RAA 2020 Vol. **20** No. **3**, 33(8pp) doi: 10.1088/1674–4527/20/3/33

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

Research in Astronomy and Astrophysics

Irregular changes in Hα emission line of V423 Aur observed by LAMOST Medium-Resolution Spectrographs

Chao-Jian Wu (武朝剑)[1], Hong Wu (吴宏)[1], Chih-Hao Hsia (夏志浩)[2], Wei Zhang (张伟)[1], Juan-Juan Ren (任娟娟)[3], Guang-Wei Li (李广伟)[1], Jian-Jun Chen (陈建军)[1], Fan Yang (杨帆)[1], Jian-Rong Shi (施建荣)[1], Yong-Hui Hou (侯永辉)[4,5] and Ji-Feng Liu (刘继峰)[1,5]

[1] Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China; *chjwu@bao.ac.cn*

[2] State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology, Taipa, Macau, China

[3] Key Laboratory of Space Astronomy and Technology, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China

[4] Nanjing Institute of Astronomical Optics & Technology, National Astronomical Observatories, Chinese Academy of Sciences, Nanjing 210042, China

[5] School of Astronomy and Space Science, University of Chinese Academy of Sciences, Beijing 100049, China

Received 2019 August 28; accepted 2019 September 29

Abstract We obtained seven spectra of the Be star V423 Aur on 2017 Dec. 5 using the LAMOST Medium-Resolution Spectrograph with exposures from 600 to 1200 seconds. These spectra show the irregular Hα emission line profile variations (LPVs). In the seven spectra, from the 4th to 7th, the left part of Hα profile even shows excess. However, no variation can be seen from the follow-up observation of photometry by 1.26-m telescope and High-Resolution spectra by 2.16-m telescope. According to the High-Resolution spectra, we conclude that it is a B7V type star with $E(B-V) = 0.709 \pm 0.036$ and its $v\sin i$ is $\sim$221.8 km s^{-1}. The short-term Hα LPVs could be explained as a result of the transient ejection of matter from rotating disk or shell around V423 Aur.

Key words: stars: emission-line, Be — stars: variables: general — stars: rotation

1 INTRODUCTION

Stellar variability can be used to study a variety of physical processes. Stellar variability is mainly due to several reasons: asteroseismology, eruptive behavior, the eclipsing binaries and period-luminosity relations of evolved stars, the explosive behavior of novae and supernovae, and so on (Conroy et al. 2018; Eyer & Mowlavi 2008; Catelan & Smith 2015). Lines variations, which are from circumstellar emission and absorption lines, are also very common to Be stars, especially, the classical Be stars (Porter & Rivinius 2003).

The classical Be stars are a heterogeneous set of non-supergiant stars with B spectral types and one or more Balmer emission lines (Jaschek et al. 1981). Besides B type and emission lines, rotation, variation and circumstellar gas are also the main features of Be stars.

Rotation is an important feature of Be stars (Struve 1931), which may be a main contributor to the generation of the circumstellar medium. However, the question of whether or not Be stars rotate at the critical limit (the gravity balances centrifugal force) has still not been answered (Porter & Rivinius 2003). Some results of studies show that Be stars rotate at values of 70% $\sim$80% of their critical rotation. Though the rotation is not 100% of their critical rotation, it is still very high and is an important index to distinguish Be stars from normal B stars.

The timescale of line variation of Be stars ranges from minutes to a few days (Porter & Rivinius 2003). Early-type Be stars (earlier than B5) usually show short-term variation (Lucy 1974; Balona 1975; Chen & Huang 1987). Cuypers et al. (1989); Balona et al. (1992) confirmed this trend. The short-periodic line variation is considered to be due to nonradial pulsation in Baade's work (Baade 1982). While Balona (1990, 1995) attributed the variation to stellar spots and corotating clouds. In the work of Smith (2001), the results seemed to be more supportive of the pulsation.

In this paper, a Be star was observed by LAMOST medium resolution spectrographs. The medium resolution spectra show obviously intensity and profile changes in Hα emission line (Sect. 2.1). However, no changes can be found from the follow-up observation of photometry (Sect. 2.2) and High-Resolution spectra (HRS) (Sect. 2.3). Some results were concluded based on these observation data in Section 3. We also discussed the reasons of Hα changes of the Be star in Section 4. Summary was presented in Section 5.

