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SPECTRAL STUDIES OF YSO ENVELOPES AND COLLIMATED OUTFLOWS

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A short review of the studies of the young nebulous objects in the dark clouds in the Byurakan Observatory. The results of the prolonged observational programme, carried out mainly on the 6-meter telescope of SAO RAS, are described, and the relation of this programme with the methodology of study the non-stable phenomena, traditional for Byurakan, is pointed out.

1. *Introduction.* As the one of the most famous features of the Byurakan Astrophysical Observatory (BAO) always was the special interest for the non-stable astronomical phenomena it is quite understandable that young non-stable stars were (and are) in the focus of the attention of BAO for a long time. Here we shall present a short overview of the observational studies of young nebulous objects in the dark clouds in BAO during the whole history of the observatory and especially in the period of last twenty years.

2. *First studies and searches.* We can assume the classic papers of Ambartsumian [1,2] as the beginning of the studies of young nebulous objects in BAO. Shortly after that several photometric and polarimetric observational works, performed with the modest size telescopes of BAO, were published (for example, [3,4]). But very soon the direction of studies was changed to the preparation of lists of new objects, discovered on the maps of the Palomar Observatory Sky Survey (POSS). The total amount of the thus found nebulous objects in the dark clouds, even after the excluding the overlaps and already known nebulae, was surprisingly high. We shall describe here only the most significant lists.

The first list of 35 new cometary nebulae (CN) in the Taurus-Auriga dark clouds was prepared by Badalian [5], and even if it did not acquired much publicity, it is worth to mention that in this search some Herbig-Haro (HH) objects and collimated outflows were found independently and also for the first time the classification of CN in 4 morphological types was suggested. Much more popularity was gained by the list of CN by Parsamian [6] (which included in particular very interesting object P21). As the next step the lists of 130 new CN, HH and other nebulous objects of Gyulbudaghian and Magakian [7,8,9] should be considered. The list of 36 HH candidates [8] with some additional data was reprinted in [10], and the objects from this work (so-called GGD objects) in the following years became the target of the rather intense studies. The coverage of sky in this survey was quite high: the surveys of Bernes [11] and Cohen [12], published shortly after and conducted on the same principles, show significant overlap with GM objects. But even then not all the young nebulous objects, visible on the POSS maps, were discovered; subsequent works of Gyulbudaghian (see, for example [13,14]) added about 60 new objects.

In the recent years the surveys of young emission and reflection nebulae, based on POSS, were replaced in the world practice by the direct imaging with narrow-band filters, and many new very small and/or very faint objects were revealed by means of this technique. On the other hand, it should be noted that the greatly increased total number of CN, HH and other nebulous objects in the dark clouds suggests the necessity of a new general catalogue of such objects. This problem is only partly covered by the electronic catalogue of HH objects of Reipurth [15], and catalogue of CN, compiled by Parsamian and Petrossian [16] is somewhat outdated and not homogeneous.

It is quite clear that full-scale investigations must include not only the searches but the detailed observational studies as well. Due to the modest capabilities of the equipment available in BAO this kind of studies for a long time were restricted by several spectral observations, obtained with the large telescopes abroad. In accordance with the idea of Ambartsumian that some unusual features of CN could be connected with the instability of their core stars and the outflow phenomena, these researches were aimed mainly to the quest and investigation of different anomalies in the spectra of CN, which could be ascribed to the non-stable activity during the early stages of stellar evolution.

In fact, many of the unusual properties of CN (their shape, colours, variability, violation of the Hubble's relation for the reflection nebulae etc.; see, for example, [16]), which previously were thought to be connected with non-thermal emission and other effects of stellar instability, afterwards were naturally explained by the existence of the absorbing circumstellar disks. But the main idea about the role of anisotropic and directed outflows was true. Just these outflows, as we know presently, are responsible for the spectral peculiarities of the certain CN. (For the review of the anomalous spectra of CN see [17]).

