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MWC 560: jets or optically thick expanding envelope?

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SUMMARY

Results of high- and low-resolution spectral and *UBV* photometric observations of MWC 560 during 1990 January–October are presented in this paper.

Strong variations in the star brightness compared with previously published observations are discussed. The presence of flickering activity from the *U*-band monitoring observations is also noted.

The most remarkable features in the spectra obtained during 1990 January–April are the strong violet-shifted Balmer absorption components with velocities of up to ~ -6000 km s^{-1} visible up to about H_{20}–H_{21}. The Balmer emission components are relatively weak and are easily visible only up to Hδ–Hε. Numerous emission lines, mainly of the ionized metals, are present as well.

The observations in 1990 October showed dramatic changes in comparison with those from the beginning of the year. The $U-B$ colour reddened by about 0.5 mag but at the same time V and $B-V$ remained almost constant. The first members of the Balmer series have P Cygni profiles, and the absorption components show violet shifts of only a few hundred km s^{-1}. Some of the strongest lines of Fe II and Ti II show similar profiles as well.

A rough estimation of ~ 1 kpc for the distance to MWC 560 is obtained. Assuming MWC 560 to be a binary system consisting of an M4.5 giant and a white dwarf (probably magnetic), we briefly discuss its nature. We suppose that there are two different types of activity shown by MWC 560: first discrete jet ejections during 1990 January–April with high velocities, and secondly quasi-stationary ejections with relatively low velocities at least from 1990 September and later.

Key words: stars: activity – binaries: close – stars: individual: MWC 560 – stars: mass-loss – stars: variables: other.

1 INTRODUCTION

MWC 560 is a star in Monoceros whose variability type is still not clear but the changes of its brightness and especially of its spectrum, observed recently, provide a new puzzle for astronomers.

The star was discovered as an emission object by Merrill & Burwell (1943) during the Mount Wilson Observatory Hα survey. In the next years MWC 560 was observed only sporadically. Sanduleak & Stephenson (1973) noted some spectral peculiarities. Later Bond *et al.* (1984) paid attention to the strange behaviour of MWC 560 but nevertheless the star was forgotten again. After the observations in 1990 January (Tomov 1990) the interest in MWC 560 rose again and many astronomers joined in its investigation.

The systematic *UBV* observations (Tomov *et al.* 1990b, and references therein) showed that the star's brightness had considerably increased. In 1990 the V magnitude changed between 10.0 and 9.2 mag in comparison with early observations of 12.5 mag (Merrill & Burwell 1943; Sanduleak & Stephenson 1973) and about 11 mag (Bond *et al.* 1984).

The most intriguing features in the optical spectrum are the violet-shifted absorption components of the Balmer lines, which are strongly variable in velocity and intensity. The greatest shift observed reached a velocity of about -6000 km s^{-1}. At the same time the emission components of the H I lines showed constant radial velocity (Tomov *et al.* 1990a). The observations in the ultraviolet (Michalitsianos *et al.* 1991a) showed a strong increase of the flux in comparison with that in 1984 and the presence of absorption lines of Fe II and other metallic ions with a violet shift of a few thousand km s^{-1}.

In 1990 September MWC 560 again surprised the observers. Michalitsianos *et al.* (1990b) reported that the ultraviolet flux in the range of 1200–3200 Å had decreased by about 10 times in comparison with the observations from the end of 1990 April. The UV flux also showed a significant change in its distribution with wavelength and the spectrum was similar to that of a classical nova a few days after its maximum in visible light (Maran *et al.* 1991). Wagner *et al.* (1990) and Bopp (1990) announced that the Hα and Hβ Balmer lines showed P Cygni profiles with violet-shifted absorptions of about -400 to -500 km s^{-1}.

Recently some preliminary observational results were published by Tomov *et al.* (1990a).

Here we present the results obtained from the 1990 January–May observations of MWC 560. The observations in 1990 October are shown too. The main purpose of this paper is to draw the attention of the observers and theoreticians to this extremely interesting star.

2 OBSERVATIONS

The *UBV* observations were carried out by two identical single-channel photometers on the 60-cm telescopes at the National Astronomical Observatory, Rozhen and the Astronomical Observatory, Belogradchik. HD 59380 was used as a comparison star. No correction for atmospheric extinction was made because of the small angular distance between the observed stars. We also implemented monitoring in the *U* band with an integration time of 10 s. The internal error did not exceed ± 0.02 mag in all filters.

In 1990 October we began *UBV* and monitoring observations in *U* at the Torun Observatory with a single-channel photometer installed on the 90-cm Schmidt–Cassegrain telescope. The precision of these observations was of the same order as those at Rozhen and Belogradchik.

The spectral observations with relatively high resolution (~ 0.35 Å) during the period 1990 January–April were carried out with the coudé spectrograph of the 2-m telescope at NAO Rozhen. Hydrogen-sensitized 103aO emulsion was used to cover the spectral interval 3600–4900 Å. The exposure times of these spectra were between 2 and 4 hr and their signal-to-noise ratios were 10–15.

Five spectra in the interval 3900–5400 Å and five spectra in the interval 5600–7200 Å, with low spectral (~ 1 Å) and high time (between 30 s and 5 min) resolution were obtained on 1990 October 26 at the NAO Rozhen. A UAGS spectrograph and a double-stage image intensifier, attached to the 2-m telescope, were used. The emulsion was 103aO as well.

The spectra were digitized using a MDM6 Joyce–Loebl microdensitometer and were processed using the ReWiA software system (Borkowski 1988).

Using the Canadian Copernicus Spectrograph with a 3.5-arcsec aperture image slicer at the Cassegrain focus of the 90-cm Torun Observatory telescope, one low-resolution spectrum (~ 2 Å) was obtained on 1990 October 24. The spectral region was 3400–5200 Å and the emulsion IIaO. It was processed with the ReWiA software system and reduced to the Hayes & Latham (1975) flux scale using standard methods with an accuracy of about 5 per cent in the range 3600–5000 Å. However, outside this interval the accuracy was 15–20 per cent.

3 PHOTOMETRIC BEHAVIOUR

The changes of the visual brightness and $B-V$ and $U-B$ colours of MWC 560 during 1990 January–October (JD2447930 - 2448190) are shown in Fig. 1. The *UBV* observations obtained by others (Michalitsianos *et al.* 1990a, 1991a; Kontizas *et al.* 1990; Feast & Marang 1990; Buckley *et al.* 1990; Michalitsianos, Maran & Oliversen 1990b, are in good agreement with ours (see for example Tomov *et al.* 1990b). As is seen (Fig. 1), in 1990 March ($\sim$JD2447980) the star was more than 3 mag brighter than when it was observed by Merrill & Burwell (1943) and Sanduleak & Stephenson (1973). During 1990 February–March (JD2447930–2447980) the brightness increase was about 1 mag. The maximum ($V \sim 9.2$ mag) was reached at the end of March ($\sim$JD2447980). At the end of April ($\sim$JD2448009) and at the beginning of May ($\sim$JD2448017) the brightness was about 9.5 mag, and in the range 9.5–9.8 mag in October (JD2448165–2448191). The scatter of the data is considerably greater than the internal errors, and possibly suggests the existence of real night-to-night variations in *V*.

The variations in the $B-V$ and $U-B$ colours, as can be seen (Fig. 1), are quite different: $B-V$ changes are small and the mean value of the colour is 0.29 ± 0.04 mag while the changes in $U-B$ are greater. The observations in 1990 October show a $U-B$ reddening of about 0.5 mag compared to those at the beginning of the year, which is in agreement with the decrease of the flux observed in the ultraviolet (Michalitsianos *et al.* 1990b; Maran *et al.* 1991).