2 OBSERVATION

2.1 Medium Resolution Spectra of V423 Aur

LAMOST (Large Sky Area Multi-Object fiber Spectroscopic Telescope; also known as Guo Shou Jing Telescope) is the first large astronomical scientific device in China. It has a five-degree field of view and can simultaneously observe the spectra of 4000 objects. From 2011 to 2017 (the pilot and the first 5 years regular survey), LAMOST has obtained more than 9 million spectra (R $\sim$ 1800). Since Sep. 2017, it started test observation with medium resolution (R$\sim$ 7500) spectrographs. There are all 16 medium resolution spectrographs, each spectrograph has two cameras, red and blue. Red camera covers the wavelength range from 4950 Å to 5350 Å, and blue camera covers from 6300 Å to 6800 Å. Since Sep. 2018, it starts the second stage survey (the Medium-Resolution spectral Survey, MRS) program.

On 2017 Dec. 5, we observed a test sky area with medium-resolution spectrographs of LAMOST. The central star of the test plate is HIP 24879. According to the corresponding Hα photometric image of IPHAS (The INT Photometric Halpha Survey of the Northern Galactic Plane), some bright stars and many bright positions of nebulae are selected as the input catalogue. The catalogue includes 47 456 positions in all. After redistribution with LAMOST Survey Strategy System (SSS), 3478 source locations (1679 stars and 1799 nebula positions) from 47 456 are allocated to 3478 fibers. The other 522 fibers are immovable. Figure 1 shows the fiber distribution.

This test sky area was observed for seven times. More detailed observation information can be seen in Table 1. The exposure time of first three spectra is 600 s, the second three spectra is 900 s and the last is 1200 s. In this observation, we obtained 1679 medium resolution stellar spectra in total. The 1D medium resolution spectra were processed by LAMOST pipeline. The procedures include standard preprocessing (like bias subtraction, flat-field correction, fiber efficiency correction, etc.), spectra extraction, wavelength calibration and skylight subtraction. Because the nebula is mixed with the skylight background, the skylight subtraction is performed only for stellar spectra.

Table 1 Observation of V423 Aur with LAMOST

Spectrum ID	Observation Time (UT)	MJD	Exposure (s)
No.1	2017–12–05T15:01:19.64	58092.6259	600
No.2	2017–12–05T15:14:41.29	58092.6352	600
No.3	2017–12–05T15:28:03.88	58092.6444	600
No.4	2017–12–05T15:47:30.74	58092.6580	900
No.5	2017–12–05T16:05:52.25	58092.6707	900
No.6	2017–12–05T16:24:13.89	58092.6835	900
No.7	2017–12–05T16:47:35.57	58092.6997	1200

After checking all of the 1D spectra of the 1679 stars, we found a star showing a variable Hα emission line, see Figure 2. By matching with Simbad, the star is V423 Aur (red dot in Fig. 1). As shown in Figure 2, the spectra are all background corrected and the continuous spectra have been scaled to equal. Obviously, the Hα emission lines changed irregularly. The 2nd (red) Hα flux is highest and the 4th (pink) flux is lowest. The 4th (pink), 5th (yellow), 6th (black) and 7th (blue) spectrum even show broader spectral line width.

Figures 3 and 4 show two normalized medium-resolution spectra of red camera and blue camera. Many emission lines and two strong absorption lines have been marked. They are almost all Fe lines and show bimodal structure. From the spectra, this star can be identified as a Be star.

2.2 Photometry of V423 Aur

We also observed V423 Aur with 1.26-m National Astronomical Observatory-Guangzhou University Infrared/Optical Telescope (NAGIOT) located at Xinglong observatory of the National Astronomical Observatories, Chinese Academy of Sciences, on 2018 Jan. 09 and 2018 Jan. 11. NAGIOT has two channels, optical and near infrared channels. The optical channel is splitted into three optical passbands by the TRIPOL5 instrument. The TRIPOL5 use three SBIG STT-8300M cameras with a CCD of 3326$\times$2504 pixels and a field of view of $6.0' \times 4.5'$. So NAGIOT enables simultaneous photometry in three optical bands (SDSS g, r and i). Three images with three different filters can be obtained simultaneously.

V423 Aur was observed for 29 times on Jan. 09 and 27 times on Jan. 11. Table 2 lists detailed information of observation. The data reductions were carried out with the PyRAF following the procedures: bias subtraction, flat-field correction. We need to use the results of differential photometry, so the flux calibration of the images was not done. Figure 5 (r band) is one of the optical images ob-

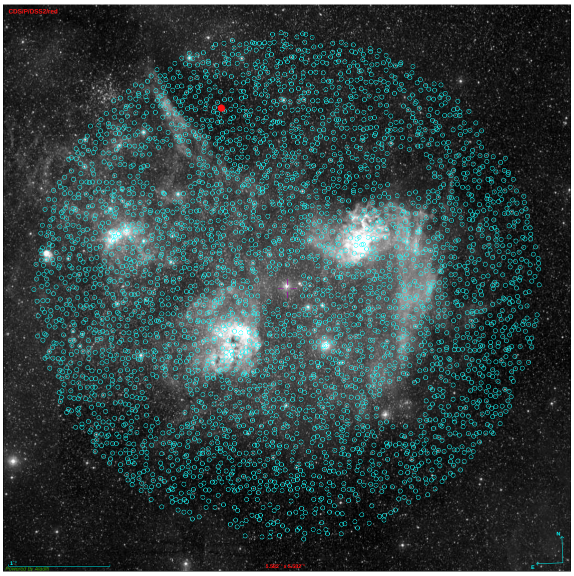

Fig. 1 Fiber distribution of test sky area. *Blue circles* are coordinates of 4000 fibers. The *purple plus symbol* is the center star HIP 24879. The *red dot* is V423 Aur.

