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ASTRONOMY

U-BAND PHOTOMETRY OF MIRA (OMICRON CETI)

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Abstract

We performed observations of the intra-night variability of Mira (Omicron Ceti) in U-band during minimum of Mira cycle. We observed flickering in U-band with amplitude of 0.14–0.22 mag on a time scale of hours. For the accretion disc around Mira B, we find colour $-0.3 \geq U - B \geq -0.9$, effective temperature 7000–12000 K, and optical luminosity ~ 1.2 $L_\odot$. Evolutionary considerations indicate that Mira probably originates from a binary, consisting of two stars with initial masses 0.6 $M_\odot$ and 0.9 $M_\odot$ and orbital period of 200 yr.

Key words: stars: binaries: symbiotic – stars: AGB and post-AGB – accretion, accretion discs – stars: individual: omi Cet

1. Introduction. Mira (Omicron Ceti, HD 14386, coordinates J2000 RA 02 19 20.7, Dec. -02 58 39) is a binary system consisting of an asymptotic giant branch star of spectral type M5-9III (Mira A) and an accreting white dwarf (Mira B). "Wonderful Star" is one of the first variable stars ever discovered because of its large regular fluctuations in luminosity and apparent magnitude. The companion (Mira B) was discovered in 1922 by A. H. Joy and R. G. Aitken [1] as a blue star located at an angular distance of 0.6 arcsec. A bow shock and a turbulent wake extending over 2° on the sky were detected in the far ultraviolet. The wind wake

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is arising from Mira's large space velocity and the interaction between its strong wind and the interstellar medium [2], indicateting that ≈ 30 000 yr ago Mira A became an asymptotic giant branch star and began to lose mass intensively. Most of its wind (about 95%) dissipates into the interstellar medium, the other part (about 5%) is captured by Mira B, forming a bridge between Mira A and Mira B [3], and an accretion disc around Mira B [4].

The brightness of Mira in the optical bands is dominated by Mira A. During the minima of the Mira cycle, the contribution of Mira B emerges in V- and B-bands [5,6]. The behaviour in U-band is unknown, although it is a priori clear that Mira B should be better visible at shorter wavelengths, as is in other symbiotic-like binaries. Here we report our observations in Johnson U-band, and estimate $U - B$ colour, the effective temperature, the radius, and the optical luminosity of Mira B. We also discuss the origin of the system.

2. Observations. The observations were secured with three telescopes: **(i)** the 1.5 m AZ1500 telescope [7] and **(ii)** the 50/70 cm Schmidt telescope [8] of the Rozhen National Astronomical Observatory, Bulgaria, and also with **(iii)** the 40 cm telescope of the Astronomical Center of Shumen University [9]. The three telescopes are equipped with CCD cameras and rotating filter wheels. The data processing was done in IRAF, and included bias removal, flat fielding, and aperture photometry.

The comparison and check stars in the field around Mira are shown in Fig. 1. They are located at angular distances less than 25 arcmin from Mira. The U and B magnitudes are synthetic photometry from GAIA catalog – Vizier catalog I/360/syntphot [10]. The exception is marked with (*) and is our measurement, using wide field images with the 50/70 cm Schmidt telescope. During the data processing, we used the following magnitudes:

No.		RA	Declination	U	B
# a	HD 14411	02 19 28.5	-02 57 58	12.27*	10.779
# b	BD-03 357	02 20 14.3	-02 52 02	10.726	13.762
# c	BD-03 356	02 20 02.1	-02 47 33	11.136	13.399
# d	– – –	02 19 53.7	-02 54 03	13.531	13.417

After a few nights of observations with 50/70 cm Schmidt telescope, we find that there is something wrong with the U-band. Mira appears to be very bright, $U \approx 7$ mag (see Fig. 1). All the other stars in the field are good and their magnitudes correspond to the GAIA values. For the 40 cm Shumen telescope and 1.5 m AZ1500 telescope a similar problem with U-band was not found. We suggest that this problem is a combination of a few coincidences: (1) leakage of the U-band filter in the infrared (probably at wavelengths longer than 1.7 μm); (2) CCD is sensitive in infrared; (3) Mira is very bright in the infrared (at 2 μm it has $K = -2.2$ mag, which is only 0.7 magnitudes fainter than Arcturus). We

