АСТРОФИЗИКА

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NEW RADIAL SYSTEMS OF DARK GLOBULES AND HH OBJECTS

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During survey of ESO/SRC plates of Southern Hemisphere we have found several dozens of new HH objects, star-forming regions, cometary nebulae [1]. There are also radial systems of dark globules in the vicinity of these new objects. Several regions, containing some of these objects, were observed on 1.54 m telescope with several narrow band filters. In this paper we present the results of observations of two new radial systems of dark globules and several HH objects and also the results of $^{12}CO(1-0)$ observations of dark cloud, the part of which is rotating with angular velocity $\Omega = 4.3 \cdot 10^{-14}$ s^{-1}.

Key words: *star forming region: molecular clouds: HH objects*

1. *Introduction. Radial systems of dark globules.* Dark GMCs often contain star-forming regions of massive stars. In these regions bright massive stars are originated. After their origin these stars ionize and evaporate molecular gas in their vicinity. Molecular clouds contain dense cores. When ionization front reaches these cores, they are evaporated if are situated close to the bright stars and are streamlined by ionized gas if the cores are situated farther from the stars. The gas gives to these cores the form of globules of radial systems: the globules are oriented so that their axis of symmetry is directed towards the central bright stars. The masses of GMCs are in the range $(10^4 - 10^5) M_\odot$, the masses of globules are in the range $(0.1\text{-}10) M_\odot$ [2].

There are two types of radial systems. Type 1. In the center of the system bright O-B2 type stars are situated, the system is embedded in HII region, the globules have such orientation that their axis of symmetry are directed towards the central stars. Type 2. In the center of system already exist stars later than B2, there is no HII region, but an HI cloud can be present, the radial orientation of globules still persists [3].

Several radial systems were considered in the literature: in Gum Nebula, around the star λ Ori, in "Rosette Nebula" (see e.g. [4-6]). A search of PSS maps for looking for new radial systems was done [7]. 17 such systems of type 1 and also 6 systems of type 2 were found. Investigation of radial systems has an important significance for making clear the evolutionary track of molecular clouds and OB stars. Type 2 radial systems can be connected with HI cloud

or can contain no noticeable amount of HI [3]. It is supposed that in the type 2 systems HII region because of weakening of central stars is transformed into HI cloud, or is dissipated under the influence of strong stellar wind and/or strong radiation from central stars. Dissipation of HI cloud, or even of initial HII region, can be due to the supernova explosion, which could take place near the location of radial system.

All type 1 radial systems are connected with OB stellar associations, but only half of type 2 radial systems are connected with OB stellar associations [8]. It is supposed that after a definite time under the influence of differential rotation of Galaxy the type 2 radial systems will be destroyed and will be transformed into separate isolated type I Bok globules. Such globules are rather numerous and occur in stellar associations as well as outside them, in the interstellar medium.

HH objects. HH objects were discovered independently by Herbig [9] and Haro [10]. They are stellar condensations, their spectra consist of strong emission lines and weak continuum. Herbig in [11] gives the following definition: HH objects have characteristic emission spectrum: emission lines of hydrogen are strong, [OI] and [SII] unusually intensive. Lines of [NII] are also strong, and the objects, which have not considerable reddening (because of absorption), have in spectra also the doublets of [OII] 3726-3729. HH objects have low degree of ionization (~50%). Van den Bergh in [12] suggested a method of discovering of new HH objects by observations with narrow band filters on 6717 and 6731 ÅÅ . It was established by Schwartz that HH objects' spectra resemble the spectra of supernovae remnants [13], it was also considered that the spectra of HH objects are originated in the shock waves.

In this paper we have investigated two regions, where there are star forming regions, radial systems of dark globules and also HH objects. The both regions were observed in optical region and one also in $^{12}CO(1-0)$.

The optical observations were done on 5th of June 2002 on Danish 1.54m telescope. That telescope is situated at La Silla, Chile, altitude is 2340m,optics is of a Ritchey-Chretien design. The observations were done with several narrow-band filters. 1. With *R* filter (ESO 452, $\lambda(nm) = 648.87$, $\Delta\lambda(nm) = 164.7$). 2. With SII filter (ESO 701, $\lambda(nm) = 672.72$, $\Delta\lambda(nm) = 6.31$). 3. With OIII filter (ESO 690, $\lambda(nm) = 500.99$, $\Delta\lambda(nm) = 5.66$).

