RAA 2020 Vol. **20** No. **4**, 53(6pp) doi: 10.1088/1674–4527/20/4/53

http://www.raa-journal.org *http://iopscience.iop.org/raa*

Research in
Astronomy and
Astrophysics

Simultaneous photometric and spectral analysis of a new outburst of V1686 Cyg

Hasmik Andreasyan, Tigran Magakian and Tigran Movsessian

Byurakan Astrophysical Observatory, NAS RA, Byurakan, Aragatzotn Prov., 0213, Armenia;
hasmik.andreasyan@gmail.com

Received 2019 October 24; accepted 2019 November 25

Abstract We present an analysis of the optical observations of Herbig Ae/Be (HAeBe) star V1686 Cyg, which is associated with a small isolated star-forming region around HAeBe star BD+40°4124. We observed this star as a part of our project investigating young eruptive stars. Observations were conducted on the 2.6-m telescope of Byurakan Observatory from 2015 to 2017. In this period, we obtained direct images of V1686 Cyg and 14 medium- and low-resolution spectra. In the course of observations, we noticed that this star underwent an atypical brightness outburst. After data reduction, we found that the full rise and decline in the brightness of V1686 Cyg had an amplitude of almost 3 magnitudes and lasted about 3 months. We were also able to track changes in the stellar spectrum during the outburst, which are correlated with the photometric variations.

Key words: stars: pre-main sequence — stars: variables: T Tauri, Herbig Ae/Be — stars: individual: (V1686 Cyg)

1 INTRODUCTION

Herbig Ae/Be (HAeBe) stars represent the more massive ($M \geq 2\,M_\odot$) class of pre-main sequence (PMS) stars. These stars are known to demonstrate different types of variability. Studies of these regular and irregular variations in brightness and spectral appearance have a great importance for better understanding the stellar envelopes and circumstellar disks surrounding these stars. Based on the features of variability (duration, spectral characteristics, amplitudes of brightening), different classifications of these stars exist (see Herbig (1977)). The reasons for difficulties in classifying HAeBe stars lie mainly in the insufficiency of simultaneous photometric and spectroscopic data. This is why we decided to start the project investigating PMS stars showing periodic or non-periodic eruptive activity. Among them, we studied a group of HAeBe stars in the vicinity of the bright star BD+40°4124, which itself is an HAeBe star with a very strong Hα emission line. One of them is LkHα 224 which is also an HAeBe star. With nearby LkH/alpha 225 they form a group of luminous emission stars, which for the first time were mentioned by Herbig (1960). With several fainter stars, they create a small young cluster, embedded in the dense molecular cloud. Shevchenko et al. (1991) estimated a distance to this group to be 980 pc.

The photometric variability of LkHα 224 was discovered by Wenzel (1980); as a variable, this star received the designation V1686 Cyg. The most complete information about its photometric behavior so far was collected in the works of Shevchenko et al. (1991, 1993) and Herbst & Shevchenko (1999). According to these data, the star fluctuates near the mean brightness level, sometimes (usually one time per year) demonstrating irregular Algol-like minima, which last one-two months: steep and rapid drops by $2 - 2.5$ mag, and afterwards a more slow and oscillating raise in brightness to the mean value. We can take into account that many HAeBe stars with the A0 or later spectral type show this kind of variability (Semkov & Peneva 2012). In addition, long-term variations exist: the mean brightness of V1686 Cyg in V decreased by ≈2.5 mag in about 8 yr, achieving a minimum in 1993 and in the subsequent 4 yr restored to the previous level; thus, its mean level of brightness itself varies from $V = 12.5$ down to $V = 15$ (Hillenbrand et al. 1995; Herbst & Shevchenko 1999; Oudmaijer et al. 2001).