In our opinion, the key object for the understanding the CN phenomenon as a whole is represented by the famous Hubble variable nebula NGC 2261. Indeed, it presents not only the classical features of CN (cometary shape with the young emission-line star in the head; bipolarity; variability; centrosymmetric polarization pattern with the indications of the presence of circumstellar dust disk), but also for the first time the spectral anomaly (the strengthening of the absorption lines in the spectrum of the nebula in comparison with that of the star) was found by Greenstein just for this object [18]. Other important steps were: the discovery of HH objects, located on the axis of the nebula [19]; the detailed study of the spectral anomalies and the idea of the existence of outflow from the central star [20,21]; and the most important one - the interpretation of these anomalies as the spectral asymmetry of the central source, caused by directed outflow [22].

The hypothesis about the collimated outflows from young stellar objects (YSO) was transformed to the established fact when these outflows were at last detected directly by Mundt and his coworkers [23,24].

3. *Observations of last twenty years*. In the 1975 the situation with the observational capabilities of BAO drastically changed when both the 2.6-meter telescope in Byurakan and 6-meter telescope of the Special Astrophysical Observatory (Russia) became operational. This offered new possibilities in the investigations of the young nebulous objects. Moreover, so large amount of the newly found objects literally was demanding the observations. Our observational programme was launched in 1976 and continues up to the present times. Of course, it was changing during these 20 years along with our understanding of the problem and the upgrading of the observational equipment as well. For all these years our programme is and remains the only one in the whole CIS aimed strictly to the studies of CN, HH and their interaction with interstellar medium. We shall briefly describe the stages of the programme and main observational results.

First studies of the new objects from Byurakan lists were performed in 1976-1985. For the morphological studies the direct images on 2.6-meter telescope were obtained. By those the new variable nebulae PV Cep and V1515 Cyg were discovered [25]. The spectral observations were carried out with one-dimensional IPCS on the 6-meter telescope. Many new emission stars and 10 HH objects were found. Especially interesting was the discovery of a new CN with anomalous spectrum - Ber 48 [26].

In 1985-1989 these exploratory observations were replaced by the detailed investigations of the optical jets and inner structures of HH objects with the long-slit equipment on the 6-meter telescope. As the most interesting results we can mention the revealing of the new optical jets CoKu Tau/1 [27] and L723 [28] and the studies of the structure and kinematics of many HH objects.

We continue the long-slit observations on 6-meter telescope up to now, but from 1989 also the new exciting possibility to observe the extended objects by means of three-dimensional spectroscopy, namely with multi-pupil field spectrograph (MPFS) became available. So our present observational programme is based both on the 2D and 3D spectral studies and encompasses the following directions.

a) Studies of shock waves in the jets and HH objects.

As the recent example, the studies in the NGC7129 star formation region could be mentioned [29,30]; for several objects complex H_α-emission profiles were found and their comparison with theoretical profiles was performed. For GGD35 and HH103 the maps of velocity components, compared to their proper motions, suggest unusual internal structures. Some new very faint HH objects, located in this field, for example HH105, were confirmed and their radial velocities obtained for the first time. We studied also the spectra of the faint emission-line stars in this field; especially interesting is the highly variable V350 Cep, for which the conspicuous spectral variations were revealed during the years of observations.

A detailed spectral analysis of the shock structure in the GM1-27 object was performed, using the long-slit spectra with a high spatial resolution [31]. The different behavior of various spectral lines inside the object suggests the presence of spatial stratification. It was concluded, that these observations enabled us to resolve not only the bow shock and Mach disk inside the HH object, but also the bow shock itself.

Just recently we obtained long-slit spectra for the very interesting, but little studied yet chains of HH objects in Orion, namely HH84, HH85, HH94. Strong variations of radial velocity and physical parameters are evident in several condensations; full reduction of the data is in progress.

