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Photometric Activity of the Herbig Be Star MWC 297 over 25 Years

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Abstract—The photometric behavior of the hot, young Herbig Be star MWC 297 on various time scales is studied using published data, as well as new observations. The series of photometric observations covers about 25 years. Over this time, the star showed low-amplitude ($\Delta V \approx 0.3^m$) irregular variability modulated by large-scale cyclic variability with an amplitude close to 0.2^m and a period (or quasi-period) of 5.4 ± 0.1 yr. A detailed seasonal analysis of the data shows that the light curve of MWC 297 displays two types of photometric features: low-amplitude Algol-like fading with an amplitude close to 0.2^m and low-amplitude flares resembling the flares of UV Ceti stars, but being more powerful and having longer durations. The variations of the stellar brightness are accompanied by variations of the $B-V$ and $V-R$ colors: when the brightness decreases, $B-V$ decreases, while $V-R$ increases (the star reddens). The reddening law is close to the standard interstellar reddening law. Although the character of the brightness variability of MWC 297 resembles the photometric activity of UX Ori type stars, which is due to variations of their circumstellar extinction, its scale is very far from the scales observed for UX Ori stars. It is difficult to reconcile the level of photometric activity with the idea that MWC 297 is observed through its own gas–dust disk viewed almost edge-on, as has been suggested in several studies.

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1. INTRODUCTION

MWC 297 (NZ Ser, Sp = B1.5 [1]) belongs to the family of young, hot Herbig Ae/Be stars. It has a strong infrared (IR) excess [2–4], providing evidence for the presence of a circumstellar gas–dust disk, and strong emission in its spectrum (the Hα equivalent width is close to 650 Å [1]). According to [2–4], the mass and radius of the star are 10 $M_\odot$ and 6 $R_\odot$, and its luminosity is of the order of $10^4 L_\odot$ (for a distance of 250 pc). MWC 297 has recently been intensively studied using IR interferometry [5–7] and spectral interferometry in the Brγ line [8–10]. These data have been used to estimate the typical dimensions of the inner region of the circumstellar disk that is responsible for the near-IR emission. The region of emission in the Bγ line is appreciably larger than the region giving rise to the continuum in the vicinity of this line, which has a typical size close to 0.5 AU.

According to the data of Weigelt et al. [10], based on high-resolution spectral interferometry of MWC 297 in the Bγ line, the hydrogen line emission in the stellar spectrum forms in a disk wind with a large opening angle and a mass-loss rate of the order of $10^{-7} M_\odot$/yr. According to [1], MWC 297 has a high rotational velocity ($v \sin i = 350 \pm 50$ km/s), which is only approximately a factor of 1.3 lower than the critical rotational velocity corresponding to the loss of stability and the onset of equatorial mass outflow. Based on these data, Drew et al. [1] inferred that MWC 297 is viewed almost along its equatorial plane. Another argument for this is the large absorption observed in the direction to the star: $A_V \approx 8^m$ [1]. However, this conclusion was questioned by Acke et al. [7], who provided arguments suggesting that the large absorption in the direction toward the star is associated with an interstellar dust cloud located between the observer and the star, rather than a circumstellar disk. They also showed that the circumstellar disk has an inclination $i = 40° \pm 10°$ to the plane of the sky. According to the Brγ-line spectral interferometry [8, 10], the inclniation may be even smaller, close to 20°.

Thus, there is an evident contradiction between

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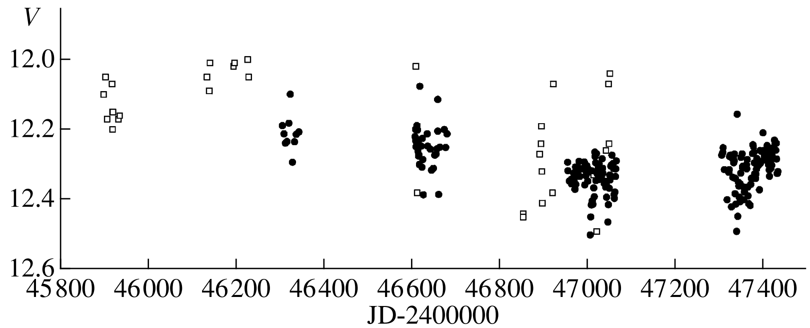

