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## SOUTHERN YSO GRV10 AND ITS ENVIRONMENT

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In the paper the southern cometary nebula GRV10 and its environment are investigated. The object is connected with a molecular cloud (its dimensions are  $\sim$ 4 pc). <sup>12</sup>CO (1-0) observations toward GRV10 revealed the presence of two molecular outflows (a bipolar outflow), a red and a blue-shifted outflow, which coincide in position, indicating that they are moving along the line of sight in opposite directions. Near GRV10 a bright IR star, GRV10 IR, is discovered (near the southern edge of the nebula) and since its spectra and near IR colours favour it to be a Mira type star, a distance of ~4.4 kpc can be estimated. Star GRV10 IR appears connected with the IRAS point source IRAS 10406-6256. The grouping of stars (YSOs - young stellar objects) connected with GRV10 and embedded in a dark nebulosity is also discussed. This grouping is associated with the IRAS point source IRAS 10406-6253, which has FIR colours typical for embedded not evolved YSOs.

# Key words: molecular clouds:bipolar outflows:Mira type stars:embedded grouping of YSOs

1. Introduction. During the survey of southern ESO/SRC plates [1,2] many non-stable young objects (cometary nebulae, HH objects, trapezium-type tight systems, etc.) have been discovered. Investigation of several of these objects has revealed the existence of molecular outflows, IR bright stars, associated with IRAS point sources (see e.g. [3,4]). In this paper one of these objects is investigated, a tail-like cometary nebula GRV10 from [1]. On DSS2 R image GRV10 looks like a double star with nebulous tails, connected with a dark cloud. The object is associated with the IRAS point source IRAS 10406-6253, which has colours characteristic of an embedded young star. On a 2MASS K image, it is evident that there is a group of stars embedded in a dark cloud. GRV10 is connected with the OB-association Car OB1, which is situated at the distance of  $\sim 2.7$  kpc. In the vicinity of GRV10 a very bright IR object GRV10 IR is located. Its spectrum and colours resemble Mira type variables. However, after making a comparison with other known distances to similar Mira type stars, we obtain a value of about 4.4 kpc for the distance of GRV10 IR.

2. <sup>12</sup>CO observations toward GRV10. The tail-like cometary nebula GRV10 appears connected with the OB-association Car OB1 [5], which is located at the distance of  $\sim 2.7$  kpc [6]. In [6] are given the mean velocity of

HII (-20 km/s) from radio recombination line measurements and mean CO velocity of -19 km/s. The both velocities are of objects belonging to Car OB1. These values are close to the value of CO velocity of GRV10 molecular cloud, given below (-15 -- 10 km/s), which is in favor of connection of GRV10 with Car OB1. The <sup>12</sup>CO (1-0) observations of the molecular cloud, associated with GRV10, were carried out on August 2003 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.

Fig.1 shows the <sup>12</sup>CO (1-0) spectra observed toward GRV10, arranged in a map-like distribution. It is evident from Fig.1 that there is a large molecular cloud in the direction of GRV10. Analyzing the data we find a main cloud



Fig.1. <sup>12</sup>CO (1-0) spectra toward GRV10, arranged in a map-like distribution.

and two outflows (a bipolar outflow with red and blue-shifted components), that is, a main cloud with velocities in the range (-15.5 to -10 km/s) (see Fig.2a), a red-shifted outflow with velocities in the range (-10 to -7 km/s) (see Fig.2b) and a blue-shifted outflow with velocities in the range (-19 to -15.5 km/s) (see Fig.2c). The red and blue outflows are seen almost at the same position indicating that they extend along the line of sight. Since the red-shifted outflow

#### SOUTHERN YS0 GRV10

shows elongation in the NE-SW direction while the blue-shifted outflow in the SE-NW direction, it appears that they are almost perpendicular to each other. The position of object GRV10 coincides with the densest part of main cloud (see Fig.2a, though we can suppose that it could be just a coincidence of coordinates, because the absorption of GRV10 is not as high as the star to be in the densest part of the cloud). The dimensions of dark cloud, connected with GRV10, are ~5', if the distance to the cloud is ~2700 pc, then the dimensions of cloud will be ~4 pc.



3. Embedded stars in the vicinity of GRV10. In Table 1 the data for stars in the vicinity of GRV10 are given. In column 1 the number of the star is presented, in column 2 - the name of the star, in columns 3 and 4 near infrared colours of the star and in column 4 - B - V of the star (all the data are taken from Vizier).

