АСТРОФИЗИКА

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CO OBSERVATIONS OF SOUTHERN MOLECULAR CLOUDS. OUTFLOWS FROM YOUNG STELLAR OBJECTS GRV 8 AND GRV 16

A.L.GYULBUDAGHIAN[1], J.MAY[2]

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^{12}CO (1-0) observations of two Southern dark clouds (globules) associated with cometary nebulae GRV 8 (a biconical nebula) and GRV 16 (a cone-like nebula) are presented. GRV 8 shows an outflow from the central part of the nebula (where in 2MASS images a star is located, which is perhaps responsible for this outflow), however, both lobes of the outflow are redshifted with a velocity of +1.95 km/s with respect to the molecular cloud. The two opposite redshifted lobes are a rather rare phenomenon that could be explained by the presence of a double star instead of a single one as the engine responsible for the outflow. The two lobes are almost parallel to the axis of symmetry of the biconical nebula. In the case of the cone-like nebula GRV 16 we observe a bipolar outflow, where the eastern blueshifted lobe has a velocity of -4 km/s with respect to the molecular cloud, and the western redshifted one has a velocity +2.5 km/s. The outflow has a direction almost coinciding with the axis of symmetry of the cone-like nebula. The star associated with the cone-like nebula is responsible for this outflow.

Key words: *ISM:molecular clouds:individual:GRV 8, GRV 16*

1. *Introduction.* This paper is the second in the series of papers devoted to the observations of Southern molecular clouds, connected with YSOs (young stellar objects) from the lists of southern unstable objects [1] and [2] (the first paper from this series is [3], where the data on fast rotation of a dark globule is presented). In several clouds we observed molecular outflows (redshifted or blueshifted, or both redshifted and blueshifted), and in one case we detected the rotation of a cloud with high angular velocity (in paper [3] the rotation of a globule connected with the YSO object CLN 127-128 is presented).

The molecular outflows can be divided in two types: 1. Outflows connected with massive stars (or protostars) in large star-forming regions (e.g. core of the Orion molecular cloud), 2. Outflows associated with stars of low and intermediate masses (e.g. T Tauri or Herbig Ae/Be type stars) [4].

In this paper we present the results of observations of two molecular clouds connected with objects GRV 8 and GRV 16, YSOs from the list [1]. In both cases we have molecular outflows; a bipolar outflow appears associated with GRV 16, while a rather peculiar one appears connected with GRV 8, where both opposite lobes are redshifted.

The ^{12}CO (1-0) observations 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 is 45" and the beam efficiency is 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-resolution acousto-optical spectrometer with 1000 channels and a velocity resolution of 0.112 km/s.

2. *Observations of a molecular cloud connected with GRV 8.* The distance to GRV 8 is estimated as 1450 pc, assuming that GRV 8 is in the OB-association Vela OB 1, which is at this distance [5] (in [5] this object

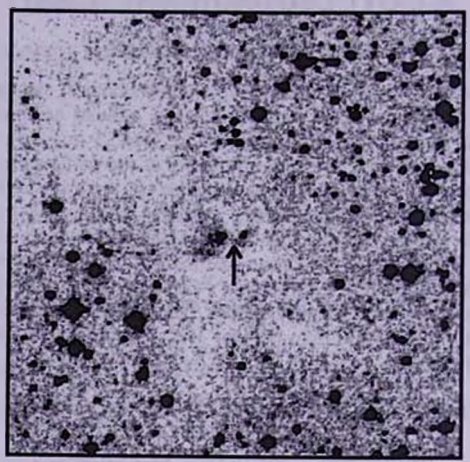

Fig.1. DSS2 *R* image of GRV 8. N is to the top, E to the left. The sizes of image are 6'x6'. The arrow shows the centre of biconical nebula, where in 2MASS images a star is situated.

