Optical spectra of five IR sources in star-forming regions.

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Introduction:

During several last years we are carrying out the searches of new sources of HH-flows and other young stellar objects, with the 1-m Schmidt telescope of the Byurakan Observatory (BNBIS-survey). We found that quite a number of IR sources were visible in optics; thus, we decided to perform their optical spectroscopy to find, what classes of stars they represent. Especially interesting were the data, obtained for star-forming regions Mon R1 and Mon R2, which partly were already published. Here we present the preliminary results for the five very unusual infrared sources.

Observations:

Observations were carried out in 2022-3 and 2025 in the prime focus of the 6 m telescope of Special Astrophysical Observatory (SAO) of the Russian Academy of Sciences with the SCORPIO-2 (Spectral Camera with Optical Reducer for Photometric and Interferometric Observations) multi-mode focal reducer in the mode of long-slit spectroscopy.

Results and discussion:

Each object is discussed separately below.

V963 Mon (IRAS 06068-0643) is a recently discovered eruptive young star (Wils et al., 2009) in the southern part of the Mon R2 star-forming. It varied between magnitude 15 and 20 over the several years and sometimes exhibited deep fades reminiscent of UX Ori-type objects (Fig.1). Its very red spectrum contained emission lines, typical for pre-main-sequence (PMS) objects. In the course of our studies of this region we found the helical jet HH 1234, driven by V963 Mon, and studied the stellar spectrum in more detail (Movsessian et al., 2025). We confirmed its PMS nature and noted the unusual broadness of forbidden lines in its spectrum. Results of the further studies of this star are presented here.

It can be seen from the light curve that in 2005-2009 the maximal brightness of the star was near V=14.5-15.0, with short-time (probably with duration smaller than 100 days) fades up to V=18.5-19. Then in 2010 the brightness of the star started to decline, lowering to V=19 and even more in 2015-2016; meanwhile the short-time drops still were taking place. In 2018-2020 its mean level of brightness was still very low (g=19.5--20.5), then in 2021 it started to rise, reaching g=17.5-18, but then probably lowered again. In 2023-2024 the star was slowly rising to g=18-18.5. Short-duration dips were present for all time.

During our long-slit spectral observations of V963 Mon in 2022 and 2025 the star had in 18.12.2022 the brightness r=19.1-19.2, and in 21.01.2025 became brighter in 2.3 mag., which can be seen also from light curve in r from ZTF archive (Fig. 1). Thus, our spectra correspond to the two states of V963 Mon. We noted that its rich emission spectrum of permitted lines, as well as Hα with strong P Cyg-type profile, keep its intensity during the light variations (their EW changes very little); however, the forbidden lines in maximum have low intensity and their multi-component structure is more pronounced (Fig. 2). Especially well it is seen in [S II] red doublet. In fact, the four components of these lines are very similar to the structure, observed by Caratti o Garatti et al. (2013) in PV Cep for infrared [Fe II] lines. Their radial velocities are -356 and +85 km/s (HVC) and -185 and – 136 km/s (LVC); probably, we see here both stellar jet and disk wind. The difference in line profiles between λ6716 and λ6730 can be explained by different physical parameters in these components. The deep UX Ori-like fades can be created by dusty disk wind, even if the disk plane is strongly inclined to line of sight. The bolometric luminosity was estimated by us before as >11 L(sun).

Further observations and analysis probably should give us answer to the following questions:

Is V963 Mon an EX Ori type object?
Is V963 Mon in the same time also an UX Ori type object?
Have we found another object like PV Cep, which can be called a "superexor"?

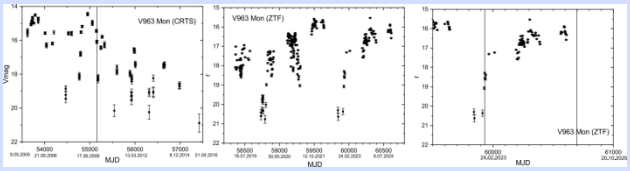

Fig.1 The light curves of V963 Mon. Vertical lines denote dates when spectra were obtained.

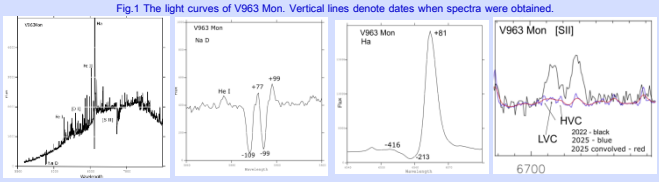

Fig.2 The spectrum of V963 Mon. Profiles of Na D, Hα and [SII] lines are shown separately.

HH83 IRS (IRAS 05311−0631) is a source of HH 83 bipolar HH-flow. It is not seen directly in optical range, though illuminates a reflection nebula. Our detailed observations of this system with Fabri-Perot scanning interferometer revealed a P Cyg type profile of reflected Hα line in the spectrum of the nebula (Movsessian et al., 2021a). To get more information for the exciting star we obtained a long-slit spectrum across the nebula. The spectrum of southern lobe, least contaminated with HH emission, is shown in Fig.3. The prominent flat-bottom P Cyg type profile of Hα is confirmed; also wide and strongly blue-shifted absorptions of Na I are well seen. No stellar absorptions, including Li I, were detected; however, several emission lines of Fe II undoubtedly are present, λ6517 being most strong. For the forbidden lines it is not possible to reliably distinguish the stellar and jet components.

We came to conclusion, that the existence of the typical T Tau-type emissions does not allow to definitely classify the HH 83 IRS star as a FU Ori-type object, notwithstanding many similarities. It is possibly a very active T Tau star like AS 353A.

