AN INTERESTING NEBULAR OBJECT IN LDN 288

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In this paper the results of multiwavelength investigation of an unusual nebular object SNO 85 are presented. In 2MASS images this object looks like a star with a jet. In DSS2 R *image the end of the jet is connected with an interesting symmetric structure, consisting of arcs and loops. Such a structure is seen also in the opposite direction from the central star; it favors the existence of two opposite jets, which repeat the rotation and precession movements of the central star. The results of* ^{12}*CO observations of the dark nebula LDN 288, connected with SNO 85, are also given. From these observations the following results were obtained: SNO 85 is situated in a dense condensation and the neighbor B type star GSC 0625400181 is surrounded by a hollow cavity. The velocity of the dark cloud is ~2.5 km/s and its distance is estimated as (380-990) pc. The object SNO 85 itself is associated with an IRAS point source IRAS 17547-1832, the infrared colors of this source are typical for a non-evolved source embedded in the dense dark cloud. This region is perhaps a star formation one because there is also another star with a straight jet in the vicinity of B type star GSC 0625400181.*

Key words: (ISM): dark nebulae - individual: LDN 288

1. Introduction

It is well known that stars of early spectral types make a cavity around themselves (in the surrounding molecular cloud, by stellar wind and/or radiation pressure) during their formation. Afterwards they ionize the matter of the cavity, and as a result we have an HII region around an early type star (see e.g. [1,2]). In this paper we investigate such an HII region around a B type star GSC 0625400181; we study also an interesting object SNO 85 [3] which looks like a star with a jet (or two jets). The latter draws a complicated figure because of simultaneous rotation and precession of the star connected with that jet. The results of ^{12}CO observations are also given, which are in favor of the existence of a cavity around the star GSC 0625400181 in the molecular cloud LDN 288. Other examples of existence of spiral jets due to rotation and precession of stars connected with them are also presented in the paper.

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2. Results of ^{12}CO observations

The B type star GSC 0625400181 and the object SNO 85 are situated in the large dark cloud LDN 288. The ^{12}CO (1-0) observations toward the vicinity of these objects were carried out in September 6, 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.

The velocity of the molecular cloud is ~2.5 km/s. In Fig.1 the radio map of distribution of ^{12}CO in the velocity range (2-3) km/s is given. We can see from Fig.1 that there is a cavity around the star GSC 0625400181, while the object SNO 85 is situated in the densest part of the cloud. This cavity in the visible corresponds to an HII region around the star GSC 0625400181.

3. The object SNO 85

SNO 85 is a very interesting nebular object in the Southern Hemisphere, discovered on ESO/SRJ plates and presented in [3]. In DSS2 images it looks like a nebular patch (see Fig. 2), while in 2MASS images it shows up as a star with a jet (see Fig. 3), and the end of this jet is seen also in the DSS2 images as a patch. This object in the CO map is situated in the dense condensation in the molecular cloud (see Fig.1). Looking at SNO 85 more carefully in the DSS2 *R* image it is possible to see a symmetric structure near the object (see Fig. 2). This structure consists of loops and arcs.

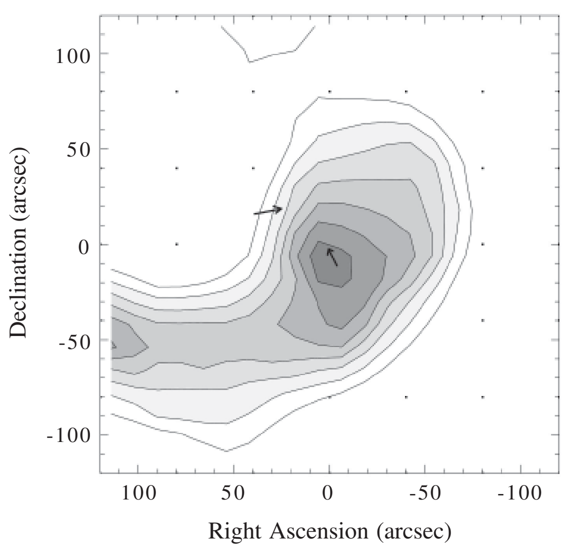

Fig.1. Integrated intensity map of CO emission toward SNO 85. The integration range is (2-3) km/s. Contours are from 12 to 18 K km/s in steps of 1 K km/s. The positions of SNO 85 (in the dense condensation) and the star GSC 0625400181 (in the cavity) are indicated by arrows.

