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IDENTIFICATION OF YOUNG STAR OBJECTS NEAR DUST BUBBLE N10

Over the past decade, the most important observations of the interstellar medium have been made in the infrared and radio regions of electromagnetic radiation. Of particular interest were GLIMPSE (Galactic Legacy Infrared Midplane Survey Extraordinaire), MIPSGAL and WISE (Wide-field Infrared Survey Explorer) surveys of several areas of star formation. Distinctive features of the infrared view of the Galactic disk at wavelengths from 3.4 μm to 22 μm include regions of ionized hydrogen HII, infrared bubbles, young stellar objects, massive star formation, infrared dark clouds, diffuse dust, include hydrocarbons and radiation from millions of stars.

Based on current literature, infrared signatures in hot regions around young massive stars have been identified as dust bubbles, so in this paper, the regions around bubble N10, one of the northern infrared bubbles included in Churchwell's catalog, were investigated. Using archival data from the WISE and 2MASS catalogs, we searched for candidates for young stellar objects around the N10 dust bubble and found 117 emission objects. Koenig et al. (2014) plotted diagrams of their color indices and energy distribution in the spectrum for each studied object under different classification conditions. According to the results of studies around the infrared dust bubble N10, objects at an early stage of evolution were discovered: 13 objects are young class I stars and 13 objects are young class II stars, 3 objects are classified as transitional disks.

Key words: N10 bubble, infrared radiation, young stellar objects, interstellar medium, astronomical catalogs, WISE, 2MASS.

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N10 шаң көпіршігі маңындағы жас жұлдыз объектілерін анықтау

Соңғы онжылдықта жұлдызаралық ортадағы ең маңызды бақылаулар электромагниттік сәулеленудің инфрақызыл және радио аймақтарында жасалды. Жұлдыздардың түзілуінің бірнеше бағыттары бойынша GLIMPSE (Galactic Legacy Infrared Midplane Survey Extraordinaire), MIPSGAL және WISE (Wide-field Infrared Survey Explorer) барлаулары ерекше қызығушылық тудырды. Толқын ұзындығы 3,4 мкм-ден 22 мкм-ге дейінгі толқын ұзындығындағы Галактикалық дискінің инфрақызыл көрінісінің айрықша белгілеріне иондалған сутегі аймақтары HII, инфрақызыл көпіршіктер, жас жұлдыздар объектілері, жұлдыздардың жаппай түзілуі, инфрақызыл қара бұлттар, диффуздық шаң, көмірсутектер мен миллиондаған жұлдыздардың сәулеленуі жатады.

Заманауи әдебиеттерге талдау жасау арқылы жас массивті жұлдыздардың айналасындағы қыздырылған аймақтардағы инфрақызыл белгілер шаң көпіршіктер екені анықталды, сол себепті бұл жұмыста Churchwell каталогына енгізілген солтүстік инфрақызыл көпіршіктердің бірі – N10 көпіршіктің айналасындағы аймақтар зерттелді. WISE, 2MASS каталогтарының мұрағаттық деректерін пайдалана отырып, біз N10 шаң көпіршігінің айналасындағы жас жұлдыздар объектілеріне үміткерлер іздедік және 117 сәулелену объектілерін таптық. Koenig et al. (2014) зерттеушілерімен жасалған жіктеудің әртүрлі шарттарына сәйкес әрбір зерттелетін объект үшін олардың түс көрсеткіштері диаграммалары және спектріндегі энергияның таралуы болды. Жасалынған зерттеудің нәтижесі бойынша N10 инфрақызыл шаң көпіршігінің айналасында эволюцияның ерте сатысындағы объектілер анықталды: 13 объект – I класс жас жұлдыздары және 13 объект – II класс жас жұлдыздары, 3 объект – өтпелі дискілер ретінде жіктелді.

Түйін сөздер: N10 көпіршік, инфрақызыл сәулелену, жас жұлдыздар объектілері, жұлдызаралық орта, астрономиялық каталогтар, WISE, 2MASS.

