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DISCOVERY OF IRREGULAR VARIABILITY OF FIVE STARS IN THE VICINITY OF THE YOUNG STELLAR OBJECT V645 CYGNI

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We carried out a search for irregular variable stars in the vicinity of the young massive star V645 Cyg. The search was performed on the basis of a set of CCD frames obtained at the Astronomical Observatory of the Ural Federal University. The data was collected in the course of the 1.5-year photometric monitoring of the young variable star V645 Cyg in filters V and R_c. All frames were obtained with the AZT-3 reflector ($D = 0.45$ m, $F_{\rm Newton} = 2.0$ m) equipped with Alta-U6 CCD camera (Kodak KAF-1001E, 1048×1048, 24-micron chip). The frames contain information on sources within about $40' \times 40'$ fields centered approximately at V645 Cyg. These sources include several suspected young stellar objects (YSOs), e.g. IRAS 21377+4955 and IRAS 21389+5003, which are poorly studied at optical wavelengths.

Search for the YSOs in the V645 Cyg vicinity is necessary to find other young stars which could be born together with this massive star which recently emerged from its cocoon. At present there are no firmly established YSOs in the vicinity of V645 Cyg. This is enigmatic because the current paradigma implies that "massive stars are seldomly (if at all) formed in isolation" (Zinnecker and Yorke 2007).

In this study we considered objects in $15'$ vicinity of V645 Cyg. YSOs are characterized by being brighter in infrared than expected for the main sequence stars. In order to identify YSO candidates in the obtained frames we carried out photometry of a number of selected stars which show infrared colour indices $H - K_s > 0\overset{\rm m}{.}3$ in 2MASS catalog. The area is rich in the sources that are surely more distant than V645 Cyg. In order to avoid them we introduced the following criterion: $K_s < 11^{\rm m}$. One object (2MASS 21385638+5012061) violates this criterion and was included in the list because of its high red colour index $V - R = 1\overset{\rm m}{.}98$ in the NOMAD1 catalogue. We did not introduce any stringent criterion on the infrared colour indices in order to avoid possible elimination of Orion variables of IN type, etc. Some young variable stars of this type have 2MASS colours close to the main sequence stars and have good chances to be associated with the massive young variable V645 Cyg. Another selection criterion was the optical brightness of objects $R < 14^{\rm m}$. The latter criterion is necessary to achieve the photometric accuracy of the order of $0\overset{\rm m}{.}01$ for the frames obtained with exposure times adjusted for the V645 Cyg photometry. The list includes three fainter objects which allowed sufficiently high photometric accuracy.

Table 1. List of target stars and comparison stars. Stellar magnitudes are taken from the NOMAD1 catalogue

Objects				Comparison stars (2MASS)		
#	2MASS	m_V	m_R	C_1	C_2	C_3
1	21395825+5014209 (V645 Cyg)	∼13	∼12	21401743+5013545	21395248+5015526	21393905+5012016
2	21392977+5009286 (IRAS 21377+4955)	14.31	12.36	21393905+5012016	21394305+5010491	21393643+5008273
3	21404646+5016489 (IRAS 21389+5003)	12.61	10.72	21403765+5016258	21405102+5017094	21394758+5017008
4	21385638+5012061	15.53	13.55	21391128+5011193	21385214+5011225	21384244+5012131
5	21390639+5004544	13.01	11.15	21384996+5007368	21391834+5003325	21390691+5003206
6	21393188+5006596	16.00	14.75	21394160+5009340	21393870+5006470	21391935+5008547
7	21402043+5020007	15.04	13.84	21403180+5019153	21403029+5017160	21401798+5022063
8	21403143+5021300	15.73	14.51	21401858+5022036	21403180+5019153	21405252+5022075
9	21403966+5010088	16.04	14.29	21404627+5010344	21404549+5007301	21403186+5009173
10	21404091+5013584	13.24	11.33	21410979+5012361	21403765+5016258	21404271+5010334
11	21410408+5010083	12.90	11.60	21410979+5012361	21410818+5008461	21404271+5010334
12	21410428+5014152	14.41	12.88	21411409+5016534	21405102+5017094	21410979+5012361
13	21410943+5018008	11.38	10.51	21411409+5016534	21410645+5017483	21412779+5018164
14	21411121+5010380	13.91	12.83	21410818+5008461	21410979+5012361	21412626+5009326

In total, 14 stars were selected for analysis. We included V645 Cyg in the analysis because it satisfies our selection criteria. Except for V645 Cyg the list includes 2 other members of the IRAS point source catalogue, the rest of the target stars have considerable red colour indices.

