | 43 | 48 | 22 | 13 | 420 | 11 | 21 | 17/17 |
| 013457.79+310054.2 | 49 | 22 | 99 | 23 | 31 | 33 | 416 | 40 | 5/4 |
| 013510.81+305146.8 | 62 | 30 | 44 | 34 | 21 | 40 | 209 | 32 | 25 | 24/14 |

1 blend of 2 lines
2 in units of 10^{-10} ergs s^{-1} cm^{-2}.

Table 4. Physical parameters of new SySt in M33.

| M33SySJ | Sp Type | Ion | T_e [10^4 K] | M_t | L(Hα) | ν_t [km s^{-1}] | Δν [km s^{-1}] |
|---------|---------|-----|-------------|-----|--------|-----------------|----------------|
| 013219.75+303731.7 | K/M | O^+5 | 114±153 | -5.0 | 3.73/97 | -145±3 | 5 |
| 013239.11+303836.5 | CH | He^+2 | 54±132 | -3.9 | 0.27/7.2 | -209±10 | -52 |
| 013303.27+303528.3 | CN | O^+5 | 114±176 | -5.1 | 1.41/37 | -169±5 | -12 |
| 013311.10+301528.2 | M5 | O^+5 | 114±159 | -4.4 | 2.22/59 | -115±20 | -15 |
| 013327.01+304045.8 | M | He^+2 | 54±131 | -4.1 | 0.30/8.3 | -170±7 | -5 |
| 013334.95+305108.3 | M | He^+2 | 54±94 | -4.2 | 0.86/23 | -223±3 | 9 |
| 013417.72+304119.5 | M | He^+2 | 54±116 | -4.4 | 0.27/7 | -206±8 | 12 |
| 013430.14+303346.0 | M2S | O^+5 | 114±169 | -4.5 | 1.12/29 | -166±13 | -1 |
| 013435.17+303409.4 | CN | He^+2 | 54±142 | -4.1 | 0.13/3.3 | -157±6 | 23 |
| 013449.50+304736.9 | CN | He^+2 | 54±144 | -5.2 | 1.56/41 | -245±12 | -5 |
| 013457.79+310054.2 | M4 | O^+5 | 114±176 | -4.1 | 0.47/12 | -230±18 | 32 |
| 013510.81+305146.8 | M4S | He^+2 | 54±127 | -4.4 | 2.17/57 | -205±8 | 30 |

1 in units of 10^{38} ergs s^{-1}/D
2 difference between the measured radial velocity ν_t and the galactic rotational velocity [Rogstad et al. 1976]

Not a single SySt is a known member of a Galactic open cluster (OC) or globular cluster (GC). (This is not very surprising, as only ~ 300 Galactic SySt are known, and only a few percent of all Galactic stars are currently in clusters.) The result of this absence of any given Galactic SySt is that the gold standard for age determination for any given Galactic SySt does not exist.

We can address the question of the ages and age distribution of the M33 SySt - and hence those of all SySt - with the data in Table 4. Beasley et al. (2015) have measured the radial velocities and ages of 77 star clusters in M33 to determine that galaxy’s age-velocity relation (AVR), shown in their figure 19. The largest observed cluster velocity dispersion is 60 km s^{-1}. Most clusters’ dispersions are in the 10–30 km s^{-1} range, similar to those of most of our SySt. We conclude that the SySt of M33 are a disc population.

The only exception is M33SyS J013239.11+303836.5, with the velocity dispersion ~52 km s^{-1}, and the only one with a CH-type giant. Table 4 also shows that it is the least luminous star in our sample, displaying M_t = -3.9, somewhat below the TRGB luminosity (see Section 4.2). Thus, this star must have mass ≥ 1.0 M_{⊙} (Schaller et al. 1992), and hence age ≥ 10 Gyr. The other SySt listed in Table 4 are all more luminous than M33SyS J013239.11+303836.5, and hence more massive – up to...
about 2 M⊙ – and with ages in the 1–10 Gyr range. We conclude that SySt can form at all times, and in all environments in M33 where binary stars are born. Cioni et al. (2008) discussed the spatial distribution of C/M ratio, mean age, and metallicity of AGB stars in M33, and found that the average outer ring and nuclear stellar population is ~ 6 Gyr whereas the central regions are a few Gyr younger. Our results are consistent with their study, as all of our C-rich SySt are located in the outer ring, and our oldest M33SyS J013239.11+303836.5 lies in the middle of the region occupied by the oldest (~ 10 Gyr) stars with the lowest metallicity (cf. figure 15 of Cioni et al. 2008).

5 CONCLUSIONS
We presented and discussed initial selection criteria and first results in M33 from a systematic survey for extragalactic symbiotic stars. We found that most of the RGs with strong nebular emission are not SySt. It is DIG that is making these objects stand out as candidates, but they are not genuine SySt. Eliminating these imposters is essential if we are to isolate uncontaminated samples of genuine extragalactic SySt.

We also presented the first 12 SySt detected in M33, and discussed their spectroscopic characteristics, and light curves (available for nine of these objects). We found a high number ratio of C to M giants in these systems which is presumably due to the low metallicity of M33. The light curves of most of our SySt reveal semi-regular variability, similar to that observed in Galactic S-type SySt, which can be accounted for by a superposition of semi-regular pulsations of the red giant with $P \sim 10^2$, and orbitally-related changes with a longer period. The only SySt hosting a Mira variable is the C-rich M33SyS J013435.17+303409.4, however its $H/K$ magnitudes and colours do not show any evidence for an optically thick dust found in the majority of Galactic symbiotic Miras.

The spatial and radial velocity distributions of the 12 new SySt we have identified in this paper are consistent with a wide range of progenitor star ages.

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