Light curves of symbiotic stars in massive photometric surveys II: 
S and D'-type systems

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ABSTRACT

We present results of period analysis of ASAS, MACHO and OGLE light curves of 79 symbiotic stars classified as S and D'-type. The light curves of 58 objects show variations with the orbital period. In case of 34 objects, orbital periods are estimated for the first time, what increases the number of symbiotic stars with known orbital periods by about 64%. The light curves of 46 objects show, in addition to the long-term or/and orbital variations, short-term variations with time scales of 50-200 days most likely due to stellar pulsations of the cool giant component. We also report eclipse-like minima and outbursts present in many of the light curves.

Key words: stars: activity – stars: binaries: symbiotic – surveys

1. Introduction

Symbiotic stars are long-period interacting binary systems, in which an evolved red giant transfers material onto its much hotter companion, which in most systems is a white dwarf. Based on their near-IR characteristics, symbiotic stars divide into two main classes (Allen 1982) depending whether the colours are stellar (S-type) or indicate a thick dust shell (D-type). The majority (≈ 80%) of catalogued systems are S-type and have near-IR colours consistent with cool stellar photosphere temperatures of ≈ 3500 – 4000 K. Most of them have orbital periods of ≈ 500 – 1000 days (e.g. Mikolajewska 2012). The near-IR colours of D-type systems indicate the presence of a dust shell which obscures the star and re-emits at longer wavelengths. Near-IR photometric monitoring has shown that these D-type systems have large amplitude variations and that they contain Mira variables with pulsation periods in
the range 300–600 days; they are often called symbiotic Miras (Whitelock, 1987). Since they must accommodate the Mira with its dust shell, these D-type systems should have much longer orbital periods than the S-types, a few tens of years and more. The latest review of symbiotic Miras and a comparison with normal Miras can be found in Whitelock (2003). There is also small subclass of symbiotic binaries contain earlier type of giant (F, G and K). These objects are called yellow symbiotics. Some of them show dust emission, these are signed as D’-type (Allen 1982).

Light curves of symbiotic stars reflect the very complex behaviour of these systems. They show high and low activity stages, flickering, nova-like outbursts originating from the hot component (S & D types), eclipses, ellipsoidal variability connected with orbital motion (S-type), radial pulsations (all D-type and some S-type) and semi-regular variation of the cool component (S-type), long-term dust obscuration (mostly D-type) and other types of variability (Mikołajewska 2001).

In this paper we analyse the light curves of 79 galactic S-type and D'-type symbiotic stars in different bands. The light-curves were provided by massive photometry surveys such as ASAS, MACHO, and OGLE. In some cases AAVSO light curves are analysed. Similar analysis of light curves of D-type symbiotic binaries was done by Gromadzki et al. (2009).

2. Data

Belczyński et al. (2000) listed coordinates for symbiotic stars, but many of these are not sufficiently accurate to identify the symbiotics unambiguously. Therefore, we first identified the 2MASS counterparts using the existing finding charts and the Aladin Java graphics interface running at the CDS in Strasbourg. This works well because symbiotic stars, which have the near-IR colours of late-type giants, are intrinsically bright in $JHK$. The 2MASS coordinates were then used to identify symbiotic stars in the OGLE, MACHO and ASAS databases.

In the ASAS database (Pojmański 2002), the data were found for 102 symbiotic stars. However, only for 69 systems the quality of light curve was good enough for period analysis. These comprise $V$-band photometry obtained between November 2000 and August 2009. There are two limitations connected with these data. The first one is related to the brightness of objects in $V$ filter. Stars brighter than 8.5 mag are saturated whereas the limiting magnitude of the photometric system is $\approx 15$ mag. However, we analysed ASAS light curves of objects brighter than 14 mag, because $\sigma_V$ in these cases was better than 0.2 mag. The second constraint is associated with the instrumental angular resolution. The scale of instrument is of about 15.5 arcsec per pixel. Since the image FWHM is of about 1.4–1.6 pixels and the size of the aperture was 2 pixels two stars are well separated if the distance

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1 official home page of ASAS project: [http://www.astrouw.edu.pl/asas/](http://www.astrouw.edu.pl/asas/)
between them is above $\approx 0.5$ arcmin. This means that in dense galactic regions objects are often blended. Information about blended objects are given in Table 1.

The OGLE-II/III database (Udalski et al. 1997, 2003)\(^2\) includes light curves for 13 S-type galactic symbiotic stars. These comprise $I$-band photometry obtained between 1997 and 2009. Three stars, Hen 2-289, AS 269 and V3929 Sgr, showed only linear trends of unknown nature. The light curves of remaining 10 were good enough for period analysis.

The MACHO database (Alcock et al. 1992)\(^3\) contains observations for 13 S-type systems obtained between 1993 and 1999. Only 9 of these light curves were good enough for period analysis. For V3929 Sgr there are a few points only, whereas SS73 129, V4018 Sgr and Hen 2-379 are saturated. The photometry was made through non-standard blue ($B_M$) and red ($R_M$) filters.

3. Period analysis

All light-curves were analysed using the program PERIOD\(^4\) ver. 5.0, based on the modified Lomb-Scargle method (Press & Rybicki, 1989). If it was necessary, long-term trends were removed by subtracting a polynomial of appropriate order. Sudden jumps of brightness (outbursts or eclipses) were also removed from light curves. The resultant power spectra of our targets were compared with the power spectra of windows. The periods were derived from the inverse of the maximum of the peak in the periodogram ($f_{\text{max}}^{-1}$), whereas their accuracy was estimated by calculating the half-size of a single frequency bin ($\Delta f$), centred on the peak ($f_c$ is the centre of the peak) of the periodogram and then converted to period units ($\Delta P = f_{c}^{-2} \cdot \Delta f$).

The highest peak in a typical power spectrum corresponds to variations with periods of 300–1000 days presumably related to orbital motion. The other strong peaks are connected with annual aliases, second and third harmonics, long-term variation and a combination thereof.

In the case of 24 objects included in our sample the orbital period was previously known from spectroscopic and/or photometric studies. These orbital periods were usually derived from observations covering longer periods than the photometric data used in our study, so we adopted them as more accurate.