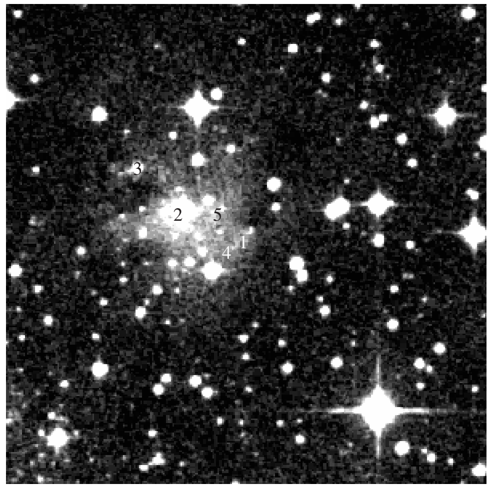

Fig. 2. DSS2 *R* image of SNO 85. *N* is to the top, *E* to the left. The size of the image is 6' × 6'. 1 - the object SNO 85, 2 - the B type star GSC 0625400181, 3 - the star with a straight jet, 4, 5 - symmetric structures, consisting of arcs and loops.

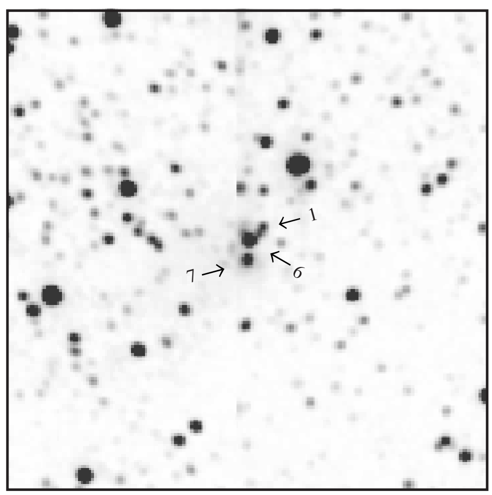

Fig.3. 2MASS *K* image of SNO 85. *N* is to the top, *E* to the left. The size of the image is 6' × 6'. 1 - the object SNO 85, 6 - the star connected with SNO 85, 7 - the neighbor star, invisible in optics.

Assuming that the jet is rotating with the star and also participating in the precession movement of the star (the star might be double to account for precession), we can explain the existence of arcs and loops at the end of the jet.

A similar structure is seen in the opposite side of the star 6 (see Fig.3). We can assume that there is a second jet in the opposite direction from star 6, and the end of this jet draws almost the same structure as the first one. The second structure in the visible coincides with the source VLA2 in [4] (see also Fig.4). The source VLA2 was obtained as a result of VLA observations at a wavelength 3.6 cm. The 3.6 cm radio continuum observations were carried out in 2004 March

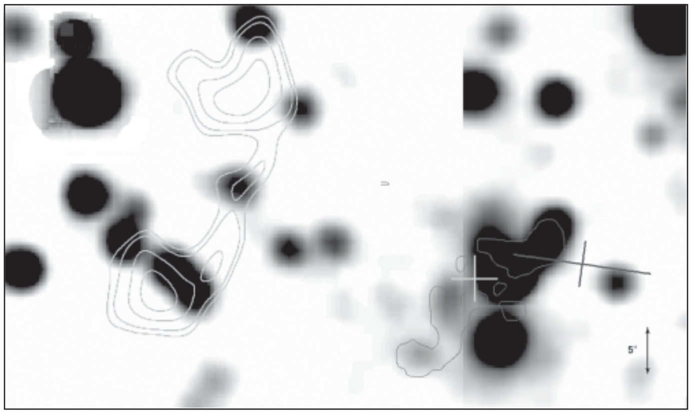

Fig. 4. VLA 2 source (eastern contour map), IRAS 17547-1832 (large cross) and MSX 6 microns source (small cross) on the 2MASS *K* image of SNO 85. *E* is to the left, *N* to the top. The shape and position of VLA 2 coincide with structure 5 in Fig.3.

27 using the VLA in the C configuration, providing an angular resolution of ~4" (see [4]).