Table 1 Log of the V1686 Cyg Spectral Observations

Date	Spec. range (Å)	Resol. ($\lambda/\Delta\lambda$)	Total exp. (min)
22.09.2015	5880–6740	2500	60
18.11.2015	5785–7315	1500	60
22.11.2015	5785–7315	1500	60
16.05.2016	5880–6880	2500	30
10.06.2016	5890–6795	2500	40
08.08.2016	5780–7300	1500	30
23.08.2016	4120–6810	800	60
24.08.2016	5895–6795	2500	40
29.08.2016	4070–7055	800	20
30.08.2016	5870–6875	2500	40
06.11.2016	5695–7360	1500	45
28.11.2016	4025–6995	800	30
20.12.2016	4025–6995	800	45
21.12.2016	5850–6850	2500	30

V1686 Cyg was the subject of many spectral studies, but prominent variations in absorption features make its spectral classification very problematic. Estimates of its spectral type vary from B2 to F9 (see Hernandez et al. 2004, and references therein). As is stated in the same work, shorter term photometric variations of V1686 Cyg could be related to the spectroscopic variability, but this question has not been investigated yet. It should be noted that emission lines in the V1686 Cyg spectrum also demonstrate significant variability (Mora et al. 2001). In Magakyan & Movsesyan (1997), the broad asymmetric profile of Hα emission with several superposed narrow absorption-like features is exhibited, suggesting the existence of expanding envelopes.

In 2015, we started systematic observations of the BD+40°4124 field, since the new outburst of V1318 Cyg S was detected (Magakian et al. 2019). In parallel to these studies, the star V1686 Cyg was also observed photometrically and spectrally. The unusual and unpredicted brightening of V1686 Cyg, up to almost 3 mag, was ascertained and tracked. This paper describes the results of these observations.

2 OBSERVATIONS AND DATA REDUCTION

In 2015, we started our project investigating eruptive stars. Observations were carried out on the 2.6-m telescope in Byurakan Observatory. We used the SCORPIO spectral camera and obtained direct images, as well as long-slit spectra (Afanasiev & Moiseev 2005). It was equipped with a TK SI-003A 1044×1044 CCD and after August 2016 with an e2v CCD42-40 2080×2048 CCD. As an object of our previous interests, we started our observations with the young variable star V1318 Cyg, and at the same time obtained data for the neighboring star V1686 Cyg. Observations were conducted from September 2015 to July 2017. Data reduction was done in the usual way, employing IRAF and ESO-MIDAS programs. Photometric estimations were completed by aperture photometry. For calibration, we relied on some stars in the field, while for comparison stars we applied data from Hillenbrand et al. (1995) and Shevchenko et al. (1991). The typical errors for our data are about $0.^{\rm m}02 - 0.^{\rm m}03$. We also obtained spectra for this star from Sept 2015 to Dec 2016, with different spectral resolutions: 0.50, 0.80, 1.50 and 2.65 Å pixel^{-1}.

More details about the methods of observation and data reduction can be found in our previous paper (Magakian et al. 2019). Here, in Table 1, we present the log of the spectral observations.

3 RESULTS

3.1 The new outburst of V1686 Cyg

Analysis of the historical light curve of V1686 Cyg (based on the encompassing eleven year photometric database: Herbst & Shevchenko 1999) with VizieR service demonstrates that from the mean level of brightness, this star decrease its brightness from time to time by $1 - 1.5$ mag, which lasts $10 - 20$ d, and then it returns to the mean value.

In our case, we observed contrary behavior: during the period from Sept 2015 to Aug 2016, i.e., almost 1 yr of regular observations, any significant photometric variability of V1686 Cyg was not detected. But in Aug 2016, we noticed that the star significantly increased in brightness. Photometric estimations demonstrated that in that period, which lasted probably several months, the brightness of V1686 Cyg unpredictably increased by more than two magnitudes in V and then gradually returned to its previous level. Table 2 presents the results of our $BVRI$ photometry, and the light curve is displayed in Figure 1.

To track the recent variations of V1686 Cyg, we checked such sources as images from the INT Photometric Hα Survey of the Northern Galactic Plane (IPHAS) (Drew et al. 2005) as well as Sloan Digital Sky Survey (SDSS) and Gaia DR2. The brightness estimates, obtained from the IPHAS images, are listed in Table 3.

The important representation of the recent brightness variations of V1686 Cyg is captured by data from the American Association of Variable Star Observers (AAVSO), which densely cover the period Aug 2014 – Aug 2018. In Figure 2, we combine the light curve in V band from AAVSO with our data and the G magnitudes from Gaia.

