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# STAR-FORMING REGION BBW 36 IN PUPPIS

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Recent studies of the star formation region BBW 36 and associated molecular clouds are presented. The $^{12}CO$ (1-0) observations, carried out with the 15-m SEST (Swedish-ESO) telescope (Cerro La Silla, Chile) revealed the existence of cloud *a*, connected with BBW 36 and of cloud *b*, having elongation in SE-NW direction. A red-shifted molecular outflow with velocity ~+5 km/s (with respect to cloud *a*), having a direction parallel to the line of sight, was also observed. VLA observations showed the presence of a source VLA 2 at 3.6 cm with an elongation in N-S direction. It is suggested that the VLA 2 source is coinciding with a dust disc (surrounding the object BBW 36). The star 3, which is one of YSOs in the star-forming region BBW 36 and is connected with a bright comma-like nebula, can be the source of the molecular outflow. The star 3 has very high IR colours and is associated with an IRAS point source IRAS 07280-1829, which has IR colours, typical for an IRAS point source, connected with a water maser. On 2MASS *K* image of BBW 36 we can see existence of a bright nebula, a group of stars is embedded in that nebula, among these stars there are stars with dust discs (or envelopes). On 2MASS *K* image several spiral jets are also present, some of them with a condensation at the end.

Key words: *star-forming region:molecular clouds:molecular outflow:spiral jets*

1. *Introduction.* We have continued with the research of some Southern interesting nebular objects, mainly star-forming regions, containing YSOs, HH objects, etc. (see e.g. papers [1,2]). In this paper an interesting star-forming region BBW 36 is studied. For investigation of star-forming regions observations in several ranges of spectrum are necessary: CO observations, VLA, infrared, optical observations. The results of such observations were used in this paper.

2. *Distance to BBW 36.* The object BBW 36 [3] and the HII region Sh 2-305 are associated to the same large molecular cloud. The first CO survey of the area including Sh 2-305 has been made by May et al. [4] with an effective resolution of 30'. Sodrosky [5] made an analysis of the spatial and velocity structure of emission features in the CO survey of May et al. [4] and found peak velocities at 18.9 km/s and 42 km/s with velocity dispersions of 5.4 km/s and 6.9 km/s, respectively. May et al. [6], studying the physical properties of 177 molecular clouds (detected in the deep survey of the third galactic quadrant made by May et al [7]), found that the kinematic distance to the molecular cloud associated with BBW 36 ($l=240°$, $b=-0°.25$, $\upsilon=43.7$ km/s) is ~4.1 kpc. Russeil et al. [8] have observed with a Fabry-Perot interferometer in H$\alpha$ light 7 fields, 38'x38' each,

including also Sh 2-305 region. Their diffuse Hα observations show two emission components, one at 16 km/s and another at 43 km/s both being detected simultaneously all over the observed area. These values are rather close to the mentioned above velocity components revealed by Sodrosky from data of May et al. [4]. Spectrophotometry of exciting stars of HII regions enabled Russeil et al. [8] to determine the distance of both complexes quite accurately, averaging several individual HII region distances. The first complex is found at ~2.1 kpc whereas the second one is found at ~4.2 kpc. Among the second complex there is a huge single molecular complex connected with Sh 2-305. The distance to that complex (and also to Sh 2-305) is 4.2 ± 0.5 kpc [8], so we can assume that the distance to BBW 36 is also about 4.2 ± 0.5 kpc. It is interesting to note that, in this particular case, there is a very good agreement between the kinematic distance obtained from radio observations (~4.1 kpc) and the distance determined from optical data (~4.2 kpc), because quite often these estimates of distance show substantial differences.

3. *$^{12}CO(1-0)$ observations.* The region in the direction of BBW 36 was observed with the 15-m SEST (Swedish-ESO Submillimetre Telescope) telescope (Cerro La Silla, Chile).

