UBVRIu' observations of the flickering of the jet ejecting symbiotic star MWC 560*

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A B S T R A C T

We report observations of the flickering variability of the symbiotic star MWC 560 on the basis of simultaneous observations in UBVR and I bands. We find that MWC 560 has a flickering source with $(U\text{-}B)_0 = -0.93 \pm 0.05$, $(B\text{-}V)_0 = 0.01 \pm 0.06$, $(V\text{-}R)_0 = 0.43 \pm 0.08$, a source temperature $T_{fl} = 11780 \pm 300$ K and luminosity $L_{fl} = 20\ L_\odot$ on 2009 November 14 (using a distance of $d = 2.5$ kpc and $E_{B\text{-}V} = 0.15$). On 2010 January 11, we find $(U\text{-}B)_0 = -0.61 \pm 0.05$, $(B\text{-}V)_0 = -0.01 \pm 0.05$, $(V\text{-}R)_0 = 0.46 \pm 0.02$, $T_{fl} = 9100 \pm 300$ K, $L_{fl} = 38\ L_\odot$. We also confirm that on a (*U-B*) vs. (*B-V*) diagram the flickering of the symbiotic stars differs from that of the cataclysmic variables. The data are available upon request from the authors.

Introduction

MWC 560 (V694 Mon) is a symbiotic binary system, which consists of a red giant and a white dwarf with orbital period $P_{orb} = 1931 \pm 162$ days (Gromadzki et al. 2007).

The most spectacular features of this object are the collimated ejections of matter with velocities of up to ~ 6000 km s^{-1} (Tomov et al. 1992) and the resemblance of its emission line spectrum to that of the low-redshift quasars (Zamanov & Marziani 2002).

The flickering (stochastic light variations on timescales of a few minutes with amplitude of a few x 0.1 magnitudes) is a variability observed in three main types of binaries that contain white dwarfs accreting material from a companion mass-donor star: cataclysmic variables (CVs), supersoft X-ray binaries and symbiotic stars (Sokoloski 2003). The systematic searches for flickering variability in symbiotic stars and related objects (Sokoloski, Bildsten & Ho 2001) have shown that among ~ 200 symbiotic stars known, to-date flickering has only been detected in 9 objects – MWC 560, RS Oph, T CrB, Z And, V2116 Oph, CH Cyg, RT Cru, o Cet and V407 Cyg. The flickering of MWC 560 was detected by Tomov et al. (1990) and Michalitsianos et al. (1993).

To improve our understanding of this object, our aims is: (1) to perform *UBVRIu'* observations of the flickering, and (2) to throw light on the origin of the flickering.

Observations

Our observations are summarized in following table:

Table 1 CCD observations of MWC 560. In the table are given as follows: the telescope, band, UT-start and UT-end of the run, exposure time, number of CCD images obtained, average magnitude in the corresponding band, minimum – maximum magnitudes in each band, standard deviation of the mean, the range of observational error.