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-100

### A.L.GYULBUDAGHIAN, J.MAY

Table 1

NN	Name (NOMADI)	J - H	H - K	B - V
1	0268-0234241	0.568	0.444	1.63
2	0268-0234223	1.074	0.866	10. 10. 10.
3	0268-0234248	1.250	0.723	5 1 1 1 1 1 1 1 1 1
4	0268-0234237	0.737	0.641	- /
5	0268-0234208	0.583	0.999	a second second second
6	0268-0234242	0.151	0.996	

STARS, EMBEDDED IN THE CLOUD, IN THE VICINITY OF GRV 10

If we look at Table 1, we can make the following preliminary conclusions: star N1 is a late-type star (this star is probably connected with cometary nebula, which has arch-like filaments, see Fig.3a); stars 2 and 3 are also late type, but there is a rather strong absorption (because of large J - H); stars 4 and 5 are also late-type but N5 has a disc (because of large H - K); star N6 is rather an early type (J - H is low) with a disc (also because of large H - K).

During this investigation a very bright star in near IR (star GRV10 IR) was discovered. In Fig.3b GRV10 IR is marked as star 3. The first impression was that that star is an YSO deeply embedded in the same cloud as GRV10.

The spectrum of GRV10 IR (see below) shows bands of CO, TiO, VO, typical for late-type stars (in Vizier for that star spectral type M9 is given). In Table 2 several Mira type variables, SR (semi-regular) supergiants and YSOs, which like GRV10 IR are rather bright in near IR, are given. Column 1 shows the star number, column 2 presents the name of each star, column 3 includes



Fig.3. a) DSS2 R image of GRV10. N is to the top, E to the left. Size of the image is  $6' \times 6'$ . 1 - cometary nebula (arch-like filaments), 2 - the bright in near IR star GRV10 IR. b) 2MASS K image of GRV10. N is to the top, E to the left. Size of the image is  $6' \times 6'$ , 1 - group of embedded YSOs, 2 - IRAS point source IRAS 10406-6253, 3 - star GRV10 IR and the associated IRAS point source IRAS 10406-6256, 4 - star 7 (nearest to IRAS 10406-6253).

the value of B - V for each star, while columns 4 and 5 - the corresponding near infrared colours and column 6 - spectral type of the star (all these values are taken from Vizier). Stars NN1 - 7 are Mira type variables, NN9 - 11 are semi-regular stars, NN12 - 14 - YSOs (N12 - star 3 from [7], N14 - star 16 from [8]). These types of stars have been chosen to compare them with GRV10 IR (they have large values of R - J and R - K like GRV10 IR). If we look at Table 2, we can conclude that the star GRV10 IR has B - V and IR colours rather close to Mira variables. Star GRV10 IR is projected on the main cloud near its southern boundary (in Fig.2a, the star is just out of the shown contour map).

Table 2

NN	Name	B - V	R-J	J - H	H - K	R - K	Sp
1	HD13913	1.439	2.89	0.9	0.32	4.112	M3e-M6e
2	HD14028	1.1	7.11	1.09	0.37	8.571	M8eg
3	R Leo	1.5	4.91	1.035	0.537	6.482	M6.5-M9e
4	Chi Cyg	1.55	7.022	1.269	0.594	8.885	M7e/S7e
5	R Hydra	1.24	7.914	0.921	0.428	9.263	M6/7 e
6	ВН Сти	2.766	4.743	1.025	0.527	6.295	SC4.5e-SC8e
7	R Lep	2.7	6.34	1.276	0.747	8.363	C7.6e, M5.1
8	IR GRV10	1.49	7.929	1.319	0.660	9.908	M9
9	RU Pup	3.72	4.621	1.289	0.695	6.635	C5.4(N3)
10	T Cae	2.438	4.143	1.069	0.450	5.662	C6.4(N4)
11	S Cen	1.995	2.815	1.085	0.406	4.416	C4.5
12	star 3 [7]	2.23	6.065	2.829	1.969	10.863	total community
13	PV Cep	- 1200	4.45	2.85	2.2	9.50	22243 276 20
14	GRV16(star)[8]	1	5.15	1.67	1.30	8.12	aner st.

### LATE-TYPE STARS BRIGHT IN NEAR IR (GIANTS, SUPERGIANTS AND YSOS)

The observations of the spectrum of GRV10 IR were carried out on the 3.5 m NTT telescope with SOFI (Cerro La Silla, Chile). The red part of the spectrum was obtained on 20 of August 2003, and the blue part on 1 of September 2003 (together they fill the spectrum from  $0.6 \,\mu\text{m}$  to  $2.6 \,\mu\text{m}$ , see Fig.4). In the spectrum of GRV10 IR the bands of CO, TiO, VO are present (see Fig.4). Lancon noticed [9] that the spectrum of GRV10 IR corresponds to a luminous red star, not a dwarf. In [10] library (Lancon [9]), it looks similar to WW Sco (Fig. B22) or to some of the bulge AGB stars (Fig. B25), it is an AGB star rather than a supergiant (static giant is rarely so cool), and also it is possible to say that it is an O-rich AGB, not a C-rich. WW Sco is a Mira type star (M6e - M9, Vizier). Its characteristics are rather similar with GRV10 IR (see Table 2): R-J=8.250, J-H=0.991, H-K=0.565, R-K=9.806 (Vizier). In [10] is shown, that the strong H,O bands are characteristic features of variability in M type stars. Inside