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Индентификация молодых звездных объектов вблизи пылевого пузыря N10

За последнее десятилетие важнейшие наблюдения межзвездной среды выполнены в инфракрасном и радиодиапазонах электромагнитного излучения. Особый интерес представляли обзоры GLIMPSE (экстраординарный инфракрасный обзор срединной плоскости галактики), MIPSGAL и WISE (Wide-field Infrared Survey Explorer) нескольких областей звездообразования. Отличительные особенности инфракрасного изображения галактического диска на длинах волн от 3,4 мкм до 22 мкм включают области ионизированного водорода HII, инфракрасные пузыри, молодые звездные объекты, массивное звездообразование, инфракрасные темные облака, диффузную пыль, включают углеводороды и излучение миллионов звезды.

Основываясь на современной литературе, инфракрасные сигнатуры в горячих областях вокруг молодых массивных звезд были идентифицированы как пылевые пузыри, поэтому в этой статье были исследованы области вокруг пузыря N10, одного из северных инфракрасных пузырей, включенных в каталог Черчвелла. Используя архивные данные из каталогов WISE и 2MASS, мы провели поиск кандидатов в молодые звездные объекты вокруг пылевого пузыря N10 и нашли 117 эмиссионных объектов. Кениг и др. (2014) построили графики их показателей цвета и распределения энергии в спектре для каждого исследуемого объекта при разных условиях классификации. По результатам исследований вокруг инфракрасного пылевого пузыря N10 были обнаружены объекты, находящиеся на ранней стадии эволюции: 13 объектов — молодые звезды I класса и 13 объектов — молодые звезды II класса, 3 объекта относятся к категории переходных дисков.

Ключевые слова: пузырь N10, инфракрасное излучение, молодые звездные объекты, межзвездная среда, астрономические каталоги, WISE, 2MASS.

Introduction

A bubble is a region filled with hot, ionized, relatively rarefied gas and surrounded by a denser cold shell [1]. The external shape of the expanded shell is directly related to the structure of the enclosed object, that is, the shell may change or disappear when it collides with seals or rarefied places. Therefore, it is difficult to study bubbles [2]. Bubbles are formed mainly with the help of energy emitted from the interior of stars [1]. Most of the interest in these infrared bubbles is related to their formation and development. In 1977, as a result of the study by B. Elmgreen and C. Lada, it was found that the shells around massive stars, accumulating matter surrounding the star or star clusters, can eventually become a large mass, as a result of which gravitational instability occurs in these shells themselves and the formation of secondary stars begins. was determined. This conclusion is now known as "collect-and-collapse", and it has been confirmed that it is one of the two main options for the formation of stars. The second version works when the bubble expands, and the already existing membrane falls on it. Due to compression by hot gas and radiation, the bubbles become gravitationally unstable again and then re-form into a star or star cluster. In infrared bubble catalogs, in addition to small (probably young) bubbles, it was found that there are larger, that is, bubbles located in the shell of an old bubble. Bubbles are closely related to HII regions [3] are infrared signatures of heated regions around young massive stars and star halos with 8 μm rings, which trace the photodissociation region (PDR), which directly borders the region formed during the cloud compression and collapse process. Information and visual inspection of 12 and 24 μm data and a catalog of known bubbles [3] exceeds 5000, so understanding how these objects interact with their environment is of great importance for galactic star formation.

The purpose of this work is to search for and identify young stellar objects near the N10 bubble based on ground-based and space infrared observations.