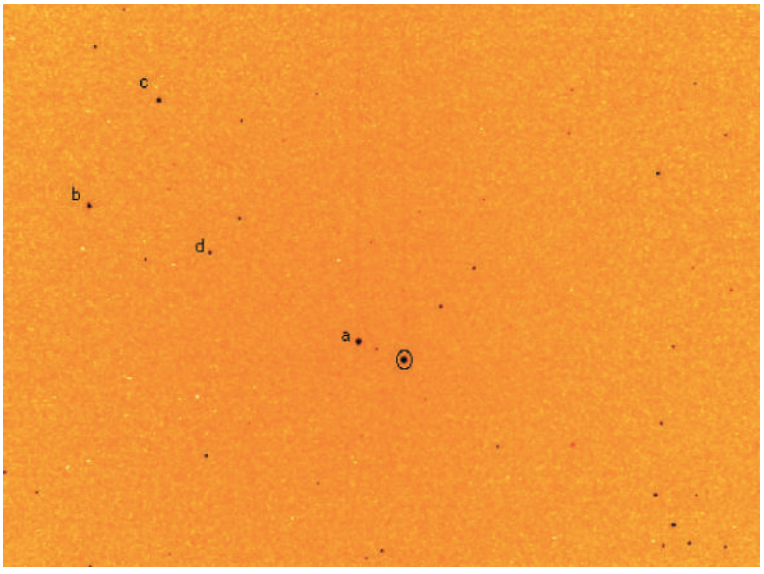

Fig. 1. The field around Mira on a frame from the 40 cm Shumen telescope with size 30 × 24 arcmin. Mira is marked with a circle. The coordinates and magnitudes of the comparison stars can be found in Section 2

note that this problem is not detected for exposure times 2 min for stars with K-band magnitude fainter than $K = +3$ mag. For example, we did not detect any inconsistency between he 50/70 cm Schmidt and the 1.5 m telescope for the U-band observations of the recurrent novae T CrB and RS Oph.

T a b l e 1

Journal of observations and measured U-band magnitudes

date telescope	UT	exposures	U min [mag]	U max [mag]	U aver [mag]	merr [mag]
2025-10-19 40 cm	20:40-00:28	236 × 30 sec	9.816	10.111	9.9442	0.050
2025-10-23 40 cm	21:13-00:01	78 × 90 sec	9.166	9.393	9.2786	0.020
2025-10-29 1.5 m	19:15-20:45	67 × 60 sec	9.166	9.261	9.2115	0.008
2025-10-31 1.5 m	22:00-23:32	110 × 30 sec	9.238	9.374	9.3084	0.010
2025-11-01 1.5 m	23:11-23:39	23 × 60 sec	9.367	9.405	9.3874	0.008

The average magnitudes in V- and B-bands are: 2025-10-19 $V = 8.6567$ $B = 10.2360$; 2025-10-23 $V = 8.5165$ $B = 10.1611$; 2025-10-29 $V = 8.4699$ $B = 9.7066$; 2025-10-31 $V = 8.5707$ $B = 10.0075$; 2025-11-01 $V = 8.5547$ $B = 9.9007$ [11].