Only sporadic estimates of the brightness in the red and infrared bands *RIJHKL* are published (Buckley *et al.* 1990; Feast & Marang 1990). These IR observations show that the

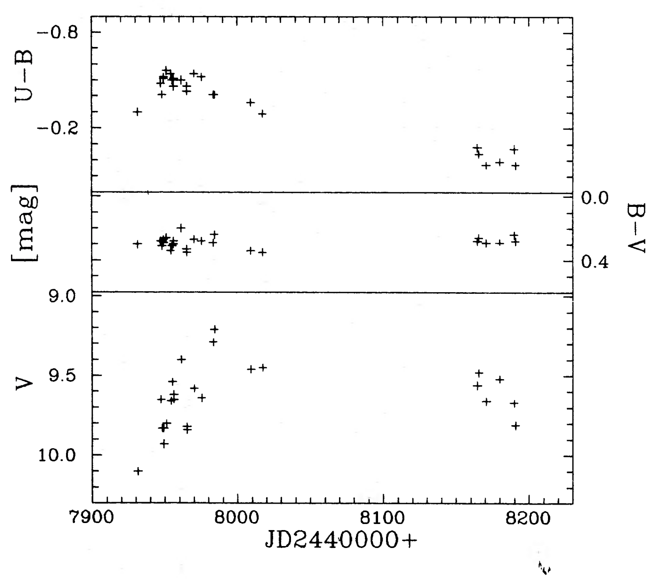


Figure 1. *V* magnitudes and $(B-V)$, $(U-B)$ colours of MWC 560 observed during 1990 February–October.

mean values are the same as during 1984–1986 and the M4 giant is the main source in the infrared, while the radiation in the *UBV* bands is dominated by the hot component.

A very important step towards understanding the nature of MWC 560 is the long-term light curve, constructed by Luthardt (1991), covering a time interval from 1928 to the beginning of 1990. The author notices that MWC 560 shows large-scale variations of about 3 mag. He suggests that, in the outbursts after ~JD2437000, the time for brightness increase is considerably shorter than the time for its decrease. We think that the character of the brightness variations of MWC 560 during the period of 1928–1990 is constant. The observations before JD2437000 were not so numerous and that is why the changes of the brightness were not present in detail. A series of short 'outbursts' with an interval of about 2000 d are clearly visible after JD2435000, around JD2436000, 2438000, 2444000 and 2446000, due to the above-mentioned reason. It is possible that such a short-term 'outburst' was the reason for the strongly increased brightness of the star observed in 1990 (~JD2448000).

The presence of rapid variations of the brightness is another peculiarity of MWC 560 first noted by Bond *et al.* (1984). Our observations (Fig. 2a–d) as well as those of Michalitsianos *et al.* (1991a) and Buckley *et al.* (1990) confirm this phenomenon. The monitoring in *U* during several nights in 1990 February and March shows the presence of flickering with a maximum amplitude of about 0.3 mag and characteristic time-scales of the changes from a few minutes up to more than an hour.

Despite the considerable brightness decrease in *U* in 1990 October, the flickering with amplitude ~0.3 mag and characteristic times of from 5 to more than 20 min (Fig. 2e) appeared again.

The nature of the flickering is not clear, but we believe that there are some indications that these variations are caused by the changes of the hot continuum as a whole but not, for example, of the hydrogen emission only. Michalitsianos *et al.* (1991a) show rapid changes in the *V* and *U* bands with characteristic time-scales of more than 1 hr, similar to ours. On the other hand, the two UV spectra in the range 1200–2000 Å obtained with a time separation of about 3 hr demonstrate considerable differences. The total flux and the equivalent widths of the strongest absorption features show changes of about 10 and 6–8 per cent respectively.

4 SPECTRAL BEHAVIOUR

Merrill & Burwell (1943) noted some of the most prominent details in the MWC 560 spectrum. Sanduleak & Stephenson (1973) observed emission components of the Balmer lines and strongly blueshifted absorption components. On the basis of the TiO bands seen in the visual and near-IR regions, they suggested the presence of an M4ep giant.

The observations of Bond *et al.* (1984) again showed blueshifted absorptions of Hβ and higher members of the Balmer series of up to -3000 km s^{-1}. The Hα region in their spectra was dominated by the spectrum of the M giant and a blueshifted absorption component of Hα was not present. The authors noted the strong variability of the absorption profiles with a time-scale of about 1 d. The first *IUE* observations of MWC 560, also reported by Bond *et al.* (1984), showed a relatively strong UV continuum and low-excitation absorption lines.

Several spectra of MWC 560 obtained during 1990 January–April are presented in Fig. 3. These spectra give an idea mainly of the changes in the Balmer line absorption components. The continuum of MWC 560 in the spectral interval considered is similar to the continuum of a relatively hot star of late B or early A spectral type. In this spectral region the 'hot' continuum completely fills the TiO bands from the M-giant spectrum. Buckley *et al.* (1990), Szkody & Mateo (1990), Sanduleak (1990) and Lynch *et al.* (1990) observed the TiO bands in their red and infrared spectra but the influence of the hot source is clearly visible – the veiling is greater at shorter wavelengths.

Numerous sharp lines of Fe I, Fe II, Ti II, Cr II etc. dominate in the emission spectrum, as can be seen in Figs 3 and 7. The emission components of the Balmer lines are also relatively sharp and are well seen only for Hβ, Hγ and Hδ (Figs 3 and 4). The radial velocities (RV) of all these lines were practically constant in our observing period (Table 1). The metallic emission lines show RVs of about +40 km s^{-1} while the Balmer line emission components have RVs of about +55 km s^{-1}. In our opinion the difference between these kinds of emissions is due to the influence of an absorption component of the hydrogen lines, forming, together with the H I emissions, a profile resembling a P Cygni type (Figs 3–5). The strong decrement of the Balmer line emissions indicates relatively low density for the regions where these components arise.

In the system of absorption lines the most remarkable changes concern the absorption components of the Balmer lines which dominate the spectrum of MWC 560 and make it unique. These lines appear without any regularity and have different intensities and blueshifts reaching values up to about -6000 km s^{-1} (Table 1). The only other relatively weak absorption lines which can be seen in the blueshifted line system (but not on all spectra) are Ca II *K*, He I 4026 and 4471 Å (Fig. 7). Lynch *et al.* (1990) observed He I 10 830 Å blueshifted to -1550 km s^{-1} with FWHM about 1800 km s^{-1}.

In some spectra the Balmer absorptions with high negative RV are wholly absent (Figs 3 and 4). Sometimes the high-velocity absorptions have very complex, multicomponent structure (Figs 3–5). The absorption components close to the hydrogen emission are present in almost all spectra and are better seen in the higher members of the series (Figs 3 and 5). The observations of Mochnacki & Thomson (1990) during six consecutive nights also confirm the strong variability of the absorption components of the Balmer lines.

The Ca II *K* line not belonging to the high radial velocity line system (Fig. 6 upper panel) can be seen when the Hϵ and Ca II *H* blueshifted components are absent or far from the position of the Ca II *K*. In the cases when this relatively faint Ca II *K* line is well visible its profile is very complicated. A comparison between the observed profile and a four-Gaussians fit is shown in Fig. 6 (lower left panel). The red wing of the Ca II *K* emission is blended with a sharp Fe II 3938-Å emission line. The resulting profile after subtraction of the Ca II *K* sharp absorption component and the Fe II emission is shown in Fig. 6 (lower right panel) as well. This profile is very similar to the classical P Cygni profile. On the other hand, significant resemblance to the Hδ emission and slightly

