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$UBV(RI)_C$ photometric comparison sequences for symbiotic stars. II.*

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Abstract. We present accurate $UBV(RI)_C$ photometric sequences for an additional 20 symbiotic stars. As for the 20 targets of Paper I, the sequences extend over wide brightness and color ranges, and are suited to cover both quiescence and outburst phases. The sequences are intended to assist both present time photometry as well as measurement of photographic plates from historical archives.

Key words. catalogs – binaries: symbiotic

1. Introduction

In Paper I (Henden & Munari 2000) we discussed the need for extended, accurate and homogeneous photometric sequences around symbiotic stars and how their lack has contributed to our currently poor photometric knowledge of these interacting binaries. We also reviewed the basic types of variability for symbiotic stars and their causes, and provided $UBV(RI)_C$ sequences for a first sample of 20 objects.

This Paper II presents accurate photometric comparison sequences for an additional 20 symbiotic stars using observing strategies, reduction methodologies and presentation layouts strictly similar to those of Paper I (to which the reader is referred for all details). The sequences are intended to allow a general observer to capture on a single CCD frame or to have in the same eyepiece field of view when inspecting archival photographic plates: (*a*) enough stars to cover the whole range of known or expected variability for the given symbiotic star, (*b*) stars of enough different colors to be able to calibrate the instrumental color equations and therefore reduce to the standard $UBV(RI)_C$ system the collected data, and (*c*) stars well separated from surrounding ones to avoid blending at all but the shortest telescope focal lengths. As for Paper I, all observations have been made with the 1.0-m Ritchey-Chrétien telescope of the U. S. Naval Observatory, Flagstaff Station with a Tektronix/SITe 1024x1024 thinned, backside–illuminated CCD and Johnson *UBV* and Kron–Cousins *RI* filters.

The sequences around the 20 symbiotic stars of Paper I have already been used by Munari et al. (2001a) and Jurdana & Munari (2001) to investigate their long term photometric behavior on the rich collection of Asiago historical photographic plates. With other observatories with historical plate archives joining the effort, the community could soon assemble complete, century-long lightcurves for a significant fraction of the symbiotic stars. Given their complex, non-periodic and usually slow photometric evolution with major outbursts appearing erratically and lasting for years or decades, the understanding of the symbiotic stars and their role in the general astrophysical context cannot progress much without a detailed knowledge of their photometric histories and habits.

2. The photometric sequences

The program symbiotic stars are listed in Table 1. An average of 11 stars around each program star have been selected to form the comparison sequences, which are given in Table 2. The stars included in the sequences have been chosen and ordered on the basis of the B band magnitude, because the latter is the band closest to the m_{pg} of the historical photographic observations and is the better suited to investigate the variability of symbiotic stars (cf. Kenyon 1986 and Paper I). The stars included in the

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* Tables 2 and 3 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via
http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/372/145
or via the personal HomePage
http://ulisse.pd.astro.it/symbio_comp_seq/

Table 1. List of program symbiotic stars. The coordinates for the symbiotic stars are from our observations (equinox J2000.0, mean epoch 2000.3). The e_α and e_δ columns list the errors in milliarcsec for right ascension and declination, respectively. l and b are the galactic coordinates. Columns 11 and 12 list the coordinates of the field centers in Fig. 1 (zoomed-in 6 × 6 arcmin fields), or in Fig. 2 when only the larger ones (11×11 arcmin) are available. The last column indicates which one of the *narrow* (i.e. 6.0 × 6.0 arcmin) or *wide* (i.e. 11.4 × 11.4 arcmin) fields are given for the given program star in Figs. 1 and 2.

