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UBVRI OBSERVATIONS OF THE FLICKERING OF THE SYMBIOTIC STAR MWC 560

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MWC 560 (V694 Mon) was discovered as an object with bright hydrogen lines (Merrill & Burwell 1943). It is a symbiotic binary system, which consists of a red giant and a white dwarf. The long term light curves (Luthardt 1991, Doroshenko et al. 1993) show that during the last century the star brightness varied in the range $m_{\rm B} = 11.0 - 12.5$, with one outburst in 1990, when it achieved $m_{\rm B} \approx 9.5$. The orbital period is estimated to be $P_{\rm orb} = 1931 \pm 162$ day (Gromadzki et al. 2007).

The flickering of MWC 560 in optical bands was first detected by Bond et al. (1984) and later reported also by Michalitsianos et al. (1993) and Tomov et al.(1996). Recently, Stute & Sahai (2009) discovered emission and quasi-periodic flickering in X-rays on timescales of minutes and hours using XMM-Newton.

On the night of 2010 December 29, we observed MWC 560 simultaneously with four telescopes equipped with CCD cameras. The 2m RCC telescope of the National Astronomical Observatory Rozhen observed in the U and V band with a dual channel focal reducer FoReRo2, equipped with CCD cameras Photometrics(1024x1024) and VersArray(512x512 px) and field of view 7.5'x7.5'. The 50/70 cm Schmidt telescope observed in the U band (CCD FLI PL 16803, 4096x4096 px, used 1024x1024 px, 18' x 18'). The 60 cm Rozhen telescope observed in the B, V and I bands (FLI PL 9000 CCD with 3056 x 3056 pixels and 18'x18'); the 60 cm telescope of the Belogradchik Astronomical Observatory in the V, R and I bands (FLI PL 9000 CCD, 3056 x 3056 px, 18'x18'). All the CCD images have been bias subtracted, flat fielded, and standard aperture photometry has been performed. The data reduction and aperture photometry were done with IRAF and have been checked with alternative software packages. The comparison stars of Henden and Munari (2006) have been used.

The results of our observations are summarized in Table 1 and plotted in Fig.1. For each run we measure the minimum, maximum, and average brightness in the corresponding band, plus the standard deviation of the run. The amplitude of variability is highest in U band, $\Delta U \approx 0.29$ mag. It decreases to longer wavelengths and in I-band is ≈ 0.07 mag. Our observations are obtained during the recent outburst, which reached the peak brightness in the end of December 2010 (Goranskij et al. 2011).

Table 1: CCD observations of MWC 560. In the table are given as follows: the 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, observational error.

band	UT start−end	exp [sec]	N_{pts}	average [mag]	min-max [mag]-[mag]	stdev [mag]	err [mag]
U	22:24−01:28	60	120	9.457	9.309 - 9.596	0.069	≤0.012
B	21:53−01:31	20	485	10.147	10.040 - 10.245	0.047	≤0.007
V	22:46−01:31	5	917	9.675	9.572 - 9.778	0.046	≤0.005
R	22:10−01:30	5	399	9.517	9.432 - 9.582	0.033	≤0.009
I	21:53−01:31	3,5	404	8.399	8.364 - 8.435	0.014	≤0.005