The power spectra of residual light curves, with removed orbital modulation and/or long-term variation, often reveal peaks corresponding to periods of 50–200 days which may reflect pulsations of the red giant. The orbital modulation was removed form light curves by fitting high (7-11) order spline polynomial. Such approach gave better results than subtracting a sinusoid because in many cases the amplitude of the orbital modulation showed cycle to cycle changes. Examples of

\(^2\)official home page of OGLE project: [http://ogle.astrouw.edu.pl/](http://ogle.astrouw.edu.pl/)
\(^3\)official home page of MACHO project: [http://wwwmacho.mcmaster.ca/](http://wwwmacho.mcmaster.ca/)
\(^4\)the source program is available on [http://www.starlink.rl.ac.uk/](http://www.starlink.rl.ac.uk/)
4. Results and discussion

Results of our period analysis are summarized in Table 1. The most important result of this study is detection of periodic light changes due to either orbital motion or pulsations or both. The light curves folded with orbital periods are plotted in Figs. 2 and 3. Orbital ephemerides can be found in Table 2. In the case of 24 objects, we used more accurate orbital periods derived by other authors. Residual light curves folded with pulsation periods are plotted in Figs. 4 and 5.
Table 1: Summary of periodicities derived from our analysis.

| No. | Name      | Survey name | \(P_{\text{orb}}\) | \(P_{\text{pul}}\) | Other periods | Remarks |
|-----|-----------|-------------|---------------------|---------------------|---------------|---------|
| 012 | S 32      | ASAS 043745-0119.2 | 628±24              | 640.5±1             |               | nc      |
| 017 | V1261 Ori | ASAS 052219-0840.0 | 323±2               | 640.5±1             |               | ecl, orb, pul |
| 023 | BX Mon    | ASAS 072523-0336.0 | 1401±1, 1259±1      | 340, 1931±1         |               | orb, pul |
| 024 | MWC 560   | ASAS 072551-0744.1 | 323±2               | 640.5±1             |               | ecl, orb |
| 025 | AS 201    | ASAS 083143-2745.5 | 628±24              | 640.5±1             |               | bl       |
| 031 | Hen 3-461 | ASAS 103909-5124.2 | 323±2               | 640.5±1             |               | orb, pul |
| 032 | SS73 29   | ASAS 110827-6547.3 | 628±24              | 640.5±1             |               | orb, pul |
| 033 | SY Mus    | ASAS 133418-2545.8 | 628±24              | 640.5±1             |               | orb, pul |
| 035 | RT Cru    | ASAS 132523-2545.8 | 628±24              | 640.5±1             |               | orb, pul |
| 039 | Hen 3-1103| ASAS 154828-4419.0 | 628±24              | 640.5±1             |               | orb, pul |
| 042 | CD-36 8436| ASAS 175013-0642.5 | 628±24              | 640.5±1             |               | orb, pul |
| 043 | V840 Cen  | ASAS 180429-270912.4 | 628±24              | 640.5±1             |               | orb, pul |

Continued on next page
| No. | Name      | Survey name       | $P_{orb}$ | $P_{pol}$ | Other periods | Remarks   |
|-----|-----------|-------------------|-----------|-----------|---------------|-----------|
| 119 | AS 270   | ASAS 180534-2020.6 | 794±61    | 671±101   | orb, out     |           |
| 121 | SS73 129 | ASAS 180706-2936.4 | 536±27    |           | orb, out     |           |
| 122 | Hen 3-1591 | ASAS 180732-2553.7 | 2350±41   |           | sat          |           |
| 123 | V615 Sgr | ASAS 180740-3606.3 | 657±39    | 70±1      | orb, pul     |           |
| 124 | Ve 2-57  | ASAS 180822-2433.8 | 450±58    |           | fin          |           |
| 125 | AS 276   | ASAS 180910-4113.4 | 155±2     |           | pul          |           |
| 127 | AS 281   | ASAS 181044-2757.9 | 103±1     |           | bl, nc       |           |
| 128 | V2506 Sgr| ASAS 181270-2832.7 | 533±30    | 65±1      | orb, pul     |           |
| 129 | SS73 141 | ASAS 181211-3310.7 | 868±80    | 93±1      | orb, pul     |           |
| 130 | V343 Ser | ASAS 181222-1140.1 | 511±22    | 820±12    | orb, pul     |           |
| 131 | Y CrA    | ASAS 181423-4250.5 | 84±1      | 118±2     | orb, pul     |           |
| 132 | YY Her   | ASAS 181434+2059.3 | 580±42    | 599.4±18  | orb, pul     |           |
| 133 | V2756 Sgr| ASAS 181434-2949.4 | 480±19    | 424±17    | orb          |           |
| 134 | FG Ser   | ASAS 181507-0018.8 | 649±36    | 50±1      | ecl, orb, pul|           |
| 135 | HD 319167| ASAS 181525-3032.0 | 1744±37   |           | orb          |           |
| 136 | Hen 2-374| MACHO 305.35744.0 | 459±33    | 54±1      | 100d         |           |
| 137 | Hen 2-376| MACHO 107.25453.25 | 511±22    |           | orb, pul     |           |
| 138 | V4074 Sgr| ASAS 181605-3051.2 | 118±2     |           | 100d         |           |
| 139 | V2905 Sgr| ASAS 181720-2810.0 | 508±9     |           | orb, pul     |           |
| 140 | StHA 149 | ASAS 181856+2726.3 | 64±2      |           | orb, pul     |           |
| 141 | Hen 3-1674 | ASAS 182019-2622.6 | 1004±20   | 1003±14   | orb, pol     |           |
| 142 | AR Pav   | MACHO 163.27426.43 | 631±35    | 604.5±19  | ecl, orb, pul|           |
| 143 | V3929 Sgr| MACHO 169.27679.3050 | 106±3    | 103.8, 519.7±208 | orb, out |           |
| 144 | V3804 Sgr| ASAS 182129-3132.1 | 426±8     |           | orb, pol     |           |
| 145 | V443 Her | ASAS 182208+2327.3 | 626±48    | 59±1      | orb, pol     |           |
| 146 | V3811 Sgr| OGLE 182329-0-215309.5 | 139±15  |           | ecl, pul     |           |
| 147 | V4018 Sgr| ASAS 182527-2836.0 | 513±22    | 93±1      | orb, pul     |           |
| 148 | V3890 Sgr| MACHO 137.29602.905 | 106±3    | 103.8, 519.7±208 | orb, out |           |
| 149 | AS 316   | ASAS 184233-2117.8 | 62±1      |           | orb          |           |
| 150 | MWC 960  | ASAS 184756-2005.8 | 183±3     |           | orb          |           |
| 151 | AS 327   | ASAS 185317-2423.0 | 823±55    | 83±1      | orb, pol     |           |
| 152 | FN Sgr   | ASAS 185355-1859.7 | 563±28    | 568±32    | ecl, orb, out|           |
| 153 | CM Aql   | ASAS 190335-0303.3 | 513±22    | 1058±22   | bl, fp       |           |
| 154 | V919 Sgr  | ASAS 190346-1659.9 | 125±2     |           | out, pul     |           |
| 155 | V1413 Aql | ASAS 190347+1626.5 | 477±28    | 434.1±23  | ecl, orb     |           |
| 156 | NSV 11776 | ASAS 190955-0247.6 | 1625±16   | 198±4     | orb, pul     |           |
| 157 | StHA 164 | ASAS 192842-0603.9 | 106±3     | 103.8, 519.7±208 | orb, out |           |
| 158 | Hen 3-1761 | ASAS 194225-6807.7 | 559±27    | 63±1      | orb, pul     |           |
| 159 | QW Sgr   | ASAS 194550-1836.8 | 390.5±25  |           | bl           |           |
| 160 | PU Vul   | ASAS 202114+2314.3 | 138±2     | 4900±26   | ecl, pul     |           |
| 161 | LT Del   | ASAS 203557+2011.5 | 476±27    |           | bl           |           |
| 162 | StHA 180  | ASAS 203920-0517.3 | 1494±38   |           | orb          |           |
| 163 | CD-43 14304 | ASAS 210006-4238.8 | 144±148   | 144±26   | ecl, orb, out|           |
| 164 | StHA 190 | ASAS 214145+0243.9 | 106±3     |           | orb          |           |
| 165 | AG Peg   | ASAS 215102+1237.5 | 743±68    | 55±1      | 816.5, 818.2±15 | orb, pul |           |
| 166 | CD-28 3719 | ASAS 070109-2906.4 | 198±3     |           | pul          |           |
| 167 | ZZ Cmi   | ASAS 072441+0853.9 | 106±3     |           | pul          |           |
Table 1 – continued

