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Original scientific paper

LUMINOSITY CLASS OF THE SYMBIOTIC STARS 4U1954+319 AND ZZ CMi

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SUMMARY: We performed optical photometry and spectral observations of the symbiotic stars 4U1954+319 and ZZ CMi. For 4U1954+319, using high-resolution spectra, we, measure the equivalent widths of diffuse interstellar bands (DIBs) and estimate the interstellar reddening $E(B-V) = 0.83 \pm 0.09$. Using the *GAIA* distances and our photometry, we find: (1) the absolute V-band magnitude $M_V = -5.23 \pm 0.08$ of 4U1954+319 and that the mass donor is a supergiant of luminosity class Ib, and (2) $M_V = -0.27 \pm 0.2$ for ZZ CMi and that the mass donor is a giant of luminosity class III.

Key words. Stars: binaries: symbiotic – Stars: individual: 4U1954+319, ZZ CMi

1. INTRODUCTION

Symbiotic stars are long-period interacting binary systems composed of a hot component, a cool giant, and a nebula formed from material lost by the donor star and ionized by the radiation of the hot component (Mikołajewska 2012). The hot component can be a white dwarf, neutron star, or main-sequence star. In the majority of cases, the donor star is a red giant but occasionally it could be an asymptotic giant branch star. The spectrum of symbiotic stars is a combination of emission lines from the hot component and the nebula, and absorption lines from the donor star. The donor star loses mass through stellar wind or Roche-lobe overflow. The hot component accretes matter and produces high-energy emission and the symbiotic phenomenon (Mikołajewska 2007).

Up to the present time (January 2024) the SIMBAD Astronomical database (Wenger et al. 2000) gives: the spectral type M4/5III (Masetti et al. 2006) for 4U1954+319, and spectral type M6I-IIep (Shenavrin et al. 2011) for ZZ CMi. We performed spectral observations and optical photometry, aiming to determine the luminosity classes of these symbiotic stars.

2. OBSERVATIONS

Five optical spectra of 4U1954+319 and two of ZZ CMi were secured with the ESpeRo Echelle spectrograph (Bonev et al. 2017) on the 2.0-m telescope

of the Rozhen National Astronomical Observatory, Bulgaria. The journal of observations is presented in Table 1, listing the following: observation dates with precise time of observations, exposure time, signal-to-noise ratio around 6570 Å, the measured equivalent width of the $H\alpha$ line, and three diffuse interstellar bands (DIBs), respectively.

The photometry using Johnson's B and V filters (the BV photometry) was obtained with the 1.88-m telescope (Azzam et al. 2010) at the Kottamia Astronomical Observatory, Egypt, with the 50/70-cm Schmid telescope at Rozhen National Astronomical Observatory, Bulgaria, and with the 0.4-m University of Jaén Telescope, Spain (Martí et al. 2017) A few stars from the APASS DR10 located close to our targets were used as comparison stars. The values of the observed B- and V- band magnitudes are given in Table 2.

3. INTERSTELLAR EXTINCTION

The NASA/IPAC Galactic Reddening and Extinction Calculator uses the Schlegel et al. (1998) Galactic reddening maps to determine the total Galactic line-of-sight extinction $E(B-V)$. For 4U1954+319 Galactic extinction $E(B-V) \leq 1.68$ and for ZZ CMi – $E(B-V) \leq 0.04$.

From the spectra of 4U1954+319, we subtract the spectrum of a red giant (in this case we use a spectrum of V1509 Cyg obtained on 26 November 2023 by the same setup). The subtraction reveals the presence of DIBs and gives us the possibility to measure their equivalent widths EWs. An example of the subtraction is shown in Fig. 1. The measured EWs are given in Table 1. The errors of EWs are ±5% for DIB 5780, ±7% for DIB6613, and ±10% for DIB5797. As expected, in our spectra of ZZ CMi, we do not detect any DIBs.

Puspitarini et al. (2013) found a set of relations between the equivalent width of the DIBs and the interstellar reddening, among them:
$E(B-V) = 2.3\ EW_{5780} + 0.0086$,
$E(B-V) = 5.1\ EW_{6613} + 0.0008$,
$E(B-V) = 6.3\ EW_{5797} + 0.0203$.
Using these relations and our measurements of the EWs (given in Table 1) as well as taking into account the individual errors, we estimate the interstellar extinction toward 4U1954+319 $E(B-V) = 0.83 \pm 0.09$.

Hereafter, we will use $E(B-V) = 0.83$ for 4U1954+319, and $E(B-V) = 0$ for ZZ CMi.

