Serb. Astron. J. № 212 (2026), 117 - 123
DOI: https://doi.org/10.2298/SAJ2612117Z

UDC 52–355.3 : 524.36
Professional paper

Hα EMISSION FROM MIRA (OMICRON CETI)

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(Received: January 6, 2026; Accepted: May 20, 2026)

SUMMARY: Here we report spectral observations of Mira (omicron Ceti). The comparison between the spectra reveals Hα emission during three minima of the Mira cycle (August 2019, January 2024, and January 2025). The emission has equivalent width EW(Hα) $\sim$ 4 Å, full width at zero intensity FWZI $\approx$ 720 km s^{-1}, and full width at half maximum FWHM $\approx$ 280 km s^{-1}. Supposing that it is coming from the accretion disc around the white dwarf, we estimate that the Hα emitting disc extends from 0.3 R$_\odot$ to 4 R$_\odot$ around the white dwarf.

The spectra are available on Zenodo: zenodo.org/records/20322950.

Key words. Stars: variables: general – Stars: AGB and post-AGB – Stars: winds, outflows – Stars: individual: Mira/omicron Ceti – Techniques: spectroscopic – Techniques: photometric – Stars: white dwarfs

1. INTRODUCTION

Mira ("The Wonderful", omicron Ceti) was identified as a variable star centuries ago (e.g. Hogg 1933) due to large cyclic changes in its brightness. In the optical V-band Mira pulsates between $2.5 < m_V < 9.0$ magnitude. This corresponds to absolute V band magnitude $-2.5 < M_V < 4$ mag for a distance of 100 pc.

Mira is a binary system consisting of an asymptotic giant branch star M5-9III (Mira A) and a hot companion (Mira B) located at an angular distance of ≈ 0.5 arcsec from the red giant (Skiff 2014, Ramstedt et al. 2014). Mira B was discovered visually one hundred years ago by A. H. Joy and R. G. Aitken (Aitken 1923) and later identified as a white dwarf (Cassatella et al. 1985, Sokoloski and Bildsten 2010). Mira is included as an accreting-only symbiotic star in the recent catalogues of symbiotic stars (Akras et al. 2019, Merc 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. The ultraviolet spectra from the International Ultraviolet Explorer (IUE), Hubble Space Telescope (HST) and Far Ultraviolet Spectroscopic Explorer (FUSE) satellites demonstrate that the UV line and continuum fluxes observed from Mira B are variable. The UV emission is associated with accretion of material onto Mira B from Mira A's wind, so the variability is presumably due to variations in accretion rate (Wood and Karovska 2006).

Typically, the spectra of the symbiotic stars are a combination of absorption features of the red giant and emission lines from the hot component and the nebula (Kenyon and Webbink 1984), although in some cases, it is difficult to detect the optical emission lines (Kumar et al. 2021, Iłkiewicz et al. 2022). The spectrum of Mira B near Mira A minimum (see Fig. 8 in Reimers and Cassatella 1985) is characterized by prominent Balmer emission lines. Balmer and

Fe emission lines are also visible in the observations of Ortiz et al. (2019).

Here we report spectral observations of Mira and detection of Hα emission from the accretion disc around the white dwarf.

2. OBSERVATIONS

In this study we use nine optical spectra secured with ESpeRo echelle spectrograph (Bonev et al. 2017) mounted on the 2.0m RCC telescope of the Rozhen National Astronomical Observatory, Bulgaria. Additionally, two spectra were downloaded from the ELODIE Archive (Moultaka et al. 2004). The ELODIE is an echelle spectrograph used at the 1.93m telescope of Observatoire de Haute Provence (OHP). The resolution of the ELODIE spectrograph is ~ 40000 and of the ESpeRo is ~ 30000. The journal of observations is given in Table 1, which includes the date of observation, observatory, UT (start of exposure), Heliocentric Julian Day (HJD), exposure time in minutes, signal-to-noise ratio (S/N ratio) at 6560 Å, and the V band magnitude from the nearest AAVSO data. The S/N-ratio depends on the brightness of the object as well as of the exposure time. The spectra were processed and analysed using standard routines *echelle*, *rvcorrect*, *dopcor*, and *splot* in IRAF (Tody 1993). All spectra were transformed to heliocentric wavelengths and normalized to the local continuum.

