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STAR FORMATION REGION IN VELA

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A star formation region connected with SNO 41 is investigated. The observations of this region were carried out in ¹²CO (1-0) line and in 1.2-mm (with SIMBA) with the 15-m SEST mm telescope (Cerro La Silla, Chile). A blue shifted outflow is revealed from the ¹²CO(1-0) observations, while a bipolar outflow is apparent from 1.2-mm SIMBA image. In CO it seems that a very faint dust envelope around SNO 41 probably exists, which is expanding with a velocity of ~10.5 km/s. The distance to SNO 41 is estimated as ~1500 pc. [There are outflows also present in 2MASS images. A spiral jet has a condensation (resembling a HH object) at the end,)Another iet has a discontinuity and a bow-shock-like structure on it. In 2MASS images there are also spots resembling HH objects. In this region there is also a rather luminous point source (IRAS 08546-4254), which has IR colours typical for an YSO connected with a water maser. The detection of a strong CS (2-1) line emission toward IRAS 08546-4254, with the same velocity as the CO line, shows the existence of a high-density core of molecular gas associated to this source. A methanol maser is also associated with that IRAS source. The existence of CS line emission and a methanol maser (at 6.669 Ghz) is an indication of the presence of a very young massive star. It is not excluded that this IRAS source is the centre of outflows mentioned above, because this source coincides with the centre of 1.2-mm SIMBA image and also with the place of origin of jet with bow-shock-like structure.

Key words: ISM: star formation - individual: SNO 41

1. Introduction. An interesting object, SNO 41, was found during the Southern Hemisphere ESO/SRC prints survey [1]. Many star-forming regions, HH objects and cometary nebulae were discovered during this survey. The star-forming region SNO 41 is a rather unique object. Outflows are found in ¹²CO (1-0) line spectra, 1.2-mm images (as a result of observations with the 15-m SEST mm telescope at Cerro La Silla, Chile), and also in 2MASS images. The sources of these outflows are most probably objects situated in this star-forming region (and embedded in the dark cloud). The distance to SNO 41 is estimated as ~1500 pc. An IRAS point source, 08546-4254, is associated with SNO 41 (this source appears to be the centre of almost all outflows).

2. Distance to SNO 41. We have estimated the distance to SNO 41. This object is situated at the edge of an HII region, formed by early type luminous stars HD 76341 and HD 75759.

HD 76341. For this star we obtain from Vizier $V = 7^{\text{m}}.17$, $B - V = 0^{\text{m}}.30$,

and the spectral type is B1-B2 Ib. For such spectral type we have in [2] $M_V = -5^{m}.9$, $(B - V)_0 = -0^{m}.15$, hence we can estimate the distance modulus $DM = V - M_V - A_V$, where $A_V = 3.2E(B - V) = 3.2((B - V) - (B - V)_0) = 1.44$ (taking $R_V = 3.2$) and DM = 11.63.

HD 75759. In Vizier for this star we find $V = 6^{m}.0$, $B - V = -0^{m}.10$, and the spectral type is O9 V. For such spectral type we have in [2] $M_{\nu} = -4^{m}.8$ and $(B-V)_{0} = -0^{m}.32$. Assuming $R_{\nu} = 3.2$ the distance modulus is DM = 10.10.

Since stars HD 76341 and HD 75759 are forming the same HII region, they are situated at the same distance. The mean distance modulus for these two stars will be DM (mean) = 10.86, and hence the distance to these stars is d = 1500 pc. Therefore, we can assume that the distance to SNO 41 is also ~1500 pc. In item 3 is shown that the radial velocity of the cloud connected with SNO 41 is ~6 km/s. At the opposite edge of the HII region, mentioned above is situated the object GRV 5 [3]. For the cloud connected with GRV 5 in [4] radial velocity $V_{LSR} = 5.4$ km/s (by CO observations) is given. The similarity in the values of both radial velocities, corresponding to these two clouds situated at the opposite edges of an HII region, is in favour of proximity of distances of these two clouds (and hence objects SNO 41 and GRV 5) and the HII region, namely ~1500 pc.

3. CO observations of SNO 41. 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.



Fig.1. ¹¹CO(1-0) spectra toward SNO 41, arranged in a map-like distribution.