date telescope	band	UT start-end	Exp-time [sec]	N_{pts}	average [mag]	min-max [mag]-[mag]	stdev [mag]	err [mag]
2004 Dec 02		JD 2453341						
2.0m LT	SDSS u'	02:04 - 03:33	60	69	10.562	10.414 - 10.757	0.084	0.010-0.011
2004 Dec 30/31		JD 2453370						
2.0m LT	SDSS u'	22:54 - 01:10	60	120	10.924	10.643 - 11.134	0.159	0.009-0.015
2009 Nov 14/15		JD 2455150						
2m RCC	*U*	23:59 - 01:28	30	159	11.358	11.234 - 11.454	0.048	0.005-0.014
50/70 cm Schmidt	*B*	00:21 - 01:33	60	60	11.850	11.767 - 11.921	0.031	0.005-0.011
60 cm Belogr	*V*	00:23 - 01:28	60	45	11.281	11.240 - 11.329	0.024	0.004-0.040
[a] part	*V*	00:23 - 00:59	60	29	11.279	11.240 - 11.329	0.025	0.004-0.012
60 cm Rozhen	*R*	00:14 - 01:35	20	221	10.499	10.435 - 10.536	0.016	0.004-0.011
2010 Jan 11/12		JD 2455208						
2m RCC	*U*	23:31 - 01:07	180	26	11.118	10.913 - 11.304	0.094	0.009-0.033
50/70 cm Schmidt	*B*	23:28 - 01:11	120,60	58	11.586	11.410 - 11.770	0.085	0.002-0.040
2m RCC	*V*	23:11 - 01:06	60,30	117	11.045	10.892 - 11.169	0.056	0.002-0.035
60 cm Rozhen	*R*	22:34 - 01:02	10,30	120	10.338	10.236 - 10.443	0.051	0.002-0.012
60 cm Rozhen	*I*	00:11 - 01:00	30,10	48	8.454	8.424 - 8.502	0.016	0.002-0.020
2010 March 15		JD 2455271						
60 cm Rozhen	*V*	18:00 - 19:16	30	82	10.183	10.087 - 10.281	0.058	0.003-0.012
60 cm Rozhen	*I*	18:00 - 19:17	3	67	7.995	7.928 - 8.033	0.021	0.011-0.015
2010 March 17		JD 2455273						
60 cm Rozhen	*V*	18:10 - 19:14	15	120	10.334	10.279 - 10.391	0.023	0.005-0.006
60 cm Rozhen	*I*	18:10 - 19:14	5	117	8.011	7.969 - 8.038	0.013	0.007-0.007

[a] only the first (better) part of the *V* band observations with the 60 cm Belogr. telescope

Light curves and data analysis

As you can see from Table 1, we obtaned six light curves: 2 one color (u'); 2 two color (VI) and 2 multicolor (UBVR and UBVRI). Here we present one of them – Figure 1.

Bruch (1992) proposed that the light curve of CVs can be separated into two parts – constant light and variable (flickering) source. We assume that all the variability in each night is due to flickering. In these suppositions the flickering light source is considered 100% modulated. Following these assumptions, we calculate the flux of the flickering light source as:

$$F_{fl} = F_{av} - F_{min}, \quad (1)$$

where F_{av} is the average flux during the run and F_{min} is the minimum flux during the run (corrected for the typical error of the observations).

F_{fl} has been calculated for each band, using the values given inTable 1 and Bessell (1979) calibration for the fluxes of a zero magnitude star.

The calculated magnitudes and colors of the flickeringlight source are given in Table 2.

The derived $(U-B)_0$ color corresponds to a B1-B5V star ($T_{eff} \approx 16\,000 - 24\,000$ K) and a black body with $T \approx 8\,000 - 12\,000$ K. The $(B-V)_0$ color corresponds to an B8-A8V ($T_{eff} = 8\,000 - 13\,000$ K) star and a black body with $T \approx 8\,000 - 15\,000$ K.

These estimates give an approximate temperature of the flickering light source $T_{fl} = 8\,000 - 15\,000$K (we note that $(V-R)_0$ gives a lower resulting temperature ($T_{eff} = 5\,000 - 5\,500$ K) but the R band is dominated by the contribution of the red giant).