3. RESULTS

Mira A is an asymptotic giant branch star, having large pulsations. It is the prototype of the Mira-type variables and is located at a distance ≈ 100 pc from the Earth (van Leeuwen 2007). The interferometric observations with ESO/VLT have directly shown that the radius of the star changes from 332 $R_\odot$ to 402 $R_\odot$ (Woodruff et al. 2004). The V band light curve (data dowloaded from the AAVSO International Database) of the Mira pulsations for the last 9 years is plotted in Fig. 1. The data analysis using the Phase Dispersion Minimization algorithm (Stellingwerf 1978) of the V band observations from JD2452000 (March 2001) to JD2460918 (September 2025) gives a period of pulsations 328.6 $\pm$ 1.8 days. This period indicates that the spectra obtained on 1998-11-07, 1999-09-29, and 2019-02-20 are near the maximum of the Mira, while the other spectra (2019-08-21, 2024-01-22, 2025-01-17) are close to the minimum (see Table 1 and Fig. 1).

3.1. The radial velocity of the Mira A

To calculate the radial velocity of Mira A on our spectra we used spectra of two red giants obtained with the Rozhen telescope, 71 Peg (M5III) and 57 Psc (M4III), whose spectral types are from Keenan and McNeil (1989). Their radial velocities are $+1.62 \pm 0.24$ km s^{-1} and -24.26 ± 0.21 km s^{-1} (Famaey et al. 2005), respectively. A comparison of the spectrum of Mira with 71 Peg for wavelength interval 6565 – 6580 Å is given in Fig. 2. Using *fxcor* in IRAF, which computes radial velocities via Fourier cross correlation, we correlate our spectra of Mira with 71 Peg and 57 Psc, and estimate heliocentric radial velocity of Mira A on our spectra to be 63.5 $\pm$ 1.6 km s^{-1}. This value is identical to 63.5 ± 0.60 km s^{-1} given by Kharchenko et al. (2007).

3.2. Hα emission

In Fig. 3 are plotted the spectra of Mira around Hα. The spectra are in heliocentric wavelengths and normalized to the local continuum. The blue line represents the spectra obtained during three minima of the Mira cycle and the red line the ones during the maxima. The subtraction of spectrum obtained during the maximum gives the difference (green). Even before subtraction, it is visible that some additional emission exists in the Hα. The subtraction reveals the Hα emission and gives us the possibility to measure some parameters. The "isolated" Hα emission (the differences from Fig. 3) during three minima of the Mira cycle (August 2019, January 2024, and January 2025) is plotted in Fig. 4. We note that in Fig. 3 the X-axis is heliocentric wavelegth, while in Fig. 4 it is heliocentric radial velocity. After the subtraction the typical root-mean-square of the continuum is 3%. The intensity of the peak of the emission is more than 1.5 for the spectra 2019-08-20 and 2024-01-22. It is 1.25 for 2025-01-17, probably because this spectrum is obtained after the minimum of the Mira (see Fig. 1), when the brightness is already increasing.

On the Hα emission we measure the following parameters: the equivalent width of the emission (EW(Hα)), full width at zero intensity (FWZI), full width at half maximum (FWHM), radial velocity of the peak ($V_{\rm r.peak}$), radial velocity of the centroid of the emission ($V_{\rm r.cen}$). The measurements are summarized in Table 2, where EW(Hα) is in Å, other measurements are in km s^{-1}. The typical error of EW(Hα) is $\pm$ 5%, of FWZI is $\pm$ 15 km s^{-1}, of FWHM is $\pm$ 7 km s^{-1}, of $V_{\rm r.peak}$ is $\pm$ 10 km s^{-1}, and of $V_{\rm r.cen}$ is $\pm$ 5 km s^{-1}.

Our measurements give that EW(Hα) is in the range 1-5 Å, FWZI is 720 ± 45 km s^{-1}, FWHM is 280 ± 35 km s^{-1}, the peak of the emission is located at heliocentric radial velocity $85 \le V_{\rm r.peak} \le 110$ km s^{-1}, and the centroid of the line is at $V_{\rm r.cen} = 138 \pm 4$ km s^{-1}. The heliocentric radial velocity of the Mira A is 63.5 $\pm$ 0.60 km s^{-1} (Kharchenko et al. 2007, see also Section 3.1). The observed peak of the Hα emission is red shifted relatively to the red giant velocity with ~ 34 km s^{-1}, and its centroid – with ~ 75 km s^{-1}.