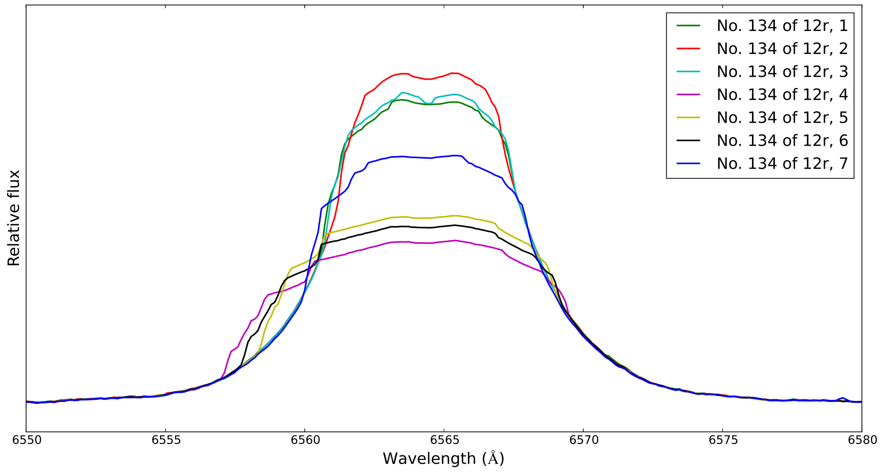

Fig. 2 Variable Hα emission line of V423 Aur observed by LAMOST. The 4th (*pink*), 5th (*yellow*), 6th (*black*) and 7th (*blue*) spectra even show broader spectral line width.

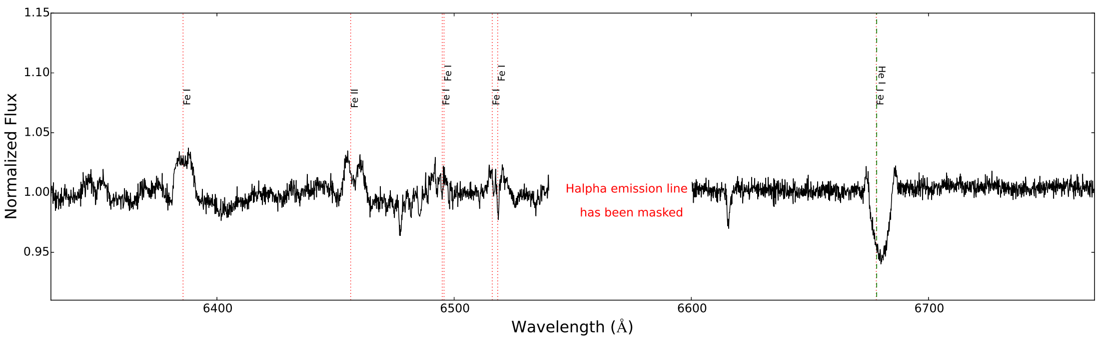

Fig. 3 Medium-resolution spectrum of V423 Aur by red camera. All Fe lines show bimodal structure. The HeI absorption line centered on 6678.15 Å was broadened.

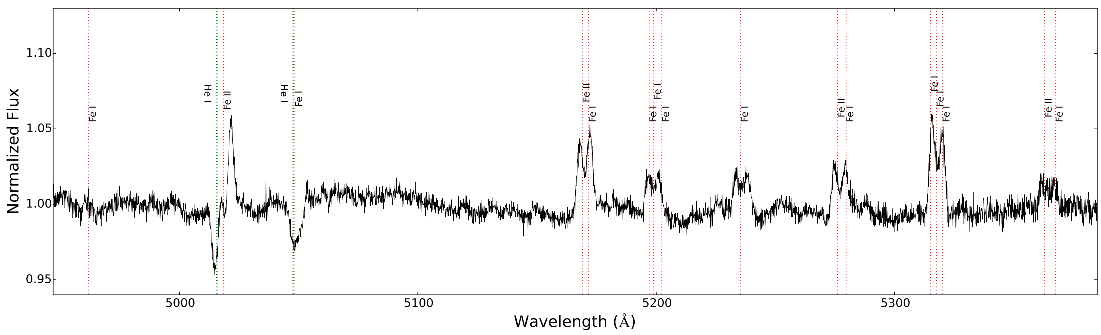

Fig. 4 Medium-resolution spectrum of V423 Aur by blue camera.