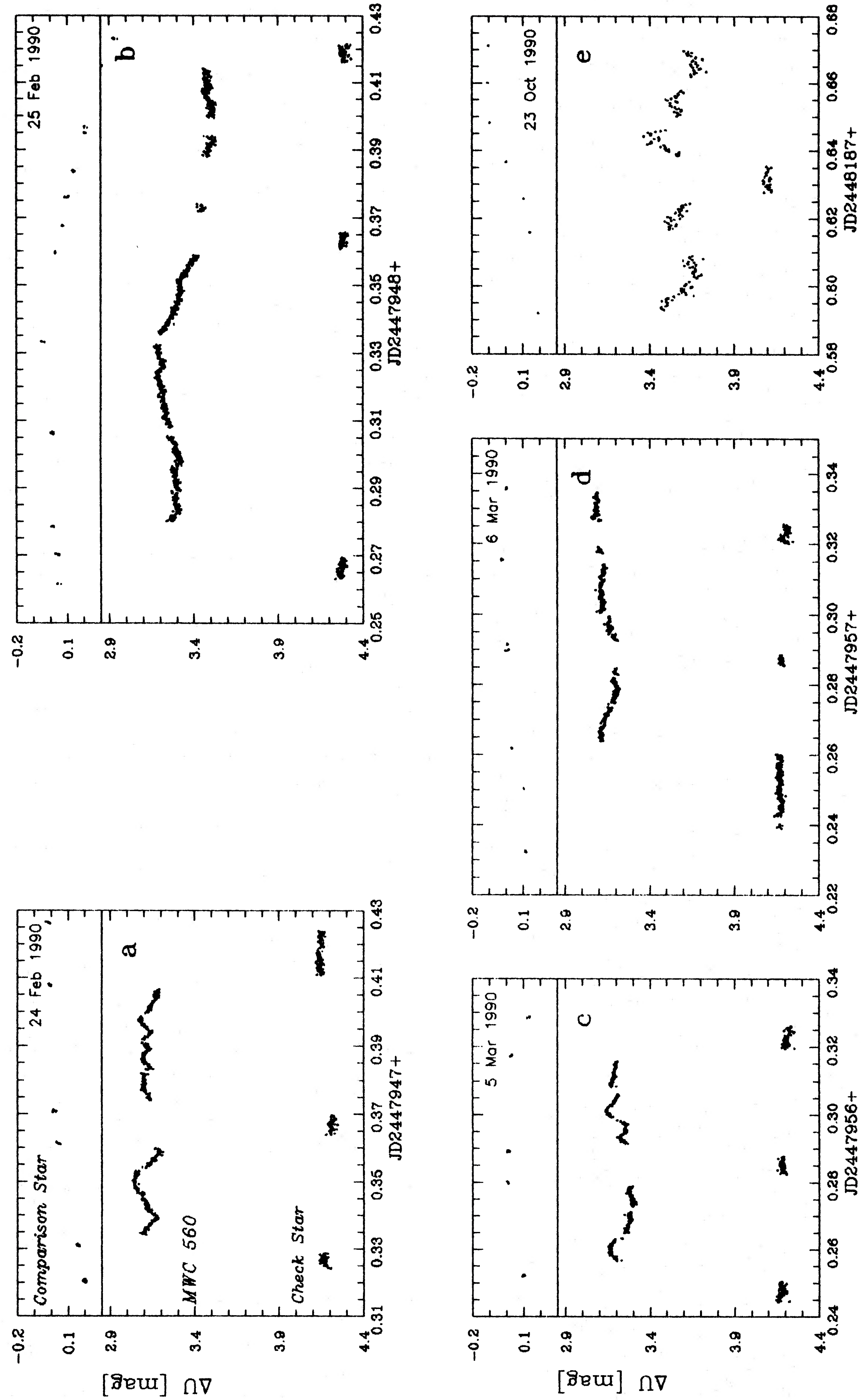


Figure 2. Examples of the flickering activity of MWC 560 in the *U* filter, observed on different dates. Each point represents a 10-s integration time in (a)–(d) and 20 s in (e).

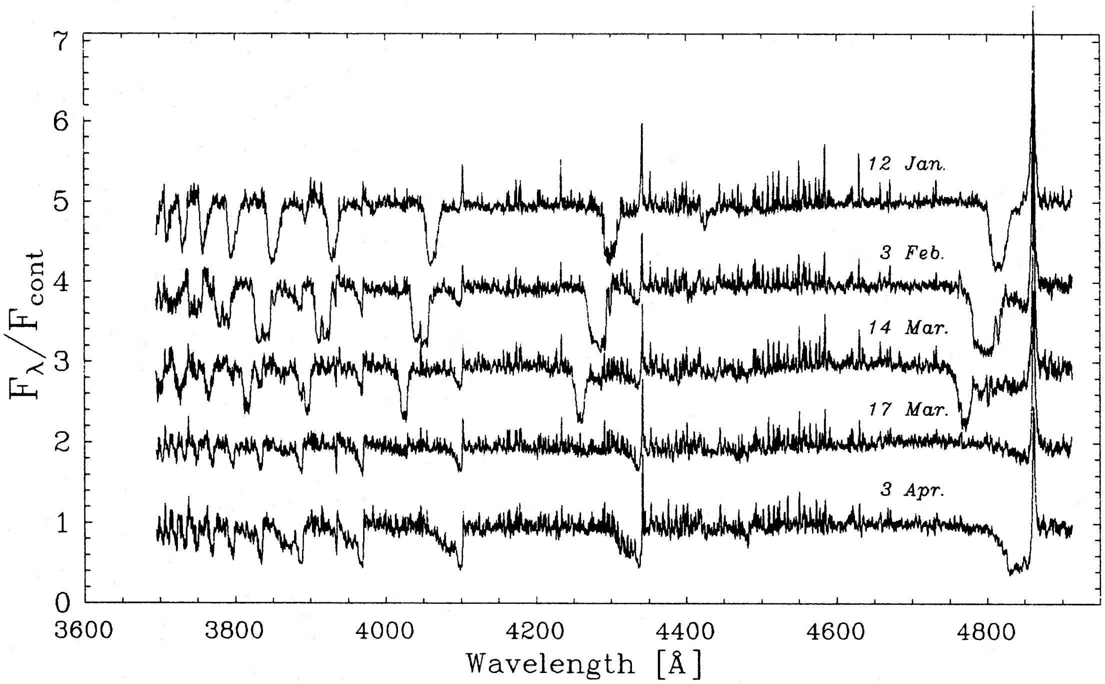


Figure 3. High-resolution spectra of MWC 560 in the spectral region of 3700–4900 Å. The spectra are normalized to the local continuum and are separated by adding a different constant shift to each one. We present this interval as a whole in order to demonstrate the unique character of the strong violet-shifted absorption lines in the optical spectrum of MWC 560.

shifted absorption components (Fig. 4b) can be seen. But in the Ca II *K* 'P Cygni' profile, the stronger and wider emission component dominates.

The radial velocity of the sharpest absorption component of Ca II *K* which can be measured with higher accuracy is about $+40$ km s^{-1} (Table 1), i.e. it is very close to the RV of the metallic emission lines. The origin of this absorption component is not quite clear but, in our opinion (Section 5.2), it probably has a circumstellar origin.

Szkody & Mateo (1990) report the presence of the narrow absorption lines Ca II 8542 and 8662 Å without strong blue-shifts.

Ultraviolet observations of MWC 560 were obtained during 1990 February–April by Dr Michalitsianos and his colleagues (Michalitsianos, Maran & Oliversen 1990a,b; Maran, Michalitsianos & Oliversen 1990; Michalitsianos *et al.* 1990a,b; Maran & Michalitsianos 1990). They noted a strong increase of the flux in UV in comparison with the observations of Bond *et al.* (1984). The UV spectra show absorptions belonging mainly to the low-excitation blends of Fe II, Cr II and Mn II. The violet shifts of these lines are in the interval -500 to -5300 km s^{-1}, corresponding to the RV shown by the hydrogen absorptions in the optical region. The high-resolution *IUE* spectra show the presence of another system of sharp absorption lines of Fe II, Cr II, Mg II and Mn II with a radial velocity of about $+40$ to $+50$ km s^{-1}. This RV practically coincides with the value for the metallic emission lines mentioned above.

Michalitsianos *et al.* (1991a) remark that the UV spectrum of MWC 560 is very similar to the spectrum of the peculiar Be star XX Oph which sometimes shows almost the same kind of displacement of absorption components of the Balmer lines but with a velocity shift of an order of magnitude less than in MWC 560. Fig. 7 presents the comparison of the optical spectra of both stars. It is clearly seen that in the spectrum of XX Oph the metallic and hydrogen lines show a pure P Cygni profile, while in the spectrum of MWC 560 the ionized metallic lines are present only in emission and the Balmer lines have more complicated profiles.