3. Results and discussion. ***3.1. Effective temperature and radius.*** Table 1 presents the date of observation, telescope, universal time of the start and end of the run (in format HH:MM), number of exposures and exposure time

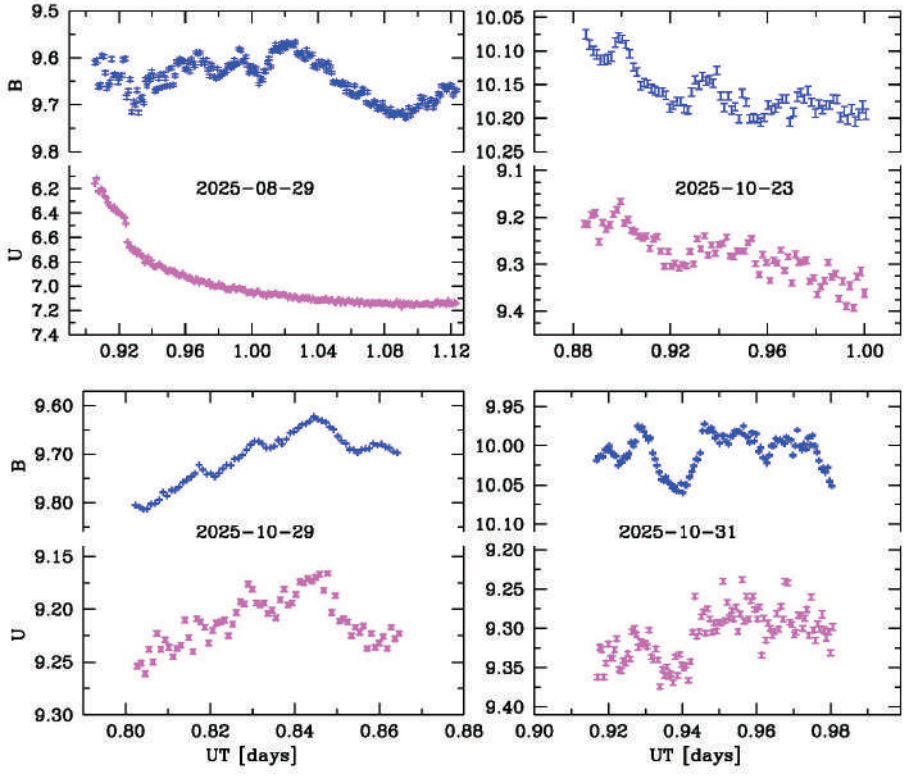

Fig. 2. Variability of Mira in U- and B-bands. Blue colour marks observations in B-band, magenta – in U-band. The U-band data for 2025-08-29 are wrong (see Sect. 2). During the other runs intranight variability (flickering) is visible. Its amplitude is 0.1–0.2 mag

in seconds, minimum, maximum, and average magnitudes of Mira in U-band, and typical observational error. The minimum magnitude corresponds to the maximum brightness. After correction of the minimum and maximum magnitudes for the observational errors, we estimate the amplitude of the flickering: 2025-10-19 $\Delta U = 0.23$, 2025-10-23 $\Delta U = 0.22$, 2025-10-29 $\Delta U = 0.09$, and 2025-10-31 $\Delta U = 0.13$ mag. The correction for the observational errors is larger for 2025-10-19, because the exposure time should be at least 2× longer. For 2025-11-01 $\Delta U \leq 0.05$, however, this run is very short, only 28 minutes.

Combining our published B-band observations [11] with the new data (Table 1), we estimate the $U - B$ colour. Assuming that U and B are coming only from Mira B, we estimate its temperature effective radius, and optical luminosity. In order to estimate temperature we used the calibration for the black body colours (Table 14 in [12]). To estimate the effective radius we used the calibration for generic B-band $\lambda_{eff} = 4380.74$ Å and zero point 6.13268×10^{-9} erg cm^{-2} s^{-1} Å^{-1}, as given in Spanish virtual observatory filter profile services [13]. The accu-

racy of the temperature is about ±2000 K and that of the radius is about ±15%. In our calculations, underestimation of the temperature leads to overestimation of the radius, and vise versa. They partly compensate each other and the accuracy of the luminosity is better than ±10%. Our results are summarized in Table 2, which presents the date of observation, $U-B$ colour, effective temperature, effective radius, and optical luminosity of Mira B. For all 5 nights these values are calculated for the average brightness. For 3 nights (long accurate runs 2025-10-23, 2025-10-29, and 2025-10-31), we calculate these parameters also for the minimum and maximum.