Table 2 Observation of V423 Aur with NAGIOT

Observation Date	Exposure (s)	Filters	Observation times
2018–01–09	150	g, r, i	29
2018–01–11	150	g, r, i	27

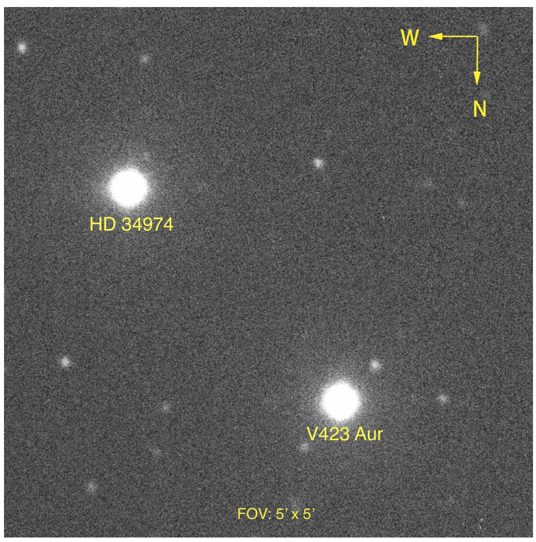

Fig. 5 r band image observed on 2018–01–09 with NAGIOT. Two brightest stars are V423 Aur and HD 34974.

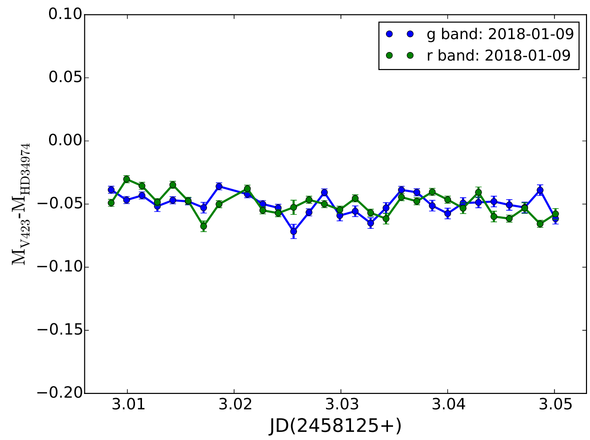

Fig. 6 g and r band light curves of V423 Aur observed on 2018–01–09.

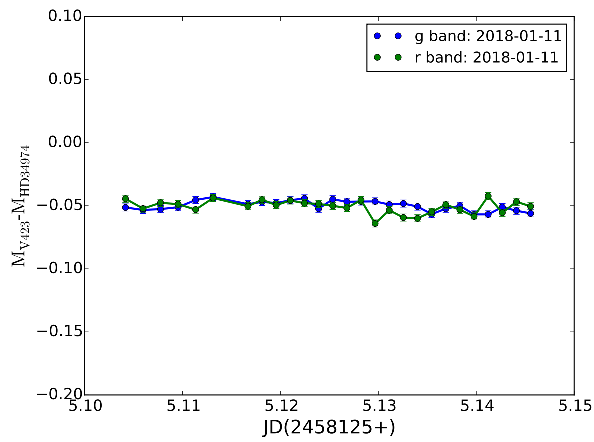

Fig. 7 g and r band light curves of V423 Aur observed on 2018–01–11.

served by NAGIOT on Jan. 09. There are two brightest stars in Figure 5, V423 Aur and HD 34974. HD 34974 is not a variable star. So by comparing with HD 34974, we can know whether V423 Aur has photometric changes. Figure 6 and Figure 7 show the results of differential photometry. By comparing the light curves of g band and r band, the g magnitudes and r magnitudes do not show the same variation trend. So we do not think that we have observed the variability of V423 Aur. The larger magnitude scatter of g and r band in Figure 6 may be due to instrumentation or weather effects. The light curves of i band were not drawn because of its large error due to the instrument itself.