As was mentioned in Section 1, during the autumn of 1990 strong changes in the UV and in the optical spectra of MWC 560 were observed. In Figs 8, 9 and 10 low-resolution spectral observations from 1990 October are illustrated. Fig. 8 shows the spectrum in the interval 3500–5200 Å on the flux scale. The spectrum observed between 5700 and 6700 Å is shown in Fig. 9 and a small region around Hβ is shown in Fig. 10. The strong decrease of the flux in the UV observed by Michalitsianos *et al.* (1990b) and Maran *et al.* (1991) is reflected in the remarkable reddening of the $U-B$ colour (Section 3) and in the weak flux in the near-ultraviolet around the Balmer jump (Fig. 8) in the spectrum from October 24. The Balmer lines have profiles resembling those of P Cygni, with intense absorption components and emission components easily visible only in Hα (Fig. 9), Hβ and Hγ (Figs 8 and 10). The violet shifts of the H I absorption lines measured from these low-resolution spectra vary from about -250 km s^{-1} in Hδ to about -400 km s^{-1} in Hβ and Hα. This result coincides relatively well with the velocities reported by Wagner *et al.* (1990) and Bopp (1990).

The absorptions of Ca II *H* and *K*, which show shifts like the lines of H I, are much more intense in comparison with those from 1990 January–April (see Figs 3 and 8). In Fig. 8 it is seen that the Hε+Ca II *H* blend is the most intense

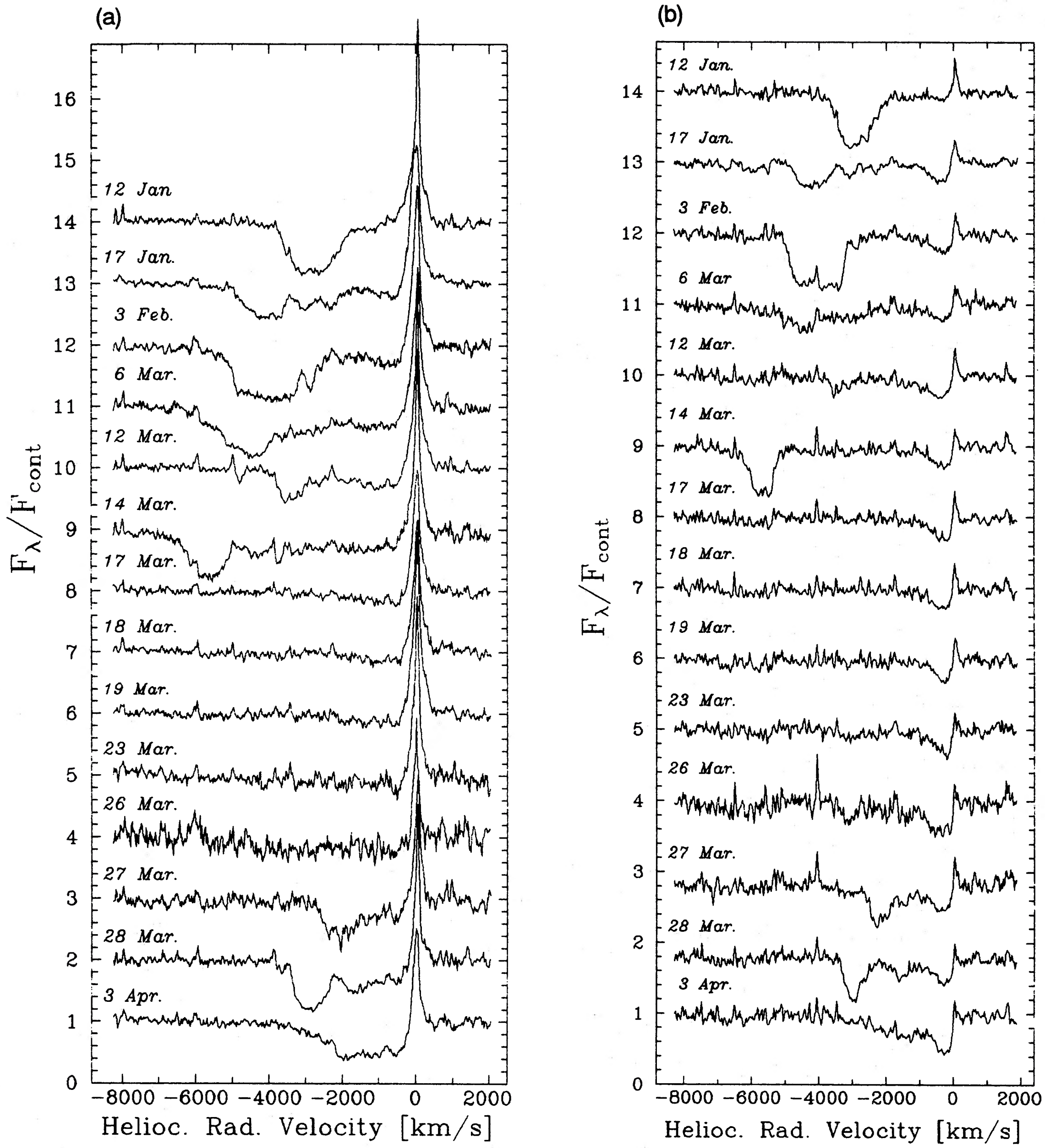


Figure 4. The evolution of the Balmer line profiles Hβ (a) and Hδ (b) in the spectrum of MWC 560 during 1990 January–April. Both of the lines are shown to demonstrate the differences between the emission components and the small-shifted absorption components. The profiles are separated as in Fig. 3.

absorption in this spectral region and the Ca II *K* absorption line is comparable in intensity with the strongest hydrogen absorptions. The situation with the Na I D_1 and D_2 lines is similar. This blend is the only strong absorption, apart from Hα, in the spectral interval shown in Fig. 9. The influence of the He I 5876-Å absorption (Fig. 9) can be seen only in the extended violet wing of the sodium blend. Some of the strongest Fe II lines, as well as those of multiplet 42 (Fig. 10), show profiles similar to Balmer lines, with intense and wide absorptions. In this way they differ considerably from the profiles observed during 1990 January–April. Some other relatively intense emission lines are present in the spectrum of MWC 560 in the interval between the lines of Na I and Hα (Fig. 9). These are the emissions of [O I] 6300 and 6364 Å as well as a few emissions of the Fe II multiplets of 40 and 74, also noted by Wagner *et al.* (1990) and by Bopp (1990). Only some of the strongest TiO bands in this region, like that at 6161 Å, can be seen in Fig. 9. Our spectral observations with high time resolution confirm the observations of Bopp (1990) and do not show considerable short-term changes of the line profiles in the spectrum of MWC 560.

5 DISCUSSION

5.1 Preliminary models

The observational data suggest that MWC 560 is a binary star consisting of an M giant and a compact companion. The observations of Sanduleak & Stephenson (1973), Buckley *et al.* (1990), Szkody & Mateo (1990), Sanduleak (1990) and Lynch *et al.* (1990) show that the spectral class of the giant is most probably M4–4.5III.

Table 1. Heliocentric radial velocities measured in the spectrum of MWC 560, during 1990 January–April. The numbers in parentheses indicate the number of measured lines. The radial velocities are in units of km s^{-1}.