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Some interesting results have been obtained after completing the data reduction of the ¹²CO (1-0) observations. In Fig.1 ¹²CO (1-0) spectra of the region around SNO 41 are shown. The main integrated emission of the molecular cloud associated with SNO 41 has a mean velocity of ~6 km/s with an elongated shape in the E-W direction (see Fig.2). Other interesting phenomenon connected with ¹²CO (1-0) observations is the presence of a



Fig.2. Contour map of the main CO emission toward SNO 41, integrated from 3 to 9 km/s. Contour levels every 5 K km/s from 45 to 75 K km/s.

molecular outflow. Since SNO 41 is located within the Vela Molecular Ridge, an extended region of intense CO emission [5], and more specifically, in the Vela C3 molecular cloud (total estimated mass of $1.8 \times 10^4 M_{\odot}$ [6]), the observations of high velocity CO toward this region are difficult. There is abundant line-of-sight CO that can be somehow confused with high velocity gas. Therefore, to be certain of the presence of high velocity CO one need to search for the characteristic line wings observed in outflowing gas. Through a close inspection, analysis and Gaussian fits to the individual CO spectra (Fig.1), a blue shifted wing has been identified at the following positions: (0, 0), (0, 40), (40, 40) and (80, 40). A contour map of the integrated CO emission between -2 km/s and 2 km/s, corresponding to this blue shifted outflow, is presented in Fig.3. The blue shifted outflow has a mean velocity of ~0 km/s, or the relative velocity of the blue shifted lobe with respect to the main molecular cloud is ~6 km/s.

It seems that the object SNO 41 is surrounded by a very faint dust

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envelope, the velocity of that envelope is \sim -4.5 km/s, which corresponds to an expansion of the envelope with a velocity of \sim 10.5 km/s with respect to the molecular cloud (see Fig.4). The mean radius of the dust envelope is



Fig.3. Contour map of blue shifted CO emission in the direction of SNO 41, integrated from -2 to 2 km/s. Contour levels every 0.5 K km/s from 1 to 4.5 K km/s.





26"; if the distance to SNO 41 is 1500 pc, then the radius of the dust envelope is ~ 0.19 pc.

4. 1.2-mm SIMBA observations. These observations were carried out with the 15-m SEST telescope at Cerro La Silla, Chile with SIMBA. The beam size (FWHM) is 24". The observations were made on 31 of July 2002. The map was calibrated with a typical value of 80 mJy/count and beam. The weather prevented to map Uranus as a calibrator. The reduced and coadded map of SNO 41 is given in Fig.5 (see also [7] for more complete SIMBA results). The 1.2-mm map of SNO 41 shows that there is a bright central source (which coincides with IRAS 08546-4254) and two outflows (or jets) in opposite directions. At the ends of outflows there are condensations, which can be HH objects, several HH objects already were observed in mm waves and show emission (these HH objects contain dust which is emitting in mm region).



Fig.5. 1.2-mm SIMBA image; rms noise (1₅): 37 mJy/beam, peak flux: 1180 mJy/beam, integrated flux: 8530 mJy.

5. IRAS 08546-4254. In the region of SNO 41 there is an IRAS point source IRAS 08546-4254 [8]. In [9] the ranges of IR colour indexes are calculated, which are valid for different kinds of objects. For $R(1, 2) = \log(F(25) \ge 12)/(F(12) \ge 25))$, $R(2, 3) = \log(F(60) \ge 25)/F(25) \ge 60)$, $R(3, 4) = \log(F(100) \ge 60)/F(60) \ge 100)$ the following ranges, corresponding to different kinds of young objects, are obtained. 1. For objects connected with water masers, R(1, 2) = (0.2 - 0.8); R(2, 3) = (0 - 1.3); R(3, 4) = (-0.3 - 0.3). 2. For 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). 3. For cold sources embedded in dark clouds, R(3, 4) > 0.3.

For the source IRAS 08546-4254 we have R(1, 2) = 0.505, R(2, 3) = 0.47and R(3, 4) = -0.05. These values correspond to the object of class 1 (see above), which has IR colours typical for an object connected with a water maser.

It is interesting to find that there is really a maser associated with IRAS 08546-4254 [10], although not a water maser, but a maser having a masing transition of methanol at 6.669 GHz. Methanol maser emission at 6.669 GHz is a good indicator of the presence of a very young massive star, and there is no evidence, so far, that such masers might be associated with other types of astrophysical objects [10]. The kinematical distance to IRAS 08546-4254 is estimated in [10] as ~1500 pc, which is in good agreement with our own estimation given above (also ~1500 pc). The maser radial velocity is ~9 km/s and its flux density is only 0.2 Jy [10]. This velocity means that the maser spots (there are two such spots [10]) are moving, away from us, with a velocity of ~3 km/s with respect to the main molecular cloud. Because the beam size of methanol observations is only 3'.3, it is very difficult to decide whether these maser spots really coincide with the condensations at the ends of outflows of the SIMBA image (see Fig.5). Notice the similarities in the shape of the SIMBA image and the main emission of the molecular gas, within the region covered by both data sets (Figs.2 and 5).

