

# Colours of the flickering source of Mira

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**Abstract.** We report photometric observations in Johnson UBV bands of the short term variability of Mira. The amplitude detected is 0.16 mag in B band. Adopting interstellar extinction  $E(B-V) \approx 0$ , we find for the flickering source colour  $B-V \approx 1.3$ , temperature  $T \approx 3700$  K, and radius  $R \approx 0.77 R_{\odot}$ . The colour of the flickering source of Mira B is considerably redder than the average B-V colour of the flickering in cataclysmic variables and in the symbiotic Mira EF Aql.

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

## Introduction

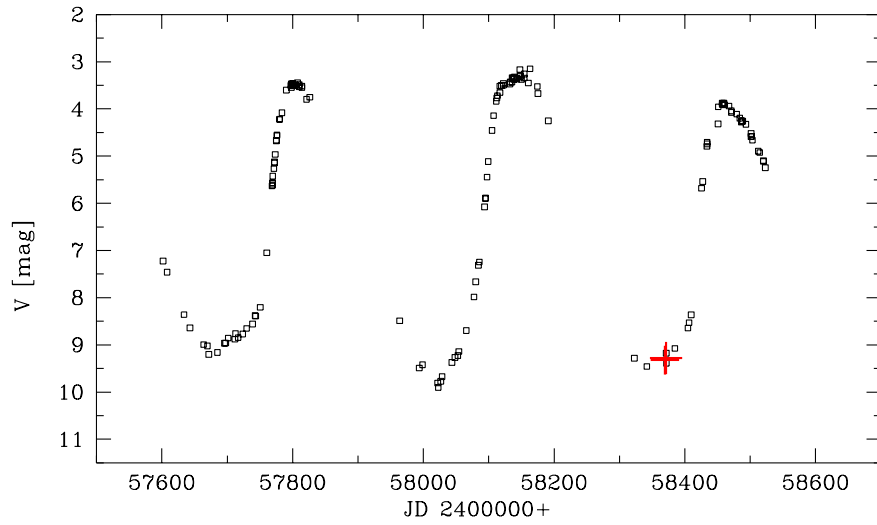
Mira (omicron Ceti) is the prototype of the Mira-type variable stars. This type stars are red giants in the very late stages of the stellar evolution, on the asymptotic giant branch (AGB), having pulsation periods of a few hundred days. Mira pulsates with a period of 332 days (Hoffleit 1997) and an amplitude of about 7 magnitudes in V band (see Fig. 1). It provides an example of a binary system consisting of a mass-losing AGB star (Mira A) and a nearby (0.6 arcsec separation) companion Mira B, which is probably a white dwarf (Karovska et al. 1997, 2005; Sokoloski & Bildsten 2010). Mira is classified as S-type symbiotic star in the recent catalogue based on the 2MASS, WISE and Gaia surveys (Akraş et al. 2019), in other words it is an interacting, wide binary system consisting of a red giant star that transfers matter to a much hotter companion.

Here we report CCD photometry of Mira and estimate colour, temperature and radius of the flickering source.