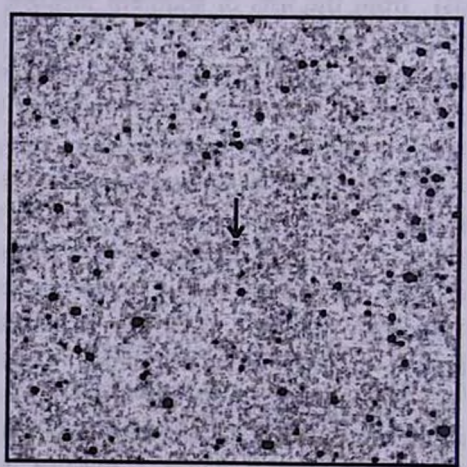

Fig.2. 2MASS *K* image of GRV 8. N is to the top, E to the left. The sizes of image are 6'x6'. The arrow shows the star, associated with GRV 8. In the very vicinity of this star several nebular objects are present.

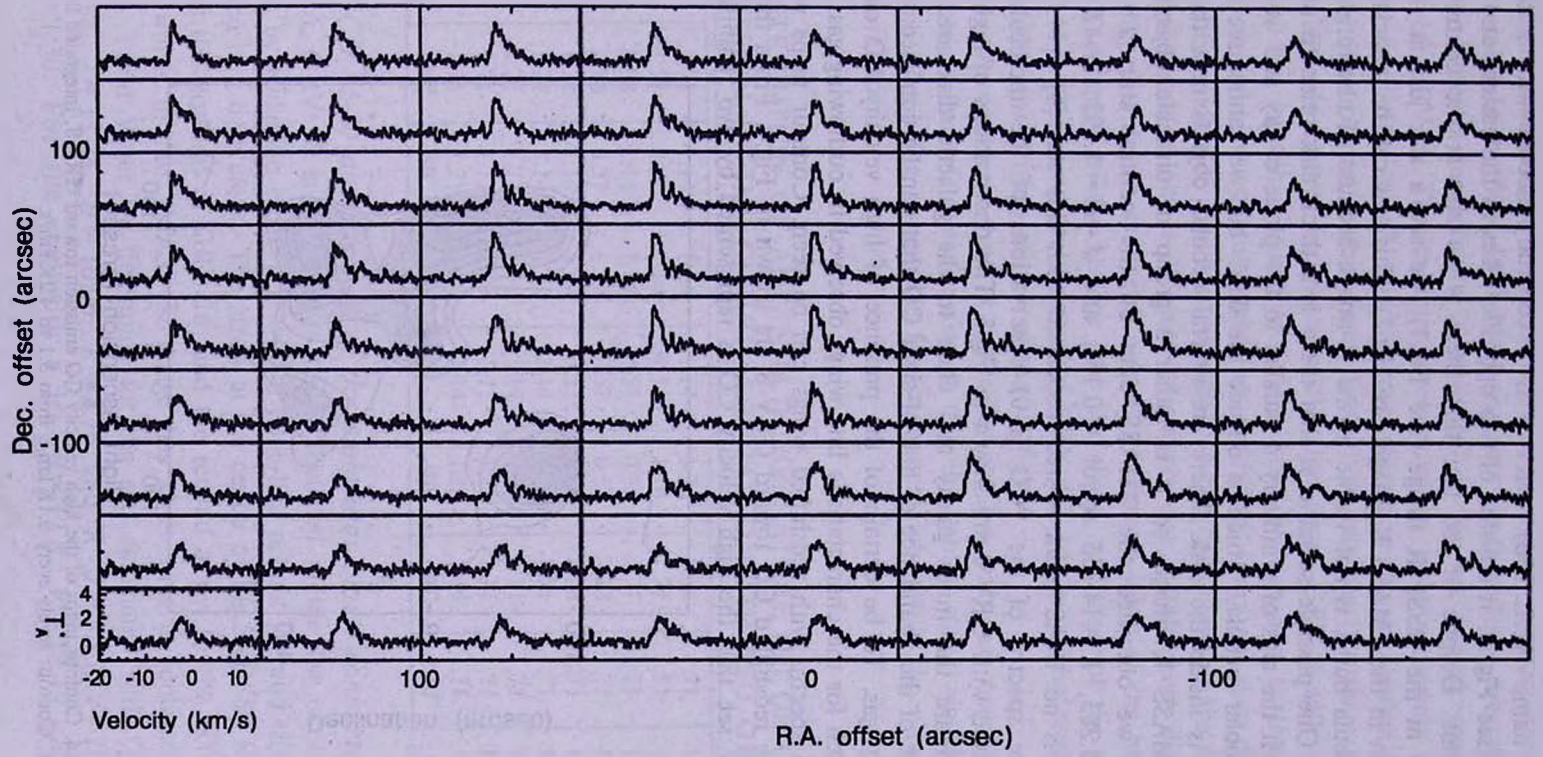

Fig.3. CO spectra of the molecular cloud associated with GRV 8 (HHL53 d).