| No. | Name   | Survey name | $P_{orb}$ | $P_{red}$ | Other periods | Remarks |
|-----|--------|-------------|-----------|-----------|---------------|---------|
| s07 | NQ Gem | ASAS 073155+2430.2 | 58±1 | | | pul |
| s08 | Wray 16-51 | ASAS 093329-4634.8 | | | | |
| s09 | Hen 3-653 | ASAS 112533-5956.5 | 115±1 | | | bl, pul |
| s11 | CD-27 8661 | ASAS 122434-2818.9 | 753±47 | 85±1 | 763.3$^{[29]}$ | orb, orb |
| s12 | AE Crt | ASAS 144451-6923.5 | | | 342$^{[30]}$ | |
| s14 | V345 Nor | ASAS 160644-5202.5 | | | | bl |
| s15 | V934 Her | ASAS 170634+2358.3 | 44.08±0.17 | | | orb/pul? |
| s16 | Hen 3-1383 | ASAS 172031-3309.9 | | | | |
| s17 | V503 Her | ASAS 173641+2318.2 | 130±2 | | | ecl, pul |
| s23 | AS 280 | ASAS 180953-3319.7 | | | | bl, nc |
| s24 | AS 288 | ASAS 181248-2821.0 | | | | bl, nc |
| s25 | Hen 2-379 | ASAS 181617-2704.5 | | | | bl, nc |
| s27 | V850 Aql | ASAS 192335+0038.0 | | | | sat |
| s28 | Hen 2-442 | ASAS 193943+2629.5 | | | | sat, bl |

Legenda: 100d - light curve covers only 100 days, bl - object blended, fp - few points, nc - none conclusive, orb - light curve shows variations with orbital period, pul - light curve shows pulsations, sat - object saturated, fnt - object too faint, out - light curve shows outburst, ecl - eclipse-like minimum in light curve.

References: [1] Jorissen et al. 1998, [2] Dumm et al. 1998, [3] Fekel et al. 2000a, [4] Gromadzki et al. 2007a, [5] Schmutz et al. 1994, [6] Schild et al. 1996, [7] Van Winckel et al. 1994, [8] Smith et al. 1997, [9] Marchiano et al. 2008, [10] Fekel et al. 2007, [11] Fekel et al. 2008, [12] Fekel et al. 2010, [13] Brandi et al. 2009, [14] Lutz et al. 2010, [15] Fekel et al. 2001, [16] Mikolajewska et al. 2002, [17] Hoffleit 1970, [18] Fekel et al. 2000b, [19] Schild et al. 2001, [20] Schaefer 2009, [21] Brandi et al. 2005, [22] Munari et al. 2001a, [23] Munari 1992, [24] Brandi et al. 2006, [25] Munari & Jurdana-Sepić 2002, [26] Nussbaumer & Vogel 1996, [27] Arkhipova, et al. 2011, [28] Schmid et al. 1998, [29] Van Eck et al. 2000, [30] Menneken et al. 2008.
Table 2: Orbital ephemerides (references the same as in Table 1).