2. *First region*. This radial system was composed by the star HD 73882 (see Fig.1). It is a double star with spectra O9III and O8V (as was mentioned above, the radial systems are composed by the stars O - B2). In Table 1 are summarized the data on stars mentioned in this paper (the data are taken from Vizier). In column 1 is the number of stars, in column 2 the name of the star, in columns 3 and 4 the coordinates, in columns 5-9 the colors of stars.

Table 1

DATA ON COLOURS OF SEVERAL STARS

N	Name	α(2000)	δ(2000)	*V*	*B - V*	*J*	*J - H*	*H - K*
1	HD 73882	8h39m09s.5	-40°25'09".3	7m.264	0m.354	6.106	0.087	0.103
2	HD 150135	16 41 19.4	-48 45 47.61	6.755	0.13	6.318	0.016	0.065
3	Nomad1 0493-0146255	8 35 22.4	-40 38 52.90	17.150	0.79	12.635	1.180	0.561
4	Nomad1 0493-0146257	8 35 22.56	-40 38 50.19	16.61	1.34	12.683	1.603	1.154
5	Nomad1 0411-0583316	16 40 11.89	-48 48 59.17	--	--	13.805	1.733	1.402

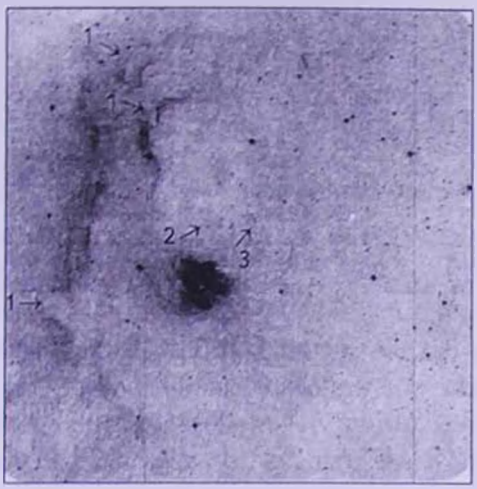

Fig.1. Image of first radial system, obtained on 1.54m telescope with Hα filter. 1 - dark globules, 2 - HH objects, 3 - double star. *N* is to the top, *E* is to the left. The sizes of image are 14' x 14'.

Low values of *J - H* and *H - K* show that this double star has no dust envelope. The absence of such envelope is common for O stars. For O9III type star from [14] we have $M_V = -5.1$ and $(B-V)_0 = -0.3$. Hence we have $A_V = 3.3E_{B-V} = 2.158$ and $V - M_V - A_V = 10.2$ and hence the distance is 1.1 kpc. The star HD 73882 has composed an HII region RCW 27. Many of dark globules, composing radial system, have bright rims. In molecular cloud, which is part of radial system, there is a bright star CD -40 4427 (B1V), which is illuminating the nebula NGC 2626. That star has a semiring nebula (see Fig.2). Near to this star in the same molecular cloud a star forming region is situated. It is an IR nebula with IR star cluster (see Fig.2).

^{12}CO(1-0) observations of the region in direction of double star (see below) were carried out with the 15-m SEST (Swedish-ESO Submillimetre Telescope)

telescope at Cerro La Silla, Chile. The telescope beam size at 115 GHz was 45" and the beam efficiency was 0.70. The positions toward the source were observed with a spacing of 40" in frequency-switched mode, with a frequency throw of 10 MHz. The telescope was equipped with a SIS detector and a high-

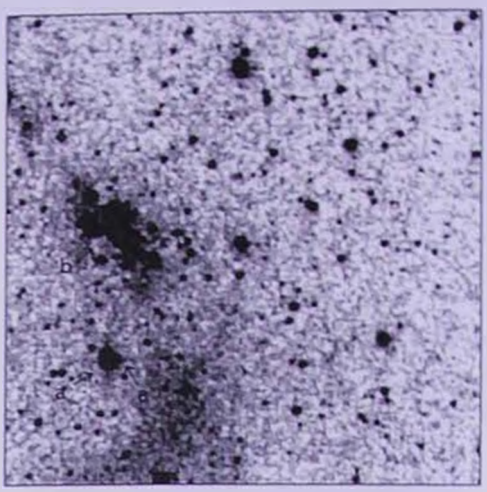

Fig.2. 2MASS K image of the star with semi ring nebula and *IR* nebula with *IR* star cluster. a - semi ring nebula, b - *IR* nebula. *N* is to the top, *E* is to the left. The sizes of image are 6' x 6'.