4. ABSOLUTE V-BAND MAGNITUDE

Using the GAIA eDR3 (Gaia Collaboration et al. 2021) the model by Bailer-Jones et al. (2021) provides distances $d = 3390 \pm 60$ pc to 4U1954+319 and $d = 1240 \pm 20$ pc to ZZ CMi. To calculate the absolute V-band magnitude we use the standard formula, $M_V = m_v - A_V - 5\log(d/10)$, where A_V is the extinction in the V-band, $A_V = 3.1E(B-V)$. Colour-magnitude diagram is plotted in Fig. 2. The

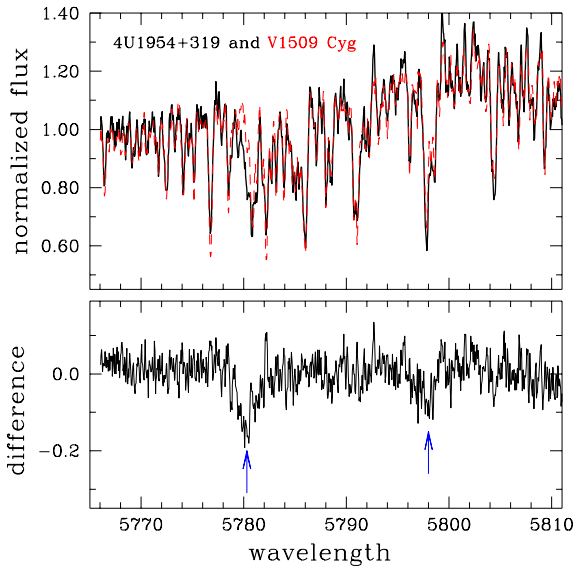

Fig. 1: The spectra of 4U1954+319 (black solid line) and V1509 Cyg (red dashed line). The subtraction of the red giant spectrum reveals the presence of diffuse interstellar bands in the spectrum of 4U1954+319. DIB 5780 and DIB 5797 are marked with blue arrows.

values of M_V and $(B-V)_0$ for different luminosity classes are taken from Straizys and Kuriliene (1981) and Schmidt-Kaler (1982), respectively.

For 4U1954+319, using our data (Table 2) and APASS DR10 photometry (V=10.01, B=12.13), we obtain $M_V = -5.23 \pm 0.08$. The position of the object in Fig. 2 indicates that it is slightly above the luminosity class Ib (supergiants) and below Iab (moderate supergiants).

For ZZ CMi, using new observations from Table 2 as well as data published in Zamanov et al. (2021), we find $M_V = -0.27 \pm 0.2$. The position of the object in Fig. 2 indicates that it is slightly above the luminosity class III (giants) and below luminosity class II (bright giants).

In the symbiotic stars, the flux in the V-band comes from three sources: a cool giant, hot component, and nebula. For the two symbiotic stars discussed here, the main source of the flux in the V-band is the mass donor. The $EW(H\alpha)$ given in Table 1 indicates that the contribution of the other sources is not more than 10% for 4U1954+319, and not more than 15% for ZZ CMi. We conclude that the luminosity class of the mass donor is Ib in 4U1954+319, and III in ZZ CMi.

5. DISCUSSION

4U 1954+319 is a member of a small group of binary systems with accreting neutron stars and late-type giant or supergiant (Masetti et al. 2006). They are called symbiotic X-ray binaries. Only about a dozen of these systems are known (Yungelson et al.

Table 1: Spectral observations of 4U1954+319: (1) observational date (in the format YYYY-MM-DD HH:MM), (2) exposure time in minutes, (3) signal-to-noise ratio S/N, and equivalelenth width of (4) DIB5780, (5) DIB5797, and (6) DIB6613.

object/date	exposure [min]	S/N	EW($H\alpha$) [Å]	EW_{5780} [Å]	EW_{5797} [Å]	EW_{6613} [Å]
4U1954+319						
2015-08-03 23:28	40	42	+1.3	0.31	0.16	0.16
2016-06-18 23:41	40	70	+0.3	0.39	0.22	0.14
2018-04-03 00:06	60	60	+1.4	0.35	0.20	0.14
2018-09-01 20:45	60	75	+1.0	0.28	0.14	0.13
2022-04-12 22:55	60	53	+0.5	0.31	0.14	0.15
ZZ CMi						
2023-12-27 00:34	45	70	−7.8	—	—	—
2024-01-26 18:56	105	45	−4.8	—	—	—

Table 2: BV photometry of 4U1954+319 and ZZ CMiCMi: (1) observational date (in the format YYYY-MM-DD HH:MM), (2) telesope name, (3) number of exposures, and (4) the B and V-band magnitudes with the corresponding errors.

object/date	telescope	N	B	V
4U1954+319				
2023-08-08 18:47	1.88m	3	12.07 ± 0.03	9.93 ± 0.02
2023-12-05 16:32	1.88m	3	12.08 ± 0.01	9.97 ± 0.01
2023-12-06 16:32	1.88m	4	12.09 ± 0.01	9.97 ± 0.01
2024-01-22 18:21	40cm	2		10.05 ± 0.03
ZZ CMi				
2023-12-12 23:19	50/70cm	3	11.04 ± 0.01	9.57 ± 0.01
2023-12-12 23:30	50/70cm	2	11.06 ± 0.01	9.57 ± 0.01
2024-01-22 18:50	40cm	2	11.3 ± 0.1	10.06 ± 0.05

2019). 4U 1954+319 can also be classified as a high mass X-ray binary that consists of an M supergiant (Hinkle et al. 2020, Bozzo et al. 2022). As far as we know, apart from 4U 1954+319, there is only one more X-ray binary that harbors a late-type supergiant as a mass donor, namely CXOGC J174528.7-290942 (Gottlieb et al. 2020). The mass of the M supergiant is considered to be ~ 9 $M_\odot$ (Hinkle et al. 2020). While belonging to a rare class of systems, 4U 1954+319 follows the evolution scenario for the high-mass X-ray binaries (Tauris et al. 2017), stemming from two massive and hot progenitors. However, it exhibits a more advanced stage of evolution compared to typical high-mass X-ray binaries. The orbital period of 4U 1954+319 is not yet confirmed but Hinkle et al. (2020) estimate it to be $\gtrsim 3$ yr.