We note that the orbital velocity of Mira B is $v_{\rm orb} \approx 2.6$ km s^{-1}. This value is calculated using a circular orbit with period 945 yr, masses of the components $M_1 \approx 1$ M$_\odot$, and $M_2 \approx 0.24$ M$_\odot$ (Snaid

Table 1: Journal of observations.

Date YYYY-MM-DD	Observatory	UT hh:mm	HJD 2400000+	exposure [min]	S/N	V [mag]
1998-11-07	OHP	23:54	51125.5018	20	90	4.8
1999-09-29	OHP	00:55	51450.5436	3	30	3.2
2019-02-20	Rozhen	17:30	58535.2330	10	250	5.5
2019-02-20	Rozhen	17:41	58535.2432	2	120	
2019-08-21	Rozhen	00:45	58716.5400	40	300	8.3
2019-08-21	Rozhen	01:26	58716.5617	20	220	
2024-01-22	Rozhen	16:41	60332.2062	20	70	8.9
2024-01-22	Rozhen	17:33	60332.2390	10	55	
2025-01-17	Rozhen	17:49	60693.2479	5	20	7.0
2025-01-17	Rozhen	17:59	60693.2551	5	30	
2025-01-17	Rozhen	18:05	60693.2642	20	60	

Table 2: Measured parameters of the Hα emission of Mira.

Date YYYY-MM-DD HH:MM	EW(Hα) [Å]	FWZI [km s^{-1}]	FWHM [km s^{-1}]	$V_{r(peak)}$ [km s^{-1}]	$V_{r(cen)}$ [km s^{-1}]
2019-08-21 00:45	3.01	710	243	84	133
2019-08-21 01:26	2.95	719	227	89	134
2024-01-22 16:41	5.34	659	270	78	141
2024-01-22 17:33	5.15	745	283	85	139
2025-01-17 17:49	1.08	698	319	123	139
2025-01-17 17:59	1.05	799	296	113	138
2025-01-17 18:05	1.19	692	326	107	145

et al. 2018, Zamanov et al. 2026). In other words, the shift of Hα is not a signature of the orbital motion.

3.3. Size of the accretion disc

Fig. 3 unveils the Hα emission. We assume that this emission is coming from a Keplerian accretion disc around the white dwarf. For emission lines coming from a Keplerian disc, FWZI can be regarded as a measure of the inner radius ($R_{\rm in}$) of the emitting disc (Casares et al. 2012):

$$FWZI = 2\,\sin i\,\sqrt{GM_{\rm wd}/R_{\rm in}}\,, \qquad (1)$$

where G is the gravitational constant, $M_{\rm wd}$ is the mass of the white dwarf, and i is the inclination of the disc to the line of sight. In the same way, FWHM can be regarded as a measure of the average radius ($R_{\rm av}$) of the emitting disc (Reimers and Cassatella 1985):

$$FWHM = 2\,\sin i\,\sqrt{GM_{\rm wd}/R_{\rm av}}\,. \qquad (2)$$

We adopt $M_{\rm wd} = 0.24$ M$_\odot$ (Snaid et al. 2018) and inclination $i = 67^\circ$ (Zamanov et al. 2026).

Using the measurements in Table 2, we estimate $R_{\rm in} = 0.31 \pm 0.02$ R$_\odot$ and $R_{\rm av} = 2.1 \pm 0.2$ R$_\odot$ for the accretion disc around Mira B. The disc rotational velocity seen in the inner parts of the Hα emitting disc is $FWZI/(2\sin i) \approx 390$ km s^{-1}. We assume that the outer radius of the accretion disc is $R_{\rm disc} = R_{\rm av} + (R_{\rm av} - R_{\rm in})$, and calculate $R_{\rm disc} = 3.8 \pm 0.4$ R$_\odot$.