Fig. 1. A fragment of the MWC 297 light curve in the V band. The data points shown by the circles and squares are from [14] and [12], respectively.

the results of Drew et al. [1], according to which the circumstellar disk of MWC 297 is viewed almost edge-on, and the later observations of Acke et al. [7], Malbet et al. [8], and Weigelt et al. [10], which point toward a significant inclination of the plane of the disk to the line of sight. This makes an analysis of the photometric behavior of the star of interest. The reason is that one of the main mechanisms for the variability of Herbig Ae/Be stars is variable circumstellar extinction, which depends sensitively on the inclination of the circumstellar disk to the line of sight [11]. In this paper, we present our analysis of currently available photometry of MWC 297, based on published data and our own observations.

2. REVIEW OF THE PHOTOMETRIC OBSERVATIONS OF MWC 297

The first observations of the photometric activity of MWC 297 [12] showed that this activity to be weak: the optical brightness varies irregularly within several tenths of a magnitude (Fig. 1). Longer photometric monitoring of MWC 297 (over about nine years) was carried out by Shevchenko et al. [13]. They found a component with a period of 12.5 day in the brightness variations, but this was not confirmed by later observations [14]. Mel'nikov [14] noted slow variation of the mean brightness of the star on a time scale of several years. Thanks to photometric data obtained over nine years by the ASAS robotic telescope [15], it has became possible to analyze the photometric activity of the star over a much longer time interval. For this, we selected only observations marked “best” and “good” from the catalog [15].

The series of ASAS observations was continued in 2010–2012 with UBV CCD photometric observations using the 0.6-m Zeiss-2 telescope and 1.25-m telescope of the Crimean Station of the Sternberg Astronomical Institute (N.A. Katysheva) and the 0.5-m G-1 telescope of the Astronomical Institute of the Slovak Academy of Sciences (S.Yu. Shugarov). The observations were processed using standard methods for CCD images and reduced to the Johnson system. Taking these data into account, the series of photometric observations of MWC 297 used in this paper covers about 25 yr.

A comparative analysis of the photometric observations of MWC 297 carried out by different groups shows (Figs. 1–3) that the most accurate observations are those obtained at the Maidanak Observatory and published in [14]. These display lower scatter within a single observational season than the observations of [12] (Fig. 1) and the ASAS data (Fig. 3). The mean uncertainty of the V-band observations published in [14] is 0.02^m, while the uncertainty in our observations, the observations of [12], and the ASAS data is close to 0.05^m. Therefore, we used only the data from [14] in our analysis of the color variations below.

The photometric catalog of Herbst and Shevchenko [16] did not provide additional information on MWC 297. However, it unexpectedly became clear that the observations of the star made at the Maidanak Observatory and published in [16] differ from the results of the same observations published in [14]. Figure 2 presents a fragment of the light curve of MWC 297 which shows the data from these two sources. The data from the two papers agree for epochs JD > 2447010, while earlier V-band observations differ by 0.1^m–0.15^m. The reason for these differences is insufficiently accurate reduction of the primary series of observations to the Johnson system, which was corrected by one of the observers in [14].

3. PECULIARITIES OF THE PHOTOMETRIC ACTIVITY OF MWC 297

Figure 3 shows the V-band light curve of MWC 297 according to [14, 15] and our own observations. The brightness of the star varies within a small range ($\Delta V \approx 0.4^m$), both during a single observing season and over longer time scales. The last feature