References

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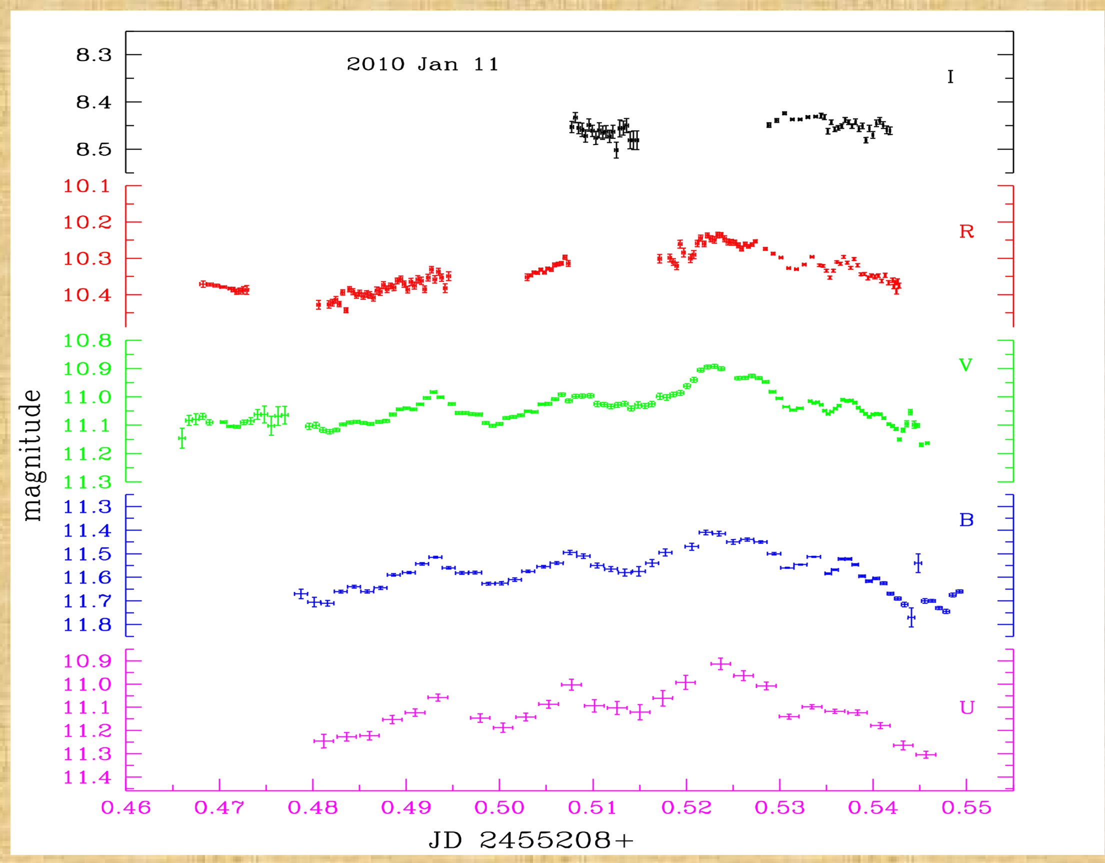

Fig.1 Variability of MWC 560: 2010 Jan 11

Results

In Fig.2 we plot *UBVRI* flickering magnitudes (2010 Jan 11) transformed to fluxes. Adopting d = 2.5 kpc and using a black body fit (*nfit1d* routine of IRAF), we calculate for the flickering light source: $T_{fl} = 11788 \pm 300$ K, $R_{fl} = 1.1\ R_\odot$, $L_{fl} = 20\ L_\odot$ (2009 Nov 14) and $T_{fl} = 9112 \pm 300$ K, $R_{fl} = 2.45\ R_\odot$, $L_{fl} = 38\ L_\odot$ (2010 Jan 11). Using all data normalized to V band we calculate T_{fl} 10100 ± 300K.

Our results are summarized in Table 2.

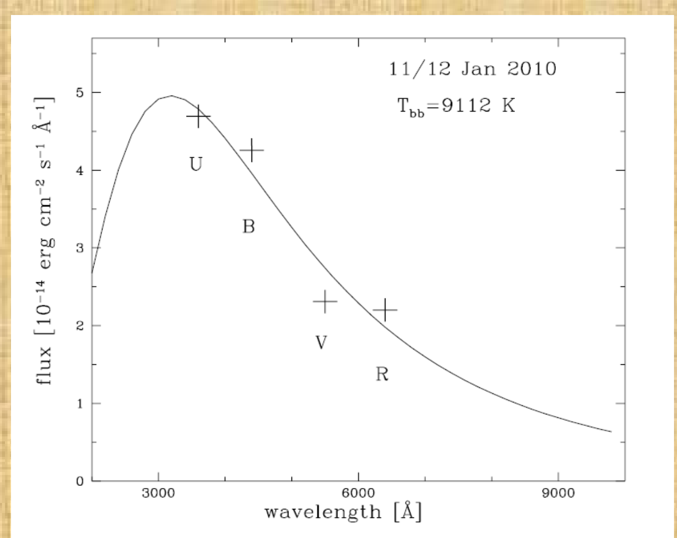

Fig.2 Dereddened fluxes of the flickering light source of MWC 560. The solid line represents a black body fit.

