SPECTRAL STUDIES OF YSO ENVELOPES AND COLLIMATED OUTFLOWS

T. Yu. Magakian and T. A. Movsessian

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

1. Introduction. One of the most famous features of the Byurakan Astrophysical Observatory (BAO) always was the special interest of non-stable astronomical phenomena. It is quite understandable that young nonstable stars were (and are) the focus of attention of BAO for a long time. Here we shall present a short overview of the observational studies of young nebulous objects in dark clouds at BAO over the entire history of the observatory and especially during the 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 at 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 number of nebulous objects thus found in the dark clouds, even after 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 acquire much publicity, it is worth mentioning 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 the 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 rather intense studies. The coverage of sky in this survey was quite high: the surveys of Berries [11] and Cohen [12], published shortly after and conducted on the same principles, show significant overlap with GM objects. But even then not all 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 recent years surveys of young emission and reflection nebulae, based on POSS, were replaced in world practice by 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 the 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 searches but detailed observational studies as well. Due to the modest capabilities of the equipment available in BAO these kinds of studies for a long time were restricted by several spectral observations obtained with 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 at the quest and investigation of different anomalies in the spectra of CN, which could be ascribed to nonstable activity during the early stages of stellar evolution.

In fact, many of the unusual properties of CN (their shape, colors, variability, violation of the Hubble’s relation for the reflection nebulae, etc.; see, for example, [16]), which previously were thought to be connected with nonthermal 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 certain CN. (For a 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 a 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 1975 the situation with the observational capabilities of BAO drastically changed when both the 2.6-meter telescope in Byurakan and the 6-meter telescope of the Special Astrophysical Observatory (Russia) became operational. This offered new possibilities in the investigations of the young nebulous objects. Moreover, such a large number of newly found objects literally was demanding observation. Our observational program was launched in 1976 and continues up to the present. Of course, it changed 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 program is and remains the only one in the whole CIS aimed strictly at the studies of CN, HH, and their interaction with interstellar medium. We shall briefly describe the stages of the program and the main observational results.

The first studies of the new objects from Byurakan lists were performed in 1976-1985. For morphological studies the direct images on the 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 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 the 6-meter telescope up to the present, but in 1989 the new exciting possibility to observe extended objects by means of three-dimensional spectroscopy, namely with multi-pupil field spectrograph (MPFS) also became available. So our present observational program is based both on 2D and 3D spectral studies and encompasses the following directions.

a) Studies of shock waves in jets and HH objects

As a recent example, studies in the NGC7129 star formation region could be mentioned [29, 30]; for several objects complex Hα-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 also studied 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.