has a name HHL 53d). GRV 8 is a cometary nebula with a biconical shape (see Fig.1). It consists of two opposite lobes in the eastern and western directions. Despite of the fact that there is no star at the centre of this nebula in the DSS2 R image (see Fig.1), we see a star just at the same position in the 2MASS K image (see Fig.2). This star can be associated with the nebula but it is not visible in the R image because of absorption in the cloud. One possible scenario is that there is a thick disk oriented in such a way that the axis of symmetry is parallel to the plane of sky and we can see the bipolar nebula, which is outside the disk, but we cannot see the star, which is inside the disk. There are several nebular objects near the star in the 2MASS K image, so it is rather a group of unstable objects. From Vizier we obtained the 2MASS data on the central star: $J = 16.876$, $H = 15.283$, $K = 14.355$ (error $= 0.15$), and $J - H = 1.593$, $H - K = 0.928$. There is no IRAS point source associated with this star [6].

The spectra of the ^{12}CO (1-0) observations of the molecular cloud connected with GRV 8 are shown in Fig.3. The observations of high velocity CO toward the inner galaxy and close to the galactic disk are difficult, because of the abundance of line-of-sight CO that can be confused with high velocity gas. To be certain of the presence of high velocity CO one needs to search for the characteristic line wings observed in outflowing gas. In Fig.3 several spectra with redshifted wings can be seen. Contour maps with high velocity redshifted CO toward GRV 8 are shown in Fig.4. From these maps we can see that the high velocity CO is represented by two redshifted lobes

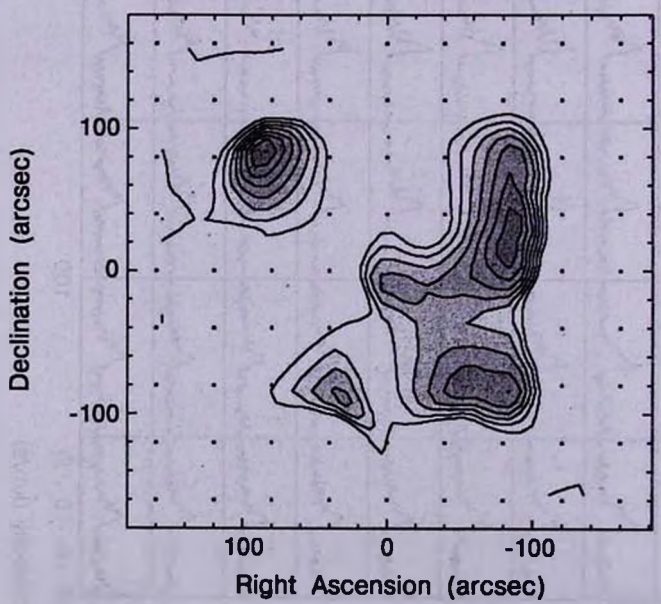

Fig.4. Contour maps of the high velocity CO emission toward GRV 8, integrated from -3 to -1.5 km/s. Contour levels every 0.1K km/s from 3.1 to 4.2K km/s.

in both eastern and western directions from the center position, showing a peculiar molecular outflow. In Table 1 the data on these lobes are presented where the antenna temperature is expressed in K. An asterisk marks the position of GRV 8. The columns correspond to right ascension (1950), increasing from right to left, and the rows correspond to declination (1950), increasing from bottom to top. From Table 1 we can see that there are two opposite lobes in eastern and western directions from GRV 8 with velocity -1.8 km/s, that is with a velocity of +1.95 km/s with respect to the cloud. It means that the two opposite lobes are redshifted. From the data of Table 1 (with equal widths of rows and columns) we can conclude that the position angle of the eastern lobe is 80°, and of western one is 285°, both directions almost aligned with the symmetry axis of the optical lobes of the biconical nebula. The length of the eastern lobe is 1.02 pc, and that of the western one is 0.44 pc (assuming the distance to GRV 8 is 1450 pc). The central star is presumably the driving source of the outflow.