#### A.L.GYULBUDAGHIAN, J.MAY

some subsamples of M type stars with similar optical spectra and global energy distributions the near IR spectra are rather different, e.g. strong H,O bands always imply large amplitude variability (see Fig.8 in [10]). None of the (quasi) static M giants of the sample show impressive H,O bands. If we look at Fig.4 of this paper, we can see that there are strong H,O bands (at  $1.1 - 1.25 \mu m$ ,  $1.35 - 1.55 \mu m$ ,  $1.7 - 2.1 \mu m$ ). It means that GRV10 IR can be a variable star. In the spectrum of GRV10 IR Lancon has noticed an absorption feature at  $1.27 \mu m$  (see Fig.4), which, if real, is rather interesting because it is absent in the spectra of other similar stars [9].



Fig.4. The spectrum of the star GRV10 IR (0.6 - 2.6  $\mu$ m), obtained on 3.5m NTT telescope with SOFI (Cerro La Silla, Chile). 1 - absorption feature at 1.27  $\mu$ m, noticed by Lancon [9]. Wavelengths are in  $\mu$ m, relative flux units are arbitrary.

For estimating the distance to GRV10 IR, we can use the distances to similar stars given in [11]. For several Mira type stars in [11] the following distances were obtained: R Aql (M5e - M9e) - 0.25 kpc; RR Aql (M6e - M9e) - 0.60 kpc; RS Vir (M6e - M8e) - 0.66 kpc; U Ori (M6e - M9.5e) - 0.27 kpc. Taking into account the J, H and K magnitudes of GRV10 IR (J=7.37, H=6.05, K=5.39 from Vizier), after comparing that value with the J, H and K magnitudes of given above Mira type stars, we obtain the following values for the distance to GRV10 IR: the data of R Aql give d=4.9 kpc, the data of RR Aql give d=5.1 kpc, the data of RS Vir give d=3.5 kpc, the data of U Ori give d=4.05 kpc. These values are rather close to each other ( $\sigma=0.32$  kpc). Then taking the mean value of the above distances, we obtain 4.4 kpc for the distance to GRV10 IR.

4. IRAS point sources near GRV10. There are two IRAS point sources in the vicinity of GRV10: IRAS 10406-6253, associated with a group of embedded YSOs, including GRV10 (see Fig.3b); and IRAS 10406-6256, associated with GRV10 IR itself [12]. In Table 3 the IR colours [13] for several IRAS point sources, associated with Mira type stars (see Table 3) are presented. In column 2 the name of the star is given, in column 3 - the IR colour  $R(1, 2) = \log((F_{25}\cdot12)/(F_{12}\cdot25))$ , in column 4 - IR colour  $R(2, 3) = \log((F_{60}\cdot25)/(F_{25}\cdot60))$  and in column 5 - IR colour  $R(3, 4) = \log((F_{100}\cdot60)/(F_{60}\cdot100))$ .

7	a	b	le	2	3

FIR COLOURS OF IRA	S SOURCES	CONNECTED	WITH
SEVERAL	MIRA TYPE	STARS	

NN	Name	<i>R</i> (1, 2)	R(2, 3)	R(3, 4)
1	WW Sco (IRAS16241-3111)	-0.699	-1.222	-0.125
2	HD14028 (IRAS02143+4404)	-0.699	-1.097	-0.6
3	R Leo (IRAS09448+1139)	-0.824	-1.15	-0.699
4	R Hydrae (IRAS13269-2301)	-0.745	-1.22	-0.699
5	GRV10 IR (IRAS10406-6256)	-0.824	0.49	1.301

From Table 3 we can see that the FIR colours for IRAS point sources, associated with Mira type stars, are rather similar for different stars. Regarding GRV10 IR, the value of R(1, 2) is close to the corresponding values of other Mira type stars, but R(2, 3) and R(3, 4) are rather different. It is possible to give two explanations: 1. there is a dust disc around that star, which increases the values of R(2, 3) and R(3, 4); 2.  $F_{60}$  and  $F_{100}$  for that star, given in [12], might not be right ( $F_{100}$  for IRAS 10406-6253 and IRAS 10406-6256 are identical [12], which is rather strange because, as a general rule, if the fluxes of neighbour IRAS sources are identical, one of them because of confusion should be wrong).