name		*star coordinates*								*field center*		fig.
		α (J2000.0)	δ	α (J2000.0)	δ	e_α	e_δ	$l(°)$	$b(°)$	α (J2000.0)	δ	
V471 Per	M 1-2	29.706997	+52.896828	01 58 49.679	+52 53 48.58	26	10	133.12	–8.64	29.6949	+52.9189	n
GH Gem		106.053261	+12.059547	07 04 12.783	+12 03 34.37	11	19	203.57	+8.23	106.0525	+12.0568	n
BX Mon	AS 150	111.344833	–3.597369	07 25 22.760	–03 35 50.53	10	15	220.04	+5.88	111.3450	–3.5974	n,w
V694 Mon	MWC 560	111.463737	–7.735578	07 25 51.297	–07 44 08.08	25	15	223.76	+4.05	111.4460	–7.7380	w
TX CVn	BD+37.2318	191.175437	+36.764117	12 44 42.104	+36 45 50.82	222	90	130.93	+80.26	191.0900	+36.7144	w
IV Vir	BD–21.3873	214.142899	–21.763964	14 16 34.296	–21 45 50.27	0	4	327.88	+36.95	214.1370	–21.8900	w
UKS Ce1		243.873331	–22.204406	16 15 29.599	–22 12 15.86	72	132	353.02	+20.25	243.8810	–22.1700	n
V503 Her		264.168671	+23.303352	17 36 40.481	+23 18 12.07	21	29	47.00	+26.23	264.1040	+23.2453	w
UU Ser	AS 327	265.660889	–15.412530	17 42 38.613	–15 24 45.11	48	58	11.23	+7.62	265.6610	–15.4130	n
DT Ser		270.467092	–1.438460	18 01 52.102	–01 26 18.46	57	168	25.92	+10.34	270.4700	–1.4425	n
YY Her	AS 297	273.642548	20.989248	18 14 34.212	+20 59 21.29	15	36	48.14	+17.24	273.6320	+21.0005	n,w
StHα 149		274.732819	+27.441065	18 18 55.877	+27 26 27.83	24	11	54.81	+18.77	274.7440	+27.4200	w
DQ Ser		281.165192	+5.047093	18 44 39.646	+05 02 49.53	0	15	36.67	+3.81	281.1710	+5.0652	n
V4368 Sgr	Wakuda's	283.667908	–19.699884	18 54 40.298	–19 41 59.58	63	18	15.59	–9.53	283.6630	–19.7010	n
NSV 11776		287.481079	–2.793644	19 09 55.459	–02 47 37.12	48	26	32.55	–5.39	287.5100	–2.7720	n
StHα 164		292.173553	–6.064318	19 28 41.653	–06 03 51.54	22	19	31.73	–11.03	292.1395	–6.0682	n
StHα 180		309.835846	–5.287825	20 39 20.603	–05 17 16.17	16	37	40.89	–26.36	309.9140	–5.3413	w
ER Del	BD+8.4506	310.693756	+8.687244	20 42 46.501	+08 41 14.08	22	36	54.46	–20.00	310.6560	+8.6738	w
StHα 190	TYC 547 712 1	325.437073	+2.731861	21 41 44.898	+02 43 54.70	0	36	58.42	–35.43	325.3711	+2.7933	w
LL Cas	K 4-46	347.332520	+54.751438	23 09 19.805	+54 45 05.18	29	6	108.47	–5.23	347.2700	+54.7900	n

comparison sequences have been checked on at least three different nights for variability (cf. Col. N of Table 2).

For 10 objects (V471 Per, GH Gem, UKS Ce1, UU Ser, DT Ser, DQ Ser, V4368 Sgr, NSV 11776, StHα 164 and LL Cas) the symbiotic star and the comparison sequence both lie inside a 6.0×6.0 arcmin field (which match in dimension the Allen 1984 finding charts) and are plotted in Fig. 1. For 8 brighter objects (V694 Mon, TX CVn, IV Vir, V503 Her, ER Del, StHα 149, StHα 180 and StHα 190) the comparison sequences are distributed over a 11.4×11.4 arcmin area and are presented in Fig. 2. The remaining two program stars (BX Mon and YY Her) are hybrid cases having their fainter comparison stars identified in Fig. 1 and the brighter, more distant ones in Fig. 2.