This case, where we have a molecular outflow with two opposite redshifted lobes is rare. Our explanation is that the central star is double, with one of the stars being responsible for the eastern lobe while the other - for the western one.

Table 1

DISTRIBUTION OF ANTENNA TEMPERATURE (K) OF CO EMISSION IN THE CLOUD ASSOCIATED WITH YSO GRV8

1.71	1.71	1.14	1.14	1.14	1.71	1.14	1.71	1.71
1.71	1.71	0.57	1.14	1.14	1.14	1.71	1.71	1.71
1.71	**2.28**	1.14	1.14	0.57	0.57	1.71	1.71	1.71
2.28	**2.28**	0.57	1.14	0.57	0.57	**2.28**	1.71	1.71
2.28	1.71	1.14	1.14	0.57*	1.14	**2.28**	1.71	1.71
2.28	1.71	1.14	1.71	1.14	1.71	1.71	1.71	1.14
1.71	1.71	1.71	1.71	1.14	1.71	1.71	1.71	1.14
1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.14
1.71	1.71	1.71	1.71	1.14	1.14	1.14	1.71	1.14
160"	120"	80"	40"	0"	-40"	-80"	-120"	-160"

3. *^{12}CO (1-0) observations of the molecular cloud connected with GRV 16.* GRV 16 is a star (this star is included in the list of suspected variables by Kukarkin et al. [7]) with a cone-like nebula [1] and this object is situated in a dark cloud. The arrow at the centre of Fig.5 (DSS2 R image) indicates the position of GRV 16, and the second arrow to the NW shows a star, which in the 2MASS K image has a jet with a condensation at the end. From Vizier we determine for the star associated with GRV 16: $R = 16.88$, $J = 11.73$, $H = 10.06$, $K = 8.76$ and $R - J = 5.15$, $J - H = 1.67$, $H - K = 1.30$. For the star with a jet: $B = 12.8$, $V = 12.19$, $R = 11.7$,

$J = 10.64$, $H = 10.35$, $K = 10.22$ and $B - V = 0.61$, $R - J = 0.86$, $J - H = 0.30$, $H - K = 0.12$. For the condensation we get: $J = 13.96$, $H = 12.14$, $K = 11.36$ (error is about 0.03) and $J - H = 1.83$, $H - K = 0.78$.

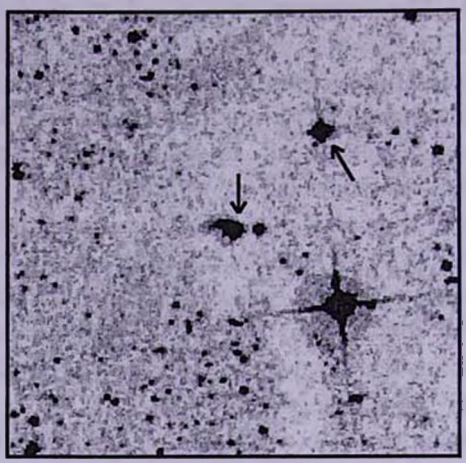

Fig.5. DSS2 R image of a cone-like nebula GRV 16. N is to the top, E to the left. The sizes of image are 6'x6'. The arrow in the centre of image shows the object GRV 16, the second arrow (to NW) shows the star with a jet, visible in 2MASS images.