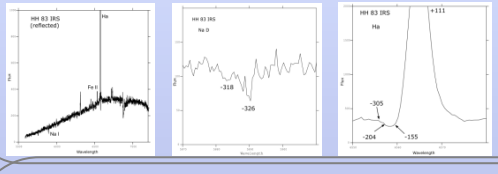

Fig. 3. The spectrum of HH 83 IRS. Profiles of Na D and Hα lines are shown separately.

IRAS 06297+1021 W This object is located in the core of Mon R1 and can be the probable source of HH and H2 outflow (Movsessian et al., 2021b; Magakian et al., 2022). It is visible in optical range, and our first spectral observations revealed the P Cyg-type Hα with wide absorption component. Actually, this star was already suspected to be a FU Ori-type object according to the data of IR-spectroscopy (Connelley & Greene, 2010,2014). However, these authors mentioned significant amount of emission lines in IR range and abandoned such classification. Its bolometric luminosity was estimated by us before as >20 L(sun).

Our new high-resolution optical spectrum of this star, besides of wide absorptions in Na I D lines and Hα P Cyg profile with flat bottom (no stellar absorption were detected), shows the presence of several Fe II and Fe I emissions (including the fluorescent λ 6137 and 6594). Besides, very wide (900-1000 km/s) and multi-component (up to 6) forbidden emissions of [SII], [O I], [Fe II] and [N II] also are present (Fig.4). In fact, their structure is similar to those found for PV Cep (Caratti o Garatti et al., 2013) and V963 Mon (see above). Thus, IRAS 06297+1021 W on the one hand, has significant similarities with FU Ori-type objects, and, on the other hand, definitely resembles V963 Mon and HH83 IRS. Can such stars belong to the same class between FUors and EXors?

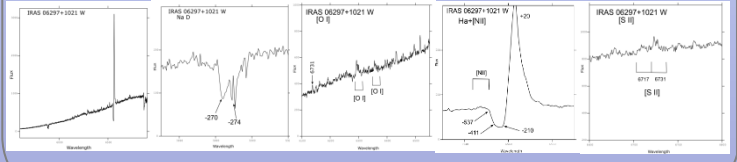

Fig. 4. The spectrum of IRAS 06297+1021 W: general view and line profiles

GM 1-39 (2MASS J05375222+3200439) is a little studied star with a bipolar cometary nebula near a compact star-forming group NGC 1985 (AFGL 5157). Its morphology is well seen in PanSTARRS survey image (Fig.5a). It was also noted in ZTF survey as ZTF18aablqni. Its light curve (Fig.5b) shows frequent and short UX Ori-type drops with amplitude up to 1 mag. The spectral type of the star was estimated as G2.

We obtained the spectrum of GM 1-39 star at 4 and 5 March 2025. The high-resolution spectrum, shown in Fig.5c, confirms spectral type as early G; narrow sharp lines correspond to giant or supergiant class, its bolometric luminosity, estimated in one of te previous studies, is about 10 L(sun). There are no emission lines, except the Hα with strong P Cyg-type profile. Heliocentric radial velocity of NaD lines is +5 km/s; the absorption component of Hα has velocity about -115 km/s. The clearly visible Li I absorption is, perhaps, split in two components. One can conclude that this object definitely is an YSO and has some similarities with FU Ori-like stars after outburst, in the same time demonstrating UX Ori-type activity. Of course, all this should be confirmed by further observations.

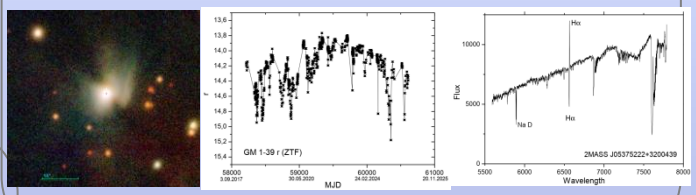

Fig. 5. a) GM1-39 in PanSTARRS color image; b) light curve of GM 1-39 in ZTF survey; c) the spectrum of the central star

CPM 19 This famous bright IR source (IRAS 05373+2349) is located in the center of compact star-forming cluster (Khanzadyan et al., 2011) with many H2 outflows. Nikogossian et al. (2009) found that this object in some period is also visible in optical range, demonstrating, however, variations of many magnitudes. Persi & Tapia (2019), analyzing these variations, suggested that the star 2MASS J05402422+2350546, which corresponds to CPM 19, is an eclipsing system of a Class I protostar and visible star of B spectral type.

We obtained the long-slit spectrum of this very faint (r = 19-20) star at 15.03.2023. As can be seen from the Fig.6, on the very red and faint continuum a powerful Hα emission is prominent. No other emission or absorption features can be detected (the traces of [S II] lines are probably from nearby HH objects). The Hα emission is rather wide (FWHM about 8 A), strong (EW about 63 A), and its heliocentric radial velocity is +4 km/sec, i.e. within measurement errors limit. One can conclude only, that the nature of the star, associated with IRAS 05373+2349, remains unclear.

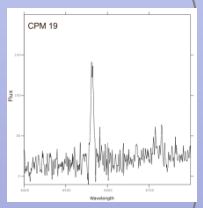

Fig. 6. CPM 19 spectrum near Hα

Conclusion:

The observational results, presented here, confirm our assumption that among the optically observable IR-sources in dark clouds (i.e. Class I objects) the amount of eruptive variables with unusual parameters should be significant. In fact, we found four stars with outflowing activity; three of them have strong resemblance with FU Ori-like objects, having in the same time definite differences with them. The existence of very wide and multi-component profiles of forbidden lines in their spectra especially should be noted.

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