Finally, for three objects (TX CVn, ER Del and StHα 190) there are no stars in the explored 11.4× 11.4 arcmin fields brighter than the symbiotic star itself (particularly important for estimates on photographic plates). For these program stars we have selected from the Hipparcos/Tycho Catalogue suitable, nearby and non-variable stars to complement our comparison sequences. The selected Hipparcos/Tycho stars are listed in Table 3, where their B_T, V_T magnitudes have been transformed to the standard Johnson's UBV system following the transformation equations provided in the explanatory notes of the Hipparcos/Tycho Catalogue:

$$V_J = V_T - 0.090 \times (B-T)_T \tag{1}$$

$$(B-V)_J = 0.850 \times (B-V)_T. \tag{2}$$

For sake of completeness we have also reported the U, R_C and I_C values as estimated from the observed $B-V$ color using the extensively calibrated relations of Caldwell et al. (1993). These transformation relations between colors in the $UBV(RI)_C$ system gives accurate results *provided* that the stars belong to the solar neighborhood population, the reddening is not large and the luminosity class is roughly known. We have assumed all the selected Tycho objects to be nearby main sequence stars. Thus, the U, R_C and I_C magnitudes reported in the last three columns of Table 3 may be considered as guidelines useful for estimating photographic plates.

3. Notes on individual symbiotic stars

A few individual notes follow on the basic photometric behavior of the program symbiotic stars. They are intended as simple guidelines for observers planning an observational campaign and cannot by any means be considered as an exhaustive review. A collected history of many symbiotic stars and a compilation of photometric information available in literature has been presented by Kenyon (1983, 1986).

While calibrating the photometric comparison sequences for this paper we have also collected data on the program symbiotic stars. These $UBV(RI)_C$ data will be presented and discussed elsewhere together with similar data for more than 130 symbiotic stars observed from ESO and Asiago. From such a $UBV(RI)_C$ survey of symbiotic stars (hereafter indicated as MHZ: Munari, Henden and Zwitter, in preparation), we report in the following average V and $B-V$ values for the year 2000 for the reader's benefit. Another large multi-epoch $UBV(RI)_C$ and $JHKL$ photometric survey has been presented by Munari et al. (1992).