Using the mass-radius relation for white dwarfs (Eq. 15 in Verbunt and Rappaport 1988), we calculate that a white dwarf with $M_{\rm wd} = 0.24$ M$_\odot$ has a radius $R_{\rm wd} = 0.02$ R$_\odot$, which means that the Hα emitting disc extends down to $\approx 15\ R_{\rm wd}$.

The Roche lobe radius of Mira B is given by the formula (Eggleton 1983):

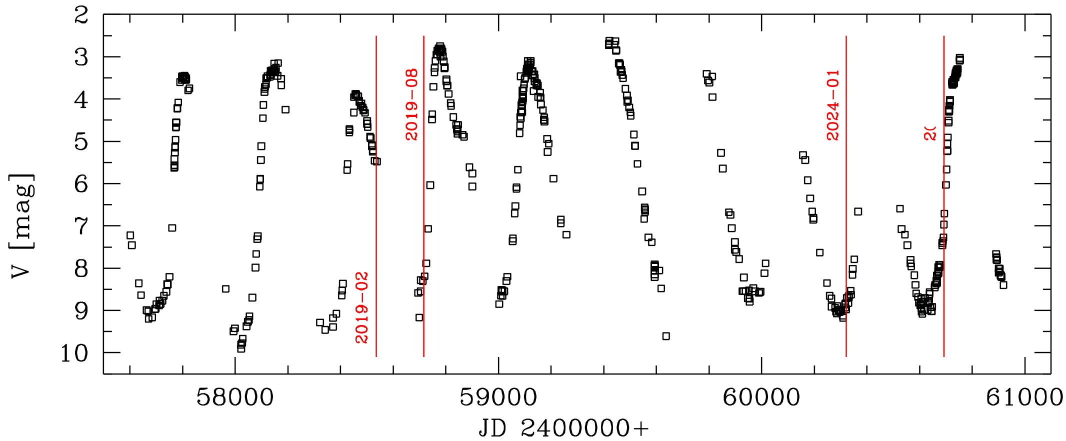

Fig. 1: The V band light curve of Mira (AAVSO data) from April 2016 to September 2025. The red lines indicate the moments of the Rozhen spectra (see Table 1).

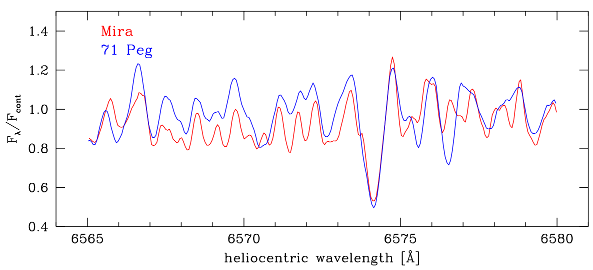

Fig. 2: A comparison of the spectrum of Mira (red line) with 71 Peg (blue line). The spectrum of 71 Peg is shifted to the red wavelegths with 62.7 km s^{-1}.

$$r_{\rm Roche}/a = (0.49q^{2/3})/[0.6q^{2/3} + \ln(1 + q^{1/3})], \quad (3)$$

where $q = M_1/M_2$ is the mass ratio. Using this formula and mass ratio $q = 0.24$, we estimate $r_{\rm Roche}/a = 0.265$ and the Roche lobe size of the white dwarf to be 5800 $R_\odot$, which means that the accretion disc is $\sim$ 1000 times smaller than the size of the Roche lobe.

4. DISCUSSION

Mira A is an asymptotic giant branch star. The asymptotic giant branch is the most luminous evolutionary stage for stars of low to intermediate mass (0.5 - 8) M$\odot$, during which they exhibit intense mass lose through cool, low-velocity winds. As a result of the wind, the star can lose up $\sim$ 80% of its initial stellar mass (e.g. Höfner and Olofsson 2018, Matthews 2024). In the Mira system, the mass loss and the presence of binary companion forms a complex morphokinematics of the circumstellar envelope (Nhung et al. 2022).

