Communications of BAO, Vol. 70, Issue 1, 2023, pp. 49-53

Spectroscopy of new Herbig-Haro objects discovered in frames of BNBIS

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Abstract

We present long-slit spectroscopy of some new Herbig-Haro objects and outflow systems discovered in the frames of Byurakan Narrow Band Imaging Survey (BNBIS) performed on 1 m Schmidt telescope of Byurakan Observatory. Spectroscopic observations were carried out with 6 m telescope (Russia) using SCORPIO2 spectral camera. All selected objects are associated with deeply embedded infrared sources in the molecular clouds. Long-slit spectroscopy allows to obtain position velocity diagrams of the emission structures like Herbig-Haro objects. Velocity fields of the outflows from IRAS 06277+1016 infrared source in Mon R1, from V963 Mon and 2MASS 06084223-0657385 in Mon R2 as well as from IRAS 06212-1049 are presented. Our spectroscopic data revealed bipolar outflow nature of the outflows associated with 2MASS 06084223-0657385 and IRAS 06212-1049.

Keywords: *Star formation, Herbig-Haro objects, jets and outflows*

1. Introduction

Herbig-Haro objects for a long time have been recognised as a sign of high activity of star formation in molecular clouds. In fact they represent shocked excitation zones where supersonic flows from young stellar objects (YSO) collide with interstellar medium and form small cloudlets with pure emission spectrum including permitted and low excitation forbidden emission lines ([O I], [S II] etc). Thus, the discovering of new HH objects is important as for the further studies of the phenomenon of directed outflows from young stars, as well as for the searches for new star forming regions and groups.

On the other hand, it is well known that the sources of directed outflows of low and intermediate mass usually are associated with compact reflection nebulae of characteristic conical shape. Moreover, deep images in the optical and infrared ranges reveal their bipolar nature. Such shape is a consequence of the presence of circumstellar disks and conical cavities near the YSOs illuminating these nebulae, created by matter outflow. In the overwhelming majority of cases HH objects and HH flows are located along the axes of these cometary nebulae, which proves a direct relationship between all these phenomena.

In this work we present some newly discovered Herbig-Haro objects and groups as well as their spectral investigations. Searches of HH objects in dark clouds were performed in the frames of Byurakan Narrow Band Imaging Survey (BNBIS), which is carried out using the 1m Schmidt telescope of Byurakan Observatory (Movsessian et al., 2021). Long-slit spectra allow to create PV diagrams of outflow systems, which provide information about velocity along the slit as well as reveal bipolar nature of some outflows.

2. Observations

Direct images were obtained with 1m Schmidt telescope of Byurakan observatory equipped with 4K×4K Apogee (USA) liquid-cooled CCD detector, which provides about 1 square degree field of view with image scale of 0.868″per pixel (Dodonov et al., 2017). During observations the narrow-band filters centered on 6560 Å and 6760 Å, both with a FWHM of 100 Å, were used to obtain Hα and [S II] images, respectively. A midband filter, centered on 7500 Å with a FWHM of 250 Å, was used for the continuum imaging.

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doi: https://doi.org/10.52526/25792776-23.70.1-49

