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First detection of the He I 10 830 Å emission in spectra of classical Cepheid X Cyg

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ABSTRACT

For the first time, we describe a detection of the emission in the infrared (IR) He I triplet at 10 830 Å in the classical Cepheid X Cyg. Emissions are clearly seen at phases approximately from 0.25 to 0.85. The IR redshifted He I emission is excited by shock wave in the uppermost layers of the star's envelope, in its falling layers. This is a first detection of the helium IR emission in the classical Cepheids.

Key words: stars: atmospheres – stars: chromospheres – stars: variables: Cepheids.

1 INTRODUCTION

Chromospheric emissions in the ultraviolet spectral range and even in the X-ray region were detected in the Cepheids by many authors (see e.g. Evans & Engle 2019; Engle et al. 2020).

A different approach to detect the chromosphere activity in Cepheids was used by Sasselov & Lester (1994a, b), who applied for this purpose infrared (IR) He I triplet 10 830 Å, whose ground level 2s ^{3}S is populated by electron collisions (the main ground level of He I atom is 1s^2 ^{1}S; therefore, the corresponding radiative transitions are prohibited). All seven observed Cepheids showed studied lines in the absorption (for three of them during the entire pulsational cycle).

Hocdé et al. (2020) have recently shown that H α and IR Ca II triplet emissions are caused by hot gas in the atmosphere layers of the Cepheids (24 observed stars with different pulsational periods). The authors confirmed the H α variations described by Gillet (2014) for the X Cyg spectra, and thus confirmed his shock wave model on a larger number of stars. They were also able to estimate the size of the atmosphere responsible for the aforementioned emission (i.e. the chromosphere). As expected, the size of the chromosphere is larger in long-period pulsators. A very interesting finding is the stationary feature in the H α line, which the authors attribute to the circumstellar envelope.

Some OB stars show small emission in the IR He I triplet 10 830 Å. This emission can be explained by the presence of the low-density disc seen pole-on (Waters et al. 1993; Murdoch, Drew & Anderson 1994).

2 OBSERVATIONS

X Cyg is a classical Cepheid with a pulsational period of 16.385 692 d, spectral type F7 Ib–G8 Ib, and visual magnitude variation 5.85–6.91 (Szabados 1991). Hintz, Harding & Hintz (2021) have shown that period of X Cyg is almost constant after 1917. The authors also concluded that the radial velocity measurements show no seasonal variations over years, and this seems to limit the possibility of a companion presence.

The GIANO spectra of the program Cepheid X Cyg were extracted from Italian Center for Astronomical Archive (IA2) for another purpose, but by a lucky chance IR emission in He I 10 830 Å was discovered. GIANO (Origlia et al. 2014) is a near-IR cross-dispersed Echelle spectrograph, operating at Telescopio Nazionale Galileo. It covers the wavelength range 9500–24 500 Å and operates at high resolving power ($R \approx 50\,000$). Information about the time, when the program spectra were observed, is given in Table 1.

The effective temperature T_{eff} was derived from line-depth ratios (Kovtyukh 2007), a technique commonly employed in studies of Cepheid variables (see e.g. Proxauf et al. 2018; da Silva et al. 2022). Optical spectra were obtained at the HARPS-N (Cosentino et al. 2012; $R = 115\,000$, $\lambda\lambda = 3750$–6950 Å) parallelly in time with IR spectra (in the same phases).

3 MAIN RESULTS

Fig. 1 shows the spectra of X Cyg in the vicinity of the IR He I triplet with indicated phases. Note that this is the first detection of 10 830 Å emission in the classical Cepheid.

Fig. 2 shows variation of the X Cyg radial velocity over the pulsational phases together with the variation of the emission radial velocity. From Fig. 2, we see that the radial velocity at the centre of the 10 830 Å in the phase range from 0.25 to 0.85 (when emission is present) decreases slightly with the small acceleration. The emission covers the phases when the star experiences contraction from maximum radius. This emission is formed in the upper layers of the star's envelope.

Wallerstein et al. (2019) performed a study of the IR Ca II triplet in the spectrum of X Cyg. According to their fig. 12, lines of the triplet