1. Data

In our study, the following catalogs of extensive surveys and infrared data were used: WISE, 2MASS. First, WISE (Wide-field Infrared Survey Explorer) is a 40-centimeter telescope in low Earth orbit. WISE maps the entire sky in four mid-infrared bands of 3.4, 4.6, 12, and 22 μm [4]. The location of these bands in the mid-infrared region corresponds to the region where excess radiation from young stars from the cool circumstellar disk or envelope material becomes important relative to the stellar photosphere. This fact suggests that WISE can easily be used as a tool for searching and classifying young stellar objects (YSOs), like the work done on Spitzer. However, given the specific set of science objectives, the WISE flux source extraction process is not optimized for the regions where these objects are most commonly encountered, including the galactic planes. Therefore, YSOs are usually found in the mid-infrared region, related to the thermal radiation of dust or the emission of polycyclic aromatic hydrocarbons (PAH) dust, and in dark areas or densely concentrated areas such as infrared dark clouds [5]. These facts call for a better evaluation of WISE's performance in such regions before designing the schemes necessary to achieve the goal of searching for YSOs. Observations of the near-infrared sky in J (1.25 μm), H (1.65 μm), and Ks (2.17 μm) obtained by 2MASS. 2MASS All-Sky Catalog of Point Sources (2003) and AllWISE Data Release (2013) were used in this work [6]. We can see results from 2MASS (Two Micron All-Sky Survey) in infrared and other wavelengths. 2MASS will make observations and collect data using two new, highly automated 1.3-meter telescopes. Each telescope here is equipped with a three-channel camera, each consisting of three different HgCdTe detectors in a 256 x 256 array that simultaneously scan the sky for J (1.25 μm), H (1.65 μm), and K (2.17 μm) waves. can observe in length. Observations are made when the arrays of 2MASS are pointed at the sky, while the telescopes are moving flat across the sky at a rate of ~1 foot per second [4].

2. N10 infrared dust bubble

N10 is one of the northern infrared bubbles in the Churchwell catalog. N10 shows a bubble centered at $\alpha_{2000} = 18^h 14^m 5{,}8^s$ and $\beta_{2000} = -17° 28' 19''$ (l = 13°.188 , b = 0°.039) [3]. This dust bubble has been identified by some scientists as MWP1G013189+000428. The kinematic distance of this bubble spans the range ~ 4.7 ± 0.5 kpc. The specifications for N10 are shown in Table 1.

Table 1. Specifications for the N10

Object	Center point coordinates				Search radius	Additional information
	Equatorial		Galactic			
	α R.A. (J2000) (hh:mm:ss.ss)	δ DE (J2000) (dd:mm:ss.ss)	l, deg	b, deg		
N10 bubble	18 14 5,8	-17 28 19	13˚,17	0˚,06	2,5 arcmin	$t = 9{,}17 * 10^4$

On Figure 1 shows an image of a dust bubble N10 with a radius of 2.5 arcmin.

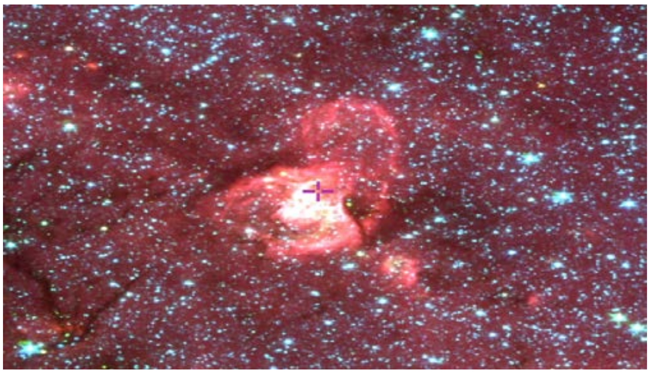


Figure 1 – An appearance of N10 dust bubble

N10 bubble distance was measured by Churchwell et al. (2006) [3] and Watson et al. (2008) [9] 4.9 kpc, Beaumont et al. (2010) at 4.1 kpc [7], Pandian et al. (2008) determined to be 4.6 kpc [8].

Based on the spectral lines of $^{12}CO(3-2)$, $HCO^+(4-3)$, $N_2H^+(4-3)$ and $CH_3OH(7(0, 7)$, a high-mass cluster interacting with the N10 dust bubble was studied in detail. $CH_3OH(7(0 , 7) - 6(0, 6))$ showed that a hot core is formed in the region of the JSON N10 bubble. And the position-velocity diagram of $N_2H+(4-3)$ shows that the cold dense core of the cluster was not destroyed by star formation. Therefore, the mass of the N10 bubble is about It was taken as 27.44 $M_\odot$ [10].