The telescope beam size at 115 GHz is 45" and the beam efficiency is 0.70. The positions toward BBW 36 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 $^{12}CO$ (1-0) spectra observed toward BBW 36, arranged in a map-like distribution.

Analyzing the data presented in Fig.1, we can realize that there are two

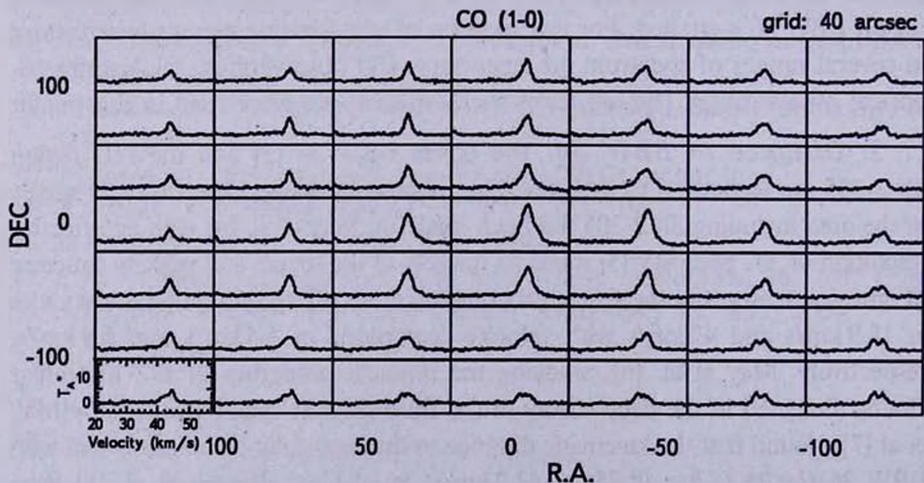


Fig.1. $^{12}CO$(1-0) spectra toward BBW 36, arranged in a map-like distribution.

clouds and an outflow in the region surrounding BBW 36. That is, a main cloud *a* with a velocity of ~44.8 km/s (see Fig.2), a cloud *b* with velocities in the range (40-44) km/s (see Fig.3) and a red-shifted outflow with velocities in the range (48-52) km/s (see Fig.4).

The red-shifted outflow is centered at the position of the object BBW 36, so this outflow is parallel to the line of sight. The velocity of the outflow is ~+5 km/s with respect to the velocity of cloud *a*.

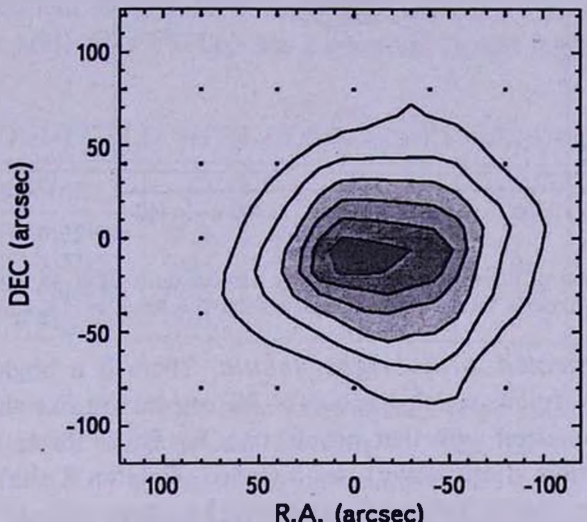


Fig.2. Contour map of the main molecular cloud *a* (connected with BBW 36), integrated from 44 to 48 km/s. Contour levels every 5 K km/s from 15 to 40 K km/s.