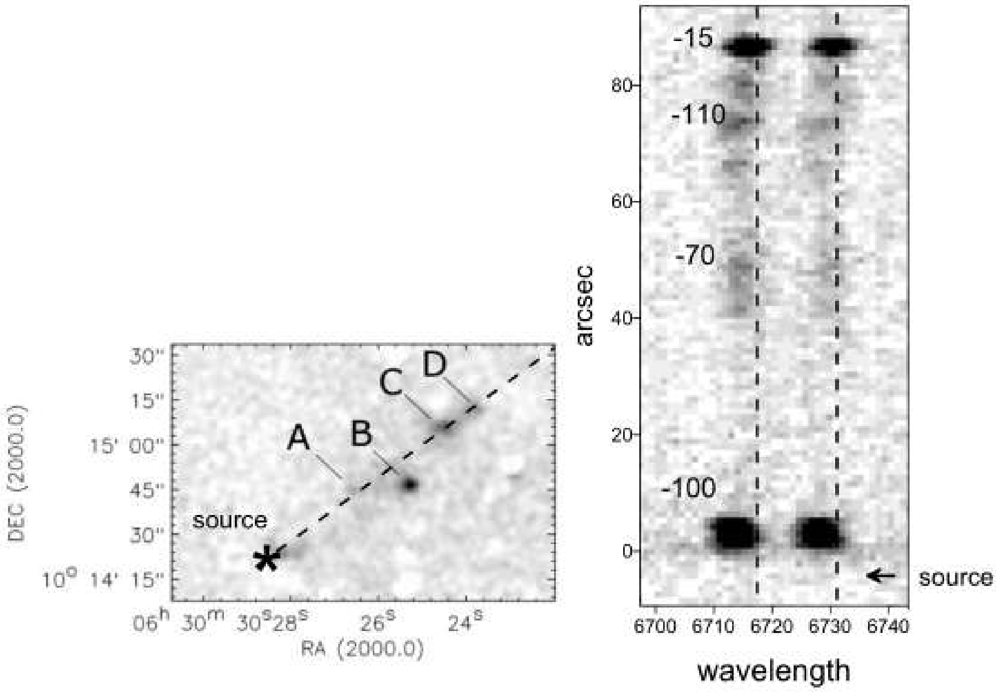

Figure 1. Direct image of IRAS 06212-1049 associated with a chain of HH objects in Hα+[S II] emission (left). HH objects are marked by letters and dotted line show the position of the slit. On the right panel the PV diagram in [S II] emission with the values of radial velocities is presented. Vertical dotted lines indicate the zero velocity of each line of the doublet.

Images were reduced in the standard manner using IDL package, which includes bias subtraction, cosmic ray removal, and flat fielding using "super flat-field", constructed by several images (Dodonov et al., 2017).

Spectral observations were performed on 6 m telescope of Special Astrophysical Observatory (SAO) of the Russian Academy of Sciences using SCORPIO-2 (Spectral Camera with Optical Reducer for Photometrical and Interferometrical Observations (Afanasiev et al., 2017) multi-mode focal reducer mounted in the primary focus of the telescope in the spectroscopic mode. As a detector CCD 261-84 of 2048×4104 pixels, with the 15×15-μm pixel size was used. To increase the S/N ratio of the observed data the 1×2 pixel binning was applied providing 0.2×0.4 image scale. The field of view was 6.1′ with a scale of 0.2″ per pixel. During the observations the VPHG 1200 grism in the wavelength range of 3650-7300Å was used. The spectral resolution was about 5.2Å across the full range of wavelengths (a mean reciprocal dispersion was 0.89Å/px) and a spatial scale along the slit was 0.4″/pixel.

3. Results

3.1. The outflow system associated with IRAS 06277+1016

IRAS 06277+1016 is located in the Mon R1 association to the north-west from the famous Mon OB1 association on the distance of 800pc. This object was discovered during the BNBIS when several new HH objects as well as collimated outflow systems were found, and was designated as HH 1203. This outflow system represents the chain of Herbig-Haro objects traced by the axis of cone shape reflection nebula associated with IRAS 06277+1016. Detailed description of the newly discovered HH objects and outflow systems in Mon R1 can be found in Movsessian et al. (2021).

On the Fig.1 the narrow band image of the outflow (left panel) with superposed position of the slit of the spectrograph, as well as the position velocity (PV) diagram in [S II] doublet (right panel) are presented. The pure emission nature of the knots in this system is obvious. As can be seen from the PV diagram, radial velocities in the knots of the outflow system are negative with values of about -100 km s^{-1}. Moreover, in a distance of 7″ from the infrared source the bright knot in [S II] emission is found, which can be an evidence of a short jet lying in the direction of the axis of HH 1203 flow. Its existence confirms the assumption that

doi: https://doi.org/10.52526/25792776-23.70.1-49

the infrared object, apparently embedded in the nebula, is the source of HH 1203.

