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Identification of V735 Sgr as an Active Herbig Ae/Be Object*

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ABSTRACT

V735 Sgr was known as an enigmatic star with rapid brightness variations. Long-term OGLE photometry, brightness measurements in infrared bands, and recently obtained moderate resolution spectrum from the 6.5-m Magellan telescope show that this star is an active young stellar object of Herbig Ae/Be type.

Key words: *Stars: variables: T Tauri, Herbig Ae/Be – Stars: individual: V735 Sgr*

1. Motivation

V735 Sgr was found to be a variable object by Luyten (1937) who analyzed photographic plates obtained in the course of the Bruce Proper Motion Survey. Due to relatively large variations in blue photographic brightness (14.2–15.5 mag) the object was supposed to be an eruptive cataclysmic variable of Z Cam type (2006 archival version of the Downes *et al.* 2001 catalog), however no evident outburst or standstill had been observed. A mistake made in the position of the variable source (Vogt and Bateson 1982) complicated the identification of the true nature of the star.

*Based on observations obtained with the 1.3-m Warsaw telescope and the 6.5-m Magellan Baade telescope at the Las Campanas Observatory of the Carnegie Institution for Science under the CNTAC program CN2018A-102.

2. Photometric Observations

V735 Sgr is located in the area monitored by the Optical Gravitational Lensing Experiment (OGLE) since the beginning of the third phase of the survey in 2001. The survey monitors the Galactic bulge, Galactic disk, and Magellanic Clouds from Las Campanas Observatory, Chile. Since March 2010 the project is in its fourth phase. The OGLE-IV camera consists of 32 CCDs with a total field of view of about 1.4 deg^2. Currently, OGLE measures brightness in the Johnson *V* and Cousins *I* passbands of over two billion stars of the Milky Way and the Magellanic System, covering a total area of about 3600 deg^2. Technical details on OGLE-IV, including data reduction, can be found in Udalski *et al.* (2015).

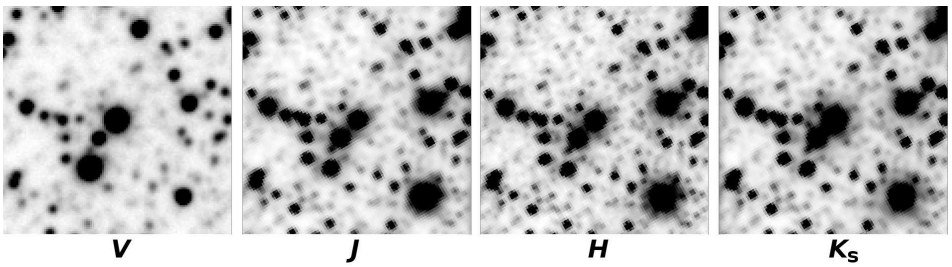

Fig. 1. Finding charts in *V, J, H,* and K_S bands, each $30''$ on a size, centered on V735 Sgr. North is up and East is to the left. The comparison constant star used to demonstrate the infrared excess in V735 Sgr (see Fig. 4) is located $7''.24$ roughly South-East of the variable. The *V*-band chart was obtained with the 1.3-m OGLE telescope, while the JHK_S-band charts were obtained in the course of the VVV survey on the 4.1-m VISTA telescope.

OGLE observations confirm the source identification of V735 Sgr given by Yoshida *et al.* (2002). The variable is located at the equatorial coordinates $(\alpha,\delta)_{2000.0} = (17^{\mathrm{h}}59^{\mathrm{m}}51^{\mathrm{s}}.78, -29^{\circ}33'55''.9)$ or at the Galactic coordinates $(l,b) = (+1^{\circ}.0372,\ -2^{\circ}.9953)$. We identify it with OGLE detection BLG505.01.92650. Fig. 1 shows finding charts in $VJHK_S$ bands centered on the variable. The *V*-band chart was cropped from the OGLE-IV reference frame for field BLG505.01. JHK_S-band charts come from images taken by the VISTA Variables in the Vía Lactea (VVV) ESO public survey (Minniti *et al.* 2010). In the upper panel of Fig. 2, we present full *I*-band light curve obtained since the beginning of OGLE-III (2001) until the middle of the ninth bulge season of OGLE-IV (2018). The rapid irregular behavior of V735 Sgr is well seen in the middle and lower panels of Fig. 2. The full *I*-band light curve consists of 1304 data points collected during OGLE-III and 15 529 data points collected during OGLE-IV by the end of June 2018. Light curve in the *V*-band, not shown here, consists of seven measurements from OGLE-III and 182 measurements from OGLE-IV. In the whole observed period 2001–2018, the *I*-band brightness varied between 12.18 mag and 15.54 mag, while *V*-band brightness ranged between 13.11 mag and 16.10 mag. This means that the full *I*-band and *V*-band amplitudes of V735 Sgr were 3.36 mag and 2.99 mag, respectively. Measured $V-I$ color index fluctuated between $+0.58$ mag and $+1.06$ mag. Mean *V*