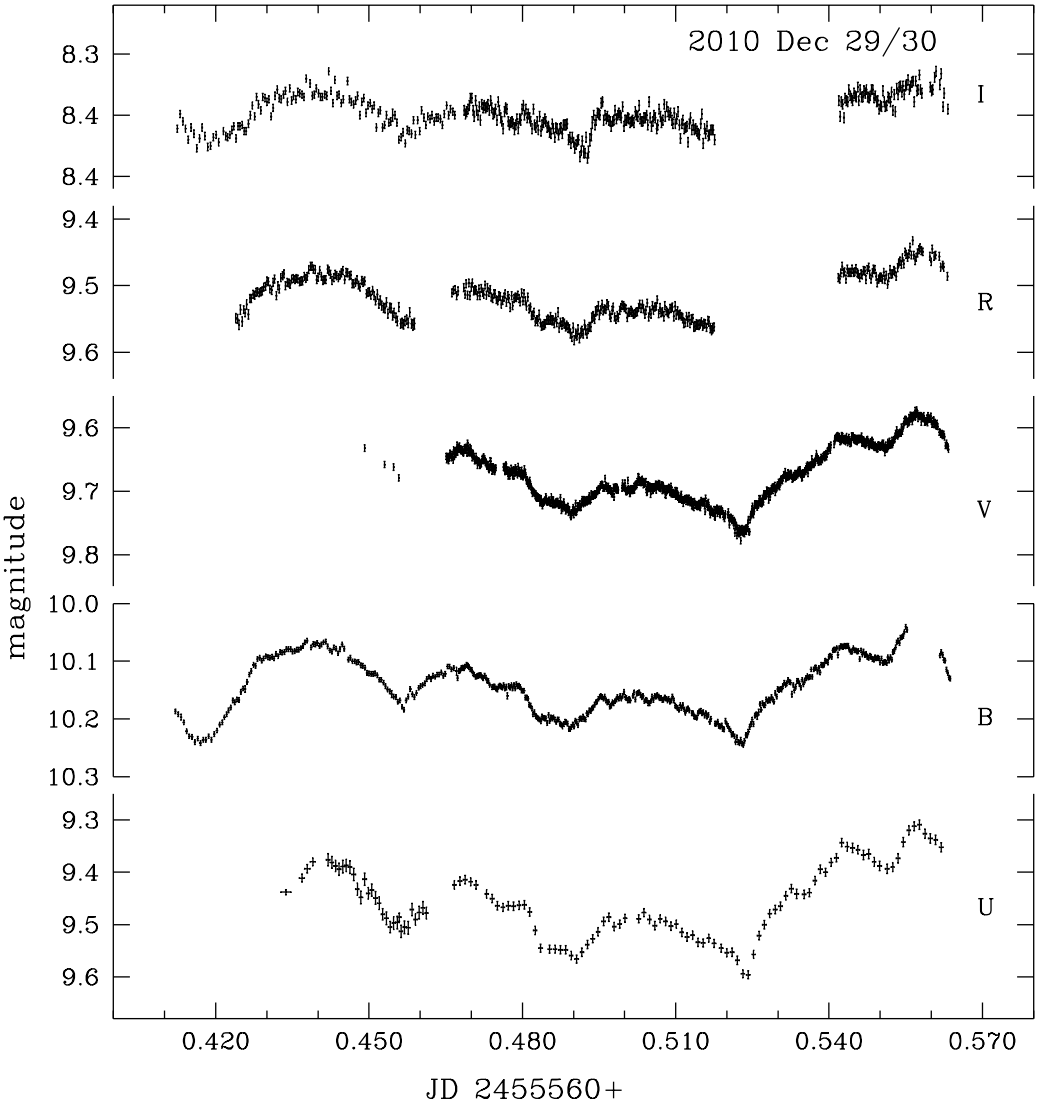

Figure 1. Variability of MWC 560 in the *UBVRI* bands on 29/30 December 2010.

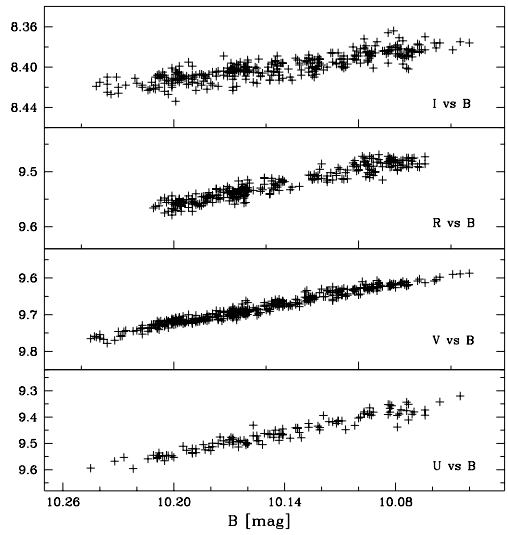

Figure 2. I, R, V, U band magnitudes versus B band magnitude

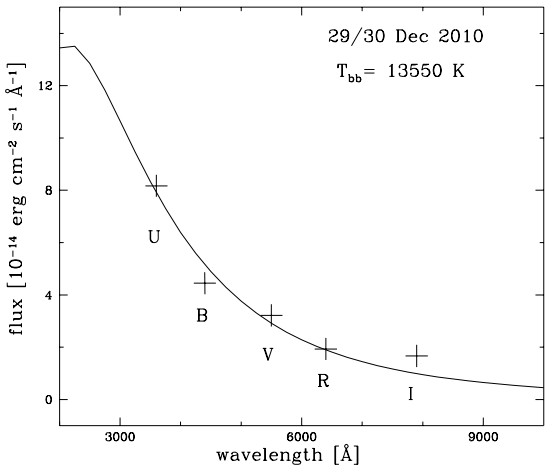

Figure 3. Dereddened fluxes of the flickering light source of MWC 560. The solid line represents a black body fit with $T_{bb} = 13550$ K, radius $R = 1.68$ R$_\odot$, located at distance $d = 2.5$ kpc.