3.2. IRAS 06068-0643 (V963 Mon)

This variable star is located in about one degree south from Mon R2 association. Mon R2 association is a well studied region of star formation which contains early-type stars (Racine, 1968), molecular outflows (Meyers-Rice & Lada, 1991), an embedded HII region (Downes et al., 1975) and clusters of infrared sources (Thronson et al., 1980). However, HH objects were searched there only episodically; some of them were found in the eastern side of Mon R2 (Carballo & Eiroa, 1993). Our attention was drawn to the area south of the central part of Mon R2, where several nebulous objects and an eruptive star V899 Mon are located.

V963 Mon is located in the southern part of the Mon R2 association about 2.5′ SW from V899 Mon. This source is associated with compact reflection nebula and shows spectral features, as well as photometric variability typical for EXOrs (Wils et al., 2009).

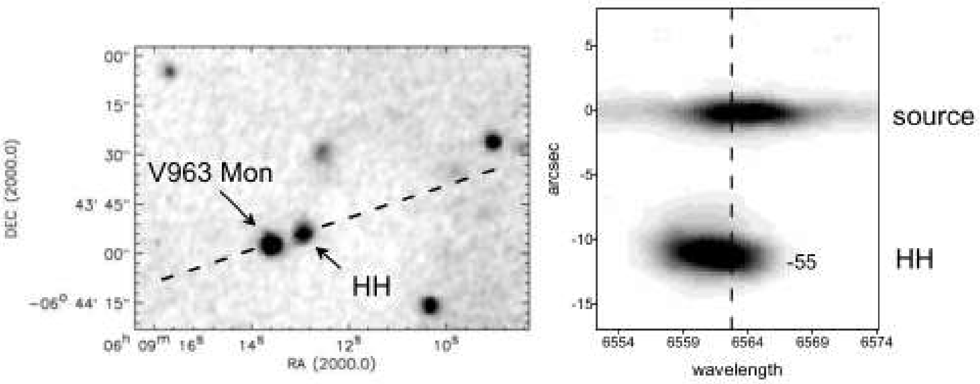

Figure 2. Direct image of V963 Mon associated with a helical chain of HH objects in Hα+[S II] emission (left). Bright HH objects are marked and dotted line shows the position of the slit. On the right panel the PV diagram in Hα emission with value of radial velocity is presented. Vertical dotted line indicate the zero velocity of the emission.

During the survey a chain of new HH objects was discovered near this object. This chain of HH objects has an unusual helical form with very bright spot near the V963 Mon. In the Hα image (Fig.2 (left panel)) the chain of HH knots is visible near the source. In the same image the position of the slit of spectrograph is shown also. PV diagram in Hα emission is presented on the right panel. Radial velocity of HH objects is about 55 km s^{-1}.

3.3. 2MASS 06084223-0657385

About 20 arcmin south-west from V899 Mon near the 2MASS 06084223-0657385 infrared source, associated with bipolar reflection nebula, several HH knots were revealed. HH objects lie along a parabolic curve, at the apex of which the infrared source is located (Fig.3, left panel). Therefore, it can be argued that we are dealing with a bipolar outflow with an unusual arc-shaped structure. Such a morphology is typical either for so-called irradiated jets or outflows from the sources with high proper motion. We incline to the second scenario, because irradiated outflows are usually represented by a very narrow emission filaments without prominent knotty structures (Bally & Reipurth, 2001). Taking this scenario into account we estimated the probable proper motion value of the source to be about 50 km s^{-1}, which is quite acceptable. The estimated total length of this bipolar outflow will be about 1.5 pc for the distance of 900 pc. This outflow system represents giant or so-called parsec-scale HH flow.