The jets ionize matter while they propagate through their trajectories. During a definite period of time the ionized matter remains unchanged (the time of relaxation), afterwards recombination takes place. In [5] a formula for calculating the time of relaxation t^* of an ionized medium, after switching off the sources of ionization, is given:

$$t^* = 1/\left(n_e \cdot \Sigma A_{ci}\right), \qquad (1)$$

where n_e is the electron density and A_{ci} are the recombination coefficients; summing is from 2 to infinity. The value of n_e in the HII regions usually is in the range (10^2-10^3) cm^{-3}, hence the value of t^* will be in the range (150-1500) years (see [6]).

The star 6 (see Fig.3) is associated with an IRAS point source IRAS 17547-1832. The infrared colors of this source are such that the value of $R(3,4) = \log((F(100) \cdot 60)/(F(60) \cdot 100))$ is $R(3, 4) = 0.5$ and hence $R(3, 4) > 0.3$. This means (see e.g. [7]) that IRAS 17547-1832 is not yet an evolved source embedded in the dark cloud.

4. Distance to SNO 85

Unfortunately we do not know the spectral type of the star GSC 0625400181 and, therefore, we cannot estimate the distance to SNO 85 directly.

SNO 85 is situated in the dark nebula LDN 288. Two stars with known spectra are projected on this cloud, and because this cloud is almost opaque, its distance should be larger or equal to the distance to these stars. These stars are as follows:

The star SAO 160937. The following data are available for this star in Vizier: $V = 8^m.8$, $B - V = 0^m.326$, spectral type is A1 III. For such a spectral type we have in [8]: $M_V = -0^m.1$, $(B - V)_0 = 0^m.1$. If we take $R_V = 3.2$, we will obtain $A_V = 0^m.823$ and hence the distance module $DM = V - M_V - A_V = 8^m.077$.

The star SAO 160953. From Vizier we have $V = 8^m.6$, $B - V = 0^m.347$, B9 IV. For B9 IV we have in [8] $M_V = -0^m.2$ and $(B - V)_0 = 0^m.0$, and if $R_V = 3.2$ we obtain $A_V = 1^m.11$ and $DM = 7^m.69$.

For the preceding two stars the mean distance module will be DM (mean) = $7^m.884$ and hence the corresponding mean distance will be r(mean) = 380 pc. This means that the distance to the cloud LDN 288 will be greater than or equal to 380 pc.

In [9] a new method of estimation of the distance to an unstable object associated with star forming regions was suggested. If an object is associated with an OB-association (the distances to OB-associations are given in [10]), we can presume that the distance to the object is the same as the already known distance to the association. An additional proof of the connection of the object with the association is the similarity of the velocity of molecular cloud with the mean radial velocity of the stars forming the OB-association.

There is an OB-association Sct OB2 near the object SNO 85. For that association in [10] there are the following data: mean radial velocity of the stars is ~1.5 km/s, the distance to Sct OB2 is ~730 pc. The mean radial velocity is in good agreement with the above given velocity of LDN 288, namely 2.5 km/s. The value of the distance to Sct OB2 can be improved by using more precise modern data for spectral types of the stars from that association. We used more precise data for these stars given in Vizier. These stars are as follows (the list of stars belonging to the OB-association Sct OB2 was taken from [11]):

The star SAO 142269. In Vizier for this star we have $V = 9^m.57$, $B - V = 0^m.401$, spectral type is B2 V. For that spectral type in [8] we have $M_V = -2^m.9$ and $(B - V)_0 = -0^m.25$. If $R_V = 3.2$, then we obtain $A_V = 2^m.08$ and distance module $DM = V - M_V - A_V = 10^m.39$.

The star SAO 142335. In Vizier we have $V = 10^m.52$, $B - V = 0^m.507$, spectral type is B2 V. For that spectral type in [8] we have $M_V = -2^m.9$, $(B - V)_0 = -0^m.25$. Taking $R_V = 3.2$, we obtain $A_V = 2^m.42$ and $DM = 11^m.0$.

The star SAO 161581. From Vizier we get $V = 9^m.8$, $B - V = 0^m.87$ and spectral type B1 V. For that spectrum in [8] we have $M_V = -3^m.5$, $(B - V)_0 = -0^m.28$. If $R_V = 3.2$, we obtain $A_V = 3^m.68$ and $DM = 9^m.62$.