resolution acousto-optical spectrometer with 1000 channels and a velocity resolution of 0.112 km/s. These observations were done with late Prof. Jorge May. Observations were done at 30 of August, 2003. Fig.3 shows the ^{12}CO(1-0) spectra observed toward double star arranged in a map-like distribution. Analyzing the

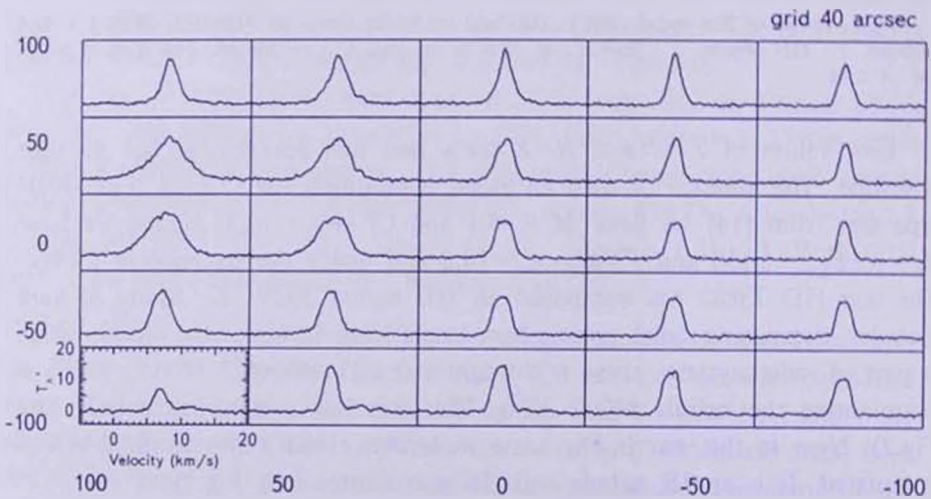

Fig.3. ^{12}CO(1-0) spectra toward double star (stars 3 and 4 in Table 1), arranged in the map-like distribution.

data presented in Fig.3 we can realize that there are three emissions: emission from main cloud and emissions from red shifted and blue shifted outflows, surrounding double star. The main cloud velocity is 7.730 km/s, velocity of red shifted outflow is 9.001 km/s (or +1.271 km/s in respect with the velocity of the cloud), velocity of blue shifted outflow is 5.910 km/s (or -1.820 km/s in respect to the velocity of the cloud).

Below is presented Table 2, in which the velocities (in km/s) of main cloud are given. The cells in Table 2 correspond to the cells in Fig.3.

Table 2

DISTRIBUTION OF VELOCITY OF MAIN CLOUD AROUND DOUBLE STAR

7.73	7.548	7.548	7.73	7.73
7.73	7.184	7.548	7.912	7.912
7.184	7.184	7.366	7.548	7.73
7.002	6.82	7.366	7.366	7.73
6.638	6.82	7.184	7.366	7.73

We can see from Table 2 that the eastern part of the region observed in ^{12}CO is rotating, because there is a gradient of velocity in N-S direction. On the length of 160" (which at the distance of 1.1 kpc corresponds to $2.31 \cdot 10^{13}$ km) the gradient of velocity is equal to 1.092 km/s. Hence the angular velocity of rotation $\Omega = \Delta V/\Delta r = 1.092\,\text{km/s}/2.31 \cdot 10^{13}\,\text{km} = 4.3 \cdot 10^{-14}\,\text{s}^{-1}$. We can obtain also the period of rotation: $T = 2\pi/\Omega = 1.44 \cdot 10^{14}\,\text{s} = 4.64 \cdot 10^{6}$ year. We can see in Fig.2, that the *IR* nebula has a bar-like structure with *NE*-*SW* orientation. Rotation of eastern part of the region is around the axis of rotation, which has *E*-*W* orientation. We can conclude, that *IR* nebula can also rotate around that axis of rotation, because eastern edge of the region coincides with that nebula. If so, it is not excluded that the *IR* nebula has a disc-like structure and we see the disc edge on. In [15] the data on several rotating dark globules are given. Their angular velocity of rotation is in the range $\Omega = (0.3-3) \cdot 10^{-14}\,\text{s}^{-1}$, so that the angular velocity obtained in this paper exceeds the velocities of dark globules given in [15].