2.3 High Resolution Spectra (HRS) of V423 Aur

At the time of photometry, we also observed V423 Aur with high resolution spectrograph (R$\sim$ 49 800) of 2.16 m Telescope, which is located at Xinglong Observatory, China. The spectrograph covers the wavelength range from 4000 Å$\sim$10 200 Å. From 2018 Jan. 9 to 11, three nights,

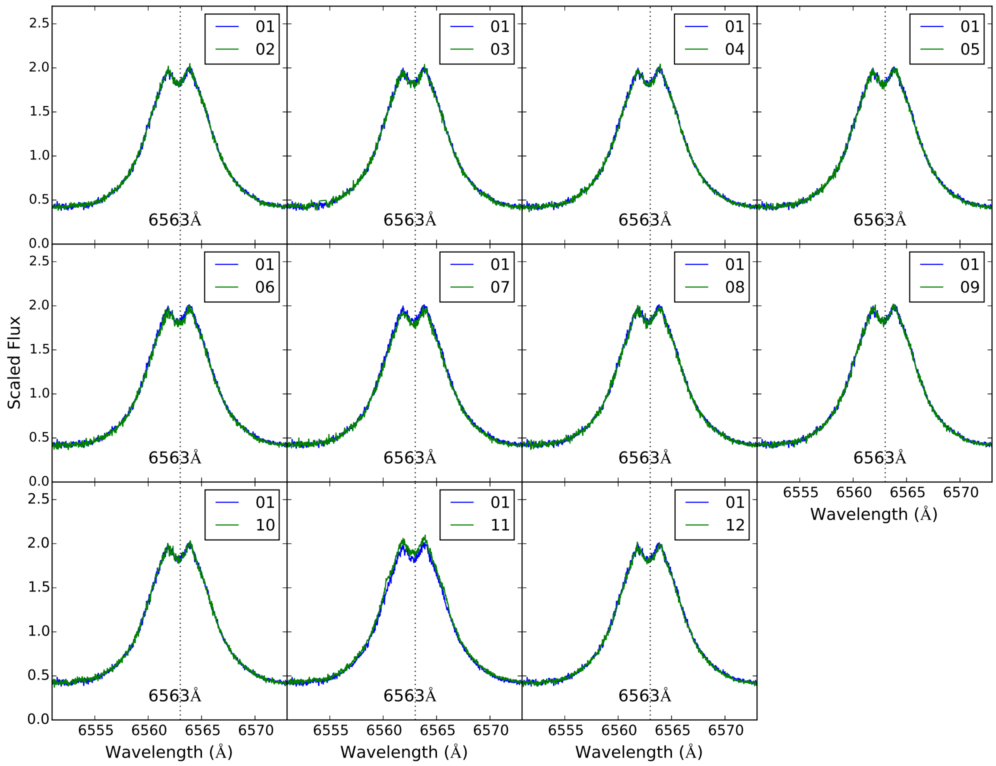

Fig. 8 HRS of V423 Aur observed on 2018–01–09. All other 11 spectra are compared to the first spectrum (*blue line*).

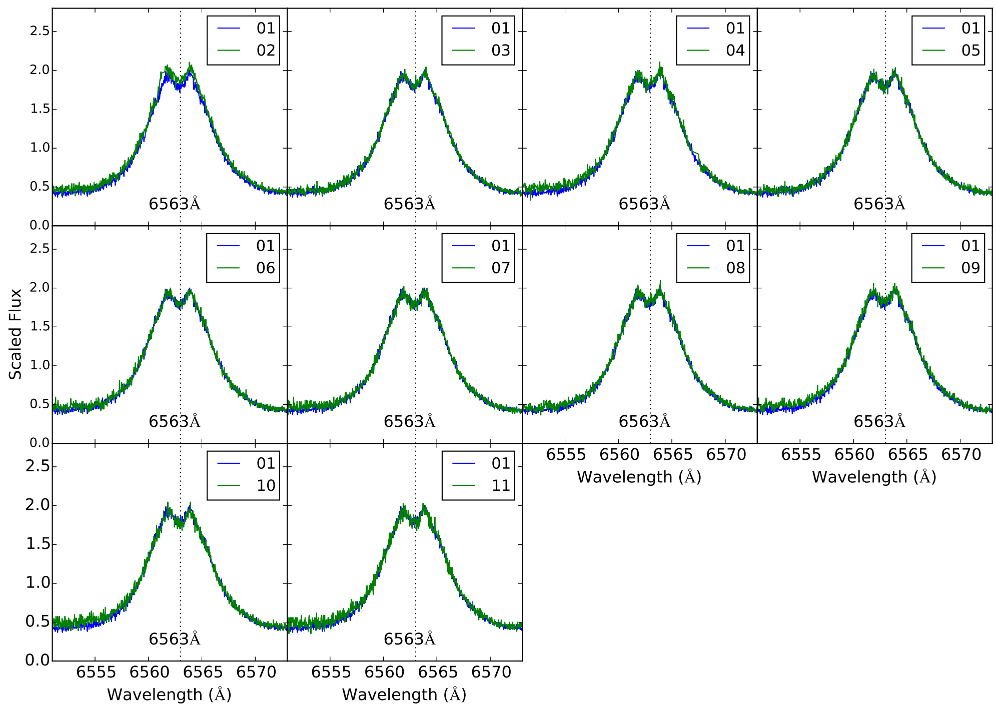

Fig. 9 HRS of V423 Aur observed on 2018–01–10. All other 10 spectra are compared to the first spectrum (*blue line*).