| No. | Name               | Ephemeris                               | Reference |
|-----|--------------------|------------------------------------------|-----------|
| 017 | V1261 Ori          | Min(V) = 2.4351990 + 640.5 × E          | [1]       |
| 023 | BX Mon             | Min(V) = 2449796 + 1259 × E             | [3]       |
| 024 | MWC 560            | Max(V) = 2448080 + 1931 × E             | [4]       |
| 031 | Hen 3-461          | Min(V) = 2452063 + 635 × E              |           |
| 033 | SY Mus             | Min(V) = 2452054 + 624.5 × E            | [5]       |
| 035 | RE Cru             | Min(V) = 2452034 + 325 × E              |           |
| 040 | Hen 3-863          | Min(V) = 2451721 + 1016 × E             |           |
| 043 | V840 Cen           | Min(V) = 2452061 + 792 × E              |           |
| 045 | RW Hya             | Min(V) = 2451738 + 370.3 × E            | [6]       |
| 046 | Hen 3-916          | Min(V) = 2452410 + 803 × E              |           |
| 050 | V417 Cen           | Min(V) = 2452613 + 1652 × E             |           |
| 051 | BD-21373           | Min(V) = 2451863 + 281.6 × E            |           |
| 054 | Hen 3-1103         | Max(V) = 2452211 + 698 × E              | [8]       |
| 055 | HD 330036          | Min(V) = 2451048 + 1678 × E             |           |
| 057 | T CrB              | Min(V) = 2447919 + 227.6 × E            | [3]       |
| 062 | QS Nor             | Min(V) = 2452024 + 244 × E              |           |
| 063 | Wray 15-1470       | Min(V) = 2451845 + 561 × E              |           |
| 065 | Hen 3-1213         | Min(V) = 2451806 + 514 × E              |           |
| 070 | HK Sco             | Min(V) = 2452023 + 488 × E              |           |
| 071 | CL Sco             | Min(V) = 2452018 + 626 × E              | [10]      |
| 073 | V445 Sco           | Min(V) = 2452641.5 + 1398 × E           | [11]      |
| 074 | Hen 3-1341         | Min(V) = 2451970 + 626 × E              |           |
| 075 | Hen 3-1342         | Min(V) = 2452287 + 562 × E              |           |
| 093 | AE Ara             | Min(V) = 2453449 + 803.4 × E            | [12]      |
| 101 | RS Oph             | Min(V) = 2451848 + 453.6 × E            | [13]      |
| 106 | Hen 2-294          | Min(I) = 2451961 + 393 × E              |           |
| 108 | B1 3-6             | Min(I) = 2451902 + 301 × E              |           |
| 114 | H 2-34             | Min(I) = 2451974 + 459 × E              |           |
| 117 | Ap 1-8             | Min(Bm) = 2448973 + 957 × E             |           |
| 118 | SS73 122           | Min(Bm/V) = 2446709 + 2409 × E          |           |
| 119 | AS 270             | Min(V) = 2451633 + 671 × E              | [10]      |
| 121 | SS73 129           | Min(V) = 2452220 + 536 × E              |           |
| 122 | Hen 3-1591         | Min(Bm/V) = 2451310 + 2350 × E          |           |
| 123 | V615 Sgr           | Min(V) = 2452168 + 657 × E              |           |
| 127 | AS281              | Min(Bm) = 2449021 + 533 × E             |           |
| 128 | V2506 Sgr          | Min(Bm) = 2448781 + 868 × E             |           |
| 130 | V343 Ser           | Min(V) = 2450724.7 + 450.5 × E          | [15]      |
| 131 | Y CrA              | Min(V) = 2454295 + 1619 × E             | [12]      |
| 132 | YY Her             | Min(V) = 2450686.2 + 589.5 × E          | [16]      |
| 133 | V2756 Sgr          | Min(V) = 2451894 + 480 × E              |           |
| 134 | FG Ser             | Min(V) = 2451665 + 633.5 × E            | [18]      |
| 135 | HD 319167          | Min(V) = 2451756 + 1744 × E             |           |
| 136 | Hen 2-374          | Min(Bm) = 2452968 + 820 × E             | [12]      |
| 139 | V2905 Sgr          | Max(V) = 2451630 + 508 × E              |           |
| 141 | Hen 3-1674         | Min(Bm/V) = 2449178 + 1004 × E          |           |
| 142 | AR Pav             | Min(V) = 2448139 + 604.5 × E            | [19]      |
| 143 | V3004 Sgr          | Min(V) = 2451439 + 426 × E              |           |
| 144 | V443 Her           | Min(V) = 2450197.3 + 599.4 × E          | [18]      |
| 147 | V4018 Sgr          | Min(V) = 2452129 + 513 × E              |           |
| 155 | AS 327             | Min(V) = 2451954 + 823 × E              |           |
| 156 | FN Sgr             | Min(V) = 2450270 + 568.3 × E            | [21]      |
| 160 | V1413 Aql          | Min(V) = 2446650 + 434.1 × E            | [23]      |
| 161 | NSV 11776          | Min(V) = 2451672 + 1625 × E             |           |
| 170 | Hen 3-1761         | Min(V) = 2451650 + 562 × E              | [24]      |
| 178 | SDHA 180           | Min(V) = 2451332 + 1494 × E             |           |
| 185 | AG Peg             | Min(V) = 2431667.5 + 816.5 × E          | [15]      |
| s11 | CD 27-8661         | Min(V) = 2452169 + 763.3 × E            | [29]      |
| s17 | V503 Her           | Min(V) = 2453145 + 1575 × E             |           |
Figure 2: ASAS light curves folded with orbital periods.
Figure 3: OGLE and MACHO light curves folded with orbital periods.
Figure 4: ASAS light curves folded with pulsation periods. In most cases, orbital variations were subtracted.
Figure 5: OGLE and MACHO light curves folded with pulsation periods. In most cases, orbital variations were subtracted.

4.1. Orbital periods

The orbitally related light changes in symbiotic binaries can be caused by: (i) reflection effect, (ii) ellipsoidal variations, (iii) eclipses, and (iv) periodic brightening caused by increasing of accretion rate in eccentric systems during the periastron passage. It is not obvious that long-period (>200 days) variations are caused by orbital motion. However, in favour of such an interpretation is fact that among 58 objects showing such changes, 24 systems have known orbital periods from previous photometric and spectroscopic studies. Most of these systems have also spectroscopic orbits determined from radial velocities of the cool component absorption features.

The main cause of orbital light curve modulation in our sample is reflection effect, observed in 37 light curves analysed for this study. However, in contrast to the classical case, in symbiotic stars the hot component radiation illuminates and partly ionizes the cold giant wind rather than its surface.

The light curves of several systems show more or less pronounced secondary minima, and their shape can be interpreted in terms of ellipsoidal changes in the red giant and variable nebular emission due to reflection effect. These are: V1261 Ori, Hen 3-863, RW Hya, BD-21 3873, T CrB, Hen 3-1341, Ap 1-8, Hen 2-374, YY Her, V1413 Aql and V934 Her. The ellipsoidal variability in RW Hya, BD-21 3873, T CrB and YY Her was reported and studied by different groups (Rutkowski et al. 2007, Smith et al. 1997, Belczyński & Mikołajewska 1998, and Mikołajewska et al. 2002, respectively) whereas in the remaining systems such variability has been detected for the first time. The ellipsoidal effect is dominating the V-band (ASAS) light curves of V1261 Ori, Hen 3-863, BD-21 3873, T CrB, i.e. systems whose hot
component have relatively low (as for a symbiotic star) luminosity, $\lesssim 100L_\odot$ or so, and their optical spectra are dominated by the cool giant. In the case of systems with more luminous hot component, the secondary minimum is partly veiled by the illumination effect (like e.g., RW Hya) and even completely obscured. The ellipsoidal changes also vanish during optical outbursts when strong blue, A/F-type, spectrum completely veils the red giant features in the optical range (Mikołajewska et al. 2003). For example, the near infrared light curves of RW Hya, SY Mus, and AR Pav are evidently ellipsoidal (Rutkowski et al. 2007) whereas the V light curves presented in this study show shallow secondary minimum only in RW Hya. The V light curve of SY Mus is dominated by illumination effect while in AR Pav a strong A/F-type shell is permanently present (Quiroga et al. 2002). Similarly, the OGLE/I light curve of Ap 1-8 shows ellipsoidal modulation, while the MACHO/$B_M$ light curve shows changes caused by reflection effect (Fig. 6).