Table3

DISTRIBUTION OF ANTENNA TEMPERATURE NEAR DOUBLE STAR

0 34 1	2 37 0	0 42 0	0 40 0	0 34 0
7 29 6	10 29 6	2 32 5	0 33 0	0 30 0
7 26 7	9 29 7	3 33 3	2 25 3	0 28 0
4 26 1	3 29 3	3 27 3	3 26 3	2 26 3
1 15 1	0 34 2	2 34 3	3 28 4	2 26 3

In Table 3 antenna temperatures of red shifted, blue shifted outflows, as well as of main cloud are given (the values of antenna temperature are taken from Fig.3). In each cell in the center is antenna temperature of main cloud, to the left - of blue shifted outflow and to the right - of red shifted outflow (in the units of $0.392T_A^*$).

We conclude from Table 3, that red shifted and blue shifted outflows are maximal in eastern direction from the object (double star). Such an eastern outflow, but in optics, is well seen in Fig.4.

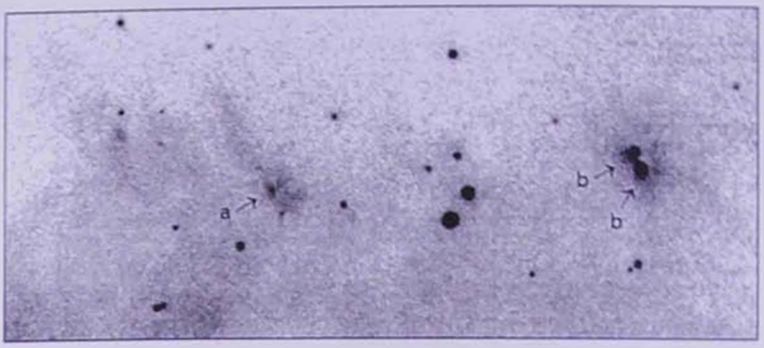

Fig.4. Image of HH objects with filaments and of double star (stars 3 and 4 in Table 1), obtained on 1.54m telescope with *R* filter. a - HH objects, b - double star. *N* is to the top, *E* is to the left. The sizes of image are 3' x 1'.3.

There is an HH object in this region (Fig.4). This object consists of two condensations with spiral filaments. The coordinates of HH objects are: $\alpha_{2000} = 8^h35^m29^s.87$, $\delta_{2000} = -40^h38'53''.8$. This object is situated in the dark cloud (near bright rim) near the region, where an *IR* nebula RCW 108-IR with *IR* star cluster is embedded in dark cloud. It is possible that this HH object was ejected from one of *IR* stars from the embedded cluster.With that HH object an *IR* star NOMAD1 0493-0146322 is associated. One criteria for classification of spectra of HH objects is SII(6717+6731)/Hα lines ratio. We have images with narrow filters, so we can make only qualitative conclusions. On image with SII filter HH is faint and on image with Hα filter HH is bright, so we can conclude that SII(6717+6731)/H < 1.5 and hence due to [16], spectrum of HH is of high or intermediate excitation. Not far from that HH object double stars with spiral jets are situated (see Fig.4). One of these stars is a variable star V384 Vela (star 3 in Table 1), the second, NOMAD1 0493-0146257 (star 4 in Table 1), has Hα emission. For both stars we can use reddening free quantity $Q = (J - H) - 1.70(H - K)$. Values of $Q < -0.10$ are indicative of an *IR* excess consistent with a dust disc [17]. For the first star $Q = 0.226 > -0.10$, that is that star does not have a dust disc. For the second star $Q = -0.359 < -0.10$, it means that star has a dust disc. On image with SII

filter spiral arms are faint and on image with Hα filter they are bright, so we can conclude that the spectra of spiral arms are also of high or intermediate excitation.