ZZ CMi is a symbiotic star that consists of a white dwarf and a red giant star, with the orbital period likely to be $\sim$ 440 d (Wiecek et al. 2010). Tshernova (1949) found that ZZ CMi is a long-period variable star. The GCVS catalog gives a classification of ZZ CMi M6I-IIep (Kholopov et al. 1998, Samus'

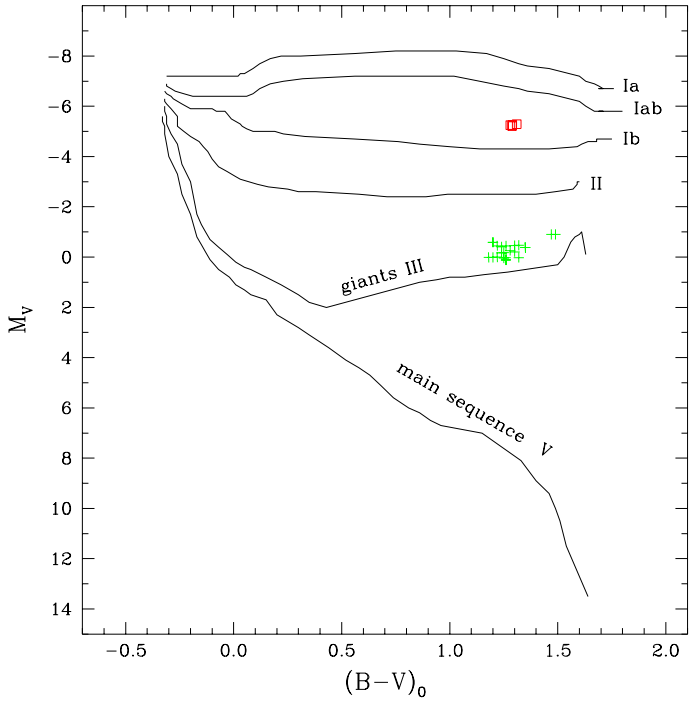

Fig. 2: Colour-magnitude diagram, M_V versus $(B-V)_0$, for 4U1954+319 (red squares) and ZZ CMi (green plusses). The lines for different luminosity classes are also plotted.

et al. 2017). Taranova and Shenavrin (2001) found M4.5-5 III, while, Shenavrin et al. (2011) obtained M6I-IIep.

The optical spectra of ZZ CMi are dominated by the red giant with weak and variable emission lines of $H\alpha$, $H\beta$, [OIII], and [Ne III] (Iijima 1984). Zamanov et al. (2021) noted that an outflow with velocity of about 150 km s^{-1} and U-band flickering with amplitude of about 0.1 mag is visible sometimes. ZZ CMi is an X-ray source from the β/δ-type, meaning that there are two X-ray thermal components, a soft and hard (Luna et al. 2013) one. Some peculiarities deviate ZZ CMi from the classical symbiotic stars – the colours are bluer at a minimum which is not typical for symbiotics and the strengths of the emission lines are unusual, with $H\gamma > H\beta$ (Belczyński et al. 2000).

6. CONCLUSIONS

Based on our spectral and photometric observations, we find for 4U1954+319 the interstellar extinction $E(B-V) = 0.83 \pm 0.09$, $M_V = -5.23 \pm 0.08$, and luminosity class Ib (supergiant) for the mass donor. For ZZ CMi we find $M_V = -0.27 \pm 0.2$, and mass donor of luminosity class III (giant).

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КЛАСА ЛУМИНОЗНОСТИ СИМБИОТСКИХ ЗВЕЗДА 4U1954+319 И ZZ CMi

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Оригинални научни рад

За симбиотске звезде 4U1954+319 и ZZ CMi спровели смо спектроскопска и фотометријска посматрања у оптичком домену. За 4U1954+319, користећи спектре високе резолуције, мерили смо еквивалентне ширине дифузних међузвезданих линија (DIB) и проценили међузвездано поцрвењење $E(B-V) = 0.83 \pm 0.09$. Користећи удаљености из *GAIA* претраге и нашу фотометрију, одредили смо (1) апсолутну V-магнитуду за звезду 4U1954+319 која износи $M_V = -5.23 \pm 0.08$, као и да је донор масе суперџин класе луминозности Ib, и (2) апсолутну V-магнитуду за звезду ZZ CMi, $M_V = -0.27 \pm 0.2$, као и да је донор масе џин класе луминозности III.