One of the IRAS sources (IRAS 21377+4955, 2MASS 21392977+5009286) was previously identified as a carbon star (Alksnis and Alksne, 1988) and suspected to be variable (NSV 25721). The list of IRAS sources and other target stars is given in Table 1 in order of increasing right ascension. Designations of the stars are given according to the 2MASS catalog. For each target star we selected three stars of comparison in its near vicinity ($r < 5'$), see Table 1.

The reduction of the CCD frames was carried out using *Muniwin* software (`http://c-munipack.sourceforge.net`). After that we calculated values of the night-average differences of the brightness for each star with respect to the three comparison stars. Before averaging all the values were reduced to a particular comparison star (C1 stars in Table 1).

In order to determine the degree of brightness variability for the investigated stars we used a simple criterion similar to the Stetson index (Stetson, 1996). Namely, we considered ratio of the root mean square (rms) brightness differences for the target stars to rms brightness differences for the comparison stars calculated for the whole period of observations. In this case the dispersion of the brightness differences for the stars of comparison characterizes accuracy of the brightness measurements for the target stars.

As a criterion for the existence of variability we adopted 3σ criterion. This means that the star was considered to be variable if the rms difference of the brightness of a target star in both filters exceeds the corresponding rms difference for the comparison stars more than three times. Tables 2 and 3 contain values of the rms brightness difference for the target stars ($\sigma_{\rm var}$) and the comparison stars ($\sigma_{\rm comp}$), correspondingly. It is seen that $\sigma_{\rm comp}$ in filter R_c is of the order of $0\overset{\rm m}{.}01$ and less. The accuracy of measurements in filter V in a few cases is about twice worse because the target stars are fainter in this passband.

Analysis of the data from Tables 2 and 3 shows that the 3σ criterion of variability is satisfied for 6 target stars including V645 Cyg. The other target stars with one exception did

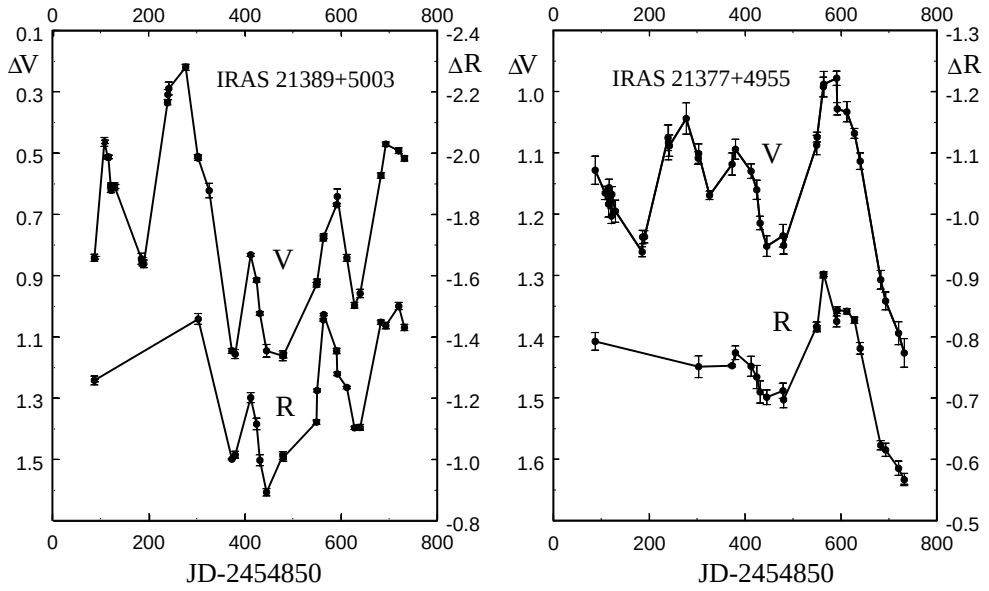

Figure 1. The light curves of the IRAS point sources. The bars correspond to the rms scatter of brightness during one night.