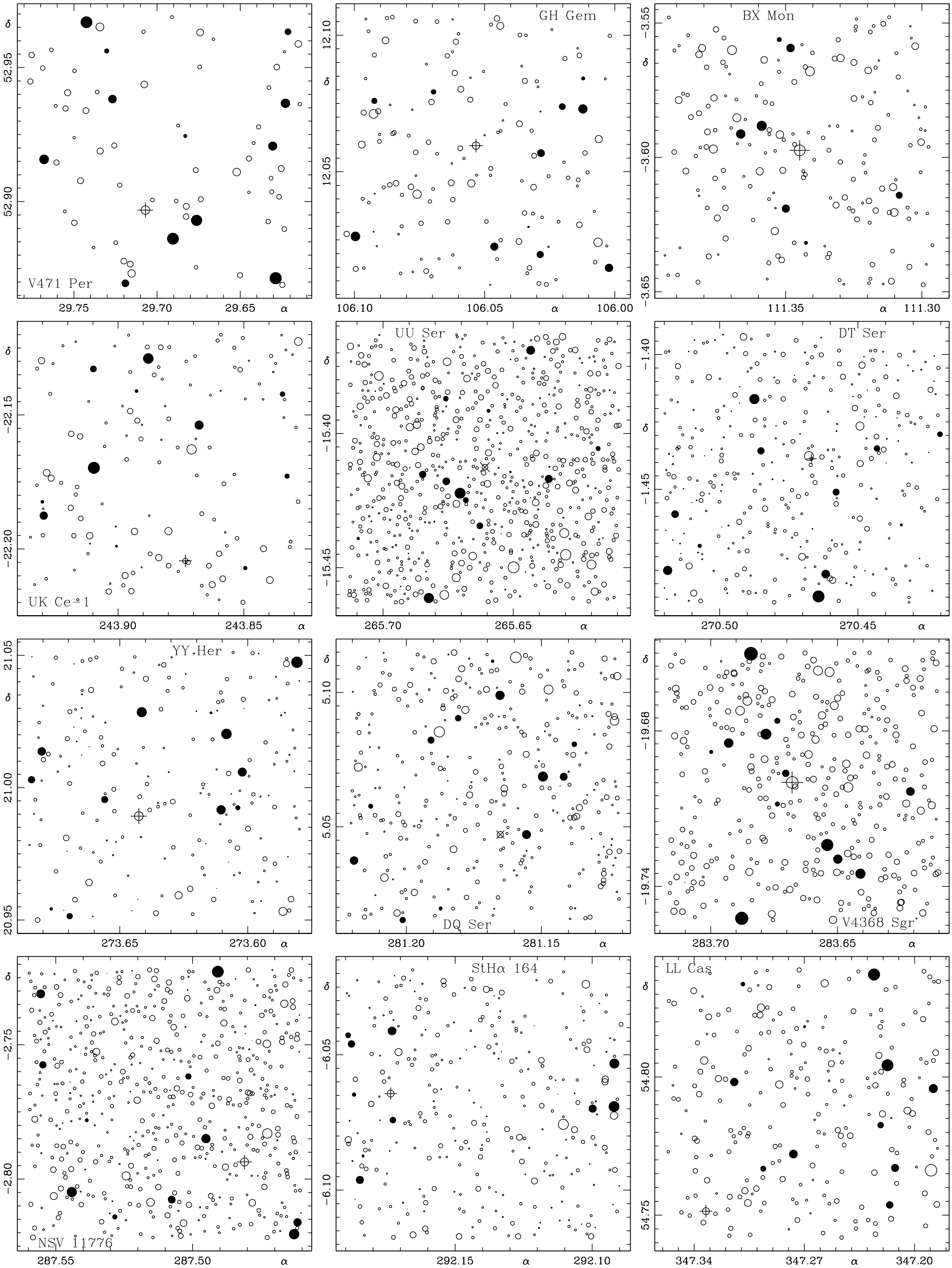

Fig. 1. Finding charts for the $UBV(RI)_C$ comparison photometric sequence around the program symbiotic stars. The fields are in the same order as in Table 1. North is up and East to the left, with an imaged field of view of 6.0×6.0 arcmin and a 6.6×6.6 coordinate grid. Stars are plotted as open circles of diameter proportional to the brightness in the V band. The stars making up the photometric sequence (see Table 2) are plotted as filled circles.