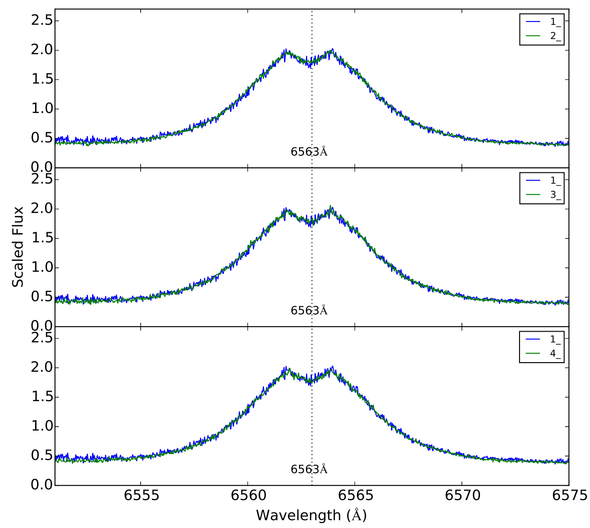

Fig. 10 HRS of V423 Aur observed on 2018–01–11. All other three spectra are compared to the first spectrum (*blue line*).

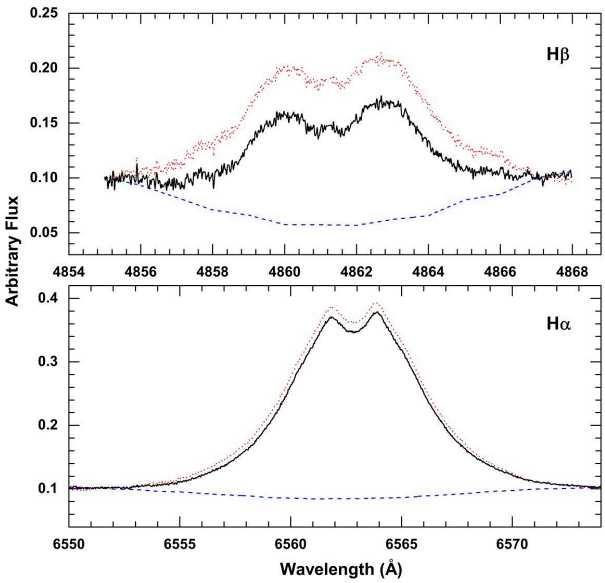

Fig. 11 The Hβ (*upper panel*) and Hα (*bottom panel*) emission line profiles. In each panel, the observed profiles and the modeled absorptions are plotted as the *black solid* and *blue dashed lines*, respectively. The *red dotted lines* represent the residual profiles after removing the modeled absorptions.

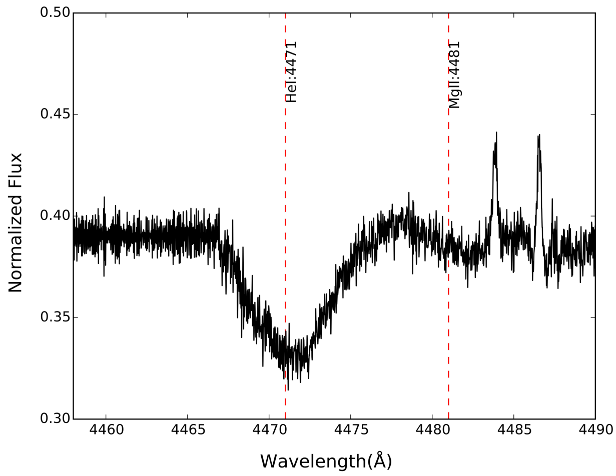

Fig. 12 HRS of V423 Aur observed on 2018–01–10. The marked HeI absorption line (λ4471 Å) and MgII absorption line (λ4481 Å) can be used to classify star.

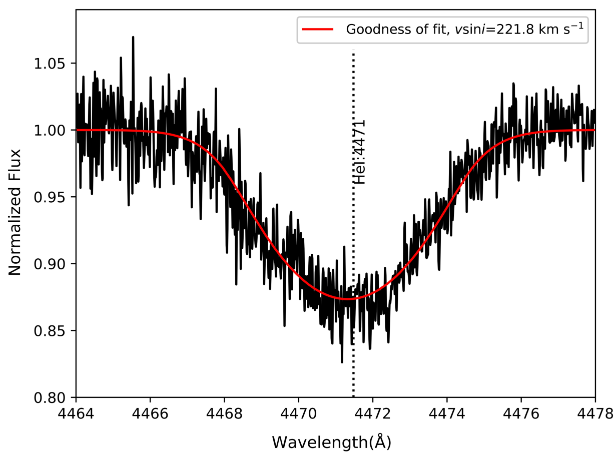

Fig. 13 HRS HeI absorption line of V423 Aur. This line is fitted to estimate the $v\sin i$ of V423 Aur.

the high resolution spectra of Hα were observed for 12 times, 11 times and 4 times.