In Table 2 we present near IR data on several types of stars, namely: T Tauri type stars (№1 and 2), Herbig Ae/Be stars (№3-8), a star associated with GRV 8 (№9), a star associated with GRV 16 (№10), a star with a jet in NW direction from GRV 16 (№11), a condensation at the end of this jet (№12), and two occasional late M type stars from [8] (№13 and 14). In Table 2 the following information is given: the number for each

Table 2

NEAR IR COLOURS FOR SEVERAL TYPES OF STARS

NN	Name	Spectra	$R-J$	$J-H$	$H-K$
1	T Tauri	F8Ve - K1IV-Ve	1.46	1.0	0.91
2	V350 Cep	M2	2.0	1.02	0.68
3	V380 Ori	A+neb	2.71	1.14	1.02
4	NX Pup	A0/F2IIIe	1.42	1.29	1.21
5	T Ori	B8 - A3eap	1.68	1.03	1.02
6	PV Cep	A5e + shell	4.45	2.85	2.2
7	HK Ori	B7 - A4ep	3.0	1.1	1.0
8	MWC 1080	B0e + shell	3.54	1.48	1.15
9	GRV 8 (star)	----	----	1.59	0.93
10	GRV 16 (star)	----	5.15	1.67	1.30
11	Bright star	----	1.06	0.30	0.12
12	condensation	----	----	1.83	0.78
13	HD 13913	M9	4.3	0.9	0.32
14	HD 14028	M9	7.1	1.08	0.38

star (column 1), the name of each star (column 2), the spectra of the stars (column 3), and the values of near IR colours (columns 4-6) (from Vizier).

From Table 2 we can conclude that the near IR colours for the stars associated with GRV 8 and GRV 16 are closer to the values for Herbig Ae/Be stars rather than to T Tauri type stars. For star with a jet (star №11) near IR colours are rather small, that is, this star has no thick circumstellar disk. Assuming that the condensation (№12) at the end of star №11 is a very red star just because it is invisible, but since the star connected with it by a jet is rather bright, we can suppose that the condensation is a late M type star. If we compare the data for the condensation (№12) with occasional late M type stars (№13 and 14), it is evident that the condensation has much larger values of near IR colours, and hence the condensation presumably has a circumstellar disk.

GRV 16 is associated with an IRAS point source IRAS 14568-6304. In [9] a rather successful attempt was done for classification of IR sources on the basis of their IR colours. Three quantities are involved: $R(1,2) = \log((F(25) \times 12)/(F(12) \times 25))$; $R(2,3) = \log((F(60) \times 25)/(F(25) \times 60))$; $R(3,4) = \log((F(100) \times 60)/(F(60) \times 100))$. For different kinds of IR sources these parameters have been computed and for the following three types of young objects these parameters are within the ranges: 1) objects associated with water masers, $R(1,2) = (0.2 - 0.8)$, $R(2,3) = (0 - 1.3)$, $R(3,4) = (-0.3 - 0.3)$; 2) T Tauri type stars, $R(1,2) = (-0.25 - 0.15)$, $R(2,3) = (-0.5 - 0.1)$, $R(3,4) = (-0.25 - 0.2)$; and 3) cold sources embedded in dark clouds, $R(3,4) > 0.3$. Since for the source IRAS 14568-6304 we obtain from [5]: $R(1,2) = -0.05$, $R(2,3) = -0.07$, $R(3,4) = -0.19$, we can conclude that this source is a type 2 source, that is, its IR colours are typical for a T Tauri type star. We could anticipate such result because all the so far known cone-like nebulae are associated mainly with T Tauri type or Herbig Ae/Be type stars.

In [5] the distance to GRV 16 is estimated as 1500 pc, assuming that the cloud is in the OB-association Cen OB 1, which is located at this distance (in [5] GRV 16 has the name HHL 53f). The position angle of the axis of symmetry of the cone-like nebula is 110°.

^{12}CO (1-0) spectra of the molecular cloud associated with GRV 16 are shown in Fig.6. The main peak at -6 km/s corresponds to the velocity of the cloud, while the weaker and high velocity emission at -10 km/s (Fig.7) and -3.5 km/s (Fig.8) indicates the presence of a bipolar molecular outflow associated to GRV 16. In Table 3 the distribution of antenna temperature (K) of the high velocity CO at -10 km/s is presented. The columns correspond to right ascension (1950), increasing from right to left (the width of each column is 40"), and the rows correspond to declination (1950), increasing from bottom to top (the width of each row is 40"). An asterisk marks