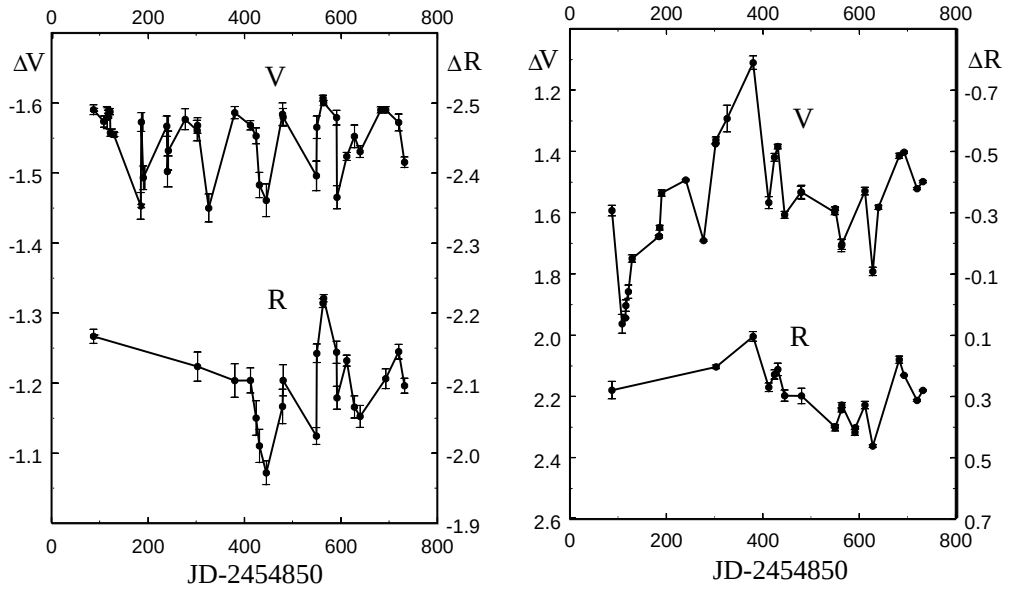

Figure 2. The light curves of 2MASS 21410943+5018008 (#13, left) and 2MASS 21403966+5010088 (#9, right). The bars correspond to the rms scatter of brightness during one night.

Table 2. Target stars with detected variability

				V		R		V	R
#	2MASS	IRAS	NSV	$\sigma_{\rm var}$	$\sigma_{\rm comp}$	$\sigma_{\rm var}$	$\sigma_{\rm comp}$	$\sigma_{\rm var}/\sigma_{\rm comp}$	$\sigma_{\rm var}/\sigma_{\rm comp}$
1	21395825+5014209	(V645 Cyg)		0.097	0.011	0.077	0.009	8.8	8.6
2	21392977+5009286	21377+4955	25721	0.104	0.009	0.093	0.006	11.2	16.0
3	21404646+5016489	21389+5003		0.265	0.015	0.190	0.008	17.5	23.8
5	21390639+5004544			0.217	0.013	0.237	0.010	16.5	23.7
9	21403966+5010088			0.187	0.007	0.090	0.006	25.9	15.6
13	21410943+5018008			0.047	0.008	0.063	0.004	5.8	15.2

Table 3. Target stars without detected variability

		V		R		V	R
#	2MASS	$\sigma_{\rm var}$	$\sigma_{\rm comp}$	$\sigma_{\rm var}$	$\sigma_{\rm comp}$	$\sigma_{\rm var}/\sigma_{\rm comp}$	$\sigma_{\rm var}/\sigma_{\rm comp}$
4	21385638+5012061	0.042	0.022	0.013	0.010	1.9	1.3
6	21393188+5006596	0.028	0.017	0.023	0.011	1.7	2.1
7	21402043+5020007	0.039	0.013	0.056	0.011	3.0	5.1
8	21403143+5021300	0.028	0.010	0.014	0.008	2.7	1.8
10	21404091+5013584	0.008	0.009	0.015	0.006	0.9	2.4
11	21410408+5010083	0.016	0.010	0.013	0.007	1.5	1.9
12	21410428+5014152	0.018	0.011	0.016	0.008	1.6	2.0
14	21411121+5010380	0.016	0.012	0.014	0.009	1.3	1.6

not show significant variability of brightness. This exception is 2MASS 21402043+5020007 (#7) for which the 3σ criterion is satisfied only in filter R_c. We consider the detection of variability of this star uncertain.

We analysed the changes of brightness of newly found variable stars and V645 Cyg during particular nights. In several cases observations during one night lasted for up to 6 hours. In most cases variability had a character of monotonic brightness changes. In a few cases one brightness extremum was registered during a single night.

We examined the brightness data of the six variable stars for possible periodicity. For this purpose we implemented the Lafler-Kinman method realized in the package winefk3 written by Goranskij V.P. (the program with comments in English can be downloaded from http://variablestars.ru/FILES/winefk.rar). Brightness changes for all newly found variable stars and V645 Cyg were found to be non-periodic.

We found that the bright infrared point sources IRAS 21377+4955 and IRAS 21389+5003 show brightness variability of irregular type with amplitudes up to $0\overset{\rm m}{.}8$. For IRAS 21389+5003 the variability of brightness is registered for the first time. For another bright infrared source IRAS 21377+4955 only photographic estimates of the optical brightness were reported (Alksnis and Alksne, 1988). In this study we present results of much more accurate CCD measurements of the brightness in filters V and R_c for a period of 1.5 years.