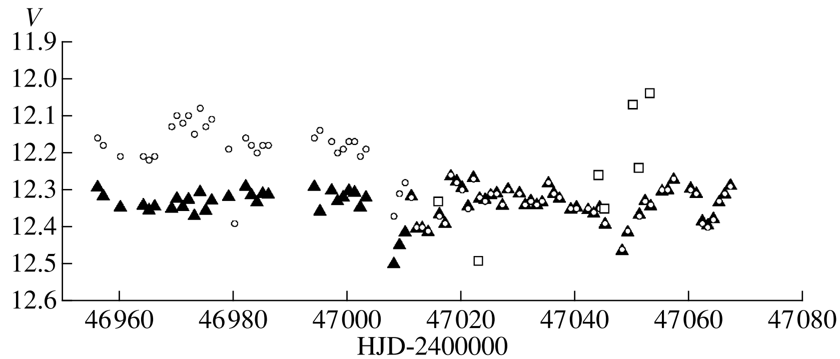

Fig. 2. V-band light curve of MWC 297 based on data obtained at the Maidanak Observatory [14] (triangles) and from the catalog [15] (circles). Several observations from [12] are marked by squares.

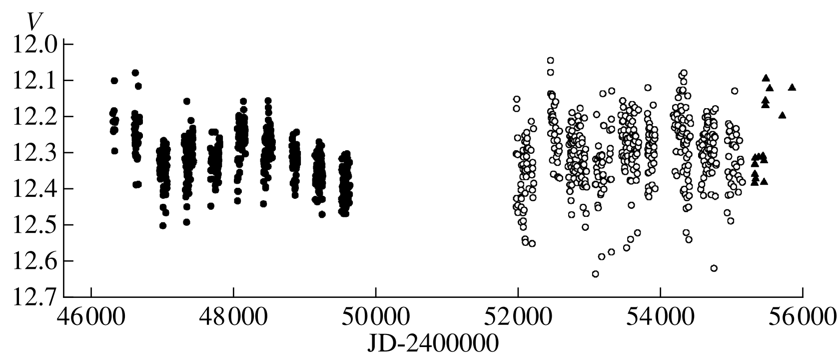

Fig. 3. V-band light curve of MWC 297: the filled circles show the data of [14], open circles the ASAS data, and triangles our new observations.

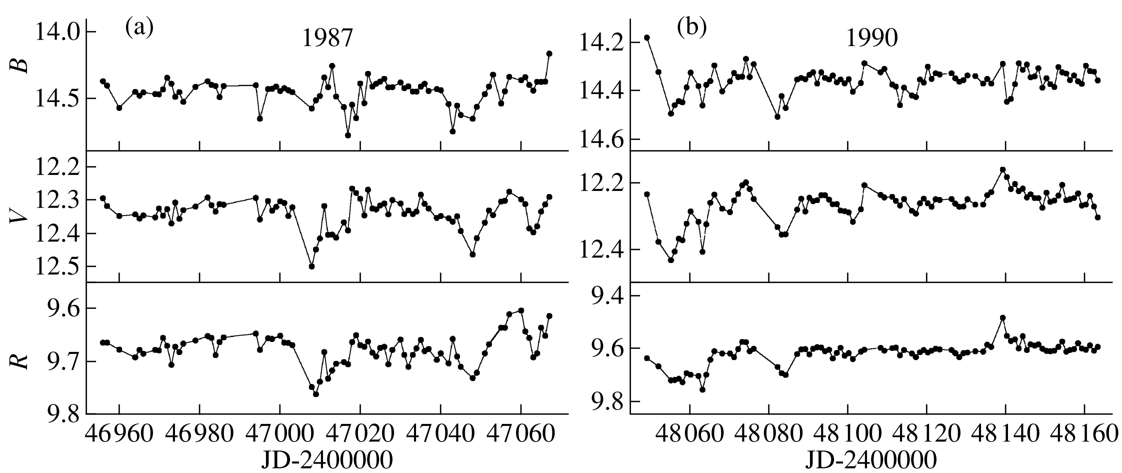

Fig. 4. Fragments of the MWC 297 B, V, and R light curves for two observing seasons: (a) 1987, (b) 1990.

is especially clear in the light curve based on the data from [14]. According to these data, the amplitude of the slow V-band variations is close to 0.2^m. The slow component of the stellar brightness variations is almost indistinguishable in the part of the light curve based on the ASAS data. We suggest that this is due to a the relatively low accuracy of these observations compared to the Maidanak data.