and *I*-band magnitudes and mean $V-I$ color during the OGLE-IV phase are the following: 14.74 mag, 13.86 mag, +0.88 mag, respectively. The most rapid brightness change was recorded on the night from July 31 to August 1, 2015 when the star faded by 0.95 mag in 7.32 h (see lower panel of Fig. 2). We report no periodic signal in the power spectrum of the variable.

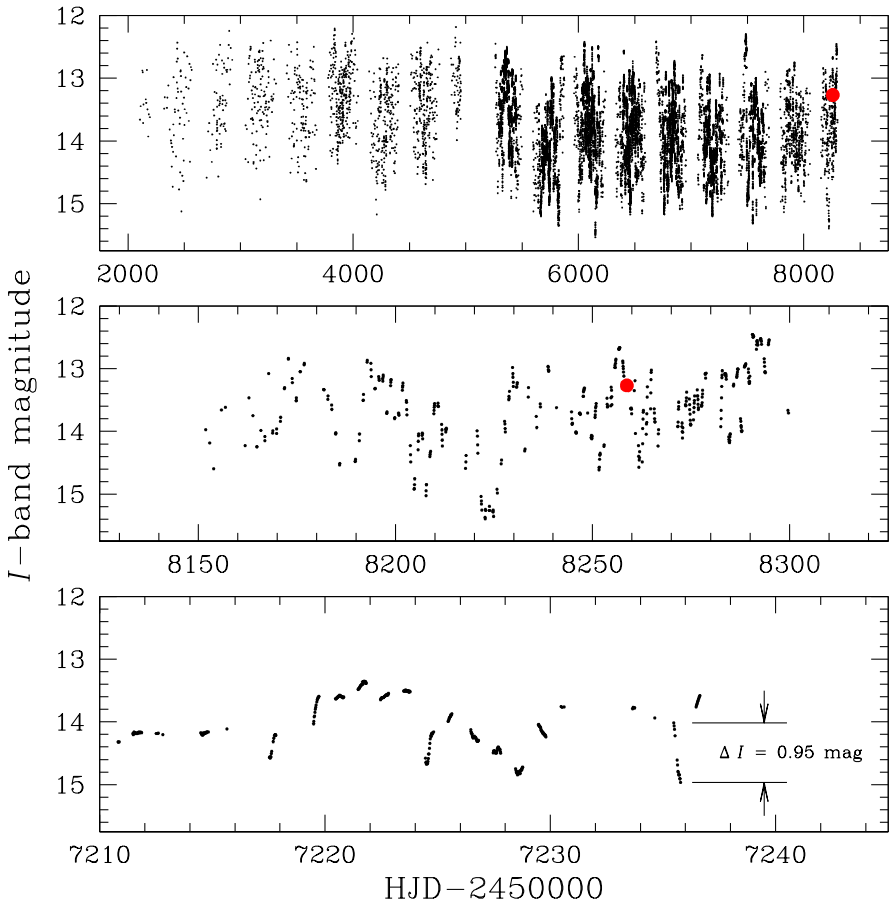

Fig. 2. OGLE *I*-band light curve of variable V735 Sgr covering years 2001–2018 (*upper panel*), with a zoom on the data collected in the first half of 2018 (*middle panel*) and on a part with the most rapid brightness change that took place in 2015 (*lower panel*). The big red dot marks the moment of the executed spectrum.

Based on the obtained time-series photometry we conclude that V735 Sgr exhibits permanent, rapid, irregular variations. No outbursts or standstills observed over 18 years clearly indicate that this object cannot be a dwarf nova of U Gem or Z Cam type. Irregular fluctuations with the amplitude of about 3 mag are too large for a novalike system. The recorded photometric behavior is characteristic for a subgroup of young stellar objects of UX Ori type. This is additionally confirmed with the observed color fluctuations and the presence of infrared excess.