Date JD 2447900+	Metallic emission lines	Hydrogen emission lines	Absorption components of the HI lines "fastest"	"slowest"	Sharp absorption CaIIK – line
12 Jan. 04.420	+45±1 (98)	+67±3 (5)	−3040±44 (12)		
17 Jan.* 09.471			−4155±60 (5)	−290±40 (3)	
3 Feb. 26.380	+40±1 (82)	+59±4 (3)	−4260±70 (13)	−220±20 (3)	
6 Mar. 57.309	+41±1 (57)	+51±4 (3)	−4440±30 (6)	−270±20 (4)	+51
12 Mar. 63.270	+39±1 (68)	+54±1 (4)	−3400±25 (6)	−270±25 (4)	+50
14 Mar. 65.313	+42±1 (47)	+62±4 (4)	−5630±10 (7)	−240±80 (5)	+49
17 Mar. 68.303	+41±1 (68)	+55±2 (3)		−150±15 (4)	+41
18 Mar. 69.286	+41±1 (80)	+65±4 (4)		−250±9 (7)	+41
19 Mar. 70.298	+37±1 (58)	+59±3 (3)		−220±13 (9)	+33
23 Mar. 74.333	+38±1 (68)	+51±1 (3)		−170±7 (5)	+32
26 Mar. 77.286		+44±10 (2)		−300±25 (4)	
27 Mar. 78.354	+40±1 (42)	+60±6 (3)	−2120±25 (5)	−280±20 (4)	+35
28 Mar. 79.294	+39±1 (66)	+60±5 (3)	−2920±30 (6)	−280±40 (5)	
3 Apr. 85.278	+41±1 (67)	+48±6 (3)	−1380±120 (5)	−220±16 (11)	+35

*The spectrum is slightly defocused

Three quite preliminary qualitative 'models' are suggested now to explain the variations in the spectrum and the brightness of MWC 560. Bond *et al.* (1984) suggest that MWC 560 is a symbiotic-like binary with components an M giant plus a compact secondary. As a result of the high mass transfer rate the matter 'is ejected in highly variable, high-speed wind from the companion'. But we believe that the shapes of the Balmer lines which do not show P Cygni profiles make the explanation of the observed spectral peculiarities in terms of a spherically symmetric stellar wind very difficult.

Michalitsianos *et al.* (1991a) interpret their UV observations from 1990 February–April by supposing that MWC 560 ejects a high-velocity, optically thick envelope. Michalitsianos *et al.* (1990b), Wagner *et al.* (1990) and Maran *et al.* (1991) noted that the ejection of such a relatively cool, optically thick envelope is confirmed by the observations during 1990 September–October.

We also suggest (Tomov 1990; Tomov *et al.* 1990a) that MWC 560 is a binary system consisting of an M4.5III star and a compact object. The high rate of mass transfer produces an accretion disc around the compact companion. The UV does not show any evidence that a white dwarf or the inner parts of an accretion disc are directly visible. This may suggest the presence of an optically thick envelope which hides the whole disc or at least its inner parts. In our opinion, the narrow Balmer emission components and the emission lines of the ionized metals which show similar small redshifts (Table 1) originate in the outer parts of the envelope and/or of the disc. Their constant radial velocities suggest that possibly the orbital plane is perpendicular to the line of sight, so that the accretion disc is probably 'face on'. The absorption lines with strong violet shifts possibly originate in ejections directed in the line of sight. To see such strong absorptions, the ejections must be highly collimated and the regions in which these lines originate must be permanently projected over a 'pseudo-photosphere' formed around the hot component. If the extents of these regions are greater than the 'pseudo-photosphere', we can see emission

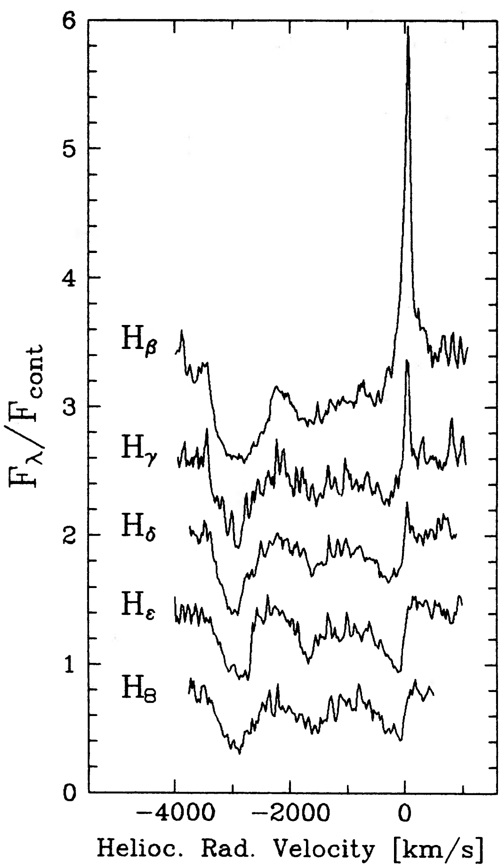


Figure 5. Multicomponent structure of the Balmer absorption lines in the spectrum of MWC 560 illustrated by the profiles observed on 1990 March 28. The profiles are separated as in Fig. 3.

components with similar violet shifts. On the other hand, if the ejections are bipolar, we can see both violet- and red-shifted emissions which could have similar velocities.

Another important question is the nature of the compact companion. If we compare MWC 560 with SS 433, another unique object, in the jet velocities context it is seen that the velocities of the ejections in MWC 560 are one order of magnitude less than the jet velocities in SS 433. Therefore the energy of the ejections in MWC 560 must be at least 100 times smaller than in SS 433. Because a neutron star or even a black hole could be a possible compact companion in SS 433, it is most probable that the companion in MWC 560 is a white dwarf. Michalitsianos *et al.* (1991a) also suggest a white dwarf for the companion and note that the observed velocities (up to -6000 km s^{-1}) are close to the value of the escape velocity for a white dwarf.

5.2 Distance and interstellar reddening

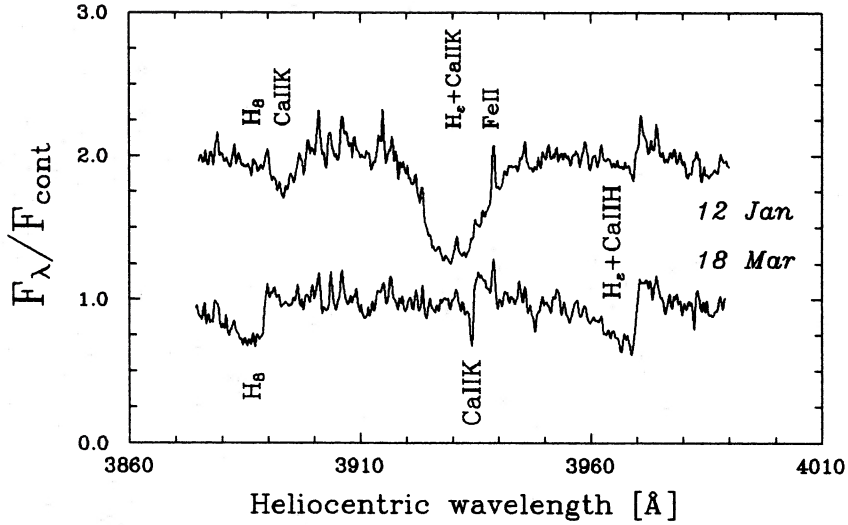
Any estimates at present have a preliminary character, the distance to the star being no exception.

There are no reliable data for the interstellar absorption toward MWC 560 ($l \sim 222°$, $b \sim +4.5°$), so it is possible to make only a rough estimate. Fortunately, some investigators note that for this region of the galactic plane we can suppose a 'rather normal' interstellar absorption law. Pandey & Mahra (1987) note that the value of A_V in the areas around $l \sim 220°$ is between 0.4–0.8 mag for a distance of 1 kpc and between 0.8–1.5 mag for 2 kpc, with mean values 0.6 and 1.4 mag respectively. The same value for A_V at a distance of 1 kpc, 0.6 mag, was obtained earlier by Sharov (1963).

The near-infrared photometry of MWC 560 by Buckley *et al.* (1990) allows us to estimate the distance to MWC 560. In the $(J-H)/(H-K)$ colour–colour diagram by Koornneef (1983), MWC 560 lies above the curve for normal giants (Fig. 11). The correction opposite to the interstellar reddening vector places MWC 560 exactly at the position of an M4–4.5III star in accordance with the estimates from the infrared spectroscopy data mentioned in Section 5.1. At the same time we obtain a quite moderate value of $E(B-V) \approx 0.23$ mag. Assuming a normal reddening law with $R=3.1$ (Pandey & Mahra 1987), we define $A_V \approx 0.7$ mag for MWC 560. The infrared colour excess $E(J-K)$ confirms this estimate – according to Koornneef's (1983) calibration a normal M4.5 giant has a colour $(J-K)_0 = 1.19$ mag while from the data of Buckley *et al.* (1990) we have $(J-K) \approx 1.31$ mag, i.e., $E(J-K) \approx +0.12$ mag for MWC 560. The relation $A_V \approx 5.6E(J-K)$ by Hyland (1981) gives practically the same value: $A_V = 0.67$ mag. Comparing these estimates of A_V with the values obtained by Pandey & Mahra (1987) and Sharov (1963) we estimate the distance to MWC 560 to be ~ 1 kpc.