The spectral reductions were carried out with the IRAF package following the standard procedures: order identification, bias subtraction, flat-field correction, scattered-light subtraction, spectrum extraction, wavelength calibration (based on Th-Ar lamp spectra), and continuum normalization.

To detect the variation of Hα intensity, we compared all other 11 spectra to the spectrum of first observation, see Figure 8. We do the same operation for the spectra of 10th Jan and 11th Jan (Fig. 9, Fig. 10). From Figures 8, 9 and 10, we cannot detect the variation of Hα intensity.

3 RESULTS

V423 Aur was detected to have a companion by Kervella et al. (2019). Halbedel (1986) reported that the V magnitde of V423 Aur is 8.68. A webpage (`https://www.universeguide.com/star/aurigae`) concluded that the star has a $B-V$ Colour Index of 0.09 which means the star's temperature can be calculated at about 9100 K. However, V423 Aur is a variable star, its B and V magnitudes are not credible. We re-certified its spectral type based on HRS. Figure 12 is segment of the HRS of V423 Aur. Its wavelength ranges from 4460 Å to 4490 Å. HeI (λ4471) and MgII (λ4481) lines are within this wavelength range. Figure 12 shows obviously that HeI (λ4471) > MgII (λ4481). By checking the HeI (λ4121) line, it is absent. So based on the criteria of classifying OB stars mentioned by Liu et al. (2019), V423 Aur is determined as a “B7 V” star with temperature about 10 300 K, which is a little different with the result (B8) from Simbad.

The webpage above also show that the brightness of V423 Aur ranges from a magnitude of 8.791 to 8.633 over its variable period. Its variable/pulsating period lasts for 0.2 d. In our photometric observations, we did not find any change in brightness. Using the newly released GAIA data, the distance of this star is estimated to be 1442 pc (Bailer-Jones et al. 2018).

The Hβ and Hα line emissions corrected by a theoretical ATLAS9 model atmosphere with effective temperature of $T_{\rm eff} = 10\,000$ K and $\log g = 4$ cm s^{-2} (Heiter et al. 2002) described by absorption profiles are shown in Figure 11. The Hα/Hβ flux ratio measured from V423 Aur is 5.61±0.19. By comparing the observed Hα/Hβ intensity ratio with the theoretical value at $T_e = 10^4$ K and $n_e = 10^4$ cm^{-3} (Hummer & Storey 1987) and by using the reddening law of Howarth (1983) for $R_V = 3.1$, we can derive the extinction coefficient $E(B-V) = 0.709 \pm 0.036$ for this object, which is consistent with the previously reported values of $E(B-V) = 0.671$ (Kervella et al. 2019) estimated from local interstellar medium. This result indicates that the target is associated with regional nebulae.

By checking other emission and absorption lines of V423 Aur, we found that the HeI absorption line centered on 6678.15 Å was broadened (Fig. 3). The broadened absorption line can be explained by stellar rotation. To estimate the stellar rotation ($v\sin i$), we fitted HeI (λ4471 Å) absorption line, which is from HRS by using a versatile and user-friendly IDL tool (Simón-Díaz & Herrero 2014). The tool is based on a combined Fourier transform and goodness-of-fit methodology for the line-broadening characterization in OB-type stars. Here we did not use HeI (λ6678.15 Å) to do fitting because it is mixed with FeI line at 6678.15 Å (Fig. 3). The fitting result shows that $v\sin i$ is about 221.8 km s^{-1} (Fig. 13), which is consistent with the general rotation velocity of Be star (McNally 1965).

4 DISCUSSION

As described in the previous sections, the medium-resolution spectra of V423 Aur show irregular changes in Hα intensity. However, no changes were detected in the follow-up photometry and HRS of V423 Aur. The photometry and HRS were observed on the same day, about one month after the observation of medium-resolution spectra. So, the changes in intensity may be due to transient phenomena of the star itself. In other words, the transient phenomena was just recorded during MRS observation of V423 Aur.

How can we understand the transient phenomena? The circumstellar disk or gas shell is very common for a Be star (Rivinius et al. 2013; Hoefner et al. 1995). The Hα emission line is from surrounding excited gas. So we explain the irregular Hα variation as follows. The change in the intensity of the Hα emission line is due to the ejection of matter from the gas shell or disk. Random ejection of matter leads to irregularity of Hα lines. The broader blue wings of Hα lines observed by LAMOST (No. 4, No. 5, No. 6 and No. 7 of Fig. 2) mean that the matter was ejected toward us. The ejection process was a short-term event, which was just observed by LAMOST and has been finished when we observed it again with NAGIOT and 2.16m telescope. So we cannot find any intensity changes from photometry and HRS.