![Figure 6: OGLE and MACHO light curves of Ap 1-8.](image)

Hen 3-1341 is very active. Its visual light curve covers an outburst associated with jets ejection (Munari et al. 2005) as well as quiescence state. Possible sinusoidal variations with a period of 626 days are visible during quiescence state (Fig. 7).

The ASAS light curve of YY Her covers the decline from its last outburst. The primary minimum is shifted, while the secondary one is barely visible. Formiggin and Leibowitz (2006) showed that $P_{\text{orb}} = 593.2$ days modulates the quiescent light curve of YY Her whereas a periodic oscillation with a shorter period of 551.4 days dominates the outburst light curve. Such a secondary periodicities, always $\approx 10 -$
20% shorter than the orbital period, are often observed in the outburst light curves of many symbiotic stars, and the nature of this behaviour is poorly understood (e.g. Mikołajewska 2003).

A weak secondary minimum may also be present in the ASAS light curve of V1413 Aql, and given its relatively short orbital period, it is very promising candidate to search for ellipsoidal changes at longer wavelengths.

V934 Her can be another possible ellipsoidal variable (it is one of the rare symbiotic systems hosting a neutron star). Although, it would require a relatively short orbital period (as for a symbiotic star), of \( \approx 44 \) days only. The nature of this variability is not clear and it could be caused by either the red giant pulsations or reflection effect. One should also mention that Masetti et al. (2002) and Galloway et al. (2002) found periodicity of 400 days based on broad-band X-ray data, and optical radial velocities, respectively. However, this period was not confirmed by analysis of longer duration X-ray light curves (Corbet et al. 2008). The ASAS light curves of V934 Her folded with periods of 44.08 and 22.04 days and corresponding power spectrum are plotted in Fig. 8.

Light curves of 15 systems show one or more sharp and deep minima which
may be caused by an eclipse. Among them, well known eclipsing systems (e.g. AR Pav and PU Vul) are present. In other cases the moment of minimum agrees fairly well with the time of spectroscopic conjunction (e.g. CD-43 14304). In the case of three objects (SS73 117, V3811 Sgr and V503 Her) it is not clear whether they are really eclipsing because their light curves show only one or two minima. The situation is much better in the case of Hen 3-863 and Hen 3-1674. The ASAS light curve of Hen 3-863 shows three minima (two primary and one secondary) and their overall shape is typical for an eclipsing binary. In the case of Hen 3-1674, the eclipse is confirmed by the spectrum available in the literature (Allen 1984, Medina Tanco & Steiner 1995, and Munari & Zwitter 2002). The eclipse of Hen 3-1674 is shown in Fig. 9. More examples of eclipses are shown in Fig. 10. The observed eclipses are summarized in Table 3. Eclipses of AS 269 and V4074 Sgr announced in Gromadzki et al. (2007b) have not been confirmed.

![Figure 9: Part of the MACHO light curve of Hen 3-1674 showing eclipse in July 1993 (≈JD 2 449 175). Open dots represent the measurements obtained in \( B_M \) filter, and filled dots in \( R_M \) filter.](image)

Two objects, BX Mon and CD-43 14304, show periodic brightenings related to the periastron passage according to their known spectroscopic orbits (Fekel et al. 2000a, Schmid et al. 1998). Light curves of these objects are shown in Fig. 11. The brightenings always happen a few hundred days after the periastron, and they are probably caused by enhanced accretion rate. In the case of BX Mon spectroscopic observations have confirmed enhancements in the hot component activity following the periastron passage (Anupama et al. 2012). Such a behaviour is also observed...
Figure 10: Examples of light curves showing eclipses.

Table 3: Symbiotic stars showing eclipses.

| No. | Name          | Observed minima (JD 2400000+) |
|-----|---------------|-------------------------------|
| 017 | V1261 Ori     | 54.352                        |
| 023 | BX Mon        | 52.022, 53.281, 54.540        |
| 033 | SY Mus        | 52.679, 54.552                |
| 040 | Hen 3-863     | 52.273, 53.261, 54.521        |
| 045 | RW Hya        | 52.108, 52.479, 52.849, 53.219, 53.960, 54.330, 54.700 |
| 115 | SS73 117      | 52.320                        |
| 134 | FG Ser        | 52.932, 53.566, 54.199        |
| 141 | Hen 3-1674    | 49.178                        |
| 142 | AR Pav        | 52.975, 53.580, 54.184, 54.789 |
| 146 | V3811 Sgr     | 50.980, 53.540                |
| 156 | FN Sgr        | 52.543, 53.112, 53.680, 54.248 |
| 160 | V1413 Aql     | 52.727, 53.162, 53.596        |
| 176 | PU Vul        | 44.550, 49.450, 54.350        |
| 182 | CD-43 14304   | 52.770, 53.570, 54.320        |
| s17 | V503 Her      | 53.145, 54.720                |
in visual light curve of MWC 560 (e.g. Gromadzki et al. 2007a). We think that the same effect can be responsible for periodic ‘outbursts’ present in light curves of V840 Cen, Hen 3-1103, and V2905 Sgr, although the orbital periods for these systems are shorter, of 500-800 days (see Fig. 2). In case of KX TrA, outburst in 2003 was also preceded by periastron passage (according orbital solution derived by Marchiano et al. 2008). However, AAVSO light curve of this object did not show brightenings after previous periastron passages (see Fig. 2 in Marchiano et al. 2008), what means last brightening had different nature that these in BX Mon or CD-43 14304 and it was most likely nova-like outburst typical for classical symbiotic stars.

The ASAS light curves of 8 systems: V417 Cen, HD 330036, Hen 3-1591, Y CrA, SS73 122, HD 319167, NSV 11776, and StHA 180 show a wave-like modulation with periods of \( \gtrsim 1500 \) days (see examples in Fig. 12). The first three of them are yellow D’-type systems. In the case of Y CrA, the similar period \( (P=1619 \) days) is present in the radial velocity curve of the cool giant, and the orbital solution (Fekel et al. 2010) indicates that the reflection effect may be responsible for optical light modulation (see Fig. 11). Spectroscopic observations of the remaining objects are needed to confirm whether these changes are caused by orbital motion or are due to some other reasons.