The orbital period of the binary system is a few hundred years. Prieur et al. (2002) estimated it of 498 yr. More recently, Snaid et al. (2018) used the measurements of the angular separation between Mira A and B for the period 1923 – 2014, and found the orbital period of 945 yr. They evaluated the physical separation between Mira A and B to be $\approx$ 95 au. Numerical simulations of wind accretion in symbiotic binaries give that for a typical slow and massive wind from an AGB star the flow pattern is similar to a Roche lobe overflow with accretion rates of 10% of the mass loss from the primary (de Val-Borro et al. 2009). In agreement with these theoretical simulations, the high resolution Chandra and Hubble Space telescope observations have shown that in the mass exchange between components, in addition to wind accretion, there are evidences for Roche-lobe like overflow (Karovska et al. 2005, Karovska 2006).

The mass loss from Mira A is estimated to be about $(2.0 - 4.4) \times 10^{-7}$ M$_\odot$ yr^{-1} (Yamashita and Maehara 1978, Knapp et al. 1998). The white dwarf accretes less than 4% of it, at a rate $1 \times 10^{-10} - 7 \times 10^{-9}$ M$_\odot$ yr^{-1} (Sokoloski and Bildsten 2010, Zamanov et al. 2025, 2026). For the symbiotic recurrent nova T CrB, a massive white dwarf with mass 1.35-1.37 M$_\odot$ (Munari et al. 2025, Hinkle et al. 2025) accretes at a rate $0.3 - 3 \times 10^{-8}$ M$_\odot$ yr^{-1} (Zamanov et al. 2023) and the outer radius of accretion disc is 89 $\pm$ 19 R$_\odot$ (Zamanov et al. 2024). In Mira a white dwarf with mass $\sim$ 0.24 M$_\odot$ accretes at $\sim$ 30 times lower mass accretion rate. As a consequence, of the lower mass of the white dwarf and lower mass accretion rate, the disc size is $\sim$ 20 times smaller.

A shock-induced variability of the Hα emission profile in Mira was detected by Gillet et al. (1983, 1985). In their spectra, they observed variable Hα emission coming from the shocks around Mira A. The Hα emission detected in our spectra is probably coming from the vicinity of Mira B, i.e. the origin is similar to that of the UV emission lines. Cassatella et al. (1985) have shown that, in the UV spectra of Mira, the UV intercombination lines of Si III] and C III] are consistent with formation in a rapidly rotating disc around the white dwarf companion Mira B with

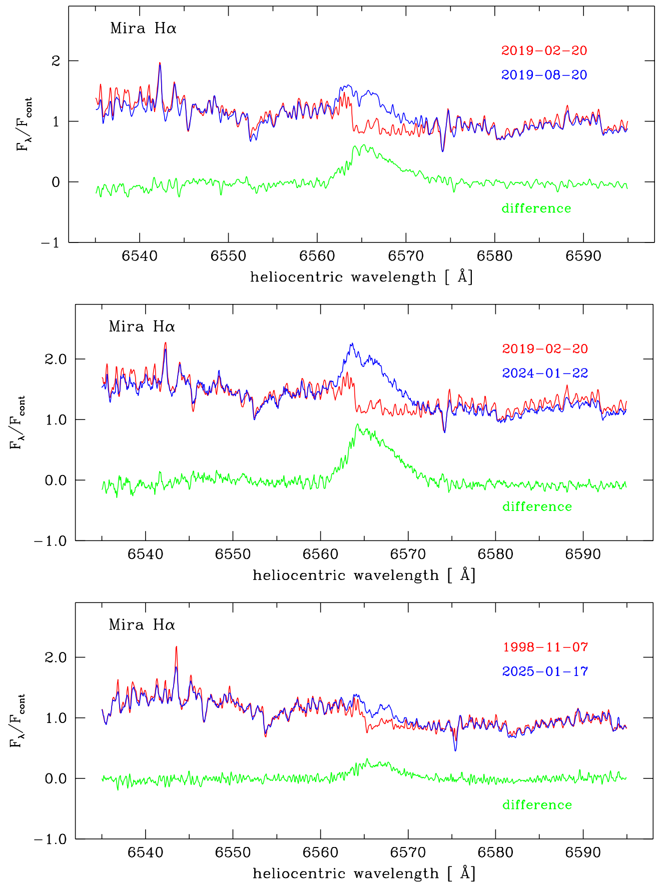

Fig. 3: The spectra of Mira around Hα in the wavelength range from 6535 Å to 6595 Å. In each panel, the red colour denotes the observations made during maximum brightness, the blue colour relates to observations obtained during minimum. The dates of observations are in format YYYY-MM-DD. The green colour is the difference between the two spectra.

typical radius of $\approx 10^{11}$ cm (1.5 $R_\odot$). The disc rotational velocity is seen to increase from 135 km s^{-1} in the cool outer layers to 1000 km s^{-1} in the innermost region (see also Reimers and Cassatella 1985). Our estimate that the Hα emitting disc extends from 0.3 to 3.8 $R_\odot$ is consistent with the results from UV spectra.