The 'standard' approach based on the distance modulus leads to great uncertainties due to the unknown visual magnitude of the M-star companion of MWC 560. There are two sources of uncertainty: in the absolute magnitude M_V attributed to M giants, and uncertainties due to the possible existence of unknown neutral extinction toward MWC 560. So, different calibrations give significantly different values for M_V – e.g. according to Allen (1973) an M4.5III star has $M_V \approx -0.6$ to -0.7 mag, while Straizys & Kuriliene (1981) give $M_V \approx -0.4$ mag. There are two estimates of the visual brightness of MWC 560 at earlier epochs, 12.5 mag (Merrill & Burwell 1943; Sanduleak & Stephenson 1973) and ~ 11 mag (Bond *et al.* 1984). According to the formula $V - M_V = 5 \log d - 5 + A_V$, we obtain (with $M_V = -0.4$ mag) $d \approx 2.7$ kpc ($V=12.5$ mag) and $d \approx 1.4$ kpc ($V=11$ mag). If we assume that $M_V = -0.7$ mag we obtain a distance twice as great, which is quite unrealistic.

On the other hand, as was mentioned above (Section 4, Fig. 6), the sharpest and the most intense absorption component of Ca II *K* shows a radial velocity of about +40 km s^{-1}. According to the Oort formula, such high velocities of the interstellar clouds can exist at this galactic longitude only at a distance $d > 2.5$ kpc! This value is unrealistic, in our opinion, because of the lack of a complex shape of the component of interest, and its very small intensity, $W_\lambda \sim 0.1$ Å, contrary to the value $W_\lambda \sim 0.8$ Å that can be expected for $d > 2.5$ kpc. Moreover, the value $d \sim 1$ kpc places MWC 560 in the well-traced Orion arm of our Galaxy, while at a distance of about 2.5–3 kpc in the direction of MWC 560 there are no noticeable structures! The radial velocity of this sharp line practically coincides with the radial velocity of the ionized metals and probably must be very close to the γ-velocity of the star if our suppositions are true. So, the assumption of a circumstellar origin of this Ca II *K* absorption component is more realistic, which is why we cannot rely on it for estimating the distance.



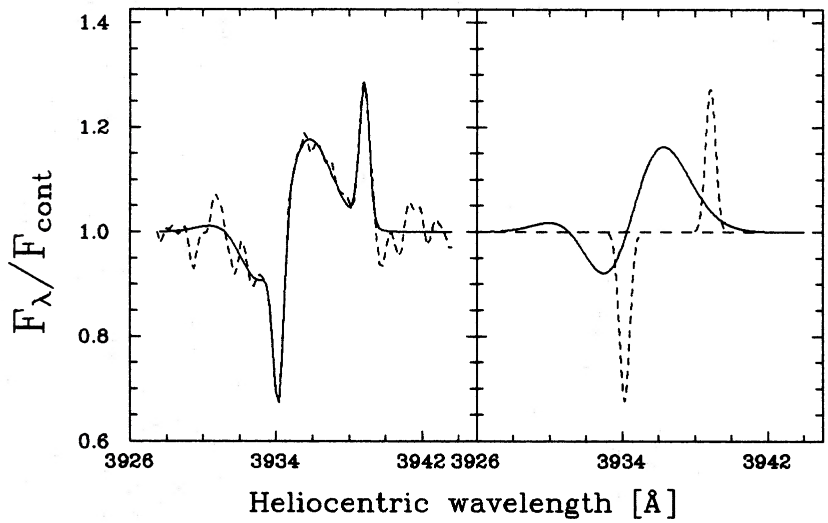


Figure 6. In the top panel the Ca II *K* region in the spectrum of MWC 560 at two different times is shown. In the first spectrum (1990 January 12) the strong violet-shifted absorption blend of Hε and Ca II *H* superimposed on the Ca II *K* position is present. In the second spectrum (1990 March 18) this blend is absent. The bottom left panel shows the observed Ca II *K* profile on 1990 March 18 (dashed line) fitted by four Gaussians (solid line). The sharp absorption peak in the red wing of the Ca II *K* emission is an Fe II 3938-Å line. After the subtraction of the sharp absorption Ca II *K* component and Fe II emission line (dashed lines) the resulting profile (solid line) is shown in the bottom right panel.

Recently Efimov (see Gershberg 1990), supposing an interstellar origin of the *UBVRI* polarization observed by him, calculated a distance to MWC 560 of ~0.5–1.0 kpc.

Even though all these estimations are quite preliminary and rather rough, for the time being we can accept the value of $d \sim 1$ kpc as an approximate distance to the star.

5.3 Luminosity of the hot component

The observed fluxes of MWC 560 in the *IUE* spectral range (1200–3200 Å) have a minimum value $F_{uv}(\mathrm{min}) \sim 2 \times 10^{-10}$ erg cm^{-2} s^{-1} for 1984 March (Michalitsianos *et al.* 1991a) and the same value was observed on 1990 September 26 (Maran *et al.* 1991). During the *IUE* observations in 1990 February–April, Michalitsianos *et al.* (1991a) registered considerably larger values – up to $\sim 10^{-9}$ erg cm^{-2} s^{-1}. Our spectrum (see Section 4, Fig. 8) was obtained a month after the UV observations in 1990 September and covers the interval 3500–5200 Å. Assuming the UV flux to be roughly constant during 1990 September–October, we extrapolated the cited data to obtain an estimate for the 'total' flux in the λλ1200–5200 range of $F_{tot} \sim 1.2 \times 10^{-9}$ erg cm^{-2} s^{-1}. As can be seen, the maximum UV flux during the active period of MWC 560 in the first half of 1990 is as large as the 'total' flux during the less active behaviour later in the year, but the UV flux drops sharply between both observational seasons while the photometric data show smaller decreases in the *B* and, especially, *V* bands (Section 3).

Assuming normal interstellar absorption towards MWC 560 (Section 5.2), we can estimate the dereddened fluxes and then the luminosity of the hot source – an accretion disc wholly or partly hidden in an optically thick

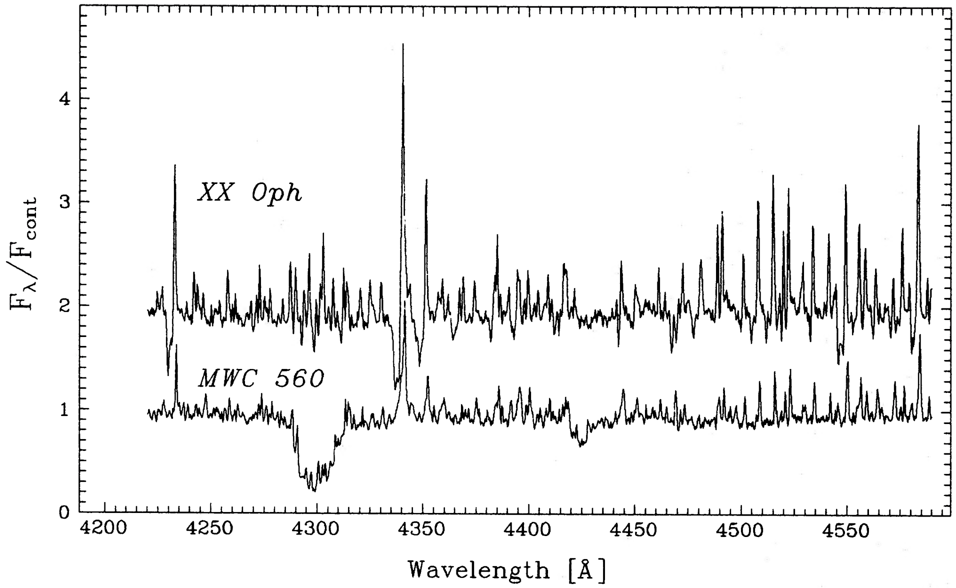


Figure 7. Comparison between the spectra of MWC 560 (obtained on 1990 January 12) and XX Oph (obtained on 1990 July 17) in the spectral region around Hγ.