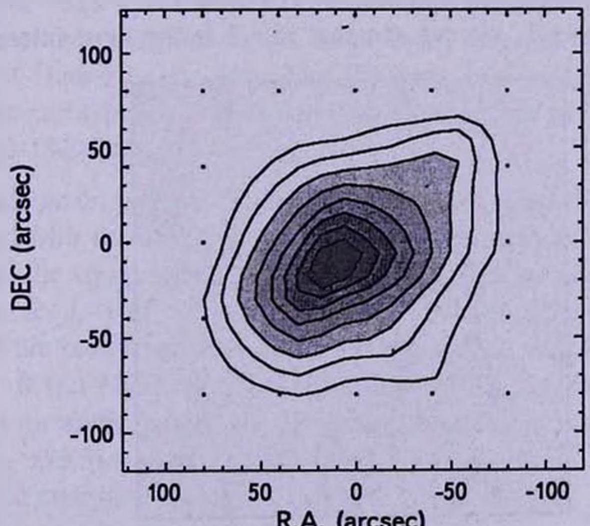


Fig.3. Contour map of the molecular cloud *b* (connected with BBW 36), integrated from 40 km/s to 44 km/s. Contour levels every 2 K km/s from 13 to 27 K km/s.

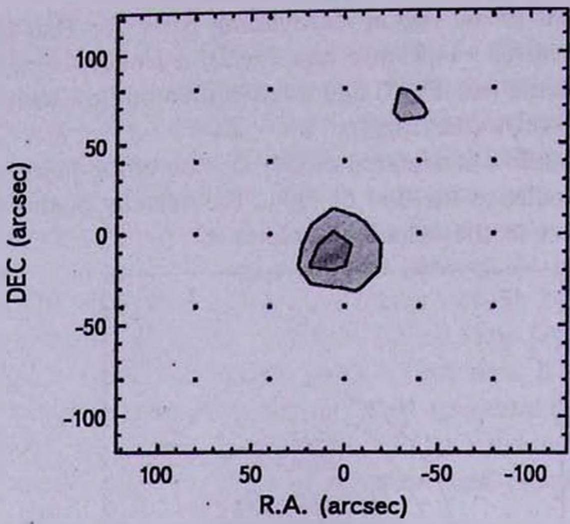


Fig.4. Contour map of the red-shifted molecular outflow from BBW 36, integrated from 48 km/s to 52 km/s. Contour levels every 1 K km/s from 3 K km/s to 4 K km/s.

4. ***Stars connected with bright nebula.*** There is a bright comma-like nebula in this region, which has a NW-SE orientation like the cloud *a*. Four stars are connected with that nebula (see Fig.5). In Table 1 the data concerning these stars (from Vizier) are included. Column 1 shows just the star number (from Fig.5), column 2 presents the name of each star from NOMAD1 [9], columns 3-5 include the corresponding *B*, *V* and *R* values for each star, respectively, while columns 6-8 - the corresponding near infrared colours (all these values are taken from Vizier).

Looking at Table 1, we can see that star 3 is the most interesting one.

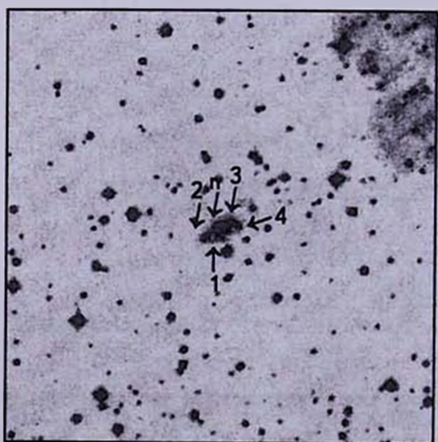


Fig.5. DSS2 R image of BBW 36. N is to the top, E to the left. The sizes of image are 6'x6', *n* - bright comma-like nebula, connected with BBW 36, 1-4 - the stars connected with bright nebula *n*.