The main conclusion is the following: the theory describes well the interaction of high-velocity jets and bullets with interstellar medium, but there exist very unusual observed cases, for which we must seek a more elaborated explanations (multiple shocks? unusual internal structure of cloudlets? very inhomogeneous surroundings?).

b) Studies of the sources of anisotropic outflows.

These investigations were performed with MPFS and are being continued.

A new source of an optical collimated outflow (Fig.1) was identified with the emission-line star $LkH_\alpha 225$ [32,33]. Subsequent observations revealed a strong variability of the both components of this double star as well as conspicuous changes in the shape of the associated nebula. But we cannot deduce from the present data, which of the two stars excites the HH emission inside the nebula.

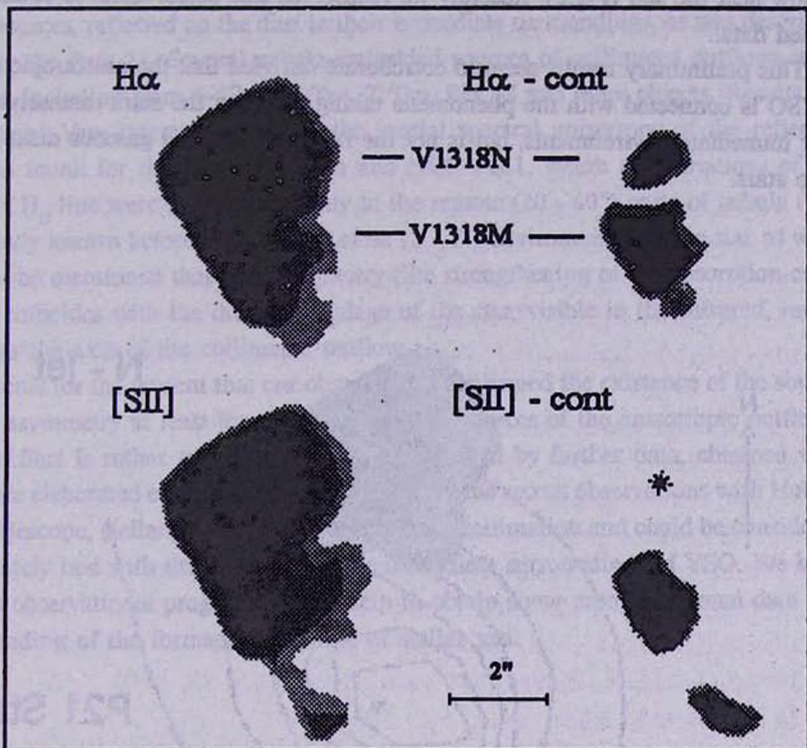

Fig 1. Images of LkH$_\alpha$ 225, restored from the spectra, obtained by multi-pupil field spectrograph (MPFS).

Also by means of the integral-field spectroscopy a small collimated jet was revealed near the faint YSO Haro 6-10 [34].

For the star in the apex of the cometary nebula Pars 21, deeply embedded in a circumstellar dusty envelope, and recently identified as a FU Ori-type object, the H$_\alpha$ absorption profiles have been studied. The undoubted asymmetry of the star image, observed in the red wing of this line, was revealed. This asymmetry is caused by the shift of the red wing of H$_\alpha$ absorption, ascribed to the anisotropy of the cool expanding envelope around the star. In reality we observe, of course, the spectrum of the star, reflected from various angles by different parts of the dusty stellar environment. It was possible also to reconstruct the shape of the both emission lobes of the collimated outflow near the star (Fig.2). Recently we reobserved this object again to obtain more refined data.

This preliminary results seem to corroborate our idea that the anisotropic activity of YSO is connected with the phenomena taking place on the stars themselves or in their immediate environments, but is not the result of dust and gaseous disks around these stars.