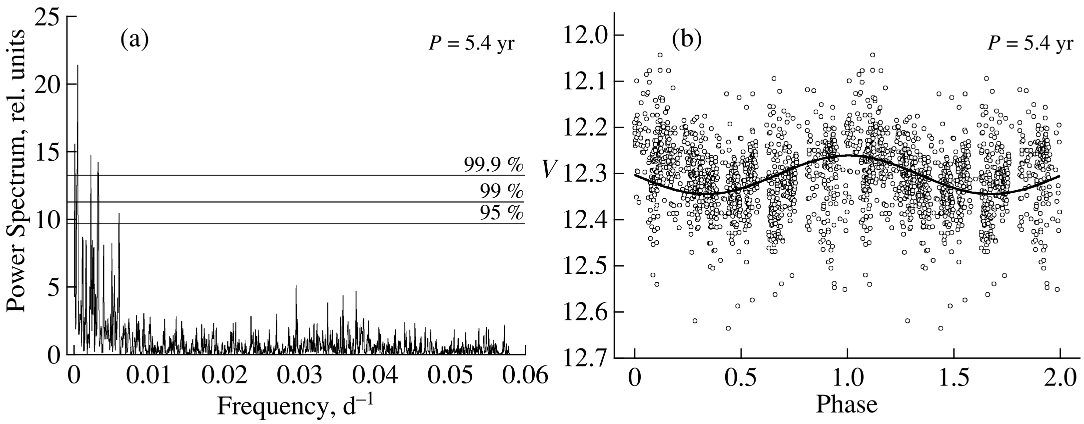

Fig. 5. Scargle–Lomb periodogram for the total photometric series of MWC 297 (a); V-band photometric series folded with the 5.4-year period (b).

Analysis of the photometric series for MWC 297 from [14] for separate observing seasons showed that the light curve has several features that are typical for both flare stars and UX Ori stars. As an example, Fig. 4 shows light curves of MWC 297 for two different seasons. Algol-like minima with an amplitude close to 0.2^m lasting for several days are visible. A small-amplitude flare observed in the V and R bands at the end of 1990 observing season can also be seen (Fig. 4b). It had a steep rise and shallower decline, and resembles (in terms of the shape of the light curve) the flares observed for flare stars (see, e.g., [17]). Another event similar to a flare was observed during the Algol-like minimum close to JD = 2447011 (Fig. 4a).

3.1. Periodogram Analysis of the MWC 297 Light Curve

We performed a periodogram analysis of the photometric series of MWC 297 using the Scargle-Lomb method. The maximum peak in the power spectrum (Fig. 5) corresponds to the period $P = 5.4 \pm 0.1$ yr. Figure 5 also shows the photometric data folded with this period.

We emphasize that this period is mainly supported by the photometric series published in [14] (Fig. 3). This series covers about 10 yr, i.e., about two periods. This cycle is essentially not visible in the series of ASAS observations, which has approximately the same length, possibly due to the lower accuracy of the latter observations. Therefore, it remains open whether the 5.4 yr period is real or is a quasi-period.

3.2. Color–Magnitude Diagrams

Figure 6 shows color–magnitude diagrams for MWC 297 based on the data of [14]. There is no relation between the fading in the V band and variations of the $U-B$ color. A weak effect is observed in the $(B-V)/V$ diagram: fading of the star is accompanied by a small decrease in $B-V$ (the star becomes bluer). A similar effect was noted earlier by de Wit et al. [18]. This behavior of $B-V$ with variations of the brightness of MWC 297 is opposite to the one observed for UX Ori stars: at brightness minima, UX Ori stars first become slightly redder due to selective absorption by circumstellar dust, and become bluer only in the deepest minima, due to the increasing input of scattered radiation of the protoplanetary disk [11]. In the case of MWC 297, the decrease of $B-V$ is observed from the very beginning of the fading of the star. Based on this, de Wit et al. [18] suggested that the variations of the visual brightness are due to fluctuations of the radiation flux of hot circumstellar gas, not to variations of the circumstellar extinction.