The distribution of orbital periods was recently discussed by Mikołajewska (2012). Above all, although the number of measured periods is continuously increasing (e.g. Miszalski, Mikołajewska & Udalski 2013 discovered 20 new symbiotic systems and found orbital period for 5 S-type systems), the main characteristics of their distribution remain practically the same as in earlier studies (e.g. Mikołajewska 2004, 2007). At the moment, simulations of the distribution of symbiotic stars over orbital periods with the population synthesis method (PSM) fail to reproduce the observed orbital period distribution of S-type symbiotic binaries. In particular, PSM produces the orbital period distribution in the range 200-6000 days with a maximum at \( \approx 1500 \) days, and up to 20 % of objects with periods below 1000 days (Lü et al. 2006) whereas the observed periods peak at \( \approx 600 \) days, and only \( \approx 30 \% \) systems have the orbital periods above 1000 days. This inconsistency cannot be accounted for by selection effects as suggested e.g., by Lü et al. (2006). At present, 87 systems have known orbital periods, which is about 54 % of the S-type symbiotic stars included in Belczyński et al. (2000) and Miszalski, Mikołajewska & Udalski (2013). Additionally, the amplitude of orbital modulation strongly depends on the intrinsically variable luminosity of the hot component, e.g. the amplitude of variation in visual light of RS Oph \( (i \approx 50^\circ, \ Brandi et al. 2009) \) varies from \( \approx 0.2 \) to 0.7 mag (Gromadzki et al. 2008). Assuming as an \( i \approx 40^\circ \) minimum orbital inclination, and the random distribution of orbital inclination angles, we estimate that we should be able to measure the orbital periods for \( \approx 65 \% \) of S-type symbiotic systems. Then, we already know about 83 % of measurable orbital periods and their distribution cannot be affected by any selec-
Figure 11: Examples of long-term variability in ASAS light curves of BX Mon, KX TrA, Y CrA and CD-43 14304. Arrows show moments of spectroscopic conjunctions (solid: inferior, and dashed: superior).
Figure 12: Examples of light curves showing modulation with long periods ($\gtrsim 1500$ days).

tion effects. Successful explanation of the origin of the orbital period distribution of S-type symbiotic binaries requires more advanced approach to mass transfer in these systems, and actually in any interacting binaries involving red giants (e.g. Posiadalowski & Mohamed 2007; Mikolajewska 2012).

Finally, in systems with eccentric orbits, brightening due to enhanced accretion rate near periastron can be observed regardless of the inclination. Such behaviour is observed in MWC 560 where orbital plane nearly coincides with the plane of the sky, as well as in BX Mon, which is an eclipsing binary. Symbiotic stars with longer orbital periods, $\gtrsim 1000$ days, tend to have eccentric orbits. Observing this kind of variability seems to be very promising and efficient way of deriving their orbital periods.

4.2. Pulsation periods

Light curves of 46 objects show, in addition to the long-term or/and orbital variations, short-term variations with time scales of 50-200 days most likely due to stellar pulsations of the cool giant component of the binary, what suggests that the red giants in these systems can be Semi-regular Variables (SRV), or OGLE Small Amplitude Red Giants (OSARG).

The semi-regular red giants are divided into two subtypes: SRa and SRb. Their basic properties and evolutionary status is described in detail in Kerschbaum & Hron (1992,1994,1996). In particular, they found that the SRa appear as intermediate objects between Miras and SRb in all aspects, including periods, amplitudes and mass loss rates. They also concluded that the SRa do not form a distinct class of variables, but are a mixture of ‘intrinsic’ Miras and SRb. The SRb split into
a 'blue' group with $P < 150$ days and no indication of circumstellar shells and a 'red' group with temperatures and mass loss rates comparable to Miras, but periods about half as long. They suggested that the 'red' and 'Mira' SRb are thermally pulsing AGB stars (Kerschbaum & Hron 1992). Wood et al. (1999) showed that SRV may obey the same P–L relation (sequence C) as Miras. They are located at the C and C’ sequences in the P–L diagram and pulsate in the fundamental mode and in the first overtone, respectively. The mass loss rate of these variables is around $10^{-7} M_\odot$ yr$^{-1}$ (Olofsson et al. 2002).

OSARG were first distinguished by Wray et al. (2004) in the Galactic bulge. They found $\approx 18000$ red objects, which show pulsation periods with $10 < P_{\text{puls}} < 100$ and the amplitude in the filter $I$ from 0.005 to 0.13. These objects obey different P–L relation than Miras and SRV. They are on A and B sequences, which are split into $a_1$, $a_2$, $a_3$, $a_4$, and $b_1$, $b_2$, $b_3$ by Soszyński et al. (2007). They pulsate in the radial modes, indexes represent the order of pulsation mode. Letter "a" means AGB objects, "b" means RGB objects. The P–L relations of $a_k$ ($k=1,2,3,4$) sequences extend above the tip of the red giant branch (TRGB), what means that objects located on these sequences are AGB stars. Whereas, the P–L relations of $b_k$ ($k=1,2,3$) sequences break off below TRGB, what means that objects located on these sequences are RGB stars (Soszyński et al. 2007). Pulsation periods of $b_k$ ($k=1,2,3$) objects are shorter than 70 days. Currently OSARG are the most common type of variable stars. Their number in the LMC, SMC and Galactic bulge is close 300,000 (Soszyński et al. 2009, 2011, 2013). Unfortunately, mass loss rates in these objects are poorly known.

It is difficult to determine what type of variables are cool giants in galactic symbiotic systems. Distance to most of them is not precisely estimated and we cannot construct for them proper period-luminosity plot. Sequences $a_1$ and $b_1$ blend with C’. Classification based on the amplitude of variation seems rather useless, mainly because we have observations in the $V$ filter and a contribution from the hot component in this band make amplitude smaller. Additionally, some pulsation periods are rather tentative due to quality of light curves and high activity of symbiotic systems. On the other hand, typical amplitude of pulsations of OSARG is smaller than scattering of points in ASAS light curves. Despite these difficulties, there is an argument, which indicates that a significant fraction of red giants in S-type symbiotic systems are AGB stars. Most of studied objects (30) show pulsation periods longer than 70 days, what means that these objects have occupied sequences $a_1$, $a_2$, $a_3$, C or C’ and they are AGB stars. They cannot develop dusty shell, like cool components in D-type systems, due to influence of nearby hot component. Objects showing pulsation periods in the range 50-70 days may belong to the $b_1$ or $b_2$ sequences, although they could be fainter members of $a_1$, $a_2$, $a_3$, C or C’ sequences. Fig. 13 shows the distribution of pulsation periods of cool components in studied symbiotic systems. More detailed investigations are needed to fully understand nature of cool companions in symbiotic systems.
Figure 13: Distribution of pulsation periods of cool components in symbiotic binaries.

It is worth mentioning that presence of pulsations has been also observed in five systems in Magellanic Clouds: SMC 1, LMC S147, LMC 1, LMC S63 and LMC N67 (Mikołajewska 2004, Kahabka 2004, Angeloni et al. 2013, Kato, Mikolajewska & Hachisu 2013). In all of these systems, red giants are AGB stars because they are brighter than TRGB and only LMC 1 is classified as D-type, others are classified as S-types.