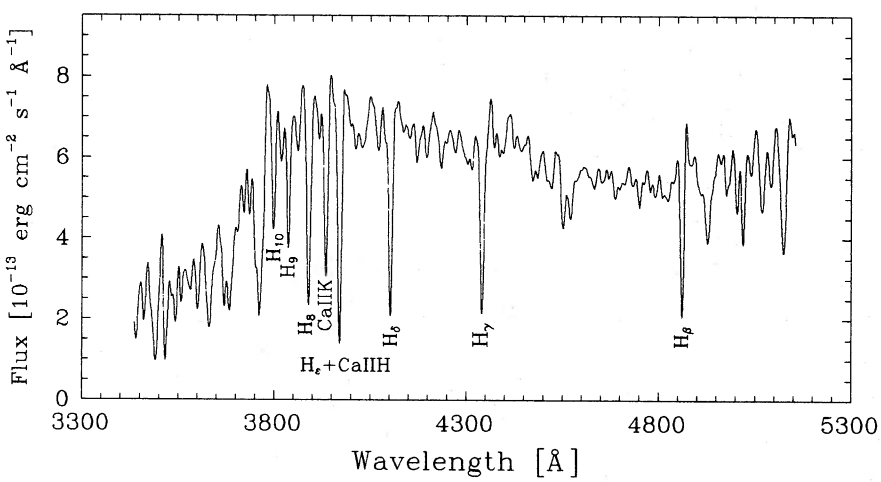


Figure 8. Absolutely calibrated spectrum of MWC 560 obtained on 1990 October 24.

envelope, as we propose. Using the data from Allen (1973) for the ratio A_λ/A_V in the spectral range of interest and a value of $A_V \sim 0.7$ mag we obtain for the dereddened fluxes from MWC 560 the following values (in erg cm^{-2} s^{-1}): $F^0_{uv} \sim 10^{-9}$ and $\sim 5 \times 10^{-9}$ during the less active and active periods in 1990 and $F^0_{tot} \sim 3.3 \times 10^{-9}$ in 1990 October. Presuming the radiation to be isotropically emitted and taking 1 kpc as the value for the distance, we obtain the following values for the luminosity of the hot source in MWC 560: (i) $L^{max}_{uv} \sim 150\ L_\odot$ (early 1990); (ii) $L^{min}_{uv} \sim 30\ L_\odot$ (autumn) and (iii) $L_{tot} \sim 100\ L_\odot$ (late 1990). We estimate the 'total' luminosity (that differs not so much from the bolometric one in this case) in the more active period to be a few hundred (250–300) solar luminosities.

5.4 Two ejection regimes?

Because of the absence of real data about the geometry of the system and the physical parameters of the components, it is difficult to say if Balmer absorptions with strong violet shifts appear in an expanding, optically thick envelope, or in strongly collimated jets. For each of these two hypotheses pros and cons can be adduced. For example, the shape of the profiles of the high-velocity absorptions are not similar either to the profiles of the hydrogen lines of any of the spectral types, or to the 'classical' P Cygni profile (Fig. 3). They are velocity profiles, which cannot be approximated with the existing model calculations and assumptions of spherical symmetry. We can still give a rough value derived by two

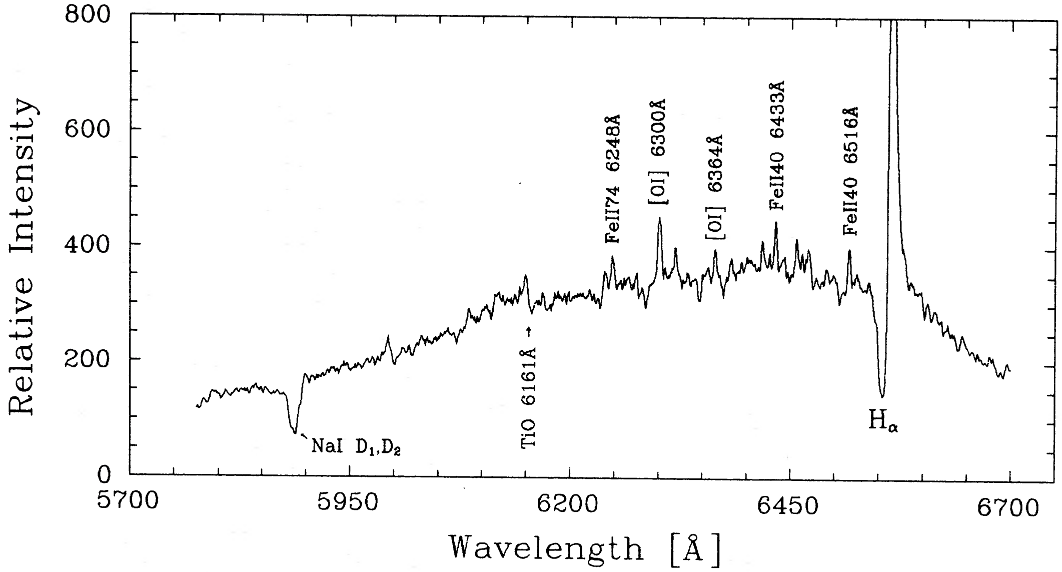


Figure 9. Mean low-resolution spectrum of MWC 560 in the spectral region between the lines Na I D_1, D_2 and Hα, observed on 1990 October 26. It is apparent that the TiO bands of the M-giant spectrum are strongly veiled. The Hα emission component is relatively strong and is truncated on this scale.

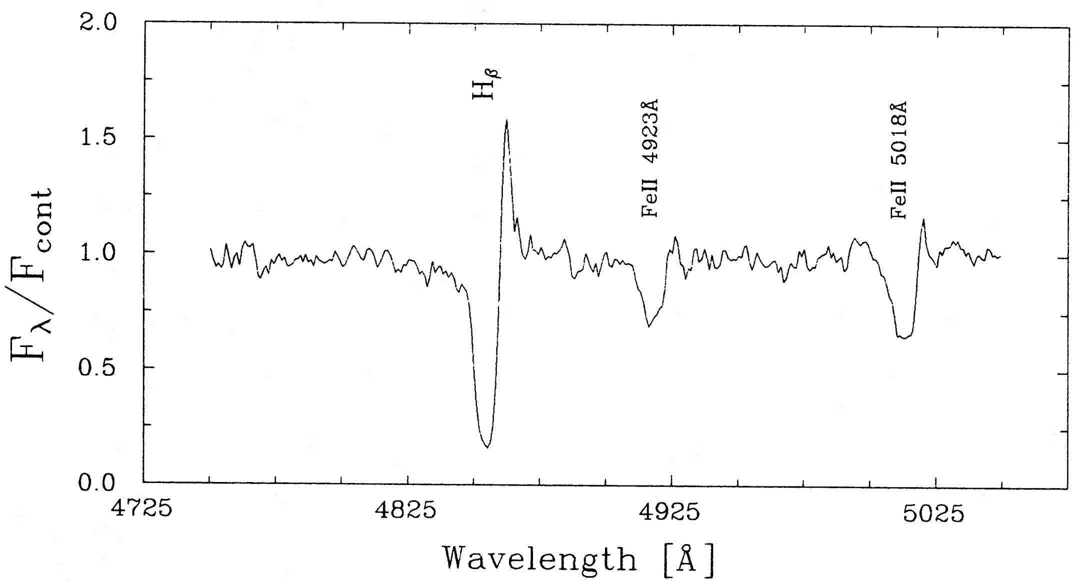


Figure 10. Lines of Hβ and Fe II 4923, 5018 Å in the low-resolution spectrum of MWC 560 obtained on 1990 October 26. The profiles differ strongly from those observed during 1990 January–April.