Though in 2000–2012, the photometric estimates are scarce, the IPHAS data (Table 3) allow us to assume that

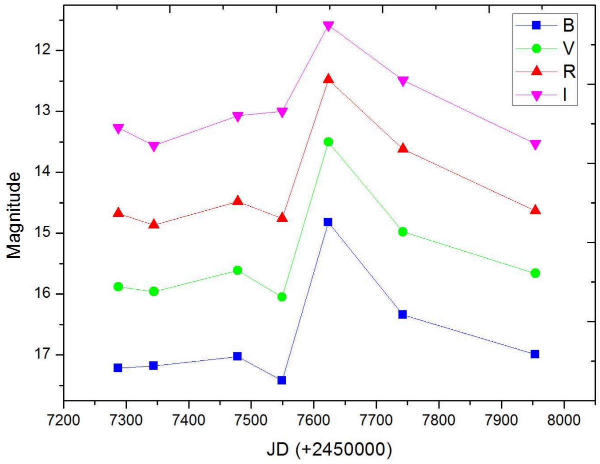

Fig. 1 $BVRI$ light curve of V1686 Cyg for the period of 2015 – 2017.

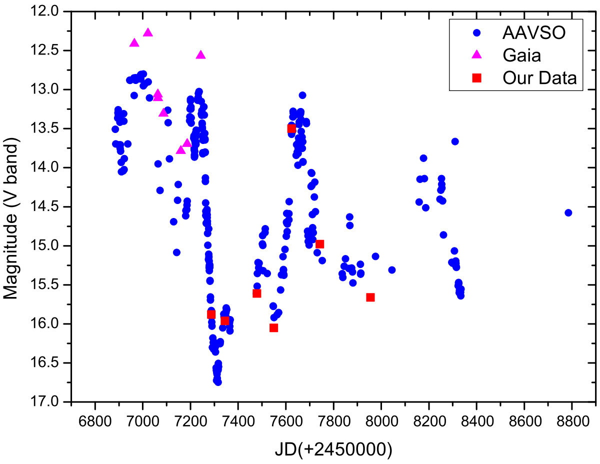

Fig. 2 The light curve of V1686 Cyg in V band, combining data from AAVSO, Gaia and our observations.

Table 2 V1686 Cyg (LkHα 224) Photometry

Date	B	V	R	I
22.09.2015	17.22	15.88	14.68	13.27
18.11.2015	17.18	15.96	14.87	13.56
31.03.2016	17.03	15.61	14.48	13.07
10.06.2016	17.42	16.05	14.76	13.00
23.08.2016	14.82	13.50	12.48	11.58
20.12.2016	16.34	14.98	13.62	12.49
20.07.2017	16.99	15.66	14.63	13.53

Table 3 V1686 Cyg Brightness in the IPHAS Images

Date	R	I
09.08.2003	13.29	12.17
10.08.2003	13.29	12.15
18.10.2003	14.53	13.37
11.10.2006	14.92	13.79

V1686 Cyg kept its typical behavior up to 2013, with more or less a persistent brightness level near $13.0 - 13.5$ (V). In the first half of 2015, the star demonstrated several characteristic minima. Then, in Aug 2015 the brightness of V1686 Cyg abruptly lowered, reaching $V = 16.7$ in Oct 2015 After that, the photometric behavior of the star drastically changed. As one can conclude from the AAVSO light curve, at least until the end of 2017, the star remained at the significantly lower level of brightness (about 15.3 in V), with occasional outbursts. During July–Oct of 2016, a prominent outburst of at least 2.5 mag in V took place, also signified by our photometry, and which by chance coincided with our spectroscopic observations. One cannot exclude another, lower amplitude brightening in the first half of 2018.

The pronounced spectral variations, observed by us during the 2016 event, are important. Such spectroscopic variability, related to photometric variations, was expected for V1686 Cyg by Hernandez et al. (2004). We describe it in the next section.

3.2 The Spectrum of V1686 Cyg

3.2.1 The spectrum of V1686 Cyg in its quiescent phase

As was mentioned above, our spectral observations encompassed the whole period of the V1686 Cyg outburst. We selected eight spectra with best signal-to-noise ratio (S/N) quality for further analysis.