Some of the open questions which should be addressed in the future are:
(i) Are there other emission lines in the Mira spectra coming from the accretion disc?
(ii) Why is the Hα emission red shifted relatively to the red giant heliocentric velocity?

5. CONCLUSIONS

Here, we analyse spectral observations of Mira (omicron Ceti) obtained between February 2019 and January 2025 at the Rozhen National Astronomical Observatory, Bulgaria and spectra from the ELODIE archive, France. The comparison between the spectra observed at minimum and maximum of the Mira brightness, reveals the presence of emission in Hα. The emission is clearly detected during three minima of the Mira cycle (August 2019, January 2024, and January 2025). The Hα emission is with EW(Hα) in the range 1–5 Å, FWZI= 720 ± 45 km s^{-1}, and FWHM= 280 ± 10 km s^{-1}. Like the UV emission lines, the Hα emission is probably coming from the accretion disc around the white dwarf. We find that the Hα emitting disc extends from 0.3 $R_\odot$ to 4 $R_\odot$ around the white dwarf. A comparison with the symbiotic recurrent nova T CrB indicates that the accretion disc around Mira B is ∼ 20 times smaller.

Acknowledgements – This work is part of the project KP-06-H98/8 Accretion flows in binary stars (Bulgarian National Science Fund). We thank K. A. Stoyanov for his support and comments. DM acknowledges support from Science Fund of Shumen University. We gratefully acknowledge the contributions of the AAVSO observer community, whose photometric data were used in this study. We thank an anonymous referee for making very valuable suggestions.

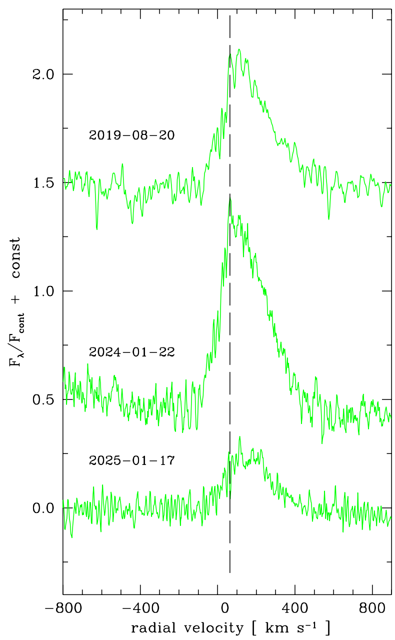

Fig. 4: The Hα emission of Mira detected during three minima of the Mira cycle – August 2019, January 2024, and January 2025. The X-axis is the heliocentric radial velocity. The vertical dashed line is at 63.5 km s^{-1}, which is the radial velocity of the red giant.

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$\mathrm{H}\alpha$ ЕМИСИЈА ЗВЕЗДЕ МИРА (ОМИКРОН КИТА)

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УДК 52–355.3 : 524.36
Стручни чланак

У овом раду представљамо спектроскопска посматрања звезде Мира (Омикрон Кита). Поређени су спектри и $\mathrm{H}\alpha$ емисија током три минимума Мириног циклуса (из августа 2019, јануара 2024. и јануара 2025. године). Емисија има еквивалентну ширину $EW(\mathrm{H}\alpha) \sim 4$ Å, ширину при нултом интензитету FWZI ≈ 720 km s^{-1} и ширину на половини максимума FWHM ≈ 280 km s^{-1}. Под претпоставком да $\mathrm{H}\alpha$ емисија потиче из акреционог диска око белог патуљка, процењујемо да се област диска која емитује $\mathrm{H}\alpha$ простире од 0.3 $R_\odot$ до 4 $R_\odot$ око белог патуљка.

Спектри су доступни на Zenodo платформи: zenodo.org/records/20322950.