It is also very interesting to point out that toward the source IRAS 08546-4254, a strong CS (2-1) line emission has been detected [11], indicating the presence of very high density molecular gas. The CS (2-1) line has an excitation threshold of $(10^4 - 10^5)$ cm⁻³ and, therefore, is an excellent tracer of high-density gas. Some of the main parameters of the CS (2-1) line emission detected toward this IRAS source are: beam size = 50"; mean radial velocity = 5.5 km/s; line-width (FWHM) = 2.3 km/s and line intensity = 2.8 K [11]. Notice that the angular resolution of the CS observations is comparable to that corresponding to the IRAS survey, ensuring that both, CS observations and IRAS, sample the dust and molecular gas in similar spatial regions. The CS line velocity is practically the same as the CO main emission, meaning that the CS emission comes from the high-density core of the molecular cloud, while the CO emission corresponds to the having much less dense outer layer of the same cloud. The existence of highdensity molecular gas associated with this IRAS source, that has FIR colours characteristics of an ultra compact HII region [12], indicates the presence of an embedded massive star in such ultra compact HII region.

It is also suggested in [10] that this source, IRAS 08546-4254, is identified with an ultra compact HII region. That HII region is illuminated in IR due to reemission by dust of energy emitting by a star (embedded in that HII region), which has a luminosity $L = 0.88 \cdot 10^4 L_{\odot}$ and can have

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a spectral type B 0.5 [10].

6. Objects in SNO 41. In Table 1 colours of several stars and condensations of the SNO 41 region are presented (the names of stars and condensations in Table 1 are the same as in Fig.6).

Table 1

COLOURS OF SEVERAL OBJECTS OF SNO 41 REGION

Star	B	V	J	J-H	<i>H</i> - <i>K</i>
а	12.7	11.8	9.31	0.49	0.21
Ь	-	-	14.5	2.0	1.07
С	19.2	-	13.62	1.44	0.58
d	-		16.35	1.68	1.0
e	-	-	16.44	1.33	1.06
f	-	-	16.26	1.39	0.96



Fig.6. 2MASS K image of SNO 41. N is to the top, E to the left. The size of the image is 6'x 6'. 1 - position of IRAS 08546-4254, 2 - jet with discontinuity, 3 - bow-shock-like structure.

In Table 1 the following information is given: the name of each object, corresponding to the names in Fig.6 (column 1), B, V and J values from Vizier (columns 2-4), and the values of near IR colours from Vizier (columns 5 and 6).

Star *a* and the bright nebula connected with it, are associated with the object VdBH25A [13]. In [14] the spectrum of star *a* is given, the emission spectrum consists of strong H β , weak H γ , and the "nebular lines" of [OIII] (λ 4959 and λ 5007). Underlying absorption spectrum shows very broad (almost invisible) lines characteristic of a late-O or early-B giant and supergiant. In [14] the spectrum is estimated as O9:I:pe. If that star is a late-O or early-B type star, then the nebula connected with that star is rather

an HII region than a reflection nebula.

Star b is the object nearest to the central condensation of SIMBA image. As is shown in Table 1, near IR colours of star b are rather large, which is in favor of star b to be a young stellar object.

Star c is connected with several jets and also has high values of IR colours, typical for an YSO.

Condensation d is situated at the end of a spiral jet (see Fig.6). It means that the object from which this jet is ejected (it is difficult to decide which object is it), is precessing.

Condensations e and f resemble HH objects. In this region there are also other spots and arcs resembling HH objects,

It is interesting to compare the values of near IR colours of condensations at the ends of jets in the star-forming region SNO 41 with corresponding values for condensations in another region. The mean near IR colours for condensations d, e and f (see Table 1) will be: (J-H) = 1.47and (H-K) = 1.01. For the condensations e and f in the star-forming region SNO 69 (see [15]) we will have: (J-H) = 1.18 and $(H-K)_{mean} =$ 0.79. Then the values for region SNO 41 are larger than those corresponding to the region SNO 69. We could anticipate such a result, because the condensations in SNO 41 are invisible while the condensations in SNO 69 are visible (due to less absorption).

7. Ejections in SNO 41 region. There are several types of ejections in SNO 41 region.

7.1. ¹²CO (1-0) outflows. It was mentioned above that there are outflows observed in CO: 1. a blue shifted outflow expanding with a velocity of ~6 km/s and 2. a probable expansion of a very faint dust envelope around SNO 41 with a velocity of ~10.5 km/s.

7.2. 1.2-mm SIMBA bipolar outflow (Fig. 5). There are condensations at eastern and western ends of bipolar outflow. These condensations resemble HH objects. In [16] two cases of mm emission of dust within HH objects are presented (HH 7 and HH 8), so that the eastern and western condensations of 1.2-mm SIMBA image can also be HH objects invisible in optics (though above was considered another possibility of coincidence of these condensations with methanol maser spots). SIMBA observations have a FWHM = 24" and a rms noise (1 sigma) = 37 mJy/beam.