The changing location of the variable in the I *vs.* $V-I$ diagram is presented in Fig. 3. The trend drawn by the star has a crescent shape, as it is observed in some young stellar objects (*e.g.*, BF Ori, Evans *et al.* 1989, UX Ori, Grinin *et al.* 1994).

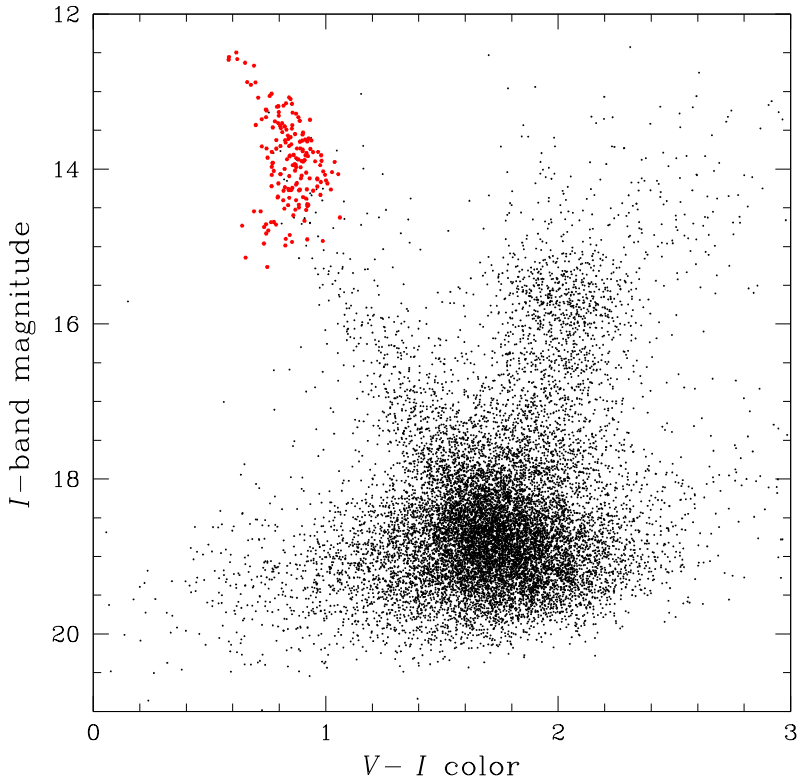

Fig. 3. Color–magnitude diagram with marked positions of the variable star V735 Sgr over years 2001–2018. The star draws a crescent shape characteristic for young stellar objects. The background is formed of stars located in the OGLE field BLG505.01 containing the variable.

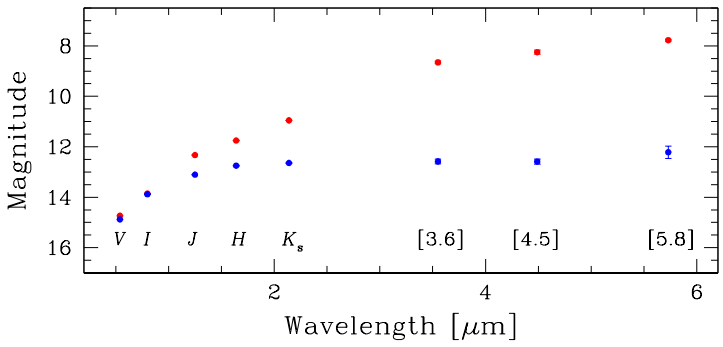

Fig. 4. Brightness of V735 Sgr (in red) *vs.* neighbor constant star BLG505.01.92647 (in blue) in the optical and infrared regimes. The used V and I-band magnitudes are average values. Note a clear infrared excess in V735 Sgr confirming its pre-main sequence nature.

The so called blueing effect is well visible – with the decreasing brightness the star gets redder but near minimum it becomes blue again mainly due to scattering light by dust.