N10 is defined as a bright MIR and radio continuum bubble with an elliptical or slightly comet-like shape, with a cutoff at 160° galactic coordinate angle. In addition, at a frequency of about 1.4 GHz, the integral flux density of this bubble was found to be 7.58 J (Helfand et al. 2006) [12].

The surroundings of the N10 dust bubble in molecular radiations were studied. Infrared bubbles discovered for the first time by GLIMPSE at a wavelength of 8.0 μm are due to the expansion of the HII region and found to be an ideal region for star formation at its boundaries. N10 is a very interesting bubble because infrared studies of the content of young stars indicate a star formation scenario that began at the edge of the HII region. PMO 13.7 m $^{12}CO(1\text{-}0)$ and $^{13}Co(1\text{-}0)$ observations were made towards the N10 bubble. Bright emission of CO was detected, and physical parameters were determined from them by detecting two molecular thrombi. By comparing the dynamical age of this region and the fragmentation time scale, the star formation mecha-nism "radiation-induced explosion" was shown. The N10 bubble was of particular interest with the gas structures in the narrow boundary between the HII region and the surrounding molecular matter, as well as the age range of YSOs located in this region, thus indicating star formation [11].

3. Search for candidates for young stellar objects

Research and analysis of different regions of the interstellar medium have shown the presence of star-forming regions near dust bubbles [13, 14]. The N10 bubble is part of a large star-forming region that contains other bubbles, i.e. several small bubbles, many dark filaments and clusters between and around the bubbles [14].

To identify candidates for young stellar objects, we searched the WISE catalog at a distance of 2.5 arcmin from the origin of N10. A total of 117 objects were found. Data from the WISE Point Source Catalog provide information on young stellar objects - this is the main table (Table 2). We first identify and then classify YSOs using a list of objects corresponding to 3.4, 4.6 and 12 μm. Scheme — K12 — Rebull et al. (2010) [15] , Andrews et al. (2011) [16] and Cieza et al. (2012) based on [17] catalogs. For a better understanding of our young star candidates in a broad space of color and color magnitudes of astrophysical contamination, we review the catalog of AGB carbon stars [18], [19] and [20] and classical Be stars [21]. Extragalactic objects are found, and there are other types of galactic objects with excess amounts of visible infrared light in the left and central parts. A band of objects with approximately zero $w1 - w2$ color but a wide range of $w2 - w3$ color will be a mixture of the original types. At the same time, they may contain photospheres or main-sequence stars with occasional galaxies that give off a distinctly red color. Finally, some objects are either young transient disc stars or old and "fragmented disc" stars similar to VEGA[22].

Class I YSOs (protostellar candidates) are the reddest objects, and if their colors match, they are classified as:

$$\begin{gathered} w2 - w3 > 2.0, \\ w1 - w2 > -0.42 \times (w2 - w3) + 2.2, \\ w1 - w2 > 0.46 \times (w2 - w3) - 0.9, \\ w2 - w3 < 4.5. \end{gathered} \quad (1)$$

These conditions modify the K12 scheme to better represent class system-based partitions and eliminate contamination by false detections in the WISE 3 band. If the colors of class II YSOs (candidate T Tauri stars and Herbig AeBe) meet the following criteria, then the rest of the objects will be classified as follows:

$$\begin{gathered} w1 - w2 > 0.25, \\ w1 - w2 < 0.9 \times (w2 - w3) - 0.25, \\ w1 - w2 > -1.5 \times (w2 - w3) + 2.1, \\ w1 - w2 > 0.46 \times (w2 - w3) - 0.9, \\ w2 - w3 < 4.5. \end{gathered} \quad (2)$$

To compensate for the relative reduction in sensitivity in WISE bands 3 and 4, we use the 2MASS J, H, Ks point source catalog automatically provided by the WISE catalog [23]. We can modify the K12 scheme and use the $H - Ks$ and $w1 - w2$ color-color diagram to search for and classify YSOs. In the $H - Ks$ color space, there is a trade-off between the reddening vector and the dust overemission vector compared to $w1 - w2$. In other words, it is easier to identify a line fitting the standard extinction law that removes most of the extragalactic contamination from the $H - Ks$, $w1 - w2$ plot than from the $Ks - w1$, $w1 - w2$ plot, because there are reddened background galaxies and main-sequence stars can have colors similar to the disc's objects.