5 SUMMARY

On 2017 Dec. 5, in LAMOST Medium-Resolution test observation, a Be star (V423 Aur), which is located in the constellation of Auriga, showing irregular changes in Hα intensity was observed. V423 Aur was observed for seven times by LAMOST. By comparing these seven results, it shows different Hα intensity. About one month later, we observed V423 Aur with NAGIOT and 2.16m telescope High Resolution spectrograph. Based on HRS, the Be star was determined as a B7V type star and associated with regional nebulae. However, there is no change in Hα intensity from HRS of 2.16m telescope. We also did not detect any magnitude variation in photometric results of NAGIOT. So we think the change in the Hα intensity is a transient phenomenon. The variable Hα line may be due to the ejection of matter from gas shell or disk. The ejection process has finished in the follow-up observation about one month later. Since Sep. 2018, LAMOST started the second stage survey program (MRS). More medium resolution spectra of Be stars will be observed. We plan to repeat the observations of V423 Aur and other similar Be stars to check if these LPVs are real.

Acknowledgements This project is supported by the National Key R & D Program of China (2017YFA0402704), and the National Natural Science Foundation of China (Grant Nos. 11733006, 11403061, 11903048, U1631131, 11973060, U1531118, 11403037, 11225316, 11173030, 11303038, Y613991N01 and U1531245), and the Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Key Research Program of Frontier Sciences, CAS (Grant No. QYZDY-SSW-SLH007).

C.-H. Hsia acknowledges the supports from the Science and Technology Development Fund, Macau SAR (file Nos. 119/2017/A3, 061/2017/A2 and 0007/2019/A) and Faculty Research Grants of the Macau University of Science and Technology (No. FRG-19-004-SSI).

Guo Shou Jing Telescope (the Large Sky Area Multi-Object Fiber Spectroscopic Telescope LAMOST) is a National Major Scientific Project built by the Chinese Academy of Sciences. Funding for the project has been provided by the National Development and Reform Commission. LAMOST is operated and managed by the National Astronomical Observatories, Chinese Academy of Sciences.

We acknowledge the support of the staff of the Xinglong 2.16 m and 1.26 m telescopes. This work was partially supported by the Open Project Program of the Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences.

References

Baade, D. 1982, A&A, 105, 65
Bailer-Jones, C. A. L., Rybizki, J., Fouesneau, M., Mantelet, G., & Andrae, R. 2018, AJ, 156, 58
Balona, L. A. 1975, MNRAS, 173, 449
Balona, L. A. 1990, MNRAS, 245, 92
Balona, L. A. 1995, MNRAS, 277, 1547
Balona, L. A., Cuypers, J., & Marang, F. 1992, A&AS, 92, 533
Catelan, M., & Smith, H. A. 2015, Pulsating Stars
Chen, H.-Q., & Huang, L. 1987, ChA&A, 11, 10
Conroy, C., Strader, J., van Dokkum, P., et al. 2018, ApJ, 864, 111
Cuypers, J., Balona, L. A., & Marang, F. 1989, A&AS, 81, 151
Eyer, L., & Mowlavi, N. 2008, Journal of Physics: Conference Series, 118, 012010
Halbedel, E. M. 1986, IBVS, 2919
Heiter, U., Kupka, F., van't Veer-Menneret, C., et al. 2002, A&A, 392, 619
Hoefner, S., Feuchtinger, M. U., & Dorfi, E. A. 1995, A&A, 297, 815
Howarth, I. D. 1983, MNRAS, 203, 301
Hummer, D. G., & Storey, P. J. 1987, MNRAS, 224, 801
Jaschek, M., Slettebak, A., & Jaschek, C. 1981, Be Star Terminology., Be Star Newsletter, 4, 9
Kervella, P., Arenou, F., Mignard, F., & Thévenin, F. 2019, A&A, 623, A72
Liu, Z., Cui, W., Liu, C., et al. 2019, ApJS, 241, 32
Lucy, L. B. 1974, AJ, 79, 745
McNally, D. 1965, Obs, 85, 166
Porter, J. M., & Rivinius, T. 2003, PASP, 115, 1153
Rivinius, T., Carciofi, A. C., & Martayan, C. 2013, A&ARv, 21, 69
Simón-Díaz, S., & Herrero, A. 2014, A&A, 562, A135
Smith, M. A. 2001, ApJ, 562, 998
Struve, O. 1931, ApJ, 73, 94