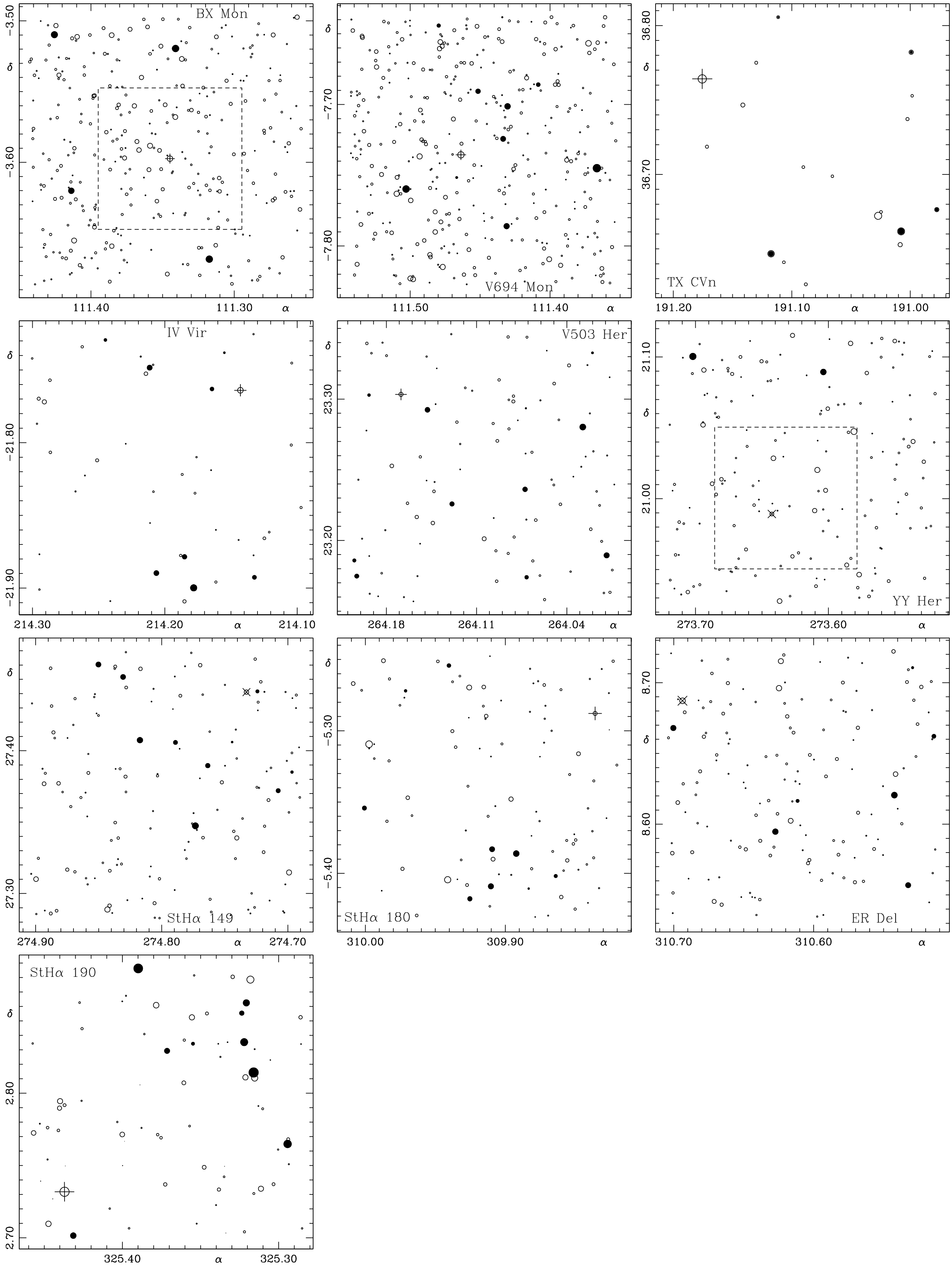

Fig. 2. Several of program symbiotic stars reach maximum magnitudes which impose looking for suitably bright comparison stars over a wider field. The symbols are the same as in Fig. 1, with an imaged field of view of about 11.4 × 11.4 arcmin and a 12 × 12 arcmin coordinate grid. The zoomed-in 6.0 × 6.0 arcmin for BX Mon and YY Her presented in Fig. 1 is outlined by a dashed square.

V471 Per. Discovery and numbering of variable stars in the Perseus constellation has not yet progressed far enough to reach entry *V741* Per with which this variable has been erroneously confused so frequently in literature, probably because of a mis-print in the Allen (1984) catalogue of symbiotic stars.

There are not much informations available on the photometric behavior of the system, which is usually observed around $V = 13.0/13.4$ and $B-V = +0.90/+1.00$. A moderate activity phase was observed in the 1990s, when on 1992 the object started a slow rise reaching $V = 12.4$ in 1994–95 and declined to $V = 13.3/13.4$ by 1996. The orbital period is unknown. MHZ lists $V = 13.10$ and $B-V = +1.00$.