De Wit et al. did not consider the $(B-V)/V$ diagram. Figure 6 shows that this diagram differs fundamentally from the $(B-V)/V$ diagram: $V-R$ increases (the star reddens) with decreasing brightness. Given that a strong Hα line is located in the R-band in the spectrum of MWC 297, this variation of $V-R$ could be related to strengthening of the line emission of the star. However, this would imply that strengthening of line emission is accompanied by fading of the star's brightness.

This is, in principle, possible. Moreover, it is observed during the minima of UX Ori stars, and is explained by a coronographic effect caused by circumstellar gas–dust clouds (see, e.g., [19]). However, in this case, the reddening of MWC 297 itself may be explained by selective absorption by circumstellar dust, but not by the enhanced input of the emission to the Hα line. In relation to this, we note that, according to Fig. 6, the reddening law for MWC 297

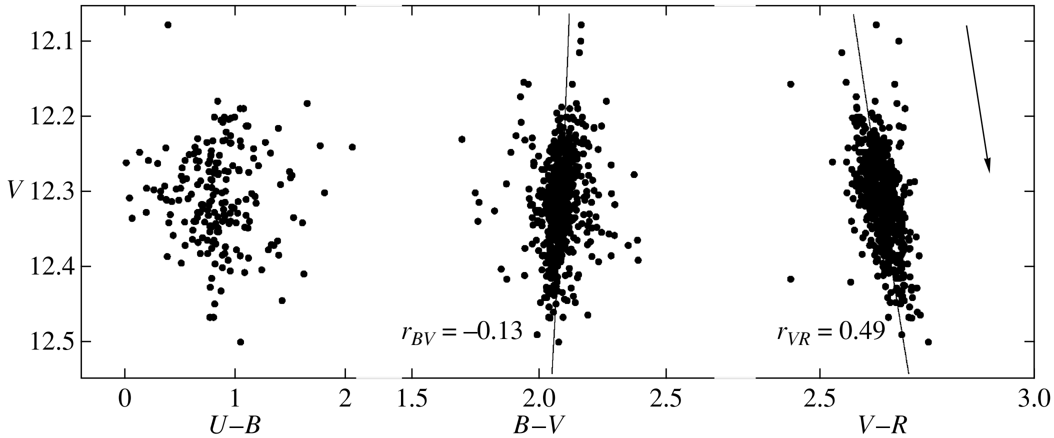

Fig. 6. Color-magnitude diagram for MWC 297 [14]. The arrow shows the direction of the standard interstellar reddening law for $V-R$.

($dV/d(V-R) \approx 0.37$) is close to the "standard" interstellar reddening law. Such a reddening law is also observed when some UX Ori stars fade (see, e.g., [20]).

4. CONCLUSION

Thus, our analysis of the photometric activity of MWC 297 has shown that the light curve of this star has Algol-like minima with durations of the order of several days. These are due to sporadic variations of the circumstellar extinction. However, their amplitude is very small (close to 0.2^m in the V band) compared to the Algol-like minima of UX Ori stars. Such photometric activity is not typical for young stars with circumstellar disks observed almost edge-on. Instead, it is typical for stars observed pole-on or at a large angle to the plane of the circumstellar disk. One example of such stars is the Herbig Ae star AB Aur. According to interferometric observations of its circumstellar disk [21], this star is observed almost pole-on ($i \leq 20°$). AB Aur has showed low photometric activity over the past several decades (see, e.g., [22]). However, Algol-like fadings of AB Aur were observed in the first half of the 20th century [23]. This means that circumstellar dust may appear in small quantities even at high lattitudes.

Our analysis of color–magnitude diagrams for MWC 297 showed that the behavior of the colors with variations of the brightness can display contradictory properties. It is possible that this reflects the influence of two different mechanisms giving rise to variabiity of the brightness: nonstationary processes in the circumstellar hot gas and variable circumstellar extinction. On the other hand, under certain conditions, circumstellar extinction may depend on the wavelength such that colors in different parts of the spectrum vary with changes in brightness in opposite senses [24, Figs. 3 and 8]). Therefore, the unusual behavior of the $B-V$ and $V-R$ colors of MWC 297 in color–magnitude diagrams requires additional consideration.

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