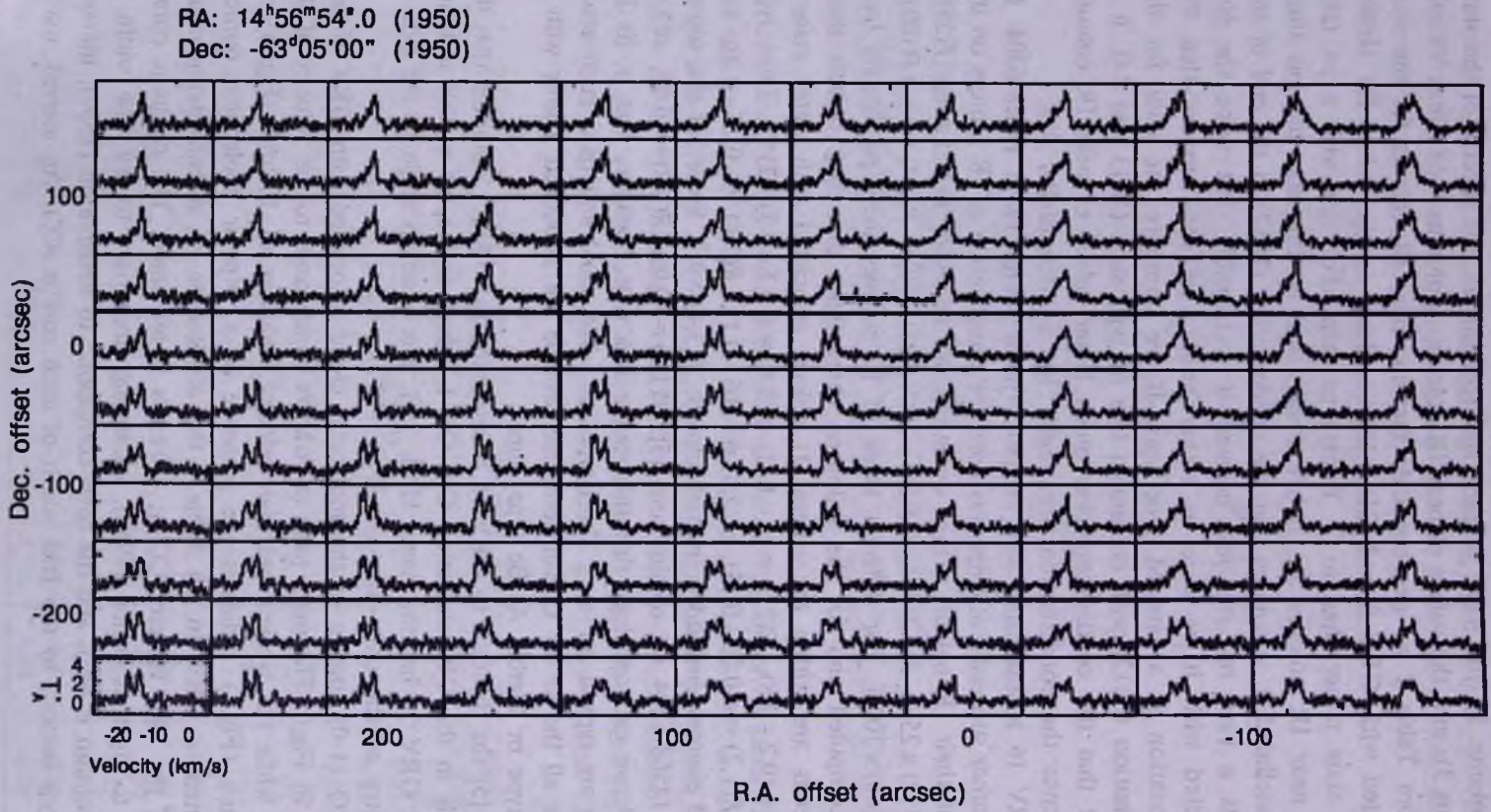

Fig.6. CO spectra of the molecular cloud associated with GRV 16 (HHL 53f).