GH Gem. Proposed by Kenyon (1986) as a possible symbiotic star, it has been observed by amateurs since then. VSNET and VSOLJ databases show the star stable at $V \sim 12.4$ from 1986 to 1990, when the star entered a gradual brightness decrease to $V \sim 13.8$ (reached by late 1993) and recovering to $V \sim 12.9$ by 1995. Descending slowly to $V \sim 13.2$ by 1999, in early 2000 it rapidly dropped to $V \sim 14.0$. Not much else is known about the photometric behavior of this star. MHZ reports $V = 14.01$ and $B-V = +1.00$. A spectrum for GH Gem from the 3200–9100 spectral atlas of symbiotic stars of Munari & Zwitter (**?**) show the continuum of a K-type giant with a weak Hα in emission.

BX Mon. Its orbital period is around 1400 days (Mayall 1940; Dumm et al. 1998). The lightcurve is varied, with relatively quite phases ($V \sim 12$) interspersed with periods of rapid and large variability ($13.0 \leq V \leq 10.2$). A fast rise, large amplitude event occurred in 1999, when BX Mon rose to $V = 9.9$ in a pattern resembling an outburst. The photometric behavior of this bright object remain poorly known and understood. It could be an eclipsing object according to Kenyon (1986). MHZ reports $B = 12.36$ and $B-V = +1.13$.

V694 Mon. The object attracted much attention when hugely blushifted absorption components (up to –6000 km s^{-1}, Tomov et al. 1990) were discovered to flank the emission line spectrum during the 1990 bright phase, when the star rose to $B \sim 9.5$ mag. Doroshenko et al. (1993) have discovered a $\Delta B \sim 0.8$ mag sinusoidal variation that they attribute to manifestations of a reflection effect following the ephemeris:

$$T(\mathrm{min}) = 2437455 \ + \ 1930 \times E. \tag{3}$$

The photometric behavior of V694 Mon over the last century has been quite active, spanning a range of ∼4 mag. The whole photometric history is covered by Luthardt (1991), Doroshenko et al. (1993) and Tomov et al. (1996). V694 Mon is well known for its rapid spectral variability, jet ejection and quasi-periodic flickering behavior (e.g. Michalitsianos et al. 1993; Tomov et al. 1995). MHZ lists $V = 10.81$ and $B-V = +0.45$.

TX CVn. This bright, isolated object has a relatively flat quiescence at $V \sim 10$. Moderate amplitude outbursts have been reported for 1920 (7 years to return to quiescence), 1945 (4 years duration), 1952, 1962 and 1986 (4 years rising, 5 years descent). At maximum the object may reach $V \sim 8$ mag. MHZ reports $V = 10.10$ and $B-V = +0.69$ (it is worth noticing that such a moderate $B-V$ color suggests that the zero point of the m_{pg} magnitude scale adopted by Mumford (1956) could be too faint by 0.7 mag compared to modern B values). Apart from the frequent outbursts, not much is known about the other photometric properties of TX CVn. Kenyon & Garcia (1989) have spectroscopically determined an orbital period of 199 days, the shortest known among symbiotic stars.

IV Vir. The orbitally modulated lightcurve ($P = 282$ days) of this bright symbiotic star ($V \sim 10.8$) is quite interesting: at longer wavelengths it is dominated by the ellipsoidal distortion of the cool giant filling its Roche lobe ($\Delta y = 0.15$ mag, with the classical pattern of two-maxima/two-minima per period; Niehues et al. 1992), while at shorter wavelengths the reflection effect takes over ($\Delta u = 1.6$ mag, with a sinusoidal pattern; Smith et al. 1997). The ephemeris for maxima in u is

$$T(\mathrm{max}) = 2449158 \ + \ 282 \times E. \tag{4}$$

The historical lightcurve and occurrence of past outbursts are unknown. MHZ lists $V = 10.71$ and $B-V = +1.41$.