We note that there should be some contribution from the red giant (Mira A) to the B-band. Our estimate is that it is less than 10% during our observations, because: (1) our observations are around the minimum of the Mira cycle, (2) the flickering is visible even in V-band (see Fig. 1 in [11]), and (3) the red giant is embedded in a dust shell which causes additional reddening. The contribution of Mira A to the U-band is negligible ($\leq 3\%$).

The results presented in Table 2 indicate that the typical colour of Mira B is $U-B \approx -0.64$. Mira B emits as black body with temperature T $\approx 9500 \pm 2500$ and effective radius $0.3 < R < 0.8$ $R_\odot$. Its optical luminosity is $1.1 \leq L \leq 1.6$ $L_\odot$.

T a b l e 2

$U-B$ colour, temperature, radius, and optical luminosity of Mira B

date		$U-B$	T [K]	$R/R_\odot$	$L/L_\odot$
2025-10-19	aver	-0.29	6233	0.899	1.09
2025-10-23	min	-0.91	13882	0.215	1.54
	max	-0.81	11509	0.264	1.10
	aver	-0.88	13145	0.223	1.33
2025-10-29	min	-0.46	7208	0.832	1.68
	max	-0.55	7946	0.614	1.35
	aver	-0.50	7500	0.731	1.52
2025-10-31	min	-0.73	10073	0.364	1.22
	max	-0.69	9482	0.389	1.10
	aver	-0.70	9635	0.387	1.16
2025-11-01	aver	-0.51	7638	0.642	1.26

The average values are $T = 9470 \pm 2500$ K and $L = 1.30 \pm 0.20$ $L_\odot$.

3.2. Luminosity and $U-B$ colour. The luminosity of Mira A is 4000–

16000 $L_\odot$ [14]. The luminosity of Mira B is more than 4000 times lower. We are able to see its contribution to UBV bands during the minimum of the Mira cycle, because Mira A has a temperature of about 3000 K and emits most of its energy in the red and infrared. The other reason is that it is embedded in a dust shell, which absorbs UBV radiation of Mira A and re-emits it at longer wavelength (infrared and far-infrared). The extinction in the dust shells of symbiotic Miras can be very large $A_V = 3 - 15$ mag [15]. In the symbiotic Miras, the hot component lies outside of the dust envelope [14], which gives the possibility to observe it in UBV bands.

$U - B$ colour of the hot component of the symbiotic recurrent nova T CrB (the accretion disc around the white dwarf) is $-0.8 \leq U - B \leq +0.2$ [16]. The colour of Mira B is similar to the colour of the accretion disc of T CrB during its super-active state.

Our observations show variability of the $U - B$ colour of Mira from night to night: $U-B = -0.88$ on 2025-10-23, $U-B = -0.50$ on 2025-10-29, $U-B = -0.70$ on 2025-10-31. The red giant will not vary on a time scale of days, i.e. this is a real variability of the colour of Mira B and its accretion disc, probably a result of variable mass accretion rate. Such a variability on a time scale of one week, is probably a clue for an unstable disc and unstable mass accretion.

3.3. Origin of the binary. The lifetime of a star on the main sequence is the period that it spends while steadily fusing hydrogen into helium, which accounts for about 90% of its total existence. It can be estimated as $\tau_{MS} = 10^{10}(M/M_\odot)^{-2.5}$ yr. The basic concept of evolution of a binary star can be found in [17]. From Kepler's third law we have:

$$a^3 = \frac{G(M_1 + M_2)}{4\pi^2}\, P^2. \tag{1}$$

The orbital angular momentum is given as:

$$J^3 = \frac{G^2(M_1 M_2)^3}{2\pi(M_1 + M_2)}\, P \quad \text{or} \quad J^2 = \frac{G(M_1 M_2)^2}{M_1 + M_2}\, a. \tag{2}$$

In our case the angular momentum stored in the rotation of the two stars is negligible compared to the orbital angular momentum. A non-conservative mass transfer and isotropic mass loss imply that $\Delta J/J = \Delta M/M$, while the conservative mass transfer requires $\Delta J = 0$.