the position of GRV 16. Table 3 and Fig.7 show that there is an eastern blueshifted component of a bipolar outflow with position angle 125°, which is rather close to the position angle of axis of symmetry of the cone-like nebula, 110°. The length of the blueshifted molecular lobe is 1.35 pc, assuming a distance to GRV 16 of 1500 pc. The velocity of blueshifted lobe with respect to the ambient material of the cloud is -4 km/s. Fig.8 shows a map of the redshifted high velocity CO emission in the western direction

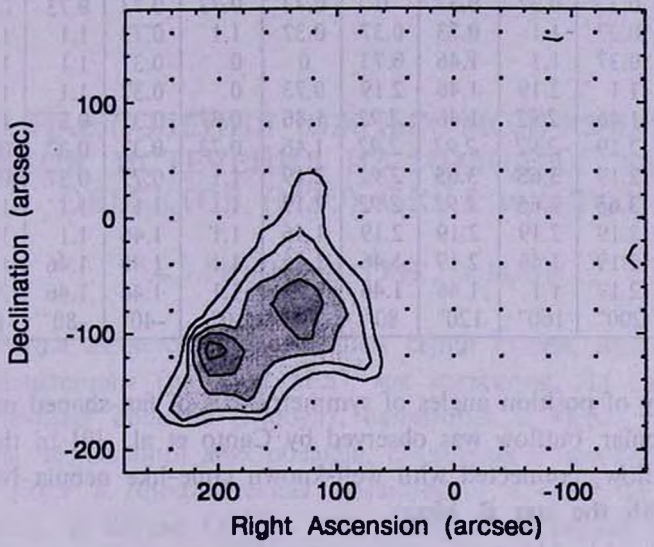

Fig.7. Contour map of the high velocity CO emission toward GRV 16 integrated from -12 to -8 km/s. Contour levels every 0.5K km/s from 5.5 to 8K km/s.

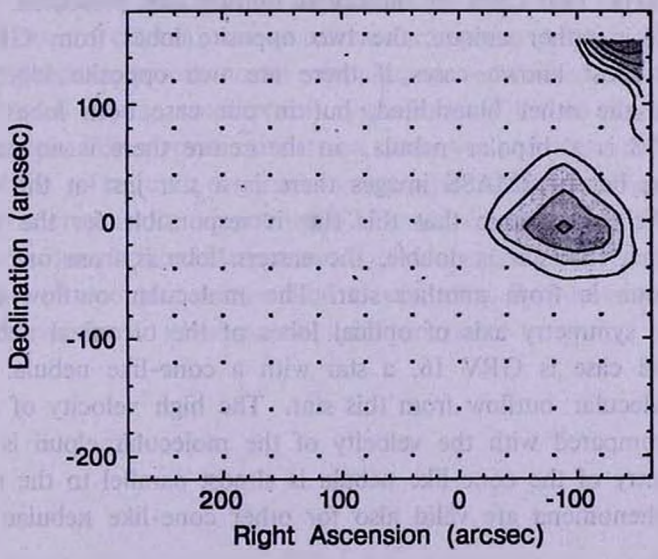

Fig.8. Contour map of the high velocity CO emission toward GRV 16 integrated from -5 to -2 km/s. Contour levels every 0.5K km/s from 1.5 to 4.5K km/s.

from GVR 16. This redshifted component is much weaker than the blue-shifted one (presumably because of absorption). The velocity of redshifted lobe with respect to the ambient material of the cloud is +2.5 km/s. The