4.3. Outbursts

In light curves of 15 systems an outburst is present. Typical duration of such phenomenon is a few years, and the amplitude is from 1 to 3.5 mag in $V$ filter. Such outbursts are common in classical symbiotic stars. Examples of light curves showing outbursts are plotted in Fig. 14. Objects showing outbursts are listed in Table 4.
Figure 14: Examples of light curves showing outbursts.
### Table 4: Observed outbursts.

| No. | Name      | Years       | Remarks         |
|-----|-----------|-------------|-----------------|
| 035 | RT Cru    | 1992-2001   | $V_{\text{max}} \approx 11$ mag |
| 068 | KX TrA    | 2003-2006   | $V_{\text{max}} \approx 10.5$ |
| 070 | HK Sco    | 2002-2005   | $V \approx 13.7 - 12$ mag |
| 071 | CL Sco    | 1996-2003, 2009-? | $V \approx 13.5 - 11$ mag |
| 074 | Hen 3-1341| 1998-2003   | $V \approx 13 - 11$ mag |
| 093 | AE Ara    | 2005-?      | $V_{\text{max}} \approx 11$ mag |
| 101 | RS Oph    | 2006        | $V_{\text{max}} \approx 5$ mag |
| 109 | B1 L      | 1998-2000   | $\Delta I \approx 1$ mag |
| 119 | AS 270    | 2001        | $V \approx 14.5 - 11.5$ mag |
| 132 | YY Her    | 2003        | $\Delta V \approx 1.5$ mag |
| 142 | AR Pav    | 1984-2003   |                 |
| 144 | V3804 Sgr | 2006        | $\Delta V \approx 1$ mag |
| 156 | FN Sgr    | 2007-?      | $\Delta V \approx 3$ mag |
| 159 | V919 Sgr  | 2005        | $V \approx 13.5 - 10.6$ mag |

### 5. Summary

In this paper we analysed 79 light curves of S and D’-type symbiotic systems available in ASAS, MACHO and OGLE databases. The light curves of 58 objects show variations with the orbital period. In most cases (37), these variations are caused by the reflection effect. The remaining objects display ellipsoid modulation and systems with eccentric orbits show brightening related to enhance accretion rate following the periastron passage. Eight systems show modulations with period of 1500-2500 days, most probably orbitally related but it may result from instability in accretion, as is the case of RS Oph (Gromadzki et al. 2008). It is difficult to establish nature of these variations without additional observations. The orbital periods of 34 S-type symbiotic systems were estimated for the first time, what increases the number of symbiotic stars with known orbital periods by about 64%. Derived orbital ephemeris cloud be very helpful for planning radial velocities campaigns.

Light curves of 46 objects show, in addition to the long-term or/and orbital variations, short-term variations with time scales of 50-200 days most likely due to stellar pulsations of the cool giant component of the binary which suggests that the red giants in these systems can be SRV or OSARG. Most of these objects (30) show pulsation periods longer than 70 days, what suggests that they are most likely AGB stars.

Light curves of 15 systems show one or more sharp and deep minima which may be caused by eclipses. Outbursts of hot companions are observed in 15 systems.