The star SAO 161701. In Vizier we have $V = 9^m.42$, $B - V = 0^m.67$, spectral type is B0 V. For that spectral type in [8] we have: $M_V = -4^m.1$, $(B - V)_0 = -0^m.31$. If $R_V = 3.2$, we have $A_V = 3^m.14$ and $DM = 10^m.38$.

The star SAO 142489. For that star in Vizier we have: $V = 7^m.62$, $B - V = 0^m.54$, the spectral type is B0.5 V. For such a star in [8] we have $M_V = -3^m.8$ and $(B - V)_0 = -0^m.30$. If $R_V = 3.2$, we will obtain $A_V = 2^m.68$ and $DM = 8^m.73$.

The star SAO 142567. We have in Vizier $V = 7^m.81$, $B - V = 0^m.21$ and spectral type B1 V. In [8] for such a star we have $M_V = -3^m.5$, $(B - V)_0 = -0^m.28$. If $R_V = 3.2$, we have $A_V = 1^m.57$ and $DM = 9^m.74$.

For the above six stars associated with Sct OB2, the mean DM will be $9^m.98$, and hence the distance to Sct OB2 is $r = 990$ (±100) pc. We can presume that this distance is more accurate than 730 pc in [10]. We can take as a distance to LDN 288 the value in the range (380-990) pc.

5. Spiral structures due to rotation and precession of central stars

There are other objects, besides SNO 85, which have also spiral structures due to rotation and precession of central stars. In Fig. 5 the DSS2 images of three such objects are given. These objects are:

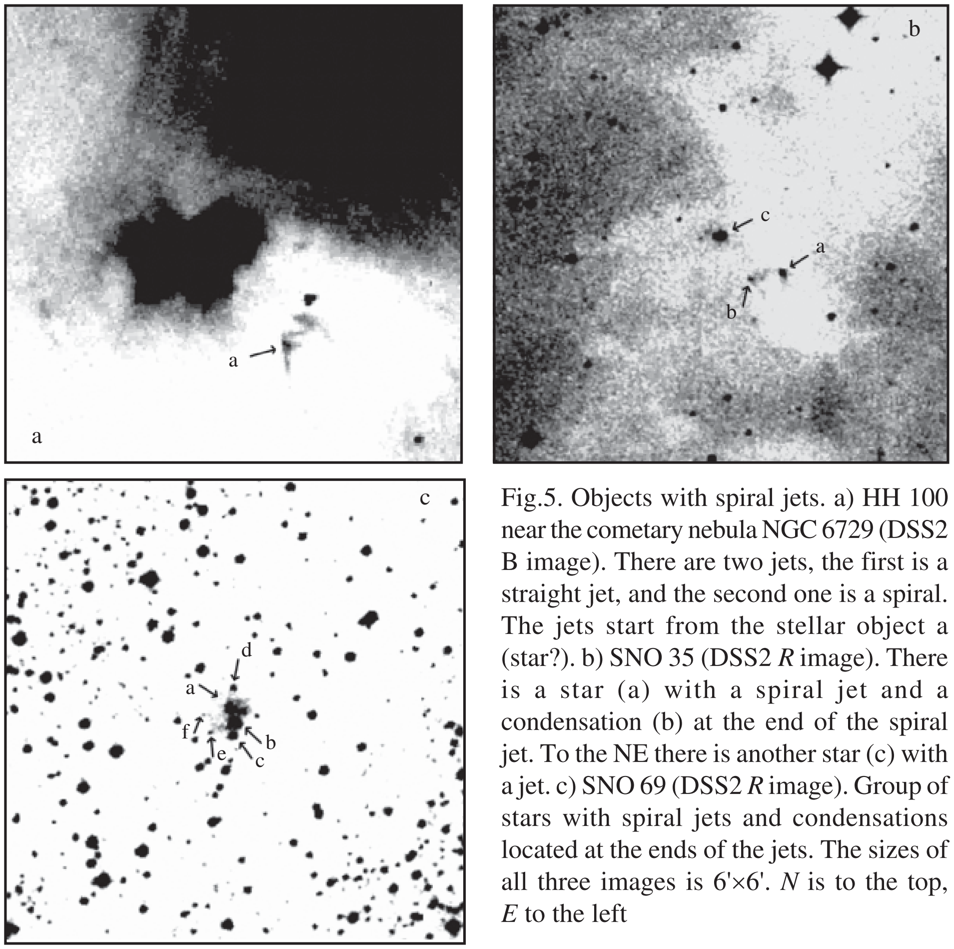

Fig.5. Objects with spiral jets. a) HH 100 near the cometary nebula NGC 6729 (DSS2 B image). There are two jets, the first is a straight jet, and the second one is a spiral. The jets start from the stellar object a (star?). b) SNO 35 (DSS2 *R* image). There is a star (a) with a spiral jet and a condensation (b) at the end of the spiral jet. To the NE there is another star (c) with a jet. c) SNO 69 (DSS2 *R* image). Group of stars with spiral jets and condensations located at the ends of the jets. The sizes of all three images is 6'×6'. *N* is to the top, *E* to the left