Spectra, taken before the outburst, are quite typical for this star, being similar to the results of Hillenbrand et al. (1995) and Magakyan & Movsesyan (1997). In the red part of the spectral range, the most conspicuous line is a broad and strong Hα emission with a superposed weak, blue-shifted absorption feature. Forbidden emissions of [OI] also are present, though very strong background emission lines make the estimations of their intensity uncertain. Besides, faint emission lines, mainly belonging to FeII (40) and not described before, were detected. NaI D lines are not seen well either in emission or absorption; it should be mentioned that previous studies demonstrate their pronounced variability.

After the end of the outburst, in Nov–Dec 2016, the spectrum returned to the same appearance, with Hα and several FeII lines in emission; besides, broad-winged Hβ and Hγ absorptions can be identified in the blue range. In fact, upper lines of the Balmer series in absorption, though not strong, probably are always present in the spectrum of V1686 Cyg (Magakyan & Movsesyan 1997; Donehew & Brittain 2011). In general, during the time of our observations, the spectral type of V1686 Cyg can be assumed as an early Ae, judging by the broad wings of Balmer absorp-

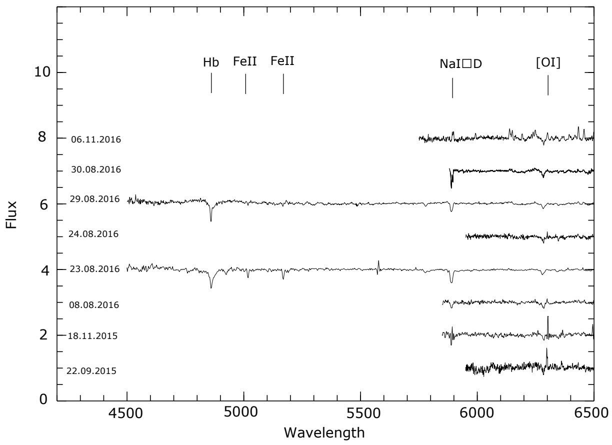

Fig. 3 Variations of the V1686 Cyg spectrum in 2015–2016, in the range $4500 - 6500$ Å. In the shorter wavelengths, Hβ and FeII absorptions are prominent. Also, an obvious increase in the chromospheric emission on 2016 June 11 can be seen.

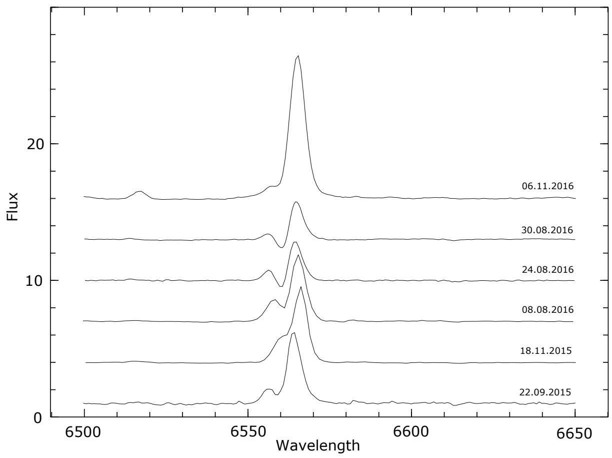

Fig. 4 The strong variations in the profile of Hα line in the spectrum of V1686 Cyg. During the outburst, the absorption component became rather intensive and even drops below the continuum.

tions and non-detection of HeI 5876 line (which also manifests prominent variability in the V1686 Cyg spectrum, according to Mendigutia et al. (2011). We did not find any other photospheric absorptions, at least with our spectral resolution.

It should be mentioned that in all spectra, we detected one of the strongest diffuse interstellar bands (DIBs) 6284 Å, also mentioned by Hernandez et al. (2004), which is easily distinguished from the nearby atmospheric absorption 6278 Å. This band with a similar intensity was previously detected in the spectrum of the nearby star LkHα 225 (Magakian et al. 2019).

3.2.2 Spectrum of V1686 Cyg during the outburst

The first significant spectral changes one could ascertain in the spectrum of the star, obtained in May 16 of 2016, when photometric variations were not detected yet. The better S/N spectrum from 2016 June 10, still before the photometric brightening, confirms this impression. The central absorption in Hα became much stronger, nearly dividing the emission line into two almost equal components. Forbidden emission lines of [OI] and [SII] are still present in the spectrum; their width confirms non-background origin.