On the PV diagram in [S II] emission (Fig.3, right panel) in the both sides of the stellar continuum, beside of the 2MASS 06084223-0657385 stellar spectrum the several emission knots are distinctly visible. One of these emission knots is not discernible on the direct image on the bright reflection nebular background. The radial velocities of emission knots indicate the bipolar nature of this outflow with positive velocities in eastern and negative ones in western branch. Vertical dotted lines indicate the zero velocity for each line of the doublet.

doi: https://doi.org/10.52526/25792776-23.70.1-49

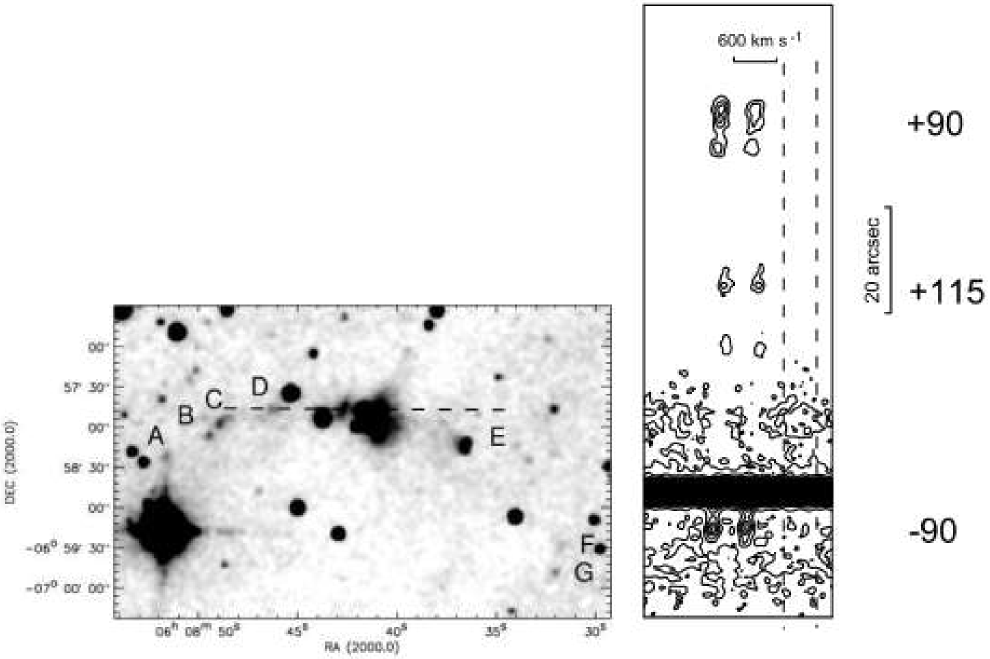

Figure 3. Direct image of 2MASS 06084223-0657385 associated with the parabolic chain of HH objects in Hα+[S II] emission (left). HH objects are marked by letters and dotted line shows the position of the slit. On the right panel the PV diagram in [S II] emission with values of radial velocities is presented. Vertical dotted lines indicate the zero velocity of each line of the doublet.

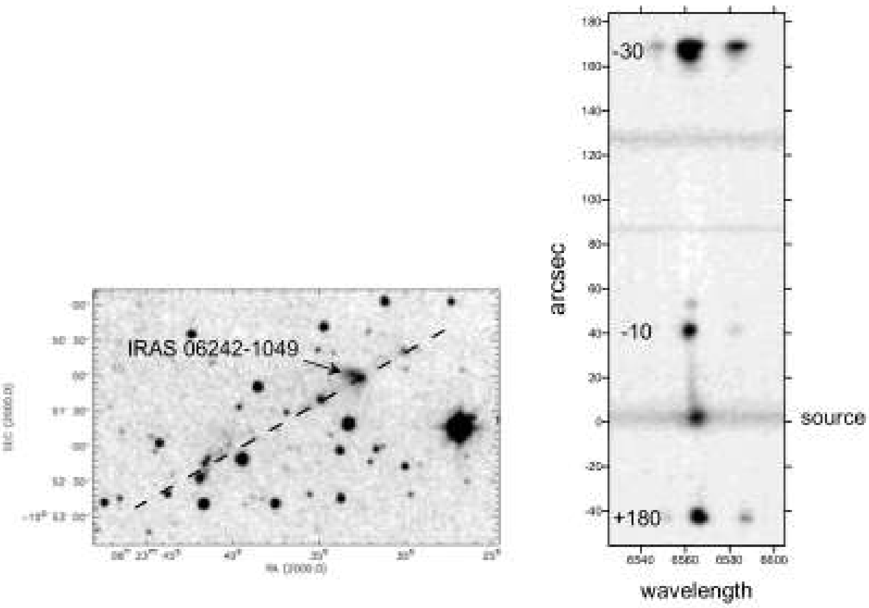

Figure 4. Direct image of IRAS 06242-1049 associated with cone shape reflection nebula and the chain of HH objects in Hα+[S II] emission (left). Dotted line shows the position of the slit. On the right panel the PV diagram in Hα emission with value of radial velocities is presented.

