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The 2016 outburst of the unique symbiotic star MWC 560 (= V694 Mon), its long-term BVRI evolution and a marked 331 days periodicity

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HIGHLIGHTS

- BVRI photometry obtained in 357 nights distributed between 2005 and 2016.
- Analysis of the long term photometric evolution and of the record breaking 2016 outburst.
- Detection of strong periodicities at 331 and 1860 days, and their relation to orbital period.

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ABSTRACT

After 26 years from the major event of 1990, in early 2016 the puzzling symbiotic binary MWC 560 has gone into a new and even brighter outburst. We present our tight BVR_CI_C photometric monitoring of MWC 560 (451 independent runs distributed over 357 different nights), covering the 2005–2016 interval, and the current outburst in particoular. A stricking feature of the 2016 outburst has been the suppression of the short term chaotic variability during the rise toward maximum brightness, and its dominance afterward with an amplitude in excess of 0.5 mag. Similar to the 1990 event when the object remained around maximum brightness for ~6 months, at the time Solar conjunction prevented further observations of the current outburst, MWC 560 was still around maximum, three months past reaching it. We place our observations into a long term contex by combining with literature data to provide a complete 1928–2016 lightcurve. Some strong periodicities are found to modulate the optical photometry of MWC 560. A period of 1860 days regulate the occourence of bright phases at BVR_C bands (with exactly 5.0 cycles separating the 1990 and 2016 outbursts), while the peak brightness attained during bright phases seems to vary with a ~9570 days cycle. A clean 331 day periodicity modulate the I_C lightcurve, where the emission from the M giant dominates, with a lightcurve strongly reminiscent of an ellipsoidal distortion plus irradiation from the hot companion. Pros and cons of 1860 and 331 days as the system orbital period are reviewed, waiting for a spectroscopic radial velocity orbit of the M giant to settle the question (provided the orbit is not oriented face-on).

1. Introduction

MWC 560 was first noted in the Mt. Wilson Catalog of emission line objects by Merrill and Burwell (1943) as a Be-type star with bright Balmer emission lines flaked, on the violet side, by wide and deep absorption lines. The presence of a cool giant, betrayed by strong TiO absorption bands visible in the red, was reported by Sanduleak and Stephenson (1973), who classify the giant as M4 and confirmed the presence next to the emission lines of deep, blue-shifted absorptions. A short abstract by Bond et al. (1984) informed that in early 80ies they measured terminal velocities up to – 3000 km sec^{-1} in the Balmer absorption components, the absoption profiles were very complex and variable on timescales of one day, and flickering with an amplitude of 0.2 mag on a timescale of a few minutes dominated high-speed photometry. Interestingly, Bond et al. mentioned that near Hα the spectrum was dominated by the M giant, and no absorption componet was seen. Compared to post–1990 spectra in which the Hα absorption is outstanding and the visibility of the M giant spectrum is confined to $\lambda \geq 6500/7000$ Å, this indicates that, at the time of the observations by Bond et al. (1984), the luminosity of the hot component was significantly lower than typical for the last 25 years.

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In keeping up with the very slow pace at which MWC 560 was attracting interest, even the promising report by Bond et al. (1984) did not much to improve upon the anonymity of MWC 560, until all of a sudden, in early 1990, MWC 560 took the scene for a few months, with a flurry of IAU Circulars and near-daily reports conveying increasing excitement. All started when Tomov (1990) reported on the huge complexity he had observed in the Balmer absorption profiles on his January 1990 high resolution spectra, suggesting "discrete jet-like ejections with a relatively high degree of collimation and with the direction of the ejection near to the line of sight". Feast and Marang (1990) soon announced that optical photometry clearly indicated that the object was in outburst, immediately followed by Buckley et al. (1990) who reported terminal velocities up to – 5000 km sec^{-1} for the Balmer absorptions, upward revised to – 6500 km sec^{-1} by Szkody et al., 1990 a few days later. By the time Maran and Michalitsianos (1990) re-observed MWC 560 with the IUE satellite at the end of April 1990, the paroxysmal phase was ending.

The nature of MWC 560 as outlined by the 1990 outburst was reviewed by Tomov et al. (1990), while the preceding photometric history tracing back to 1928 was reconstructed, from archival photographic plates, by Luthardt (1991). A few observations reported by Doroshenko et al. (1993) extend the time coverage back to ∼1900. Tomov et al. (1992) and Michalitsianos (1993) modelled MWC 560 with a non-variable M4 giant and an accreting – and probably magnetic – white dwarf (WD), surrounded by an (outer) accretion disk, and subject to a steady optically thick wind outflow and a complex pattern of mass ejection into discrete blobs. Stute and Sahai (2009) deduced however a non-magnetic WD from their X-ray observations. A fit with a variable collimated outflow that originates at the surface of the accretion disk and that is accelerated with far greater efficiency than in normal stellar atmospheres was considered by Shore et al. (1994). The collimated jet outflow was also investigated by Schmid et al. (2001). A strong flickering activity has been present at all epochs in the photometry of MWC 560, with an amplitude inversely correlated with then system brightness in the *U* band (Tomov, 1996). A search for a spectroscopic counterpart of the photometric flickering was carried out by Tomov et al. (1995) on high resolution and high S/N spectra taken during 1993–1994 when the object was in a quiescent state. In spite of the very large amplitude of the photometric flickering recorded on simultaneous *BV* observations (∼0.35 mag in *B*, ∼0.20 mag in *V*), no significant change in intensity and profile (at a level of a few %) was observed both for the emission lines and their deep and wide absorption components.