a. HH 100 (see Fig.5a). It is situated near the well-known cone-like cometary nebula NGC 6729. There are two jets: one is a straight jet while the second one is spiral.

b. SNO 35 [3] (see Fig.5b). This object (a in Fig.5b) has a spiral jet, at the end of which there is a condensation (b in Fig.5b). There is another star with a jet in its vicinity (object c in the Fig.5b).

c. SNO 69 [3] (see Fig.5c). This looks like a trapezium-like system, consisting of four stars. There are spiral jets, at the ends of which there are condensations. It seems that not only the jets, but also the condensations at their ends, were thrown away from the stars (the same can be concluded regarding the preceding object).

In Table 1 we present R and near IR data on stars and condensations which were described in this paper. In Table 1 the following information is given: the number for each star (column 1), the name of each star (column 2), the values of *R* (column 3) and IR colors (columns 4-6) (from Vizier).

The first four objects correspond to objects with numbers 2, 3, 6 and 7 in Fig. 2; the fifth one to object a in Fig.5a; 6, 7 and 8 correspond to objects a, b, and c in Fig.5b; and finally numbers 9-14 correspond to objects a - f in Fig.5c.

If we look at Table 1, we can see that the highest value for *H - K* correspond to the star 6, connected with the jet (jets). This means that the object has a rather low temperature. We assumed above that the star 6 is associated with the IRAS point source IRAS 17547-1832, which has IR colors, corresponding to the colors of a source not yet evolved,

TABLE 1. Near IR Colors for Sevral Stars

NN	Name	*R*	*R - J*	*J - H*	*H - K*
1	Fig.2 N2	12.3	2.24	0.37	0.26
2	Fig.2 N3	14.9	1.58	1.41	0.11
3	Fig.2 N6	---	---	1.32	3.13
4	Fig.2 N7	---	---	2.28	1.86
5	HH100 a	12.7	-2.02	1.26	-0.54
6	SNO 35 a	16.2	3.32	1.37	0.75
7	SNO 35 b	17.3	1.87	0.74	0.17
8	SNO 35 c	13.8	1.03	0.53	0.25
9	SNO 69 a	15.58	1.98	0.75	0.0
10	SNO 69 b	13.5	1.02	0.69	0.44
11	SNO 69 c	15.5	1.37	-0.14	0.99
12	SNO 69 d	17.0	1.46	0.60	0.06
13	SNO 69 e	17.6	2.69	1.06	0.83
14	SNO 69 f	17.32	2.59	1.29	0.74

which also means a low temperature.

We can also mention here the close similarity of IR colors of the two condensations connected with spiral jets in SAO 69 (objects e and f in Fig.5c).

6. Conclusions

A multiwavelength investigation of a star-forming region embedded in the dark cloud LDN 288 was carried out. There are several objects in this region: a B type star GSC 0625400181 surrounded by an HII region (object 2 in Fig.2), a star with a straight jet (object 3 in Fig.2), and a unique object SNO 85 [3] (object 1 in Fig.2). The results of ^{12}CO (1-0) observations of the region are given. The B type star is situated in a cavity in the molecular cloud, and the object SNO 85 is embedded in a dense condensation in the molecular cloud. The object SNO 85 in the 2MASS K image is a star with a jet, while in the DSS2 R image only the end of the jet is visible and the star has disappeared. There is a strange symmetric object connected with the jet. A similar object is in the opposite direction from the star coinciding with a VLA source (at 3.6 cm) VLA2. These symmetric objects consist of arcs and loops and perhaps are due to the existence of two opposite jets connected with the star and participating in the simultaneous rotation and precession of the star.

In the paper three other examples of objects with spiral jets due to simultaneous rotation and precession of stars connected with these jets are also given.

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