UKS Ce1. The photometric properties and history of this carbon symbiotic stars are unknown. MHZ reports $V = 15.89$ and $B-V = +1.88$. A field star of similar brightness lies 5.9 arcsec from UKS Ce1 toward the SSW, at $\alpha = 243.871767$ (± 0.055 arcsec) and $\delta = -22.205167$ (± 0.177 arcsec), with magnitudes $V = 16.732$ (± 0.023), $B-V = +0.840$ (± 0.033), $U-B = +0.286$ (± 0.045), $V-R = +0.606$ (± 0.030) and $R-I = +0.482$ (± 0.042).

V503 Her. In the GCVS it is reported as a long period variable varying between $14.4 \leq B \leq 13.1$. Kenyon (1986) suggested its possible symbiotic nature but Bond (1978) and Munari & Zwitter (2001) observed an early M spectrum without emission lines, so its nature remains unclear. The VSOLJ data for 1988-1990 shows a relatively constant brightness at $V = 12.3$, with a slightly brighter phase at $V = 11.7$ in 1987 and a few doubtful reports about very faint states. The more recent VSNET lightcurve reports a $V \geq 14$ in 1997 and 1999, $V \sim 12.3$ in 1998 and $V \sim 12.7$ in 2000. MHZ lists $V = 12.67$ and $B-V = +1.28$.

UU Her. After the initial discovery by Reinmuth (1926) reporting the object to vary between $16.0 \leq m_{\mathrm{pg}} \leq 14.6$, not much else has appeared in literature. The photometric properties of this symbiotic star remain essentially unknown. MHZ gives $V = 15.47$ and $B-V = +1.79$.

DT Ser. This is an interesting case. The GCVS lists the variability range as $13.9 \leq m_{\mathrm{pg}} \leq 13.2$. Cieslinski et al. (1997) have shown that the symbiotic star is indeed a faint star ($B = 15.91$, $V = 15.40$) about 5 arcsec from a much brighter field star (that we have measured at $B = 13.550 \pm 0.003$, $V = 12.772 \pm 0.014$, $U-B = +0.109 \pm 0.004$, $V-R = +0.462 \pm 0.017$ and $R-I = 0.475 \pm 0.006$). The $B = 13.55$ of the nearby field star (not variable between the three observations we have obtained in separate nights) well matches the mean brightness of DT Ser listed in the GCVS. Thus, we believe that GCVS data refer to the combined light of (a) the much brighter, probably not variable field star, and (b) the faint, nearby symbiotic star that cannot be easily resolved under normal seeing conditions and with small telescopes. If the nearby field star is not itself variable, than DT Ser must vary by a large amount to account for the observed $\Delta m_{\rm pg} = 0.7$ mag, as if undergoing outbursts, and indeed the slow, long term variability exhibited by the pair combined light in the VSOLJ data (up-and-down time of ~8 years) could support this interpretation. MHZ lists $V = 16.23$ and $B - V = +0.37$.

YY Her. The complete photometric history of YY Her over 1890–1996 has been reconstructed by Munari et al. (1997). The quiescent lightcurve (at $V = 13.2$) is modulated by a $\Delta V = 0.3$ sinusoidal reflection effect, with minima given by the ephemeris

$$T(\min) = 2448945(\pm 10) \; + \; 590(\pm 3) \times E. \quad (5)$$

YY Her underwent outbursts in 1914–19, 1930–33, 1981–82 and 1993–96 with additional bright phases in 1890, 1903, 1942, 1954, 1965 and 1974. Each outburst has its own lightcurve, different from the others. A few enigmatic brightness drops brought the star down to $V = 14.8$. MHZ gives $V = 12.93$ and $B - V = +1.38$.

StHα 149. In spite of its brightness (MHZ lists $V = 12.06$ and $B-V = +1.55$), it is photometrically unknown.

DQ Ser. This moderately bright symbiotic star has been so far largely ignored by observers and its photometric properties are unknown. The GCVS gives a variability range $16.0 \le m_{\rm pg} \le 13.9$. Cieslinski et al. (1997) list $V = 14.5$ and $B - V = +1.23$, while MHZ reports $V = 14.94$ and $B - V = +1.34$.