Far infrared colour indices of IRAS 21377+4955 and IRAS 21389+5003 are characteristic of the YSOs. Brightness of these stars as point sources of the WISE (Wide-Field Infrared Survey Explorer) survey increases with wavelength (the longest wavelength of the survey is 22 microns). However, combination of the colour indices and irregular type of variability cannot be used as a strict proof of the YSO nature of the sources. For example, IRAS 21377+4955 was identified as a carbon star on the basis of its photographic spectrum in the red part of the optical range (Alksnis and Alksne, 1988). However, no other carbon stars were reported in our field though it was inspected by Alksnis and Alksne (1988). Additional spectroscopy is necessary to establish the nature of the sources.

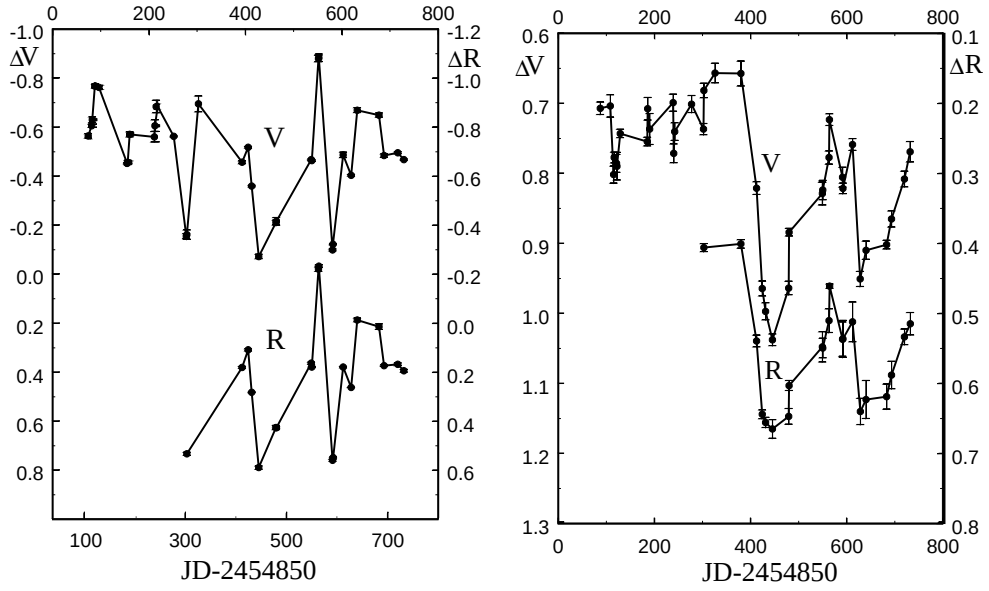

Figure 3. The light curves of 2MASS 21390639+5004544 (#5, left) and V645 Cyg (right). The bars correspond to the rms scatter of brightness during one night.

In this study we have registered the irregular type of optical variability of the mentioned IRAS sources by means of CCD photometery.

Brightness changes of similar character were detected for 3 other target stars and V645 Cyg. Variability of brightness had considerable amplitudes $\Delta m = |m_{max} - m_{min}|$:

- $\Delta m \sim 1\overset{\text{m}}{.}0$ – 2MASS 21390639+5004544 (#5),
- $\Delta m \sim 0\overset{\text{m}}{.}9$ – 2MASS 21403966+5010088 (#9),
- $\Delta m \sim 0\overset{\text{m}}{.}3$ – 2MASS 21410943+5018008 (#13),
- $\Delta m \sim 0\overset{\text{m}}{.}4$ – 2MASS 21395825+5014209 (V645 Cyg).

The light curves of the 5 target stars and V645 Cyg with variability detected in filters V and R_c are shown in Figures 1-3. Measured values of the brightness changes for the 5 newly found variable stars and V645 Cyg are presented in Table 4 (online only).

Thus, in the course of the current study we have found 4 new variable stars in 15′ vicinity of the young massive variable star V645 Cyg and confirmed variability of one suspected variable. All of these stars show variability of irregular type and have considerable infrared colour indices characteristic of the young stellar objects. Amplitudes of variability of the newly detected variables are similar to those of some Orion variables of IN type. According to the General Catalogue of Variable Stars (GCVS) the amplitudes of the IN type variables have values in the range from 0.5 to 1-2 magnitudes on the time scale of several tens to hundreds of days. The nature of these sources and their association with V645 Cyg will be discussed in a forthcoming paper.

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