A change to our K12 scheme and the original concept of Spitzer-2MASS [24] is to not apply bias to the colors of the sources we classify. Without an independent loss reduction method for each source, we would make the wrong choice and classification based on photographs. Thus, the extinction vector in H-Ks compared to $w1 - w2$ is <0.3 mag, but in most cases it can be greater or less than 1, which means that some objects classified as class I protostars in this part of the sequence, red-painted class II stars are quite possible.

We search for YSO candidates among previously unclassified objects with a non-zero photometric error in 2MASS H and Ks using the following conditions and omit the conditions for the WISE 3 band:

$$H - Ks > 0.0,$$

$$H - Ks > -1.76 \times (w1 - w2) + 0.9, \qquad (3)$$

$$H - Ks < (0.55/0.16) \times (w1 - w2) - 0.85,$$

$$w1 \leq 13.0.$$

Some objects were originally assigned to class II. Class I stars are then grouped as subset candidates if the following condition is met:

$$H - Ks > -1.76 \times (w1 - w2) + 2.55. \qquad (4)$$

The ratio under the above conditions (0.55/0.16) is obtained from the calculation of the ratio of color levels calculated with $Ks > 1$, so $H - Ks, w1 - w2$ has the most accurate representation of galaxies [25]. The general list of YSO candidates determined according to the conditions of [25] is given in Table 2.

On Figure 2 shows the dependence of color indicators according to the AllWISE catalog. It can be seen from Figure 2 that the color indicators of transitory disks occupy a smaller area than objects of class I. Candidates for class II objects will have a smaller difference in infrared fluxes than candidates for class I. Thus, we see candidates for young stellar objects grouped according to their stage of evolution.

The diagram in Figure 2 shows class I objects with red squares, class II objects with green circles, and transition disks with blue rhombuses. We identified 29 objects that confirm the previously established status of young stellar objects in various catalogs. Figure 3 shows the energy distribution spectrum (SED) for several candidates for young stellar objects. As can be seen from Figure 3(a), a class I candidate is in good agreement with the conventional energy distribution diagram. Therefore, we can say that the objects we found are young stellar objects of class I. If class I, then they have high or flat SED. Then it can be assumed that the age of these objects is about $2 \cdot 10^5$ years, and the mass is 0.1 M_{Sun}. Figure 3(b) shows the SED for a candidate for class II young stellar objects. Class II objects are pre-main-sequence stars with optically thick disks and must be up to about 10^6 years old and have a near-stellar disk mass of 0.01 M_{Sun}. Transition disks are young stellar objects with optically thick excess emission at long wavelengths and no emission at short wavelengths. They are intermediate between classes II and III, so their age is about $0.5 \cdot 10^7$ - $0.8 \cdot 10^7$ years.