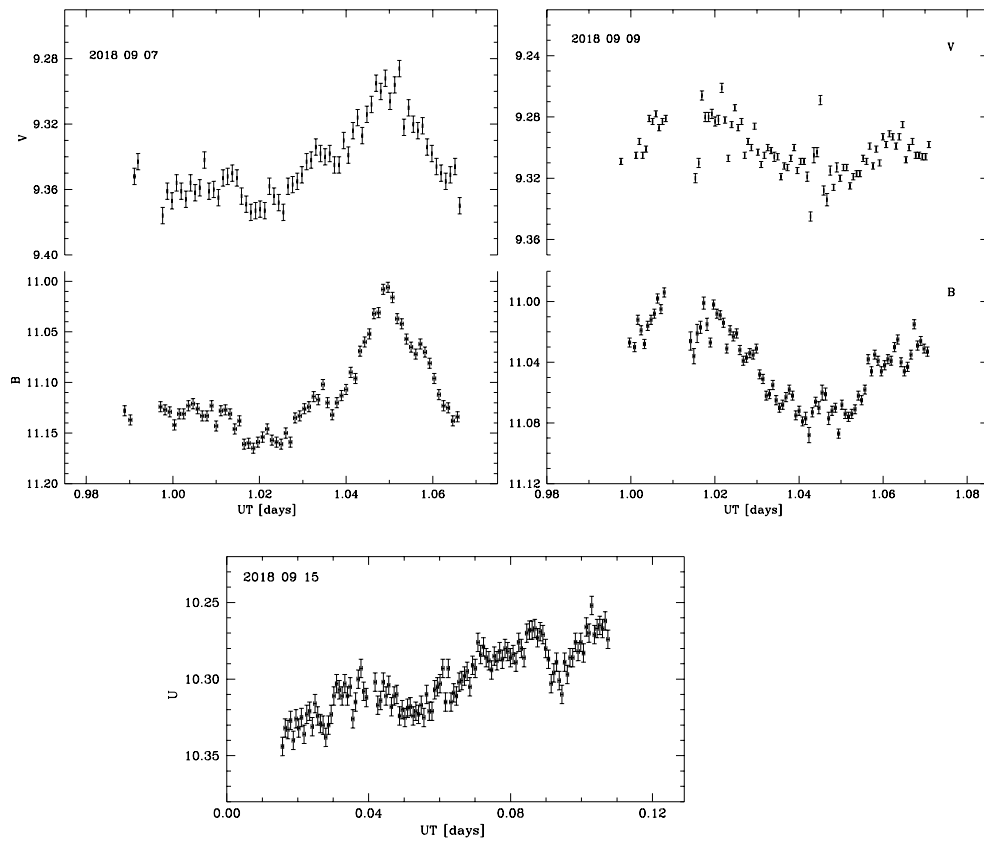
## 1 Observations

The observations were performed with two telescopes equipped with CCD cameras: the 60 cm telescope of the Belogradchik Observatory, Bulgaria (Strigachev & Bachev 2011) and the 50/70 cm Schmidt telescope of the Rozhen National Astronomical Observatory, Bulgaria. Two comparison stars were used during the data reduction. Both are taken from AAVSO data base: HD 14411 (U=12.501 B=10.794 V=9.330) and the star located at J2000 coordinates RA=02:19:08.51 Dec=-02:54:51.0 (U=14.754 B=14.471 V=13.740).

The journal of observations is given in Table 1 and the light curves are plotted on Fig. 2. The detected amplitude in V band is  $\approx 0.1$  mag, in B band is 0.16 mag, and in U band is 0.09 mag. In Table 2 are given the



**Fig. 1.** Light curve of Mira in V band (AAVSO and British Astronomical Association Variable Star Section data). The two red crosses indicate our V band runs.



**Fig. 2.** Short term variability of Mira. The date of observations is in format YYYYM-MDD.

**Table 1.** Journal of the CCD observations of Mira. The columns give date of observation (in format YYYYMMDD), the telescope used, band, number of data points in the run and exposure time, UT-start and UT-end of the run.

date	telescope	band	$N_{pts}$	UT start - end hh:mm - hh:mm
20180907	60cm Belogradchik	B	67 x 60 sec	23:44 - 01:34
		V	67 x 15 sec	23:47 - 01:35
20180909	60cm Belogradchik	B	81 x 40 sec	23:57 - 01:42
		V	83 x 10 sec	23:57 - 01:42
20180915	50/70cm Schmidt	U	119 x 60 sec	00:22 - 02:34

**Table 2.** Photometry of Mira. In the table are given: date of observation, band, minimum, maximum and average magnitudes in the corresponding band, standard deviation of the mean, typical observational error.

date	band	min [mag]	max [mag]	average [mag]	stdev [mag]	merr [mag]
20180907	B	11.006	11.165	11.1115	0.041	0.004
	V	9.286	9.376	9.344	0.023	0.003
20180909	B	10.998	11.088	11.0427	0.023	0.004
	V	9.261	9.345	9.3022	0.016	0.003
20180915	U	10.2523	10.3440	10.3008	0.0210	0.006

**Table 3.** Estimated parameters of the average flickering source of Mira for  $E(B-V)=0$ ,  $E(B-V)=0.04$  and  $E(B-V)=0.70$ .

date	parameter	$E(B-V)=0$	$E(B-V)=0.04$	$E(B-V)=0.70$
20180907	B-V	1.22	1.18	0.52
	T [K]	3556	3896	6375
	R [ $R_{\odot}$ ]	0.66	0.65	0.45
20180909	B-V	1.36	1.32	0.66
	T [K]	3253	3604	5636
	R [ $R_{\odot}$ ]	0.89	0.87	0.60

measured magnitudes in each run. Fig. 1 illustrates that (1) Mira’s V-band brightness varies during the last 1000 days; (2) our V band observations are in agreement with other data and (3) our runs are close to the minimum of the Mira cycle.

## 2 Flickering source

Following Bruch (1992), we separate the light curve into two parts – constant light and variable (flickering) source. We calculate the flux of the flickering light source as  $F_{\text{fl1}} = F_{\text{av}} - F_{\text{min}}$ , where  $F_{\text{av}}$  is the average flux during the run and  $F_{\text{min}}$  is the minimum flux during the run (corrected for the typical error of the observations). An extension of the method is proposed by Nelson et al. (2011), who suggests to use the  $F_{\text{fl2}} = F_{\text{max}} - F_{\text{min}}$ , where  $F_{\text{max}}$  is the maximum flux during the run. Practically, the method of Bruch (1992) refers to the average luminosity of the flickering source, while that of Nelson et al. (2011) – to its maximal luminosity.  $F_{\text{fl1}}$  and  $F_{\text{fl2}}$  have been calculated for each band, using the values given in Table 1 and the calibration for a zero magnitude star  $F_0(B) = 6.293 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ ,  $\lambda_{\text{eff}}(B) = 4378.12 \text{ \AA}$ ,  $F_0(V) = 3.575 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$  and  $\lambda_{\text{eff}}(V) = 5466.11 \text{ \AA}$  as given in the Spanish virtual observatory Filter Profile Service (Rodrigo et al. 2018, see also Bessel 1979).