different 'standard' methods. Using the method of Unsold and the spectrum from 1990 January 12, for the column density of hydrogen atoms in the second level along the line of sight, we obtain a value $N_{02}(\mathrm{H}) \approx 6.3 \times 10^{15}$ cm^{-2}. From the high-velocity absorption profiles in the 1990 January 12 and February 3 spectra and integrating the relative intensity directly, for the column density of the hydrogen atoms in the second level we obtain $N_{02}(\mathrm{H}) \sim 3\text{–}4 \times 10^{16}$ cm^{-2}. These two values are of the same order and as a first, rough estimation of $N_{02}(\mathrm{H})$ along the line of sight we can accept the value 10^{16} cm^{-2}. Using the standard methods based on the intensities of the hydrogen absorption lines we estimate the electron density to be $\log n_e \sim 12.8\text{–}13.5$. Assuming a temperature $T \sim 10^4$ K and local thermodynamic equilibrium (LTE), for the concentration of the hydrogen atoms at the second excitation level (from the Saha–Boltzmann relation) we obtain $n_{02} \sim 10^6\text{–}10^7$ cm^{-3}. So, for the extent of the region where the high-velocity hydrogen absorptions originate we obtain $l \sim 10^9\text{–}10^{10}$ cm.

It is difficult to accept an expanding, relatively cool, optically thick envelope in which the observed spectrum of MWC 560 originates. The disagreement between such an envelope and the observations during the last few months is obvious. It is true that the observations of Michalitsianos *et*

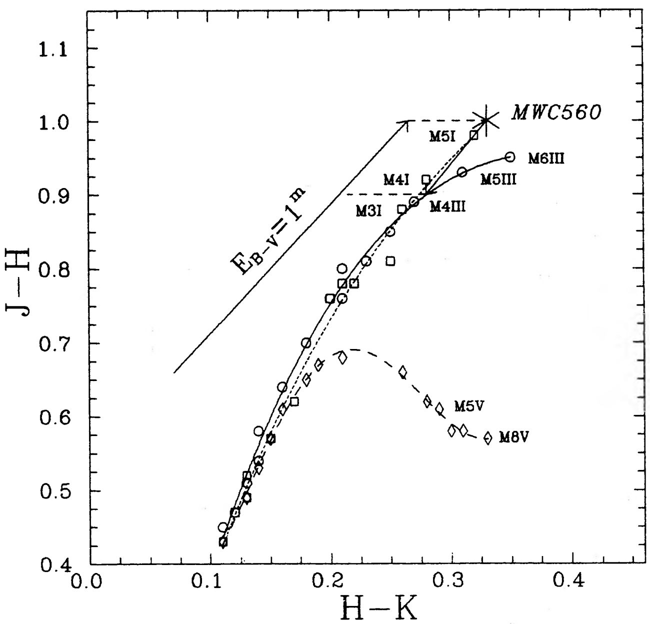


Figure 11. MWC 560 on the $(J-H)/(H-K)$ diagram. The data for the normal stars are from Koornneef (1983) and for MWC 560 from the observations of Buckley *et al.* (1990). Open squares and the short-dashed line represent luminosity class I, open circles and the solid line – luminosity class III, and open diamonds and the long-dashed line – luminosity class V. The reddening vector $E(B-V)=1$ mag, from Koornneef's data, is shown as well.

al. (1990b), Wagner *et al.* (1990) and Maran *et al.* (1991), as well as our own described above (Figs 8, 9 and 10), show that UV and optical spectra of MWC 560 in the autumn of 1990 are similar to that of a nova several days after maximum. Based on the preliminary results from our spectral observations during 1990 December–1991 March we can say that in general in the optical range the spectrum of the star remains almost the same. At the same time our photometric observations show that the star brightness in the V filter changes irregularly between 9.5 and 9.9 mag. If the star actually ejects an envelope, the observations suggest that its expansion velocity is of the order of a few hundred km s^{-1} (Section 4; Wagner *et al.* 1990; Bopp 1990). Therefore, if the ejected envelope remains optically thick, it is very strange that the star's brightness is almost constant, and we do not observe any light variations typical of novae and nova-like stars. On the other hand, it is difficult to suppose that the envelope becomes optically thin, because up to now the expected spectrum (Michalitsianos *et al.* 1990b; Wagner *et al.* 1990) which is typical during the nebular phases of novae has not appeared.

The latest changes in the spectrum of MWC 560 are not in contradiction to the preliminary 'model' we proposed. Our suggestion for the discrete jet ejections is based on the Balmer absorption components showing velocities between -1000 and -6000 km s^{-1} observed during 1990 January–April (Table 1). Since the autumn of 1990 the Balmer absorption lines have shown violet shifts of the order of ~ -200 to -500 km s^{-1}. Their profiles are not of the P Cygni type but only resemble this kind of line. We suppose that during the last few months the star has ejected matter in a quasi-stationary regime with relatively constant rate, and smaller, almost constant velocity.

5.5 Mechanism of activity

Speculating in this way, it is possible to explain the changes observed in the optical spectrum and the relatively constant stellar brightness. This quasi-stationary regime could result from many causes. It is possible that they are connected with considerable changes in the mass exchange rate as a result of the orbital movement of the components and/or pulsations of the M giant. The long-term light curve of MWC 560 (Luthardt 1991) shows that the changes of the brightness are various, with different characteristic time-scales. For example, it is possible that the short-term, sharp local maxima in the light curve separated by about 2000 d, mentioned above (Section 3), are close to the orbital period. In this case these maxima could be a result of the increase of the mass transfer rate during the periastron passage of the companion which moves on a high-eccentricity orbit. Unfortunately, the lack of information about the orbit of the system does not permit us to check such a suggestion.

The question of the mechanism of the supposed jet ejections is very complicated. The two possible mechanisms which can produce such high-velocity and highly collimated ejections are supercritical accretion through the polar columns of a magnetic compact object (probably a white dwarf in MWC 560) or a geometrically thick disc (see for example Calvani & Nobili 1981; Lipunov 1987). In both cases the compact object cannot be observed directly because of the optically thick envelope which transforms its high-energy radiation into lower energies. If we have a similar situation, the moderately hot UV continuum and the presence of low-excitation absorption lines observed by Michalitsianos *et al.* (1991a) do not contradict the supposition of the 'face on' location of the disc.

The maximum luminosity of the hot component estimated above (Section 5.3) is far from the critical Eddington luminosity in the case of spherically symmetric accretion. This result could indicate that the column supercritical accretion is more probable if the matter accretes on to less than ~ 1 per cent of the white dwarf's surface.

6 CONCLUDING REMARKS

The lack of enough observational data at present makes the choice of a concrete mechanism and the detailed discussion of it very difficult. As is mentioned by Maran *et al.* (1991): 'MWC 560 may represent either a new type of cataclysmic variable star, a new type of symbiotic star, or a previously unobserved and possibly short-lived phase in the evolution of an interacting binary system'. A new, hitherto unknown mechanism may cause the observed jet ejections from the compact component of MWC 560. We assume that it is possible that the exceptionally strong decrease of the UV flux, without considerable changes of the brightness in the optical, are connected with the mechanism of ejection. This may be a consequence of the change of the regime from discrete (1990 January–April) to quasi-stationary ejections (at least from 1990 September).

Finally, on the basis of our and other published observations we can speculate that the present state of MWC 560 is temporary. In our opinion, Balmer absorption components with strong violet shifts and lifetimes of a few hours or days will appear again in its spectrum in the next few months. The UV flux will increase again. Other remarkable, sudden changes in the spectrum and the brightness of the star will not occur. If our supposition is confirmed, that will be an indication that the model we suggested is more realistic than the model of a nova-like envelope.*

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*Between 1991 September 27 and 30, while this paper was being revised, we obtained four spectra of MWC 560. Intense Balmer absorption components, violet-shifted by about -1800 km s^{-1}, appeared again (Tomov & Kolev 1991). At the same time, Michalitsianos *et al.* (1991b) observed a strong increase of the UV flux.

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