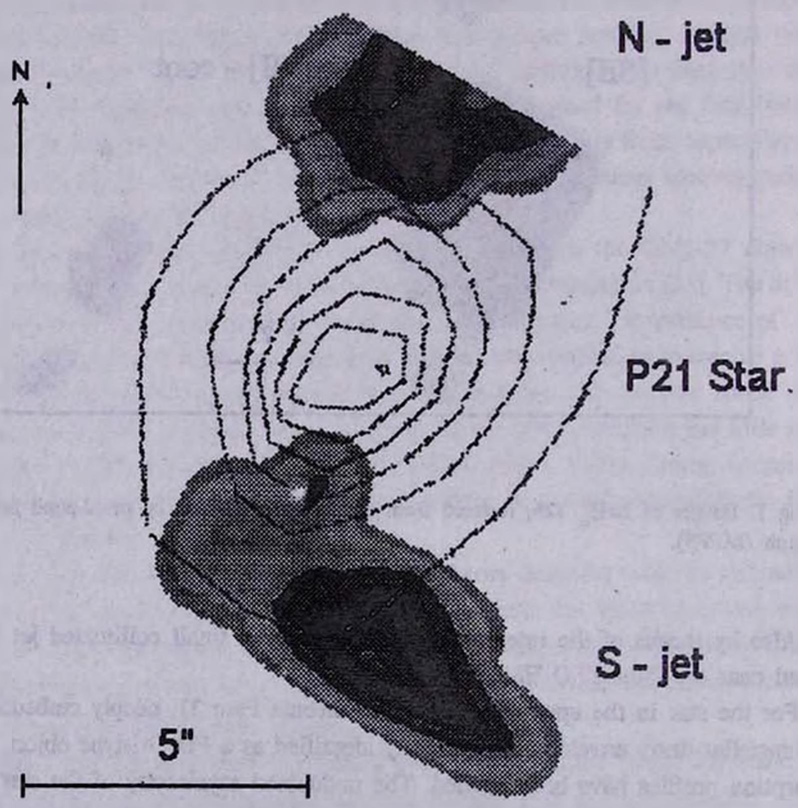

Fig 2. Emission lobes of the bipolar jet from P21 FU Ori-type star, restored from the MPFS spectra.

c) Studies of the reflected spectra of cometary nebulae.

We tried to apply the integral-field spectroscopy to analyze the spectra of the central sources, reflected on the dust in their immediate surroundings, as was described above for the Pars 21. Several nebula-embedded sources of collimated outflows were observed, including Haro 6-5B, CW Tau, T Tau, Ber 48 and other objects. Results are under study. Very interesting case of the spatial spectral anisotropy of the reflected light was found for the famous R Mon and NGC 2261, where the variations of the profile of H_α line were revealed not only in the remote (20 - 40") parts of nebula (this was already known before), but for the close (5 - 7") environments of the star as well. It should be mentioned that this asymmetry (the strengthening of the absorption component) coincides with the dusty appendage of the star, visible in the infrared, rather than with the axis of the collimated outflow.

It seems for the present that our observations confirmed the existence of the sought spectral asymmetry at least for the several stars - sources of the anisotropic outflows, but this effect is rather subtle and must be confirmed by further data, obtained with even more elaborated equipment. As was shown by the recent observations with Hubble Space Telescope, stellar jets indeed have very high collimation and could be considered as intimately tied with the processes in the immediate surroundings of YSO. We hope that this observational programme will help to obtain some more additional data and understanding of the formation and role of stellar jets.

СПЕКТРАЛЬНЫЕ ИССЛЕДОВАНИЯ ОБОЛОЧЕК И КОЛЛИМИРОВАННЫХ ПОТОКОВ МОЛОДЫХ ЗВЕЗДНЫХ ОБЪЕКТОВ

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Краткий обзор исследований молодых туманных объектов в темных облаках в Бюраканской обсерватории. Описаны результаты продолжительной наблюдательной программы, выполняемой в основном на 6-метровом телескопе САО РАН, и отмечена взаимосвязь этой программы с традиционным для Бюракана методологическим подходом к изучению нестационарных явлений.

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