3. *Second region*. This radial system (see Fig.5) is in the region, where an OB-association Ara OB1 is situated. In [17] this association is divided in two parts, Ara OB1a and Ara OB1b. Ara OB1a is associated with open clusters NGC 6193 and NGC 6167, while Ara OB1b was found to be about twice as distant. NGC 6193 is an open cluster, dominated by a pair of O stars, HD 150135 and HD 150136. These are the brightest optically revealed O stars in the association and are thought to be responsible for ionizing the bright rim of emission to the W (NGC 6188). Ara OB1a is a compact association covering ~1 sq. degree (~25 pc in a side) around a central cluster NGC 6193. The distance to NGC 6193 is estimated as 1.3 ± 0.2 pc. The mean extinction is low towards NGC 6193.

This radial system was composed by the double star HD 150135/136. The spectrum of that star is O7V. The data on that star are in the Table 1. From that table we can see, that the values of $J-H$ and $H-K$ are very low, which indicates that there is no dust envelope around that star. For O7V type star in [14] we have $M_V = -5.3$, $(B-V)_0 = -0.35$, hence $E_{B-V} = 0.48$ and $A_1 = 1.584$. We have $V - M_V - A_V = 10.47$ and for the distance we have 1.23 kpc.

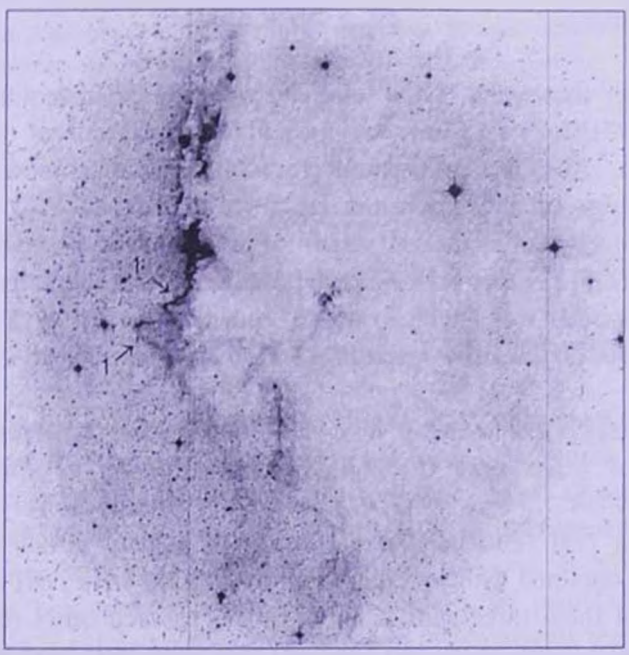

Fig.5. Image of second radial system, obtained on 1.54m telescope with SII filter. 1 - dark globules. *N* is to the top, *E* is to the left. The sizes of image are 14' x 14'.

There are two HH objects in this region. 1. This object looks like a spiral galaxy (a condensation with two spiral arms, see Fig.6a). The coordinates of that object are: $\alpha_{2000} = 16^h40^m11^s.89$, $\delta_{2000} = -48^\circ48'59''.2$. The object is situated in the dark cloud near the bright rim, originated by the star HD 150135/136. On 2MASSS K image on the place of the HH object a star NOMAD1 0411-0583316 (star 5 in Table 1) is situated. IR colors indicate that the star has a dust envelope or disc, because for that star $Q = 1.733 - 1.7 \cdot 1.402 = -0.65 < -0.10$. This object coincides with an X-ray source SRC 414 [18]. For that HH object our image

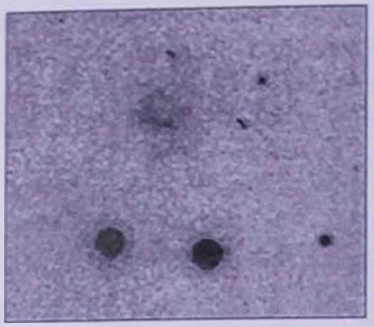

Fig.6a. Image of HH object, looking like spiral galaxy, obtained on 1.54m telescope with R filter. N is to the top, E is to the left. The sizes of image are 35" x 35".