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REFERENCES

Alcock, et al. 1992, in "Robotic Telescopes in the 1990s", ASP Conf. Ser. No. 34, ed. A.V. Fillippenko, p.193.
Allen, D.A. 1982, in "The nature of symbiotic stars", IAU Coll. Vol. 95, Astrophysics and Space Science Library, eds. M. Friedjung & R. Viotti, p.27.
Allen, D.A 1984, Proceedings of the Astronomical Society of Australia, 5, 369.
Angeloni, R., Ferreira Lopes, C., Masetti, N., et al. 2013, accepted in MNRAS, arXiv:1309.7345.
Anupama, G.C., Kamath, U.S., Gurugubelli, U.K., and Mikolajewska, J. 2012, Baltic Astronomy, 21, 172.
Arkhipova, V., Esipov, V., Ikonnikova, N., et al. 2011, Astronomy Letters, 37, 343.
Belczyński, K., Mikolajewska, J. 1998, MNRAS, 296, 77.
Belczyński, K., Mikolajewska, J., Munari, U., Ivison, R. J. and Friedjung, M. 2000, A&A S. 146, 407.
Brandi, E., Mikolajewska, J., Quiroga, C., et al. 2005, A&A, 440, 239.
Brandi, E., García, L.G., Quiroga, C., and Ferrer, O.E. 2006, Boletín de la Asociacion Argentina de Astronomia La Plata Argentina, 49, 132.
Brandi, E., Quiroga, C., Mikolajewska, J., Ferrer, O.E., and García, L.G. 2009, A&A , 497, 815.
Corbet, R., Sokoloski, J., Mukai, K., et al. 2008, ApJ, 675, 1424.
Dumm, T., Mürset, U., Nussbaumer, H., et al. 1998, A&A, 336, 637.
Fekel, F.C., Joyce, R.R., Hinkle, K.H., and Skrutskie, M.F. 2000a, AJ, 119, 1375.
Fekel, F.C., Hinkle, K.H., Joyce, R.R., and Skrutskie, M.F. 2000b, AJ, 120, 3255.
Fekel, F.C., Hinkle, K.H., Joyce, R.R. and Skrutskie, M.F. 2001, AJ, 121, 2219.
Fekel, F.C., Hinkle, K.H., and Joyce, R.R. 2003, in "Symbiotic Stars Probing Stellar Evolution", ASP Conference Proceedings, eds. R.L.M. Corradi, J. Mikolajewska and T.J. Mahoney, p.113.
Fekel, F.C., Hinkle, K.H., Joyce, R.R., Wood, P.R., and Lebzelter, T. 2007, AJ, 133, 17.
Fekel, F.C., Hinkle, K.H., Joyce, R.R., Wood, P.R., and Howarth, I.D. 2008, AJ, 136, 146.
Fekel, F.C., Hinkle, K.H., Joyce, R.R., and Wood, P.R. 2010, AJ, 139, 1315.
Formigini, L. and Leibowitz, E. 2006, MNRAS, 372, 1325.
Galloway, D., Sokoloski, J., and Kenyon, S. 2002, ApJ, 580, 1065.
Gromadzki, M., Mikolajewska, J., Whitelock, P.A., and Marang, F. 2007a, A&A , 463, 703.
Gromadzki, M., Mikolajewska, J., Borawska, M., and Lednicka, A. 2007b, in "Evolution and chemistry of symbiotic star binary post-AGB and related objects", eds. J. Mikolajewska & R. Szczerba, Baltic Astronomy, 16, 37.
Gromadzki, M., Mikolajewska, J., and Lachowicz, P. 2008, in “RS Ophiuchi (2006) and the recurrent nova phenomenon”, ASP Conference Series, Vol. 401, eds. A. Evans et al., p.219.
Hoffleit, D. 1970, IBVS, 469, 1.
Jorissen, A., Van Eck, S., Mayor, M., and Udry, S. 1998, A&A , 332, 877.
Kahabka, P. 2004, A&A , 416, 57.
Kato, M., Hachisu, I. Mikolajewska, J. 2013, ApJ, 763, 5.
Kerschbaum, F. and Hron, J. 1992, A&A , 263, 97.
Kerschbaum, F. and Hron, J. 1994, A&A S, 106, 397.
Kerschbaum, F. and Hron, J. 1996, A&A, 308, 489.
Lü, G., Yungelson, L., and Han, Z. 2006, MNRAS, 372, 1389.
Lutz, J., Fraser, O., McKeever, J., and Tugaga, D. 2010, PASP, 122, 524.
Marchiano, P., Brandi, E., Quiroga, C., et al. 2008, Boletín de la Asociación Argentina de Astronomía, 51, 117.
Masetti, N., Dal Fiume, D., Cusumano, G., et al. 2002, A&A, 382, 104.
Medina Tanco, G., and Steiner, J. 1995, AJ, 109, 1770.
Mennickent, R., Greiner, J., Arenas, J., et al. 2008, MNRAS, 383, 845.
Mikołajewska, J. 2001, in "Small-Telescope Astronomy on Global Scale", eds. B. Paczyński, W.P. Chen & C. Lemme, ASP Conf. Ser. 246, p. 167.
Mikołajewska, J. 2003, in "Symbiotic Stars Probing Stellar Evolution", ASP Conference Proceedings, eds. R.L.M. Corradi, J. Mikołajewska and T.J. Mahoney, p.9.
Mikołajewska, J. 2007, in "Evolution and chemistry of symbiotic star, binary post-AGB and related objects", eds. J. Mikołajewska & R. Szczepańska, Baltic Astronomy, 16, 1.
Mikołajewska, J. 2004, in "Compact Binaries in the Galaxy and Beyond", IAU Coll. No. 194, ed. G. Tovmassian & E. Sion, Revista Mexicana de Astronomía y Astrofísica, Vol. 20, p.33.
Mikołajewska, J. 2012, Baltic Astronomy, 21, 5.
Mikołajewska, J., Brandi, S., Hack, W., et al. 1999, MNRAS, 305, 190.
Mikołajewska, J., Kolotilov, E.A., Shugarov, S.Y., and Yudin, B.F. 2002, A&A, 387, 139.
Mikołajewska, J., Kolotilov, E.A., Shugarov, S.Y., Tatarnikova, A.A., and Yudin, B.F. 2003, in "Symbiotic Stars Probing Stellar Evolution", ASP Conference Proceedings, eds. R.L.M. Corradi, J. Mikołajewska and T.J. Mahoney, p.151.
Miszalski, B., Mikołajewska, J., & Udalski, A. 2013, MNRAS, 432, 3186.
Munari, U. 1992, A&A, 257, 163.
Munari, U., Jurdana-Sepić, R., and Moro, D. 2001a, A&A, 370, 503.
Munari, U., and Jurdana-Sepić, R. 2002, A&A, 386, 237.
Munari, U., and Zwitter, T. 2002, A&A, 383, 188.
Munari, U., Siviero, A., & Henden, A. 2005, MNRAS, 360, 1257.
Nussbaumer, H. and Vogel, M. 1996, A&A, 307, 470.
Olofsson, H., González Delgado, D., Kerschbaum, F., and Schöier, F. 2002, A&A, 391, 1053.
Podsiadlowski, P., and Mohamed, S. 2007, in "Evolution and chemistry of symbiotic star, binary post-AGB and related objects", eds. J. Mikołajewska & R. Szczepańska, Baltic Astronomy, 16, 26.
Pojmański, G. 2002, Acta Astron., 52, 397.
Press, W.H. and Rybicki, G.B. 1989, ApJ, 338, 277.
Quiroga, C., Mikołajewska, J., Brandi, E., Ferrer, O. and García, L. 2002, A&A, 387, 139.
Rutkowski, A., Mikołajewska, J., and Whitelock, P.A 2007, in "Evolution and chemistry of symbiotic star, binary post-AGB and related objects", eds. J. Mikołajewska & R. Szczepańska, Baltic Astronomy, 16, 49.
Schaefer, B.E. 2009, ApJ, 697, 721.
Schilizzi, R.T., and Mluiri, W. 1996, A&A, 306, 477.
Schilizzi, R.T., and Mluiri, W. 2001, A&A, 366, 972.
Schmid, H.M., Dumont, T., Mürset, U., et al. 2001, A&A, 368, 819.
Smith, V.V., Cunha, K., Jorissen, A., and Boffin, H.M. 1997, A&A, 324, 97.
Soszyński, I., Dziembowski, W., Udalski, A., et al. 2007, Acta Astron., 57, 201.
Soszyński, I., Udalski, A., Szymański, M., et al. 2009, Acta Astron., 59, 239.
Soszyński, I., Udalski, A., Szymański, M., et al. 2011, Acta Astron., 61, 217.
Soszyński, I., Udalski, A., Szymański, M., et al. 2013, Acta Astron., 63, 21.
Udalski, A. 2003, Acta Astron., 53, 291.
Udalski, A., Kubiak, M., and Szymański, M. 1997, Acta Astron., 47, 319.
Van Eck, S., Jorissen, A., Udry, S., et al. 2000, A&A S, 145, 51.
Van Winckel, H., Schwarz, H.E., Duerbeck, H.W., and Fuhrmann, B. 1994, A&A, 285, 241.
Whitelock, P.A. 1987, PASP, 99, 617.
Whitelock, P.A. 2003, in "Symbiotic Stars Probing Stellar Evolution", ASP Conference Proceedings, eds. R.L.M. Corradi, J. Mikolajewska and T.J. Mahoney, p.41.
Wood, P.R., Alcock, C., Allsman, R.A., et al. 1999, in IAU Symposium, Vol. 191, Asymptotic Giant Branch Stars, eds. T. Le Bertre, A. Lebre, and C. Waelkens, p.151.
Wray, J., Eyer, L., and Paczyński, B. 2004, MNRAS, 349, 1059.