In Fig. 4, we compare brightness from optical to mid-infrared regime of V735 Sgr and a neighbor constant star BLG505.01.92647 located 7.″24 South-East of the variable. Near-infrared JHK_s magnitudes were taken from the VVV survey, while mid-infrared data come from Spitzer/GLIMPSE 3D catalog[†]. The comparison star has very similar magnitudes in the optical bands (that is also similar color) to average values for the variable: $V = 14.88$ mag and $I = 13.88$ mag ($V - I = +1.00$ mag). V735 Sgr clearly shows a strong excess in infrared, as it is observed in pre-main sequence stars. However, a definitive classification of the variable star required spectroscopic observations.

3. Spectroscopic Data and Results

Two subsequent spectra of V735 Sgr were obtained with the 6.5-m Magellan Baade telescope at Las Campanas Observatory in dark time on the night May 19/20, 2018. The night was not photometric due to the presence of some thin cirrus clouds, but with stable seeing of about 0.″6. We used the Magellan Echellette (MagE) spectrograph with a 1.″0 slit giving an average spectral resolution of $R \approx 4100$ over wavelength range between 3200 Å and 10 000 Å. After two 300-s science exposures a ThAr lamp was exposed for 15 s. Initial reductions, that is flat-field correction, rectification of spectral orders, wavelength calibration and combination of the two single exposures with rejection of cosmic rays, were performed with the CARPY software (Kelson 2003) on the site. Using utilities provided in the IRAF package[‡], we normalized and also calibrated for flux each order separately. For the calibration we used a spectrophotometric standard star, white dwarf LTT7987 exposed in the dawn of the night (2×200 s with the same instrument setup). Then, all orders were combined to form one normalized spectrum and the other one in units of flux. Due to low intensity at the blue end and the presence of many atmospheric features in the near-infrared part of the spectrum, we rely only on orders from 8 to 17, covering wavelength range 3500–8100 Å.

Mean moment of the spectroscopic observation (HJD=2458258.71054) is marked on the *I*-band light curve in Fig. 2. At that time the variable had $I = 13.27$ mag and was fading down from a local maximum of $I = 12.66$ mag for almost two days. Unfortunately, there is no OGLE observation in the *V*-band from that night.

In Fig. 5, we present the flux-calibrated spectrum of V735 Sgr covering the whole optical regime. The dominant stellar feature is the hydrogen Balmer series

[†]*https://irsa.ipac.caltech.edu/Missions/spitzer.html*

[‡]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

with Hα in strong emission. Such a spectrum is typical for a young stellar object of spectral type A. Thus, V735 Sgr is an intermediate-mass object of Herbig Ae/Be type. The star seems to be mildly reddened, likely due to its relative proximity (855 ± 44 pc based on Gaia Data Release 2, Gaia Collaboration *et al.* 2018) and location in the direction of Baade's Window. The most prominent lines are marked in the normalized spectrum in Fig. 6. Beside Hα also [OI] and [SII] lines are in emission. The spectrum reveals the presence of HeI and MgII lines being indicators of early type A of the underlying star. There are absorption lines of singly-ionized metals such as CaI and FeI and the multiplet FeII (42) containing relatively strong lines at 4924Å, 5018Å, and 5169Å. All of these features are specific for young stellar objects.