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3.4. IRAS 06212-1049

The infrared source IRAS 06212-1049 is associated with a cone-shaped reflection nebula, the axis of which is oriented to the southeast. The deep images of the PanSTARRS survey show also a faint nebula in the opposite direction from the source, which indicates the bipolar morphology. The object is located near the dark cloud LDN 1652, which has a distance of 830 pc, so its distance can be considered the same. On the images obtained in the Hα and [S II] emission lines, several HH knots, located along the axis of the reflection nebula, were detected (Fig.4, left panel). Obviously, they represent a collimated optical flow. In the distance of about 830 pc the total length of the outflow will be about 0.9 pc.

As in the all previous cases we present PV diagram of this outflow system (Fig.4, right panel), which indicates the bipolar nature of this outflow with very high positive velocity in the western knot and low negative velocities in knots of the eastern branch. This again confirms the bipolar nature of the collimated outflow from IRAS 06212-1049.

4. Conclusion

Since the beginning of 2019, when the BNBIS survey was started, more than 100 new HH objects and outflow systems have been found. Among them the several giant outflow systems, narrow jets as well as the curved HH flow should be mentioned. The sources of outflows are associated with cone shape reflection nebulae, often of bipolar structure. Moreover, all collimated outflows are directed along the axes of these reflection nebulae.

This article presents long-slit observations of some selected objects and HH groups from the survey, performed with the 6-meter telescope. In the several cases outflows are bipolar with two branches with positive and negative radial velocities. e.g. of 2MASS 06084223-0657385 and IRAS 06212-1049.

In addition to the all results presented above, this work demonstrates that the 1-m Schmidt telescope of Byurakan Observatory, which was used several decades ago for well-known surveys of active galaxies such as the First Byurakan Survey and Second Byurakan Survey, can still lead to important discoveries.

Acknowledgements

This work was partly supported by the grant 21T-1C031 of the RA State Committee of Science.

References

Afanasiev V. L., Amirkhanyan V. R., Moiseev A. V., Uklein R. I., Perepelitsyn A. E., 2017, Astrophysical Bulletin, 72, 458

Andre P., Montmerle T., 1994, Astrophys. J. , 420, 837

Bally J., Reipurth B., 2001, Astrophys. J. , 546, 299

Carballo R., Eiroa C., 1993, in Errico L., Vittone A. A., eds, Astrophysics and Space Science Library Vol. 186, Stellar Jets and Bipolar Outflows. p. 213, doi:10.1007/978-94-011-1924-5˙37

Dodonov S. N., Kotov S. S., Movsesyan T. A., Gevorkyan M., 2017, Astrophysical Bulletin, 72, 473

Downes D., Winnberg A., Goss W. M., Johansson L. E. B., 1975, Astron. Astrophys. , 44, 243

Meyers-Rice B. A., Lada C. J., 1991, Astrophys. J. , 368, 445

Movsessian T. A., Magakian T. Y., Dodonov S. N., 2021, Mon. Not. R. Astron. Soc. , 500, 2440

Racine R., 1968, Astron. J. , 73, 588

Reipurth B., Bally J., 2001, Ann. Rev. Astron. Astrophys. , 39, 403

Thronson H. A. J., Gatley I., Harvey P. M., Sellgren K., Werner M. W., 1980, Astrophys. J. , 237, 66

Wils P., Greaves J., Drake A. J., Catelan M., 2009, Central Bureau Electronic Telegrams, 2033, 1

doi: https://doi.org/10.52526/25792776-23.70.1-49