Its IR colours are very high; especially the value of $R-J=6.065$ is unique. In [2] there are data on $R-J$ for different YSOs, the highest value is at the stars GRV 16 ($R-J=5.15$) and PV Cep (A5e + shell): $R-J=4.45$. The other colours for PV Cep are close with the corresponding values for star 3 (see Table 2 in [2]): $J-H=2.85$, $H-K=2.2$. Star GRV 16 has also colours similar to star 3 from present paper: $J-H=1.67$, $H-K=1.3$ (see Table 2 in [2]). Stars PV Cep and GRV 16 are connected with cone-like cometary nebulae. The star PV Cep and its associated cometary nebula are both extremely variable (see e.g. in [10]). Star PV Cep has a spectrum typical for Herbig Ae/Be type

*Table 1*

STARS CONNECTED WITH COMMA-LIKE NEBULA "n" IN BBW 36

| NN | NOMADI | *B* | *V* | *R* | *R - J* | *J - H* | *H - K* |
|---|---|---|---|---|---|---|---|
| 1 | 0713-0137199 | 17.54 | 16.99 | - | - | 0.553 | 0.684 |
| 2 | 0713-0137192 | 19.45 | 17.07 | 12.21 | -1.46 | 1.005 | 0.760 |
| 3 | 0714-0136444 | 18.82 | 16.59 | 16.92 | 6.065 | 2.829 | 1.969 |
| 4 | 0714-0136438 | 19.53 | - | 10.69 | - | - | - |

stars (emission lines with variable components). If we assume that the absorption is almost the same toward the stars PV Cep, GRV 16 and star 3, we will have for $(B-V)_0$ the following values (if $R_V=3.2$): 1) for GRV 16 $(B-V)_0 \approx 1^m.0$ (we used for GRV 16 the value of $B-V=1^m.67$ from Vizier); 2) for star 3, $(B-V)_0 \approx 1^m.6$ (we used for star 3 the value $B-V=2^m.23$ from Vizier). If these two stars are main sequence stars, we will have ~K3 V for GRV 16 and ~M5 V for star 3 (we used data from [11]). Certainly these estimates are very rough, but almost definitely we can conclude that these two stars are not Herbig Ae/Be stars (like PV Cep), but rather T Tau type stars with late spectral type. Star 3 has coordinates very close to the coordinates of IRAS 07280-1829 [12] (see below).

5. *IRAS point source IRAS 07280-1829.* This IRAS point source is associated with the object BBW 36. The coordinates of this IRAS source are close to the coordinates of star 3, which has rather high values of near IR colours: $R-J=6.65$, $J-H=2.829$, $H-K=1.969$. The colours of IRAS 07280-1829 are consistent with colours of the source associated with a water maser [13]: $R(1,2)=0.53$, $R(2,3)=0.01$, $R(3,4)=0.08$. In [13], for the sources associated with water masers, the IR colours must be in the ranges: $R(1,2)=$ $=(0.2-0.8)$, $R(2,3)=(0-1.3)$, $R(3,4)=(-0.3-0.3)$, and IRAS 07280-1829 satisfies these criteria.

6. *Spiral jets, bright nebula and a group of embedded stars on 2MASS K image of BBW 36.* There are spiral jets on the 2MASS

*K* image of BBW 36 (see jets 1 and 2 in Fig.6, other faint spiral jets can be also seen, including jets with condensations at the ends). Jet 1 has a condensation (or a star) *a* at its end. This condensation has the following IR colours: $J-H=1.762$, $H-K=1.181$ (see Vizier). If we compare these results with the corresponding values for other condensations connected with already known spiral jets, we can arrive at the following conclusion: several condensations at the ends of spiral jets have IR colours rather close to the above values for condensation *a*. Such condensations are the following:

1. Condensation *d* in the star forming region SNO 41 (see Fig.6 in [14]): $J-H=1.68$, $H-K=1.0$.
2. Condensation *a* in the object SNO 35 (see Fig.5b in [15]): $J-H=1.37$, $H-K=0.75$.
3. Condensation *e* in SNO 69 (see Fig.5c in [15]): $J-H=1.29$, $H-K=0.74$.