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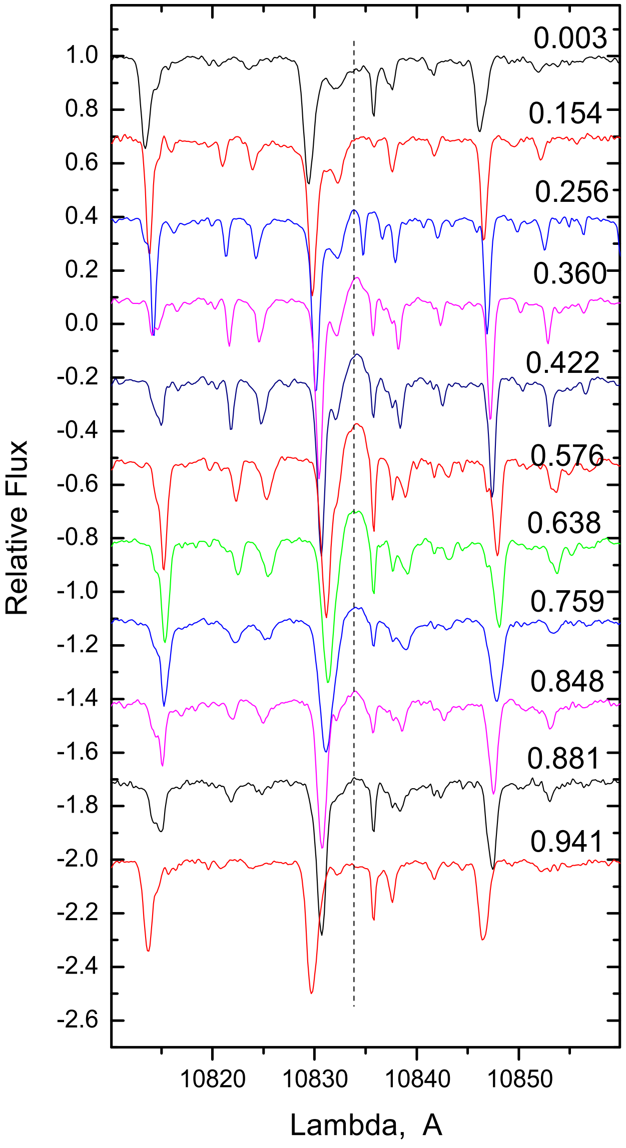

Figure 1. Observed He I 10 830 Å emission.

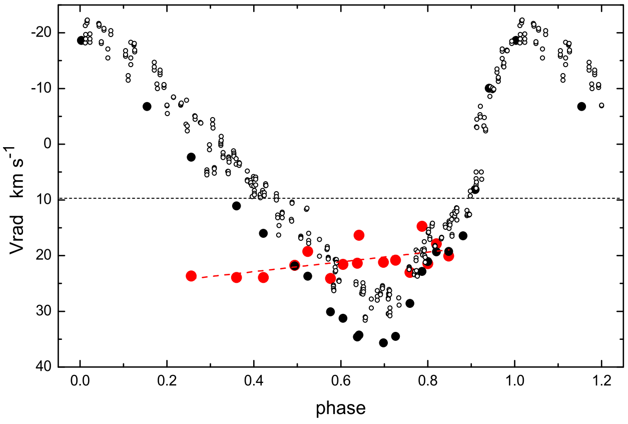

Figure 2. Radial velocities of the pulsating star and helium emission lines. Filled circles – our *Vr* for X Cyg, blue squares – Bersier et al. (1994), open circles – Hintz et al. (2021), and red circles – He I emission. Dashed line indicates the γ-velocity of X Cyg according to data by Bersier et al. (1994).

experience splitting at some phases. Similar behaviour demonstrates also the Balmer H α line. Gillet (2014) examined the behaviour of the H α line in the X Cyg, and built a model of shock wave propagation in this star. We will consider this model in more detail in connection with H and K Ca II, h and k Mg II, and He I emission (reported here) in our next paper.

We have made a very preliminary attempt to synthesize the emission profile of the IR helium lines. In modelling the emission in the He I 10 830 Å lines, we considered the effect of departure from local thermodynamical equilibrium (non-LTE effect) on the calculated spectrum. Our non-LTE model consists of 55 He I atomic levels and He II ground level, which are considered in detail. The model was described in Korotin & Ryabchikova (2018). To find the level populations, we applied the MULTI code by Carlsson (1986). This code was slightly modified by us (Korotin, Andrievsky & Luck 1999) in order to use the opacities from ATLAS9 (Castelli & Kurucz 2003). Our He I model has been earlier applied for B–A stars, but we consider it also applicable to the chromospheres of the late-type stars, since the temperature in the chromosphere is comparable to that of, say, B stars.

A very simple simulation of the X Cyg chromosphere at the pulsational phase 0.42, where the helium emission is well observed, was performed. For this purpose, we set the linear temperature rise as a function of the logarithm of the mass number. The point of the temperature minimum was selected as a starting point. Thereafter, in such primitive chromosphere using the ATLAS9 code we calculated the electron concentration and gas pressure. The slope of the temperature distribution as a function of height in the chromosphere was selected empirically by comparing the observed and calculated helium emission-line profiles. It should be noted that in all of the cases considered, the cores of the helium triplet are formed at temperatures of about 12 000–15 000 K and gas concentration of about 10^{10} cm^{-3}. A fairly good agreement between the observed and calculated profiles is seen if we use a chromosphere model with $T_{\rm min} = 2960$ K, $m_{\rm min} = 0.03$. The fit between synthetic and observed spectra is shown in Fig. 3. The synthetic spectra were produced with the help of the SYNTHV code (Tsymbal, Ryabchikova & Sitnova 2019) with helium line profiles computed in non-LTE (using the level populations obtained with MULTI) and profiles of other lines synthesized in LTE. Atomic line data for these lines treated in LTE were taken from the VALD3 data base (Ryabchikova et al. 2015).