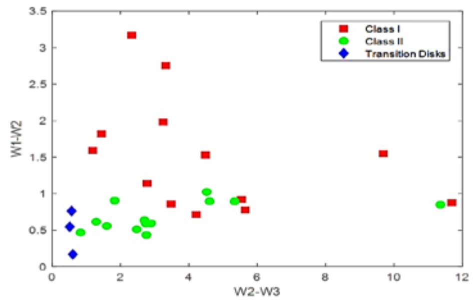


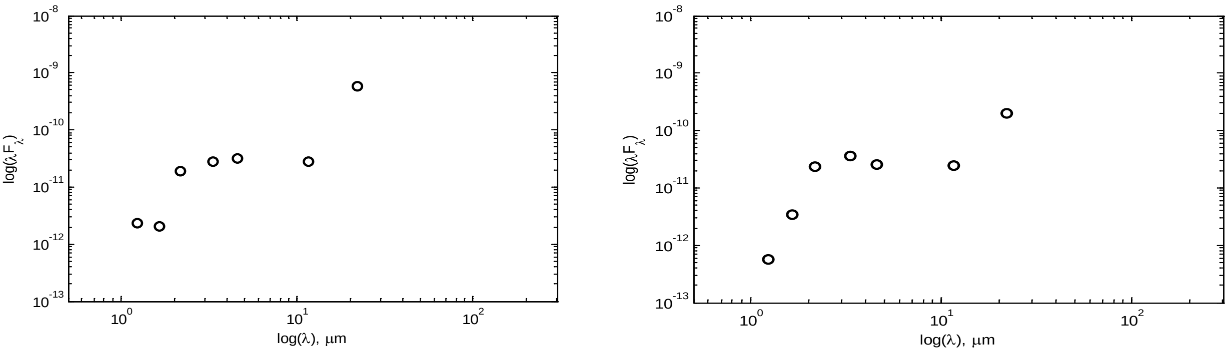
Figure 2 – Color diagram of sources found near the N10 dust bubble

Thus, as our analysis shows, Koenig et al. (2014) [25] algorithm detects young stellar objects well.

Objects N10_2 and N10_15 are listed in the astronomical catalog as stars of spectral classes O4-6 and 06.5V. Stars of spectral class O have a high surface temperature — above 30000 Kelvin and are characterized by blue color. Spectral lines of ionized metals and ionized helium are found in their spectra. Neutral helium and hydrogen lines are also present, but they are weaker, and emission lines are also often present in their spectra. Class O is divided into subclasses from the earliest O2 to the late O9.7. When moving to later subclasses, the intensity of the neutral helium lines increases, and the ionized lines decrease. Only the most massive and brightest stars belong to this class. Their mass exceeds 20 M_{Sun}, and their luminosity can reach several tens of thousands of solar luminosities and millions. Such stars live for a short time: in the main sequence, stars of such a mass and such a spectral class are about 3-6 million years old, so stars of the O class are very young objects. Therefore, such stars are indicators of recent star formation in the visible region, for example in OB communities where all stars formed from a single molecular cloud. Accordingly, we correctly identified N10_2 and N10_15 as young stellar objects. At the same time, we see that object N10_2 is indeed smaller than N10_15, which corresponds to the spectral type and our criteria (N10_2 belongs to class I, and N10_15 belongs to class II).