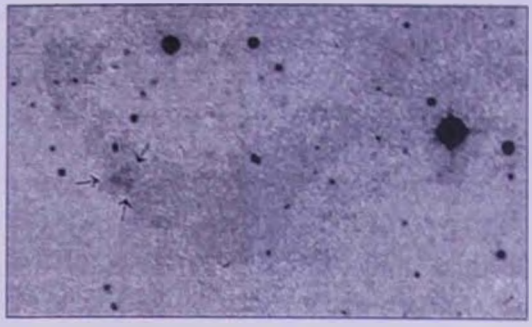

Fig.6b. Image of trapezium-like HH object, obtained on 1.54m telescope with Hα filter. N is to the top, E is to the left. The sizes of image are 1' x 2'.

with SII filter shows that HH is faint and with Hα filter very faint and hence $SII(6717+6731)/H\alpha > 1.5$ and due to [16] the spectrum of HH is of low excitation. 2. This object consists of a group of three condensations (see Fig.6b). The coordinates of that group are: $\alpha_{2000} = 16^h40^m36^s.56$, $\delta_{2000} = -48^\circ52'29''.8$. The object is situated in the HII region of radial system, originated by the star HD 150135/136. For that HH object our SII filter image shows that HH is bright and with Hα filter very bright, so we can conclude that $SII(6717+6731)/H\alpha < 1$, and hence due to [16] the spectrum of HH object is of high or intermediate excitation.

In this region exists also a very interesting object, trapezium-like system, consisting of three stars (the coordinates of center of this system are: $\alpha_{2000} = 16^h39^m39^s.7$, $\delta_{2000} = -48^h46'42''.5$). Such systems are very unstable, and hence young [19]. The stars of the system have very similar brightness. In our images, obtained with different filters (B, R, Hα, Hβ, SII and OIII), the brightness of these three stars is almost equal to each other (in R the mean value is 16.27 ± 0.20), so we can conclude that these stars have similar spectral types. The distance between the stars is about 4", or if the distance to this object is 1.3 kpc, for the distance between the stars we will have 4200 A.U.

In [20] were discussed the trapezium-type systems and was suggested a special class of tight systems, which have dimensions in the range 2000 - 20000 A.U. This system has dimensions, which are within above mentioned range, and hence the system is a trapezium-type tight system.

3. *Conclusions.* In this paper two new radial systems of dark globules as well as several new HH objects were found in Southern Hemisphere due to optical observations with narrow band filters.These objects are connected with star forming regions.Both radial systems are illuminated by O type stars. HH objects have interesting configurations: one of them resembles spiral galaxy, the other consists of three condensations, which have trapezium-type configuration, the third has configuration of spiral tails. With one HH object an X-ray source is connected. ^{12}CO(1-0) observations revealed existence of red shifted and blue shifted outflows around double stars with nebular tails. We also discovered rotation of a part of dark cloud with angular velocity $\Omega = 4.3 \cdot 10^{-14}\ s^{-1}$. This rotation is supposed to be a part of rotation of *IR* nebula. In the dark nebula, connected with the second radial system, a tight trapezium-type system, consisting of three stars with almost equal brightness in different spectral regions, was discovered.

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НОВЫЕ РАДИАЛЬНЫЕ СИСТЕМЫ ТЕМНЫХ ГЛОБУЛ И ОБЪЕКТЫ ХЕРБИГА-АРО

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Во время поиска на картах Южного неба мы нашли несколько десятков новых объектов Х-А, областей звездообразования, кометарных туманностей [1]. Около этих объектов имеются также радиальные системы темных глобул. Ряд областей с этими объектами были пронаблюдены на 1.54-м телескопе с несколькими узкополосными фильтрами. В этой статье мы представляем результаты наблюдений двух новых радиальных систем темных глобул, а также результаты ^{12}CO(1-0) наблюдений темного облака, часть которого вращается с угловой скоростью $\Omega = 4.3 \cdot 10^{-14}\ c^{-1}$.

Ключевые слова: *область звездообразования: молекулярные облака: объекты Хербига-Аро*

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