In Fig.2, I, R, V, U band magnitudes are plotted versus the B magnitude. Linear fits (of type y = a + bx) to the data points in Fig.2 give:

$$U = -4.64(\pm0.17) + 1.39(\pm0.02)B \quad (1)$$

$$V = 0.43(\pm0.08) + 0.91(\pm0.01)B \quad (2)$$

$$R = 2.83(\pm0.09) + 0.65(\pm0.01)B \quad (3)$$

$$I = 6.04(\pm0.06) + 0.23(\pm0.01)B \quad (4)$$

The errors of the coefficients are given in brackets. These relations are obtained on the basis of our observations from 2010 Dec 29. They are valid over the range $10.05 \leq B \leq 10.25$ mag.

The Spearman's (rho) rank correlation gives $\rho = 0.96$ for Eq.1, $\rho = 0.98$ for Eq.2, $\rho = 0.93$ for Eq.3, $\rho = 0.94$ for Eq.4. The significance in Eq.1-Eq.4 is $< 10^{-10}$ indicating that all these correlations are highly significant.

The distance to MWC 560 is estimated to be $d = 2.5 \pm 0.3$ kpc (Meier et al. 1996). Schmid et al. (2001) give $d = 2.5 \pm 0.7$ kpc and $E_{B-V} = 0.15 \pm 0.05$ mag. We assume $d = 2.5$ kpc, $E_{B-V} = 0.15$ mag, and an extinction law as given in Zombeck (1990). This gives the interstellar absorption to MWC 560: $A_U = 0.754$ mag, $A_B = 0.628$ mag, $A_V = 0.477$ mag, $A_R = 0.400$ mag, $A_I = 0.304$ mag.

As a quantitative way to investigate the flickering properties Bruch (1992) proposed that the light curve of CVs can be separated into two parts – constant light and variable (flickering) source. In these suppositions the flickering light source is considered 100% modulated and it is assumed to be the modulated part of the emission from the boundary layer or the bright spot (see also Warner & Cropper 1983; Nelson et al. 2011). In a statistically representative light curve the difference between the radiation flux at a given moment and the minimum flux is then equal to the flux of the flickering light source at that moment.

Following these assumptions, we calculate the flux of the flickering light source as $F_{\rm fl} = F_{\rm av} - F_{\rm min}$, where $F_{\rm av}$ is the average flux during the run and $F_{\rm min}$ is the minimum

flux during the run (corrected for the typical error of the observations). $F_{\rm fl}$ has been calculated for each band, using Eq.1-Eq.4 (in the interval $10.22 > B > 10.147$) and Bessel (1979) calibration for the fluxes of a zero magnitude star. The calculated magnitudes and colours of the flickering light source are:

$U = 12.08 \pm 0.07$, $B = 13.11 \pm 0.07$, $V = 12.75 \pm 0.06$, $R = 12.94 \pm 0.09$, $I = 12.92 \pm 0.20$,

$(U-B)_0 = -1.16 \pm 0.08$, $(B-V)_0 = 0.21 \pm 0.09$, $(V-R)_0 = -0.26 \pm 0.10$, $(V-I)_0 = -0.35 \pm 0.20$. The colours are corrected for interstellar extinction.

In Fig.2 (right panel) we plot these magnitudes transformed to fluxes and dereddened. Adopting $d = 2.5$ kpc and using a black body fit, we calculate for the flickering light source: $T_{\rm fl} = 13550 \pm 500$ K, $R_{\rm fl} = 1.68 \pm 0.16$ $R_\odot$ and $L_{\rm fl} \approx 88$ $L_\odot$.

Conclusion: We report simultaneous observations in 5 bands ($UBVRI$) of the flickering of the jet ejecting symbiotic star MWC 560.

The colours of the optical flickering source we have obtained are $(U-B)_0 = -1.16 \pm 0.08$ and $(B-V)_0 = 0.21 \pm 0.09$. The temperature of the flickering source derived is $T_{\rm fl} = 13550 \pm 500$ K, and the luminosity is $L_{\rm fl} \sim 88$ $L_\odot$.

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