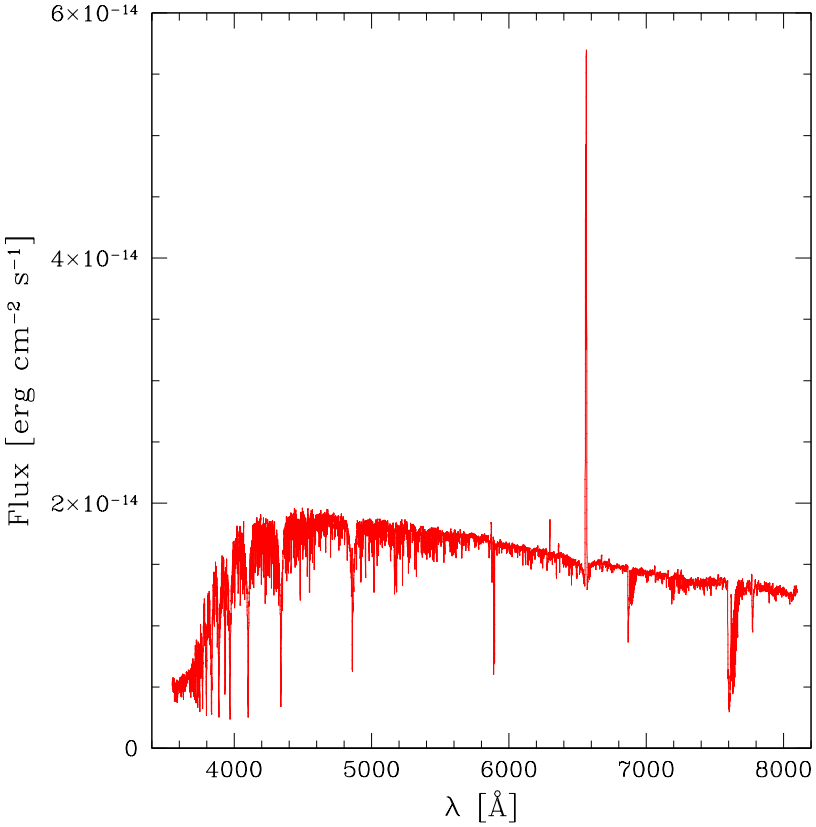

Fig. 5. Flux-calibrated spectrum of V735 Sgr. Note the presence of the dominant hydrogen Balmer series with a strong emission in Hα line characteristic for young stellar objects of spectral type A. The spectrum is not corrected for atmospheric absorption features.

In Fig. 7, we show four lines with asymmetric profiles: Hα, Hβ, HeI 5876, and HeI 6678. The Hα profile has two peaks with the secondary peak located blueward of the primary one and reaching 87% of its intensity. Such a two-component profile stems from the presence of a circumstellar accretion disk observed at large incli-

nation angle (almost edge on). According to the work by Grinin and Rostopchina (1996) the double-peaked Hα line is characteristic for active Herbig Ae/Be stars, that is intermediate-mass stars showing rapid, large-amplitude, irregular brightness variations caused by dust clouds orbiting the central star in the disk. Similar Hα profile is observed in known UX Ori-type variables such as HK Ori, VV Ser, WW Vul (Reipurth *et al.* 1996). The absorption line of Hβ in V735 Sgr has a blueshifted central emission. The two lines of HeI have the inverse P Cygni profile indicating mass inflows onto the central star.

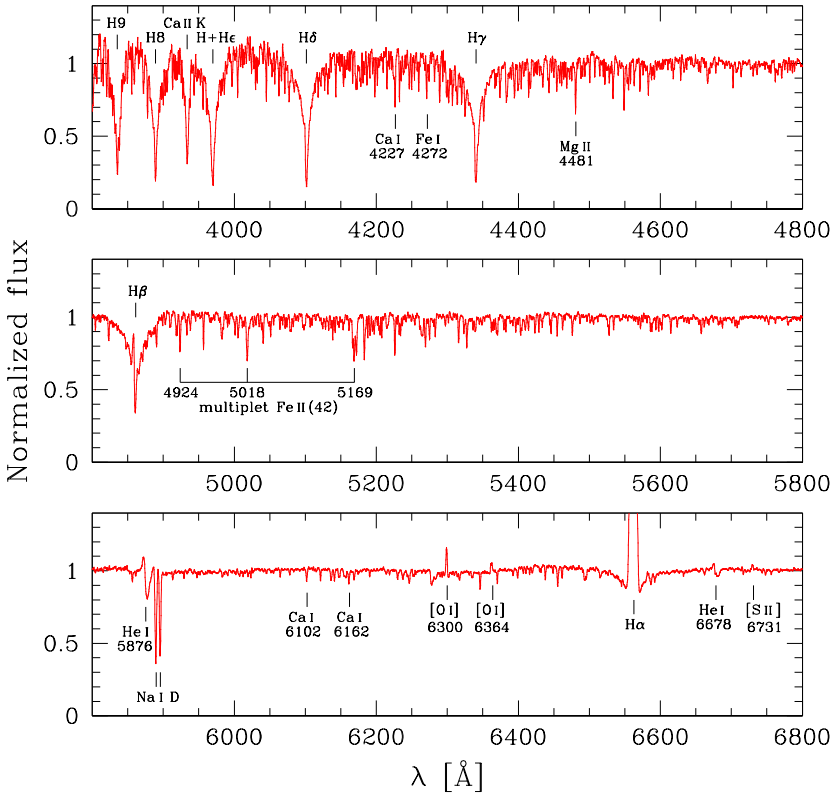

Fig. 6. Normalized spectrum of V735 Sgr in the range 3800–6800 Å. Some lines observed in young stellar objects of spectral type A are marked. Note the presence of [OI] and [SII] lines in emission.