The point IRAS source IRAS 10406-6253 is associated with a group of YSOs (see Fig.3b). From [12] it is possible to obtain the following IR colours: R(1, 2) = -0.046, R(2, 3) = 0.253, R(3, 4) = 0.4. According to the classification in [13], this source is of type 3 (R(3, 4) > 0.3), that is, we are in the presence of a cold not evolved source, embedded in a dark cloud. It is not excluded the possibility that this source might be associated with one of the YSOs included in the grouping discussed above (with one of the stars with discs). The star 7 from Fig.3b is the nearest to IRAS 10406-6253. It has the following colours: B - V = 1.22, R - K = 4.35, J - H = 0.981, H - K = 0.328 (from Vizier). Due to these colours we can suppose, that star 7 is a late type star (mainly due to B - V it is a K - M type star).

5. Conclusions. Investigation on the environment of the southern taillike cometary nebula GRV10 has given some interesting results. <sup>12</sup>CO (1-0) observations of the molecular cloud associated with GRV10 (the dimensions of that cloud are ~4 pc) show that there is a bipolar outflow with its red and blue-shifted components directed along the line of sight. GRV10 appears connected with a grouping of YSOs, which are embedded in the molecular cloud and containing stars with dust discs. At the periphery of the molecular cloud a rather bright star in near IR (star GRV10 IR) is projected. Since the near IR colours and spectra of GRV10 IR are rather similar to the corresponding values for 5 already known Mira type stars (especially with the star WW Sco), a distance of  $\sim$ 4.4 kpc can be estimated. Two IRAS point sources are situated in the GRV10 region, one is associated with the star GRV10 IR, and the second with the grouping of YSOs. The second IRAS source has FIR colours typical for embedded not evolved YSOs.

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# ЮЖНЫЙ M3O GRV10 И ЕГО ОКРУЖЕНИЕ

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В статье исследована южная кометарная туманность GRV10 и ее окрестность. Объект связан с молекулярной туманностью (размеры этой туманности ~4 пк). Приведены результаты <sup>12</sup>CO (1-0) наблюдений этой туманности, из которой выходят два противоположных истечения (биполярное истечение), причем красное и синее истечения совпадают, т.е. они двигаются вдоль луча зрения в противоположных направлениях. Близ GRV10 (у южной границы туманности) обнаружена яркая ИК-звезда (GRV10 IR), спектры и ближние ИК-цвета которой свидетельствуют в пользу того, что это звезда типа Mira, которая возможно находится на расстоянии ~4.4 кпк. Звезда GRV10 IR связана с точечным ИК источником IRAS 10406-6256. Обсуждена также группа звезд (M3O - молодых звездных объектов), связанных с GRV10 и погруженных в темную туманность. Эта группа звезд связана с точечным ИК-источником IRAS 10406-6253, который имеет далекие ИКцвета, типичные для погруженных непроэволюционировавших M3O.

Ключевые слова: молекулярное облако:биполярное истечение:звезда типа Mira:погруженная группировка M30

#### REFERENCES

- A.L.Gyulbudaghian, L.F.Rodriguez, V.M.Villanueva, Rev. Mex. Astron. Astrofis., 25, 19, 1993.
- 2. A.L.Gyulbudaghian, J.May, L.Gonzalez, R.Mendez, Rev. Mex. Astron. Astrofis., 40, 137, 2004.
- 3. A.L. Gyulbudaghian, J. May, Astrofizika, 50, 5, 2007.
- 4. A.L. Gyulbudaghian, J. May, Astrofizika, 51, 470, 2007.
- 5. А.Л.Гюльбудагян, Астрофизика, 41, 382, 1982.
- 6. D.A. Grabelsky, R.S. Cohen, L.Bronfman, P.Thaddeus, Astrophys. J., 331, 181, 1988.
- 7. A.L. Gyulbudaghian, J. May, Astrofizika, 51, 469, 2008.
- 8. A.L.Gyulbudaghian, J.May, Astrofizika, 48, 101, 2005.
- 9. A.Lancon, private communication.
- 10. A.Lancon, P.R.Wood, Astron. Astrophys. Suppl. Ser., 146, 217, 2000.
- 11. J.Herman, J.H.Burger, W.H.Penninx, Astron. Astrophys., 167, 247, 1986.
- 12. IRAS Point Source Catalog, Version 2, 1988, Washington, D.C.
- 13. J. Wouterloot, C. Walmsley, Astron. Astrophys., 168, 237, 1986.