The difference in positions of the central condensation of 1.2-mm SIMBA image and IRAS 08546-4254 is ~14", which is less than the error of IRAS source position (~20"). Also the center of the integrated CO emission is closer to the center of SIMBA emission than to IRAS 0854-4254.

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7.3. 2MASS images. In Fig.6 (2 MASS K) a spiral jet with a condensation d at the end is marked. There are also other condensations (e and f) near this jet. In Table 1 the IR colours of these condensations are presented.

In the theory of origin of HH objects by propagation of supersonic shock waves two cases are considered (see e.g. [17]). 1. The HH objects at the ends of jets (the heads of jets). 2. Discontinuities with bows in the middle (bow-shock-like structures). In our region both cases are taking place. Number 2 in Fig.6 marks the second case. The place, where starts this jet, coincides with IRAS 08546-4254. In 2MASS images there are also other spots resembling HH objects.

8. Conclusions. A star-forming region, SNO 41, is investigated. Several outflows and ejections have been observed. The $^{12}CO(1-0)$ observations, carried out with the 15-m SEST telescope (Cerra La Silla, Chile), revealed the presence of a blue shifted outflow and the probable existence of a very faint expanding envelope around this region with an expansion velocity of ~10.5 km/s. The SIMBA image consists of a condensation in the centre and two opposite jets with condensations at the ends.

In this region there is also a rather luminous $(L \sim 0.88 \cdot 10^4 L_{\odot})$ IRAS point source (IRAS 08546-4254), with IR colour characteristics of an ultracompact HII region [12], coinciding with a dense molecular gas core, revealed by the detection of a strong CS (2-1) line emission toward this source [11]. This CS (2-1) line has a velocity of 5.5 km/s, which is practically the same as the CO (1-0) (~6 km/s). IRAS 08546-4254 is perhaps a pumping agent of methanol maser at 6.669 GHz, described in the literature [10]. CS line and methanol maser emissions are excellent indicators of the presence of a very young massive star. The velocity of methanol maser spots is ~3 km/s (with respect to the ambient cloud), which coincides with the upper limit of the integrated velocity of the CO main emission. IRAS 08546-4254 might be also the source of the CO blue shifted outflow and the 1.2-mm bipolar ejection (SIMBA image), because the difference in the coordinates between IRAS source and the central condensation in CO and 1.2-mm image is less than the coordinate errors.

There are spots resembling HH objects and ejections in 2MASS images (a spiral jet with a condensation at the end and other condensations), and also a jet with discontinuity and a bow shock at this discontinuity. All these condensations resemble HH objects, and both cases of HH ejections, described so far in the literature, occur in SNO 41 region: jet with condensation (head) at the end and a jet with discontinuity and a bow-shock-like structure on this discontinuity. The jet with bow-shock-like structure starts from the site where the IRAS 08546-4254 is situated. It is also possible that this jet is ejected from this IRAS source.

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ОБЛАСТЬ ЗВЕЗДООБРАЗОВАНИЯ В ПАРУСАХ

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Исследована область звездообразования, связанная с SNO 41. Наблюдения этой области проведены в линии ¹²СО и на 1.2-мм (с SIMBA) на 15-м миллиметровом SEST телескопе (Ла Силья, Чили). При ¹²СО (1-0) наблюдениях было выявлено синее истечение, а на 1.2-мм изображении видно биполярное истечение. На СО картах, по-вилимому, присутствует очень слабая оболочка вокруг SNO 41, которая расширяется со скоростью ~10.5 км/с. Расстояние до SNO 41 оценено в ~1500 пк. Имеются истечения также на 2MASS изображениях. Спиральный выброс имеет сгущение (напочинающее объект Х-А) на конце. Другой выброс имеет разрыв и структуру, похожую на дугообразную ударную волну. На 2MASS изображениях имеются также пятна, напоминающие объекты Х-А. В этой области имеется также довольно яркий точечный источник (IRAS 08546-4254), которь й имеет ИК цвета, типичные для МЗО, связанного с мазером воды. Обнаружение сильной эмиссии в линии CS (2-1) по направлению IRAS 08546-4254, с такой же скоростью, что и в СО линии, указывает на наличие высокоплотного ядра в молекулярном газе, связанном с этим объектом. Мазер метанола также связан с этим источником IRAS. Наличие эмиссии в линии CS и мазера метанола (на 6.669 Гпц) явлыется индикатором присутствия очень молодой массивной звезды. Не исключено, что этот источник IRAS является центром упомянутых выше истечений, потому что этот источник совпадает с центром изображения, полученного на 1.2-мм с помощью SIMBA, а также с местом образования выброса со структурой в виде дугообразной ударной волны.

Ключевые слова: ISM: звездообразование - объект: SNO 41

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