For Mira the present day orbital period is 945 yr, the semimajor axis is $a = 103$ au [18], the masses of the components are $M_1 = 1\ M_\odot$ and $M_2 = 0.25\ M_\odot$ [11], and the orbital angular momentum is $J = 2.04 \times 10^{53}$ g cm^2 s^{-1}. Here we will calculate three scenarios:

(i) conservative mass transfer: we assume that during the evolution of the initially more massive star (the present day white dwarf) 100% of its mass loss is accreted on the companion, and nothing is lost from the system. The initial

masses of the components should be 0.6 and 0.65 $M_\odot$, and present day masses are 1.0 and 0.25 $M_\odot$. The initial period of the system should be 250 yr and semimajor axis $a \approx 43$ au. For a 0.65 $M_\odot$ star $\tau_{MS} \approx 2.9 \times 10^{10}$ yr, and the age of the binary system would be ≈ 30 Gyr.

(ii) semi-conservative mass transfer: we assume that during the evolution of the initially more massive star 50% of its mass loss is accreted on the companion, and 50% is lost from the system. In this case, the initial masses of the components should be 0.6 and 1.0 $M_\odot$, and present day masses are 0.97 and 0.25 $M_\odot$, respectively. The initially more massive component has lost 0.75 $M_\odot$ during its evolution, from which 0.375 $M_\odot$ are accreted onto the companion and 0.375 $M_\odot$ are ejected into the interstellar medium. The initial period of the system was ≈ 200 yr and $a \approx 40$ au. For a 1.0 $M_\odot$ star $\tau_{MS} \approx 10^{10}$ yr, and the age of the binary system is ≈ 11 Gyr.

(iii) fully non-conservative mass transfer: we assume that during the evolution of the initially more massive star 100% of its mass loss is ejected from the binary. The initial masses of the components should be 1.0 and 1.1 $M_\odot$, and present day masses are 1.0 and 0.25 $M_\odot$. The initial period of the system should be 90 yr and semimajor axis $a \approx 25$ au. For a 1.1 $M_\odot$ star $\tau_{MS} \approx 7.9 \times 10^9$ yr, and the age of the binary system is ≈ 8.7 Gyr.

Mira is located at galactic coordinates J2000 167.75502902 -57.9826, i.e. it is in the halo of the Milky Way. The stellar halo of our Galaxy is very old, with most of its stars having formed about 10–12 billion years ago [19].

This indicates that scenario **(i)** is not possible, because the age of Mira A+B should be ≤ 12 billion years. Scenario **(iii)** also seems to be unlikely, because white dwarfs with low masses originate from stars with initial mass ≤ 1.0 $M_\odot$, see Fig. 7 in [20].

The three scenarios indicate that Mira A+B system probably originates from a binary which initially had orbital period 200–250 yr and semimajor axis $a = 40 - 43$ au. This binary was formed about 11 Gyr ago. The initial mass of Mira A was ≈ 0.6 $M_\odot$, and it accreted an amount ≈ 0.4 $M_\odot$ during its evolution. The initial mass of Mira B was 0.8–1.0 $M_\odot$.

4. Conclusions. We report observations of the flickering of Mira (Omicron Ceti) in U-band. For Mira B (the accretion disc around low mass white dwarf), we find $U-B$ colour in the range $-0.3 \div -0.9$, and estimate its optical luminosity 1.1–1.6 $L_\odot$. Mira A+B system probably originates from a binary (0.6 $M_\odot$ + 0.9 $M_\odot$), which initially had orbital period ≈ 200 yr and semimajor axis $a \approx 40$ au.

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