If we look at 2MASS *K* image of BBW 36, we can see that there is a very bright nebula in the place of BBW 36 (nebula 3 in Fig.6). There is a group of stars embedded in that nebula (see Vizier). Among these stars there are ones, which have high values of infrared colours, which is in favour of existence of dust discs or envelopes around them. In Table 2 there are data

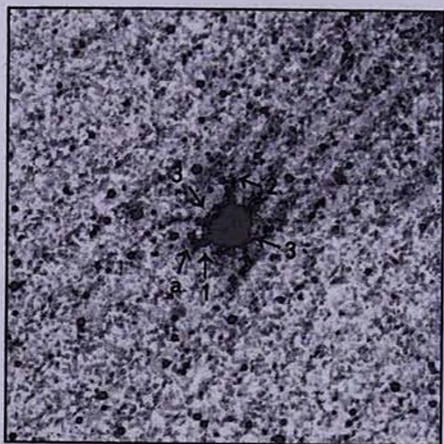


Fig.6. 2MASS K image of BBW 36. N is to the top, E to the left. The sizes of image are 6' x 6', 1 and 2 - the spiral jets, *a* - condensation at the end of spiral jet 1, 3 - the bright nebula, in which a group of stars is embedded.

*Table 2*

STARS EMBEDDED IN INFRARED BRIGHT NEBULA 3

| NN | NOMAD1 | $J$ | $J-H$ | $H-K$ |
|---|---|---|---|---|
| 1 | 0714-0136446 | 13.077 | -0.151 | 2.827 |
| 2 | 0714-0136447 | 13.608 | 1.349 | 3.0 |
| 3 | 0713-0137182 | 15.234 | 1.388 | 2.466 |

on these stars taken from Vizier. In first column are the numbers of stars, in column 2 there are the names of the stars from NOMAD1 [9], in columns 3-5 - the near infrared colours of these stars (data are taken from Vizier).

If we look at Table 2 we can see that the value $J-H$ for the star N1 is negative and differs from values of $J-H$ for other stars from Tables 1 and 2 of this paper. In Table 2 of [16] several stars have negative values of $J-H$ and high positive values of $H-K$ (these stars are embedded in bright nebula in the central part of star-forming region RCW 38). In [16] is supposed that these stars are early-type stars with dust discs, so that we can also suppose that the star N1 from Table 2 of this paper is an early-type star with dust envelope (or disc) and other stars from Tables 1 and 2 of this paper are late-type stars with dust discs (or envelopes).

7. *VLA source associated with BBW 36.* Object BBW 36 is also associated with a VLA source, VLA 2 (see Fig.7). This source is elongated in the N-S direction. It is not excluded that there is a dust disc surrounding the object BBW 36 and coinciding with VLA 2 (also has elongation in N-S direction). The source VLA 2 was obtained as a result of VLA observations at a wavelength of 3.6 cm. The 3.6 cm radio continuum observations were carried out in 2004 March 27, using the VLA in the C configuration, providing