*Hipparcos* gives parallax of Mira  $10.91 \pm 1.22$  milliarcseconds, which corresponds to distance  $d = 92$  pc (No GAIA parallax is available for Mira). Mira is very close to the Earth and the interstellar extinction is probably  $E(B - V) \approx 0$ . However the neutral hydrogen absorbing column  $N_H = 2.24 \times 10^{20} \text{ cm}^{-2}$  is derived from UV spectral modeling (Wood et al. 2002). From model fitting of ROSAT and XMM-Newton X-ray data, Kastner & Soker (2004) find  $2.0 \times 10^{21} \text{ cm}^{-2} < N_H < 4.5 \times 10^{21} \text{ cm}^{-2}$ . This X-ray derived  $N_H$  is a factor of  $> 20$  larger than the neutral H absorbing column determined from analysis of the HI Ly $\alpha$  line (Wood et al. 2002). This discrepancy suggests that the UV and X-ray emission arise in different zones around Mira B and, specifically, that the X-ray emitting region may be embedded within accretion streams that effectively attenuate the X-rays, as described by Jura & Helfand (1984). Following the relation between  $N_H$  and reddening  $N_H/A_V = 1.79 \times 10^{21} \text{ cm}^{-2} \text{ mag}^{-1}$  (Predehl & Schmitt 1995), we estimate that  $N_H = 2.24 \times 10^{20} \text{ cm}^{-2}$  corresponds to  $E(B-V)=0.04$ ,  $N_H = 2 \times 10^{21} \text{ cm}^{-2}$  – to  $E(B-V)=0.35$ , and  $N_H = 4.5 \times 10^{21} \text{ cm}^{-2}$  – to  $E(B - V) = 0.79$ .

In Table 3 are given the parameters of the flickering source, calculated using  $F_{\text{av}}$  and following Bruch (1992). Assuming  $E(B - V) \approx 0$ , we estimate colour and temperature of the flickering source  $B - V = 1.29 \pm 0.10$  and  $T = 3400 \pm 200 \text{ K}$  – see Table 3 for more details. Using the method of Nelson et al. (2011) and  $E(B - V) = 0$ , we estimate similar colour and temperature:

$$\begin{array}{ll} 20180907 & B - V = 1.14, T = 3979 \text{ K}, R = 0.97 R_{\odot}; \\ 20180909 & B - V = 1.52, T = 3250 \text{ K}, R = 1.88 R_{\odot}. \end{array}$$

As can be expected the size is larger, because this method refers to the maximum of the flickering.

### 3 Discussion and Conclusion

Mira AB is a very wide binary system. The infrared spectroscopy (Hinkle et al. 2013) detected no orbital motion in agreement with previous estimates of the orbital period  $\geq 100$  yr and semimajor axes  $\sim 50$  au. ALMA observations revealed a mass of gas surrounding Mira B, with a size of a few tens of AU, which is interpreted as gas flowing from Mira A toward Mira B (Nhung et al. 2016). Hence the white dwarf in Mira accretes material via gravitational capture of the red-giant wind.

Sokoloski & Bildsten (2010) detected optical flickering from Mira with amplitude 0.15 - 0.30 mag in B band during 5 runs in 1997 - 1998. Snaid et al. (2018) found flickering with amplitude 0.05 mag in g' band in September 2015. The amplitude of the flickering in our data is similar to these results. Given the discussion in Sect. 6.2 of Sokoloski, Bildsten & Ho (2001) about the difficulty of producing rapid variability from the nebular emission, we expect the rapidly variable component of Mira to reflect the physical origin of the variations in the accretion disc around white dwarf.

For the flickering source of the symbiotic Mira EF Aql, Zamanov et al. 2017 calculated  $(B - V) = 0.35 \pm 0.05$ , which is considerably more blue than the colour of the flickering source of omi Cet. The B-V colour of the flickering source is calculated in a number of cataclysmic variables and two recurrent novae (Bruch 1992; Zamanov et al. 2015). It is in the range  $-0.19 \leq B - V \leq 1.09$ , with average value of 0.16, median value of 0.11, and standard deviation of 0.24. Our results for Mira indicate that if the interstellar extinction is low, its flickering source is considerably more red than the average colour of the cataclysmic variables. Possible reasons can be:

- (1) the flickering source of Mira has lower temperature than the flickering source in cataclysmic variables;
- (2) the flickering of Mira is coming from almost the same place, where the X-rays are generated and the flickering source is embedded within the accretion flow (like the X-ray source, see Kastner & Soker 2004) which makes it to appear redder.

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