Table 2 - General list of YSO candidates

Object	Catalog name	A R.A.(J2000) (hh:mm:ss.ss)	δ DE (J2000) (dd:mm:ss.ss)	W1, mag	W2, mag	W3, mag	W4, mag	J, mag	H, mag	K, mag	Class
N10_1	J181405.80 -172812.8	18 14 05.802000	-17 28 12.80784	9.100	7.552	-2.134	3.268	17.625	16.218	13.638	I
N10_2	J181405.47 -172837.9	18 14 05.473824	-17 28 37.90236	9.417	8.541	-3.149	-6.181	13.511	11.846	10.730	I
N10_3	J181404.94 -172730.5	18 14 04.948992	-17 27 30.56832	10.081	8.552	4.069	-0.537	16.467	14.594	13.589	I
N10_4	J181401.37 -172823.3	18 14 01.372344	-17 28 23.35404	11.937	8.766	6.442	0.629	0.000	0.000	0.000	I
N10_5	J181410.77 -172819.3	18 14 10.775064	-17 28 19.36740	9.995	8.855	6.081	0.734	15.537	14.912	11.744	I
N10_6	J181407.98 -172708.4	18 14 07.982064	-17 27 08.48700	9.978	7.224	3.903	1.187	18.125	17.128	13.945	I
N10_7	J181409.60 -172722.1	18 14 09.603312	-17 27 22.19616	9.274	7.294	4.049	1.312	18.123	16.575	13.071	I
N10_8	J181402.15 -172708.2	18 14 02.155800	-17 27 08.24940	10.877	10.015	6.538	2.244	16.499	15.563	13.141	I
N10_9	J181405.84 -172950.7	18 14 05.840856	-17 29 50.76600	11.121	10.199	4.665	0.042	17.874	15.135	14.087	I
N10_10	J181406.20 -173003.7	18 14 06.209568	-17 30 03.72852	10.611	9.836	4.188	-0.772	17.926	15.238	13.688	I
N10_11	J181408.31 -173019.1	18 14 08.310768	-17 30 19.10520	10.302	9.588	5.375	0.938	15.555	14.157	12.576	I
N10_12	J181410.34 -173022.8	18 14 10.344744	-17 30 22.82112	10.494	8.677	7.236	2.815	18.150	16.970	12.274	I
N10_13	J181400.12 -173021.6	18 14 00.129936	-17 30 21.63060	8.125	6.532	5.350	2.657	14.680	13.343	10.818	I
N10_14	J181404.45 -172830.7	18 14 04.458000	-17 28 30.71244	9.933	9.084	-2.273	0.708	17.100	14.203	13.417	II
N10_15	J181409.41 -172739.6	18 14 09.412776	-17 27 39.63744	10.355	9.331	4.811	0.229	17.644	14.938	14.223	II
N10_16	J181407.30 -172715.1	18 14 07.309056	-17 27 15.18696	10.302	9.408	4.072	-0.324	13.103	12.728	12.483	II
N10_17	J181403.92 -172659.9	18 14 03.920952	-17 26 59.96436	10.817	9.921	5.318	1.958	13.328	13.038	12.572	II
N10_18	J181411.09 -172903.8	18 14 11.090736	-17 29 03.84108	11.423	10.865	9.270	2.260	18.122	16.646	13.158	II
N10_19	J181413.58 -172903.9	18 14 13.581408	-17 29 03.91200	9.707	8.801	6.974	2.114	15.092	13.550	11.229	II
N10_20	J181403.36 -172617.6	18 14 03.369576	-17 26 17.64708	10.970	10.459	7.987	4.483	17.847	15.143	12.545	II
N10_21	J181414.64 -172821.2	18 14 14.647296	-17 28 21.24660	9.698	9.104	6.214	1.898	17.067	14.393	11.512	II
N10_22	J181411.42 -172958.4	18 14 11.427360	-17 29 58.42752	10.984	10.516	9.688	3.001	13.501	12.817	12.723	II
N10_23	J181407.78 -173031.9	18 14 07.789776	-17 30 31.92372	9.323	8.688	5.991	2.136	17.838	13.488	10.757	II
N10_24	J181406.92 -173036.4	18 14 06.921120	-17 30 36.46620	9.450	8.858	6.121	2.438	14.900	13.041	10.901	II
N10_25	J181358.24 -172953.7	18 13 58.241160	-17 29 53.78964	9.997	9.382	8.095	4.876	17.897	14.556	11.672	II
N10_26	J181411.88 -173020.6	18 14 11.887104	-17 30 20.65536	10.801	10.366	7.612	3.212	17.822	14.973	2.667	II
N10_27	J181411.53 -172925.0	18 14 11.532360	-17 29 25.03392	7.226	6.464	5.898	1.992	17.557	12.077	9.006	disk
N10_28	J181406.92 -173036.4	18 14 06.921120	-17 30 36.46620	9.450	8.858	6.121	2.438	14.900	13.041	10.901	disk
N10_29	J181403.02 -173042.0	18 14 03.021120	-17 30 42.06708	10.622	10.453	9.851	5.419	17.639	14.745	12.205	disk



a) N10_2 - I class б) N10_15 - II class

Figure 3 – SED candidates for young star objects

Conclusion

Using multiwavelength surveys and catalog data, we have investigated infrared emission objects around the N10 bubble. We have found 117 sources that we believe may be objects of young stars. However, due to 22 objects having unreliable fluxes at the considered wavelengths, we studied 95 objects. The classification was carried out according to the criteria of [25]. Among them, 13 objects - class I young star objects, 13 objects - class II young star objects, 3 objects - transitional disks were identified. The rest of the sources do not correspond to these two classes and the transition disk according to all the classification criteria, so they require further investigation at other wavelengths of infrared radiation.

In conclusion, the study showed that all objects in the early stages of evolution are located around the N10 infrared dust bubble.

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