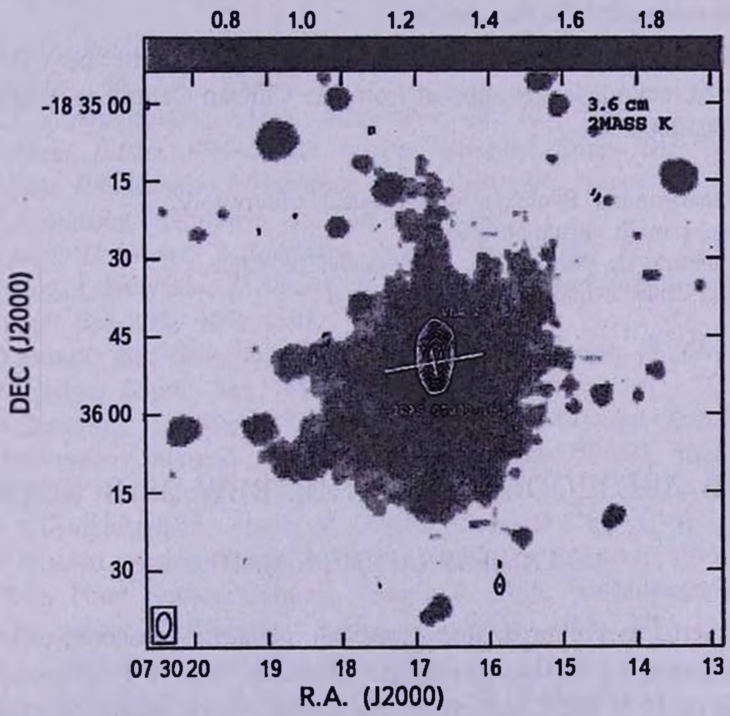


Fig.7. Overlay of the 3.6 cm radio continuum emission from BBW 36, VLA 2 and 2MASS K image. Contour levels are -4, -3, 3, 4, 8, 16, 32, 64, 128 and 256 times the rms of the map, 40 mJy beam$^{-1}$. The cross marks the position of IRAS 07280-1829.

an angular resolution of ~4" (see [17]).

8. *Conclusions*. In this paper a star forming region BBW 36 is investigated. The star-forming region BBW 36 is situated in a large complex of molecular clouds including also the HII region Sh 2-305. $^{12}CO(1-0)$ observations of the region around BBW 36 revealed the existence of two clouds connected with BBW 36: a main cloud *a* (mean velocity ~44.8 km/s), a cloud *b* (velocities in the range 40-44 km/s) with elongation in SE-NW direction, and a red-shifted outflow (the velocity of the outflow is ~+5 km/s with respect to the mean velocity of cloud *a*) which is parallel to the line of sight. Also a bright nebula appears connected to BBW 36, having elongation in SE-NW direction (the same as molecular cloud *b*). A star with unusual IR colours (star 3, probably a T Tau type star) is connected with that nebula. The star 3 is associated with an IRAS point source, IRAS 07280-1829, which has IR colours typical for IRAS point sources connected with water masers. VLA observations showed the existence of a VLA source at 3.6 cm, VLA 2, having elongation in N-S direction. In a 2MASS *K* image of BBW 36 several spiral jets (some of them with a condensation at the end) are present, on the same image a bright nebula is seen. A group of stars, including stars with high values of near infrared colours (it means that these stars are surrounding with dust discs or envelopes) is embedded in that nebula.

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# ОБЛАСТЬ ЗВЕЗДООБРАЗОВАНИЯ BBW 36 В КОРМЕ

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Представлены результаты исследований области звездообразования BBW 36 и связанных с ней молекулярных облаков. $^{12}CO$ (1-0) наблюдения, проведенные на 15 м SEST телескопе (Ла Силья, Чили) выявили наличие облака *a*, связанного с BBW 36, и облака *b*, вытянутого вдоль направления ЮВ-СЗ. Обнаружено также красное истечение со скоростью ~+5 км/с (по отношению к облаку *a*), имеющее направление, параллельное лучу зрения. VLA наблюдения выявили наличие источника VLA 2 на 3.6 см с вытянутостью в направлении С.-Ю. Предположено, что источник VLA 2 совпадает с пылевым диском (окружающим объект BBW 36). Звезда 3, которая является одной из МЗО в области звездообразования BBW 36 и связана с яркой дугообразной туманностью, может являться источником молекулярного истечения. Звезда 3 имеет очень высокие значения ИК цветов и ассоциируется с точечным источником IRAS 07280-1829, который имеет ИК цвета, типичные для точечного источника IRAS, связанного с мазером воды. На 2MASS *K* изображении можно увидеть наличие яркой туманности, в которую погружена группа звезд, среди которых есть и звезды с пылевыми дисками (или оболочками). На 2MASS *K* изображении имеется также несколько спиральных выбросов, некоторые из них со сгущением на конце.

Ключевые слова: *область звездообразования:молекулярные облака: молекулярное истечение:спиральные выбросы*

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