As can be seen from Table 2, the maximal brightness of V1686 Cyg was reached in Aug 2016. Despite the different spectral resolution, all our five spectrograms of that period have certain similarity. Especially impressive are the further variations in the profile of the Hα line, where the absorption component decreases beneath the continuum. As the strength of iron emissions decreases, forbidden lines of [OI] nearly disappear. On the another hand, rather intensive NaI D absorption lines become visible in the spectrum. In the shorter wavelength range, which was observed only with lower resolution, in addition to Hβ and Hγ with typical shell cores, we also see absorptions of FeII (42). It is worth mentioning that after one week these blue iron absorptions disappeared, though the red part of the spectrum kept the same appearance at least until the end of Aug of 2016.

To better represent the changes, we display parts of the normalized V1685 Cyg spectrum (in the range up to Hα line), in various periods in Figure 3, and the variations in the Hα profile are presented in Figure 4.

In Oct 2016, the star started to lower its brightness (see Fig. 1). During that period the spectrum, obtained on Nov 6, is very interesting. It significantly differs from the outburst spectra, as well as from the other spectra in the quiescent stage. On the one hand, strong NaI D absorptions and the Hα line absorption component disappeared. On the other hand, all emission lines became obviously stronger than before the outburst. The emission line spectrum in the range $6000 - 6500$ Å appears much more rich, with lines of FeII, FeI and CaI. We can note remarkable similarity to the spectra of PV Cep and V350 Cep, shown by Magakian et al. (2019). Subsequent spectra, though with lower S/N, are more like the pre-outburst spectra, as was already mentioned in the previous section.

3.3 Equivalent Widths and Radial Velocities

For a better representation of the spectral changes, described above, we estimated the equivalent widths (EWs) of most typical emission and absorption lines. The general picture seems consistent with the conclusion mentioned above, that the strength of emission lines relative to continuum significantly dropped during the maximal brightness period. For example, EW of the Hα emission component changed from $\approx -35\,$Å to $\approx -12\,$Å at the end of Aug 2016; then high values again were restored. In the spectrum from 2016 Nov 6, described above with very strong emissions, EW(Hα) exceeded $-50\,$Å. A similar behavior can also be seen for the $\lambda 6300\,$Å [OI] line. On the other hand, EW of NaI D absorption in the period of the outburst reached 5 Å, but it was actually invisible before. Pronounced variability of emission as well as absorption lines in the V1686 Cyg spectrum was also previously described by Mora et al. (2001) and by Hernandez et al. (2004).

We measured the heliocentric radial velocities of several lines and found a pattern, very typical for young stellar objects. All measurable absorption lines demonstrated negative velocity. For example, the mean velocity of the absorption component of Hα is $-97 \pm 47\,\mathrm{km\,s^{-1}}$. Such large dispersion is natural, because the previous observations also have demonstrated the existence of blue-shifted absorption components in the Hα line profile with various, but always negative, radial velocities. The narrow absorption cores in Hβ and Hγ have similar velocities, though these values cannot be measured with sufficient accuracy because of the lower spectral resolution. FeII(42) absorptions, seen in only one lower resolution spectrum, also manifest ambiguous velocities, probably because of the same reason. Both lines of the NaI D doublet have velocity near $-57\,\mathrm{km\,s^{-1}}$, and $\lambda 6300$ Å [OI] emission also has similar negative velocity. The peak of Hα emission has positive radial velocity: $+95 \pm 29\,\mathrm{km\,s^{-1}}$. Velocities of the iron emissions cannot be measured because of their faintness. All these data are in sufficiently good compliance with high-resolution measurements, as presented by Cauley & Johns-Krull (2015).

4 DISCUSSION AND CONCLUSIONS

Our combined data allow us to make several conclusions about the observed spectral variability of V1686 Cyg. These observations fully confirm what was already described by the authors listed above in that the pronounced changes in the strength of certain absorption and emission lines, which easily explain the large range of the spectral types, assigned to this object. Actually, V1686 Cyg is one of the most photometrically and spectrally variable HAeBe star, and as one can see (at least in this present case), the spectral and photometric variations of V1686 Cyg are directly related.