Determination of effective temperature in young stellar objects is complicated. Application of the standard spectral classification from normal stars has to be treated with caution (Gray and Corbally 2009). The measured equivalent widths of W(CaII K) = 5.2 Å, W(CaII H + Hε) = 12.5 Å, W(Hδ) = 13.7 Å and the presence of emission features indicate type A3e for V735 Sgr. However, the real spectral type of the underlying star may be slightly different, since the CaII K line is partially formed in the circumstellar disk and thus it is variable in time. Helium lines and high order Balmer lines can also be affected by disk absorption. Precise temperature determi-

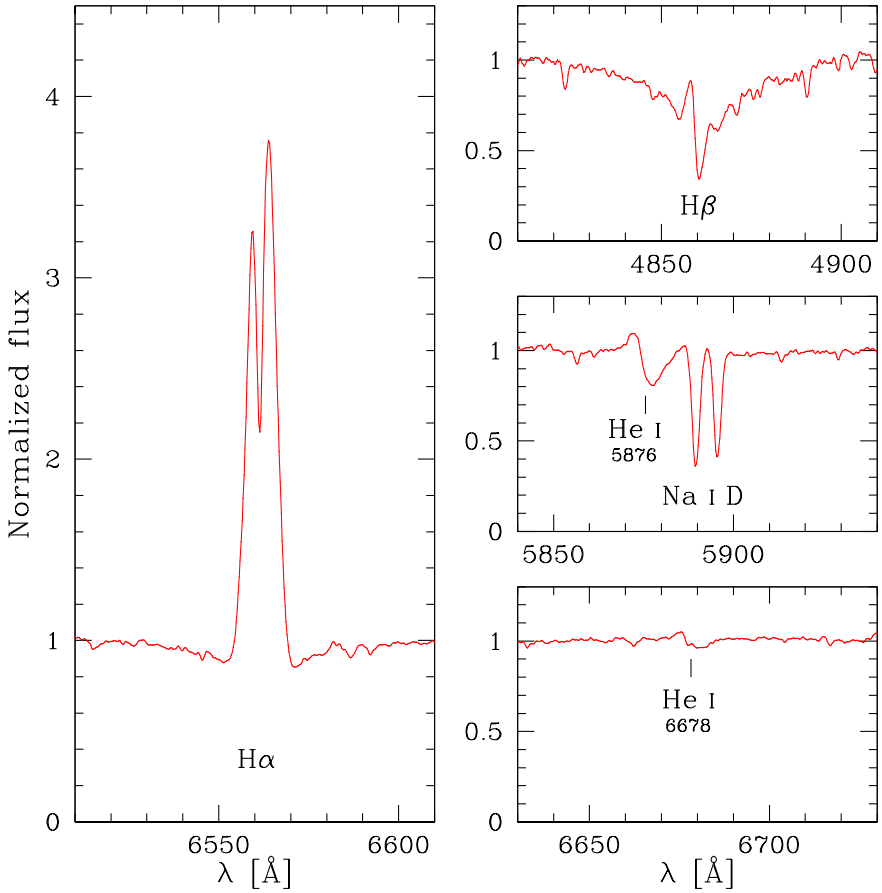

Fig. 7. Profiles of four dramatically distorted lines, Hα, Hβ, HeI 5876, and HeI 6678, due to disk accretion in V735 Sgr. The wavelength and intensity are to scale in *all panels*.

nation requires a dedicated spectral variability campaign that would help to identify constant photospheric features (usually singly-ionized metals) and to compare them with standards as proposed by Gray and Corbally (1998) or Mora *et al.* (2001), for instance.

4. Conclusion

Based on long-term OGLE photometry, brightness measurements in infrared bands, and a moderate-resolution optical spectrum we showed that, so far mysterious, rapidly varying star V735 Sgr is an active young stellar object of Herbig Ae/Be type. This classification is confirmed by irregular 3-mag variations (of UX Ori type), the early spectral type of A3e and a significant infrared excess, though the star does not seem to be associated with a diffuse nebula and the absorption line LiI 6707 is absent in the spectrum. The OGLE light curves, flux-calibrated and normalized spectra of V735 Sgr are available at

ftp://ftp.astrouw.edu.pl/ogle/ogle4/V735Sgr/

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