V4368 Sgr. This probable symbiotic nova was discovered at $V = 10.7$ in 1994 by M. Wakuda. The progenitor is not visible in ESO/SERC photographic atlas (limiting magnitude ~21.5), and searches in the Harvard and Sonnerberg plate archives have failed to reveal anything at this position since the earliest images obtained in 1888 (Grebel et al. 1994; Hazen 1994). Since then the object has remained close to maximum brightness, in a photometric and spectroscopic pattern reminiscent of PU Vul, another symbiotic nova (cf. Grebel et al. 1994; Bragaglia et al. 1995). According to the VSOLJ database V4368 Sgr has slowly risen to $V = 10.2$ by 1997 and descent to $V = 10.5$ by 1999. MHZ reports $V = 10.57$ and $B - V = +0.63$.

NSV 11776. Scanty photometric information exists for this relatively bright symbiotic star. Cieslinski et al. (1994) reported about $UBV(RI)_C$ photometry secured in 1991–1992 that did not revealed variability or the presence of flickering activity. MHZ lists $V = 13.47$ and $B - V = +0.92$, which are identical to the mean values $V = 13.46$ $B - V = +0.92$ of Cieslinski et al. for 1991–92, which suggests limited variability for NSV 11776. Such a tight photometric stability is surprising in view of the very intense, high ionization emission lines indicating the presence of a very hot and luminous accreting white dwarf in the system.

StHα 164. The photometric history, type of variability, presence of outbursts and orbital period are unknown. MHZ reports $B = 14.48$ and $B - V = +2.03$.

StHα 180. Another example of a bright symbiotic star completely unknown in its photometric properties. MHZ lists $V = 12.68$ and $B - V = +1.40$.

ER Del. ER Del is one of the rare symbiotics whose cool giant is an S star. It attracted attention when IUE spectra showed a high ionization emission line spectrum, revealing the symbiotic nature (as much as it happens with EG And). Little is known about its photometric properties. The poorly sampled VSNET lightcurve over the last six years may be described as a slow, linear descent to $V \sim 10.3$ to $V \sim 10.8$, with fluctuations overimposed. MHZ reports $V = 10.33$ and $B - V = +1.78$.

StHα 190. The Hipparcos/Tycho did not detect variability for this object which is however close to the sensitivity limit, so a limited variability (some tenths of a magnitude) can surely be accommodated by the noise in the data. The Tycho $B_{\rm T} = 11.1$ and $V_{\rm T} = 10.30$ when transformed to the standard UBV system ($V = 10.23$, $B-V = +0.68$) are close to the values reported by MHZ, namely $V = 10.50$ and $B-V = +0.84$. Stephenson (1986) discovered StHα 190 at $V \sim 10.5$, Robertson & Jordan (1989) re-discovered it (as RJHα 120) at $V \sim 10.1$ and Downes & Keyes (1988) measured it at $V = 10.5$. Thus over the last 15 years the system mean brightness has remained fairly constant, and similarly went for the optical spectra very similar one to the other (Downes & Keyes 1988; Whitelock et al. 1995; Munari & Zwitter 2001), with no report of outbursts. Variability has been instead firmly established in the infrared by Whitelock et al. (1995) who reported $\Delta K = 0.16$. Munari et al. (2001b) have recently discovered a fast evolving and complex mixture of spectral signatures produced by high variable bipolar jets and P-Cyg profiles, with indication of a high orbital inclination and a possible 171 day orbital period. Therefore, searches for flickering and eclipses in the bluest photometric bands could pay dividends over a single observing season.

LL Cas. Originally listed among the planetary nebulae it has been later reclassified as an Me star by Sabbadin et al. (1987) and finally as a symbiotic star by Kondrateva (1992) that reports about a $\Delta m \sim 3.5$ mag variability with a period $P = 286.6$ days.

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