As was already stated above, the observed short-term brightening is not typical for V1686 Cyg, at least in the sense that similar events cannot be found in the previous long-time light curve, presented by Herbst & Shevchenko (1999). It can be considered as an outburst, because its accompanying spectral changes could be interpreted as the formation of a dense expanding envelope around the star, with its subsequent dissipation during several months. This envelope, emitting mainly in the continuum, covered up lower layers of the stellar chromosphere, making the metallic emissions invisible and even diminishing the very strong emission component of the Hα line. On the other hand, the envelope was sufficiently dense to produce absorption lines with negative radial velocity.

The permanent existence of the blue-shifted absorption components in the Hα line profile, demonstrated by the previous observations (Magakyan & Movsesyan 1997), allows us to conclude that similar expanding envelopes, though of much lower density, are nearly always present around the star V1686 Cyg.

Currently, we do not know how long V1686 Cyg will remain in its present lower brightness state. Only the new photometric observations can make the situation more clear. This star definitely deserves continued monitoring.

Several authors make analogies between V1686 Cyg's short-term light drops and UX Ori type variability. However, this question remains to be investigated. In fact, this star may be an object, which combines two types of PMS variability, like V2492 Cyg, V350 Cep or V582 Aur (Giannini et al. 2018; Jurdana-Šepić et al. 2018; Ábrahám et al. 2018).

Acknowledgements This work was supported by the RA MES State Committee of Science, in the frame of the research project number 18T-1C-329.

This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France (DOI: 10.26093/cds/vizier). This paper also utilizes data obtained as part of the INT Photometric Hα Survey of the Northern Galactic Plane (IPHAS) carried out at the Isaac Newton Telescope (INT). The INT is operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. All IPHAS data are processed by the Cambridge Astronomical Survey Unit, at the Institute of Astronomy in Cambridge. We acknowledge with thanks the variable star observations from the AAVSO International Database mainly contributed by observer James McMath, which were used in this research.

The authors are grateful to the referee for valuable suggestions and comments.

References

Ábrahám, P., Kóspál, Á., Kun, M., Fehér, O., Zsidi, G., Acosta-Pulido, J.A., Carnerero, M.I. et al. 2018, ApJ, 853, 28.

Afanasiev, V.L. & Moiseev, A.V. 2005, Astronomy Letters, 31, 194

Cauley, P.W. & Johns-Krull, C.M., 2015, ApJ, 810, 5

Donehew, B. &Brittain, S. 2011, AJ, 141, 46

Drew, J. E., Greimel, R., Irwin, M. J., et al. 2006, MNRAS, 362, 753

Giannini, T., Munari, U., Antoniucci, S., et al. 2018, A&A, 611, A54

Herbig, G. H., 1960, ApJS, 4, 337

Herbig, G. H., 1977, ApJ, 217, 693H

Herbst, W., & Shevchenko, V. S. 1999, AJ, 118, 1043

Hernández, J., Calvet, N., Briceño, C., Hartmann, L., Berlind, P. 2004, AJ, 127, 1682

Hillenbrand, L. A., Meyer, M. R., Strom, S. E., & Skrutskie, M. F. 1995, AJ, 109, 280

Ibragimov, M. A., Melnikov, S. Y., Chernyshov, A. V., & Shevchenko, V. S. 1988, Astrofizika, 29, 633

Jurdana-Šepić, R., Munari, U., Antoniucci, S., Giannini, T., & Lorenzetti, D. 2018, A&A, 614, A9

Magakyan, T. Y., & Movsesyan, T. A. 1997, Astronomy Letters, 23, 666

Magakian, T. Yu., Movsessian, T. A., Andreasyan, H. R., et al. 2019, A&A, 625, A13

Mendigutia, I., Eiroa, C., Montesinos, B., et al. 2011, A&A, 529, A34

Mora, A., Merín, B., Solano, E., et al. 2001, A&A, 378, 116

Oudmaijer, R.D., Palacios, J., Eiroa, C., et al. 2001, A&A, 379, 564

Semkov, E. H., & Peneva, S. P. 2012, Ap&SS, 338, 95S

Shevchenko, V. S., Ibragimov, M. A., & Chenysheva, T. L. 1991, Soviet Ast., 35, 229

Shevchenko, V. S., Grankin, K. N., Ibragimov, M. A., et al. 1993, Ap&SS, 202, 121

Wenzel, W. 1980, Mit.VS, 8, 182