4 CONCLUSION

For the first time, we detected emission in the IR He I 10 830 Å triplet. It is also very important to note that X Cyg according to Barmby et al. (2011) shows extended IR emission among several other Cepheids. This fact indicates a loss of mass by these Cepheids (X Cyg, in particular), which may be caused by running waves in the upper atmosphere layers. Perhaps, these very distant layers are responsible for the emission in the He I lines, as well as for the X-ray emission that was detected in the Cepheid survey by Engle et al. (2017) (phases near to the minimum light). A more detailed consideration of the emission activity of X Cyg will be presented in the next paper.

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Table 1. Time moments of spectroscopic observations, radial velocities, and effective temperature values of X Cyg.

Date, UT time	HJD 2458000+	Phase	V_r (km s^{-1})	σ (km s^{-1})	V_r (He I) (km s^{-1})	T_{eff} (K)	σ (K)	N	$\sigma/\sqrt{N}$ (K)
2019-04-27T05-10-08	600.7154	.360	11.09	0.42	23.93	5094	114	60	14.7
2019-04-28T05-32-30	601.7309	.422	15.96	0.44	23.92	5016	90	70	10.8
2019-05-01T05-37-25	604.7343	.605	31.26	1.00	21.58	4865	90	52	12.5
2019-05-03T05-13-56	606.7180	.726	34.51	1.14	20.83	5183	112	41	17.6
2019-05-04T04-58-11	607.7071	.787	22.85	0.41	14.72	5366	78	59	10.2
2019-05-05T04-54-06	608.7042	.848	19.26	0.76	20.06	5376	77	67	9.4
2019-05-06T04-57-28	609.7066	.909	8.14	0.74	–	6008	141	80	15.8
2019-05-10T05-18-49	613.7214	.154	–6.77	0.62	–	5432	124	74	14.5
2019-05-17T03-30-41	620.6463	.576	30.07	0.61	24.11	4851	76	57	10.0
2019-05-18T03-56-20	621.6641	.638	34.59	0.88	21.35	4913	97	55	13.1
2019-05-19T03-15-30	622.6358	.698	35.67	1.43	21.18	5068	130	57	17.2
2019-05-20T03-29-31	623.6455	.759	28.59	0.80	23.01	5339	104	53	14.3
2019-05-21T03-26-24	624.6433	.820	19.30	0.97	17.87	5346	72	60	9.3
2019-05-22T03-20-50	625.6395	.881	16.45	0.76	–	5667	73	80	8.2
2019-05-23T02-59-07	626.6244	.941	–10.07	0.77	–	6109	137	72	16.1
2019-05-24T03-24-59	627.6423	.003	–18.65	0.66	–	5963	117	79	13.1
2019-06-06T04-54-08	640.7042	.800	21.05	0.58	21.45	5347	78	61	9.9
2019-08-08T03-46-45	703.6575	.642	34.24	1.37	16.35	4924	111	55	15.0
2019-08-22T02-45-33	717.6150	.494	21.84	0.88	21.73	4935	84	67	10.3
2019-09-07T23-41-56	734.4874	.524	23.69	0.84	19.23	4914	97	65	12.0
2019-09-19T23-41-13	746.4869	.256	2.32	0.52	23.64	5220	72	72	8.5

Note. Remark: phases were calculated according to Hintz et al. (2021). N is the number of temperature relations used.

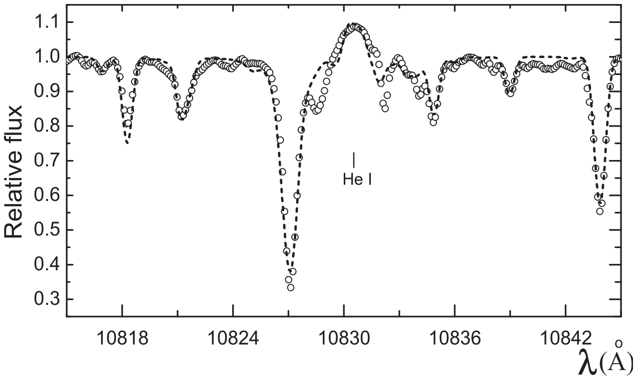

Figure 3. Observed and synthesized spectra of X Cyg in the vicinity of the helium IR lines at pulsational phase 0.42.

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DATA AVAILABILITY

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