Table 3

DISTRIBUTION OF ANTENNA TEMPERATURE (K) OF CO EMISSION IN THE CLOUD ASSOCIATED WITH YSO GRV 16

0	0	0.37	0.37	0.37	0	0.73	0.73	0.73	0.73	0.73	1.46
0	0	0.37	1.1	0.73	0.37	0.37	1.1	0.73	1.1	1.1	1.46
0.37	0.37	0.37	1.1	1.46	0.73	0	0	0.37	1.1	1.1	1.46
0.73	1.1	1.1	2.19	1.46	2.19	0.73	0	0.37	1.1	1.46	1.46
1.46	1.1	1.46	*2.92*	1.46	*2.92*	1.46	0.37*	0.37	0.37	1.1	1.46
2.19	2.19	2.19	*2.92*	*2.92*	*2.92*	1.46	0.73	0.37	0.37	0.73	1.46
2.19	2.19	2.19	**3.65**	**3.65**	*2.92*	2.19	1.1	0.73	0.37	0.73	1.46
2.92	2.19	**3.65**	**3.65**	*2.92*	*2.92*	2.19	1.1	1.1	1.1	1.46	1.46
2.19	*2.92*	2.19	2.19	2.19	2.19	1.46	1.1	1.46	1.1	1.46	2.19
2.92	*2.92*	2.19	1.46	2.19	1.46	1.46	1.1	1.46	1.46	1.46	2.19
2.92	*2.92*	2.19	1.1	1.46	1.46	0.73	1.1	1.46	1.46	2.19	1.46
280"	240"	200"	160"	120"	80"	40"	0"	-40"	-80"	-120"	-160"

same similarity of position angles of symmetry axis of fan-shaped nebula and bipolar molecular outflow was observed by Canto et al. [9] in the case of molecular outflow, connected with well-known cone-like nebula NGC 2261 (associated with the star R Mon).

4. *Conclusions.* This paper is the second in the series of ^{12}CO (1-0) observations of dark clouds, connected with interesting southern YSOs (from lists [1] and [2]). Two cases of molecular outflow are presented. The first case, GRV 8, is rather unique: the two opposite lobes from GRV 8 are redshifted. In most known cases if there are two opposite lobes, one is redshifted and the other blueshifted, but in our case both lobes are red-shifted. GRV 8 is a bipolar nebula, in the centre there is no star in the optical images, but in 2MASS images there is a star just at the centre of the nebula. We can assume that this star is responsible for the molecular outflow and that this star is double, the eastern lobe is from one star, and the western one is from another star. The molecular outflow is almost parallel to the symmetry axis of optical lobes of the biconical nebula.

The second case is GRV 16, a star with a cone-like nebula. There is a bipolar molecular outflow from this star. The high velocity of the blue-shifted lobe compared with the velocity of the molecular cloud is -4 km/s. Axis of symmetry of the cone-like nebula is almost parallel to the molecular lobes. Such phenomena are valid also for other cone-like nebulae (e.g. for NGC 2261).

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[1] Byurakan Astrophysical Observatory, Armenia, e-mail: agyulb@bao.sci.am
[2] Departamento de Astronomia, Universidad de Chile, Chile, e-mail: jmay@das.uchile.cl

CO НАБЛЮДЕНИЯ ЮЖНЫХ МОЛЕКУЛЯРНЫХ ОБЛАКОВ. ИСТЕЧЕНИЯ ИЗ МОЛОДЫХ ЗВЕЗДНЫХ ОБЪЕКТОВ (МЗО) GRV 8 и GRV 16

А.Л.ГЮЛЬБУДАГЯН[1], Х.МАЙ[2]

Эта статья является продолжением серии статей, посвященных CO (1-0) наблюдениям (на 15-м SEST мм телескопе, Ла Силлья, Чили) южных темных облаков (глобул), связанных с МЗО. Представлены результаты наблюдений двух облаков, связанных с кометарными туманностями GRV 8 (биконическая туманность) и GRV 16 (коническая туманность). В случае GRV 8 обнаружено биполярное истечение из центра кометарной туманности (где на 2MASS изображении есть звезда, ответственная за это истечение), обе половинки истечения сдвинуты в красную сторону спектра со скоростью +1.95 км/с по отношению к скорости самого облака, что является достаточно уникальным явлением. Оба молекулярных потока почти параллельны оси симметрии биконической туманности. В случае конической туманности GRV 16 зарегистрированы две половинки. Восточная половинка сдвинута в синюю сторону спектра со скоростью - 4 км/с по отношению к скорости самого облака, а западная - в красную сторону со скоростью +2.5 км/с, так что истечение, связанное с GRV 16, биполярное. Истечение имеет направление, почти совпадающее с осью симметрии конической туманности. За истечение ответственна звезда, связанная с конической туманностью.

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