Table 2 Magnitudes and colours of the flickering light source of MWC 560 (only the colours are corrected for interstellar extinction).

	14.11.2009	11.01.2010
U	14.04 ± 0.05	13.12 ± 0.04
B	14.85 ± 0.06	13.60 ± 0.02
V	14.69 ± 0.06	13.46 ± 0.02
R	14.19 ± 0.07	12.93 ± 0.02
$(U-B)_0$	-0.93 ± 0.05	-0.61 ± 0.05
$(B-V)_0$	0.01 ± 0.06	-0.01 ± 0.02
$(V-R)_0$	0.43 ± 0.08	0.46 ± 0.02
L_{fl} $[L_\odot]$	20 ± 2	38 ± 3
T_{fl} [K]	11800 ± 300	9100 ± 300
R_{fl} $[R_\odot]$	1.1 ± 0.1	2.8 ± 0.2

In Fig.3 are shown the histograms for $(B\text{-}V)_0$ and $(U\text{-}B)_0$ colors of the flickering light source of CVs (solid line) and symbiotic stars (dashed line). The Kolmogorov-Smirnov test for $(B\text{-}V)_0$ – histograms gives a probability p = 0.34 (Kolmogorov-Smirnov statistic D = 0.32).

This means that we do not detect a statistically significant difference in the $(B\text{-}V)_0$ colors. However, we do detect a highly significant difference in $(U\text{-}B)_0$ color with $p < 2 \times 10^{-5}$ (D = 0.82). The results confirm with higher significance our early findings based on a smaller amount of data (Zamanov et al 2010a).

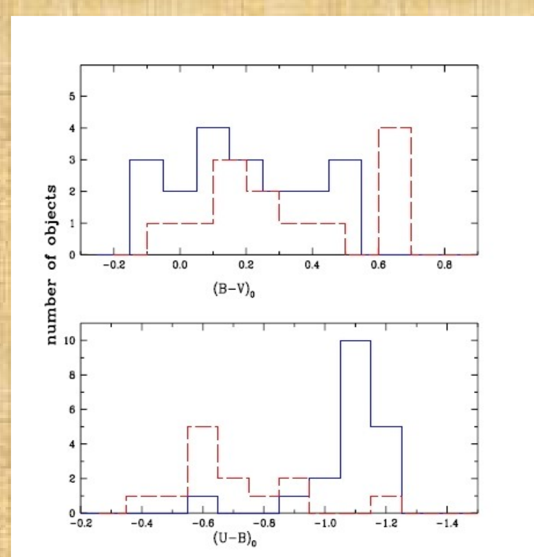

Fig.3 The histograms for $(B\text{-}V)_0$ and $(U\text{-}B)_0$ colours of the flickering light source of CVs (solid line) and symbiotic stars (dashed line).

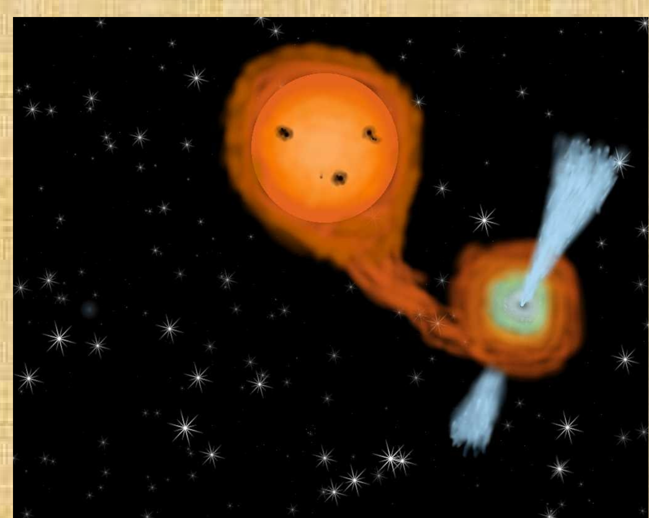

Fig.4 Symbiotic star – artist vision

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