With MWC 560 at quiescence and not much going on with its photometric and spectroscopic behavior, the interest in the object progressively declined after the 1990 outburst. The situation could now reverse following our recent discovery (Munari et al., 2016) that MWC 560 is going through a new outburst phase, *brighter* than that of 1990. This has immediately prompted deep X-ray observations by Lucy et al. (2016) that found a dramatic enhancement in the soft ($<$ 2 keV) X-rays, compared to the observations by Stute and Sahai (2009) obtained in 2007 when MWC 560 was in quiescence. The report on the optical outburst also prompted VLA observations that detected for the first time radio emission from MWC 560 Lucy, Weston and Sokoloski (2016), at least an order of magnitude enhanced over a VLA non-detection on 2014 October 2, during the quiescence preceding the current outburst.

In this paper we present the results of our 2005–2016 BVR_CI_C photometric monitoring of MWC 560, with an emphasis on the current outburst phase. This is placed into an historical context by combining with existing data that provides an optical lightcurve of MWC 560 covering almost a century. Finally, a search for periodicities is carried out, especially taking advantage of our unique set of I_C data which is dominated by the emission from the M giant.

2. Observations

BVR_CI_C optical photometry of MWC 560 is regularly obtained since 2005 with nine of the ANS Collaboration telescopes, all of them located in Italy. A total of 431 BVR_CI_C independent runs are presented here, obtained during 357 different nights distributed between Feb 9, 2005 and Apr 29, 2016. The operation of ANS Collaboration telescopes is described in detail by Munari (2012) and Munari and Moretti (2012). The same local photometric sequence, calibrated by Henden and Munari (2001) against Landolt equatorial standards, was used at all telescopes on all observing epochs, ensuing a high consistency of the data. The BVR_CI_C photometry of MWC 560 is given in Table 1, where the quoted uncertainty is the total error budget, which quadratically combines the measurement error on the variable with the error associated to the transformation from the local to the standard photometric system (as defined by the photometric comparison sequence). All measurements were carried out with aperture photometry, the long focal length of the telescopes and the absence of nearby contaminating stars not requiring to revert to PSF-fitting.

Low and high resolution spectra of MWC 560 are routinely obtained with the Asiago 1.22 m + B&C and 1.82 m + REOSC Echelle, and with Varese 0.61 m + Astrolight mk.III multi-mode spectrograph. One of the low resolution spectra is shown in Fig. 1 as representative of the typical appearance of MWC 560, broadly similar both in quiescence and outbursts, with the continuum from the M giant becoming rapidly dominant for $\lambda > 7000$ Å and over the Landolt's I_C band. The results of the spectroscopic campaign on MWC 560 will be discussed elsewhere.

3. Long term photometric evolution

The BVR_CI_C lightcurve of MWC 560 covering the last eleven years is presented in Fig. 2. This time interval corresponds to slightly more than two full cycles of the 1900÷2000 days periodicity frequently associated to MWC 560 (see Section 5 below). The presence of such a periodicity ($\simeq$ 5.2 years) is evident in the *B*-band panel of Fig. 2, where the maxima of 2006, 2011, and 2016 clearly modulate the lightcurve. Contrary to what found by others (eg. Tomov (1996), their Fig. 1), our data in Fig. 2 show that the *B* - *V* color of MWC 560 remains essentially stable in spite of the large changes recorded in *B* band. A variation at the level of ∼1 mag is instead observed in the *V* - I_C color, with MWC 560 being redder when fainter at *B*. The lightcurve of MWC 560 in the I_C band is completely different from those at shorter wavelengths, in particular: (*a*) the large scatter that dominates the *B* lightcurve, which is caused by the accretion flickering, is null at I_C, (*b*) the large amplitude maxima of 2006, 2011, and 2016 that dominates the *B*-band lightcurve are barely recognizable at I_C, and (*c*) a clear, large amplitude (∼0.35 mag) and periodic modulation governs the I_C lightcurve.

The above is consistent with a hot component that completely dominates the emission at *B* and *V*, and contributes the majority of the flux at R_C, while the M4 giant accounts for nearly all the brightness recorded in I_C. The hot component, presumably a massive accretion disc around the WD companion, is the one producing the continuum mimicking an A-type star which dominates shortward of 6000 Å in the spectrum of Fig. 1, while the TiO bands that dominate longward of 7000 Å come from the M4 giant. The M4 giant is intrinsically variable, and entirely responsible for the periodic changes seen in I_C. They could either be the result of an ellipsoidal distortion (in which case the M4 giant would fill the corresponding Roche lobe) or be caused by a radial pulsation (in which case the M4 giant would *not* fill its Roche lobe; see Section 5). The flickering that affects the emission from the hot component causes a large dispersion of the observations at BVR_C