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O-LIKE STARS IN THE DIRECTION OF THE NORTH AMERICA AND PELICAN NEBULAE

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Abstract. In the area covering the complex of the North America and Pelican nebulae we identified 13 faint stars with J–H and H–K_s color indices which simulate heavily reddened O-type stars. One of these stars is CP05-4 classified as O5 V by Comerón and Pasquali (2005). Combining magnitudes of these stars in the passbands I_C, J, H, K_s and [8.3] we were able to suspect that two of them are carbon stars and five are late M-type AGB stars. Interstellar extinction in the direction of these stars was estimated from the background red clump giants in the J–H vs. H–K_s diagram and from star counts in the K_s passband. Four or five stars are found to have a considerable probability of being O-type stars, contributing to the ionization of North America and Pelican. If they really are O-type stars, their interstellar extinction A_V should be from 16 to 35 mag. Two of them seem to be responsible for bright E and J radio rims discovered by Matthews & Goss (1980).

Key words: ISM: dust clouds: individual (L 935) – H II regions: individual (W80) – stars: early-type – stars: fundamental parameters (classification, colors)

1. INTRODUCTION

In the past there were numerous attempts to identify the star (or stars) responsible for the ionization of the North America and Pelican nebulae (the H II region W80). The history of the search has been described recently by Comerón & Pasquali (2005).

The first true candidate for the ionizing star was HD 199579 ($V = 6.0$), a single-line spectroscopic binary of spectral class O6 Ve, proposed by Sharpless & Osterbrock (1952). The star is located in the upper part of the North America Nebula and there are some signs of its interaction with the nearby gas – within about 0.5 degree from the star the thermal radio flux in decimeter waves has somewhat larger intensity (see, e.g, Matthews & Goss 1980). However HD 199579 alone cannot be responsible for the ionization of all the H II region since it is located too far from the center of the complex. Therefore a search for other ionizing stars has been continued. Herbig (1958) suggested that the true ionizing star can be located behind the dust cloud L 935 which separates the North America

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and Pelican (hereafter NAP) nebulae.

Additional important information about the ionizing star was presented by Bally & Scoville (1980) who investigated the complex in ^{12}CO radio line at 2.60 mm. From the analysis of line profiles they concluded that the molecular complex expands with a velocity of 5 km/s from the point near the peak of the thermal radio emission. This expansion was interpreted as the remnant of the ionization shock front system from the H II region which was once formed by a young O-type star (or stars) born off-center in the original molecular cloud about 3–8 million years ago. When the shock reached the back edge of the molecular cloud, an asymmetric flow of ionized gas was established, depressurizing the inner H II region. This outflow has formed a huge outer H II region on the opposite side of the L 935 dust and molecular cloud, the present NAP nebulae. In the direction of the Sun the front edge of dust/molecular cloud was much thicker and remained almost unaffected. In an attempt to find the ionizing O-B stars behind the L 935 cloud Bally & Scoville (1980) identified 11 infrared sources which might be the candidates.

This model was extended by Wendker et al. (1983) using the thermal radio continuum observations at 11 cm. The decimeter continuum reveals a complicated picture of the flux distribution with a number of local maxima, ridges, bright rims and other structural details. To explain these features, Wendker et al. proposed a model of the complex containing a group of eight O-stars, ionizing so-called cavities in the parent dust/molecular cloud. They supposed that the resulting small H II regions form the local radio flux maxima in the three ridges of increased radio emission crossing the L 935 cloud. No candidates for the ionizing stars were proposed.

One more feature which has played a significant role in the search for the ionizing stars were the bright rim structures. In the NAP nebulae Pottasch (1956) described seven rims seen in the optical. The bright rims are usually located at the edges of dark clouds where they meet the ionized region. The rims are sharply defined, especially from the dark side. The brightest portion of each rim is usually directed to the exciting star. In space they have a form of flat or curved sheets of ionized gas, and are best seen when viewed edge-on. Matthews & Goss (1980) identified some of the Pottasch optical rims in the thermal radio map at 49 cm and nine additional rims which are seen only in radio – optically they are completely obscured by the dark cloud. Four new radio rims were added by Wendker et al. (1983). The orientation of the rims was an important factor in searching for places of the ionizing stars.

2. THE CAMERÓN AND PASQUALI STAR

Comerón & Pasquali (2005) in their search for the ionizing star have used the J–H vs. H–K_s and K_s vs. H–K_s diagrams in a circle of 0.5° radius centered on the coordinates RA (2000) = $20^{\rm h}55^{\rm m}17^{\rm s}$, DEC (2000) = $+43°\,47'\,30''$, near the geometric center of the complex. They identified 19 infrared objects lying near the interstellar reddening line of O-type stars in the J–H vs. H–K_s and K_s vs. H–K_s diagrams. For these objects the infrared spectra between 1.5 and 2.4 μm were obtained, and two early-type stars were found. Finally, optical spectra of these two stars were used for the identification of the star 2MASS J205551.25+435224.6 (hereafter CP05-4) as the best candidate. This star was classified as O5 V and recognized as the ionizing star for the entire H II complex. This star is present in the list of Bally & Scoville (1980) of the potential ionizing objects.

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In one of our papers (Laugalys et al. 2006) we have measured the CP05-4 star in the 7-color *Vilnius* photometric system and confirmed that it is a reliable candidate for a ionizing source of the nebulae. If the star indeed is of spectral type O5 V, then *Vilnius* photometry would give its $E_{Y-V} = 2.20$ and $A_V = 9.2$ for the normal interstellar extinction law. Adopting $V = 13.24$ and $M_V = -4.5$ we obtain a distance of 520 pc, which is approximately the cloud distance. If the star is more luminous, its distance should be larger. Since we have no accurate estimation of its luminosity, the relation of this star to the ionization of the entire NAP complex is not secure. If the star is responsible for ionizing the complex, then, to avoid shielding of the ultraviolet photons, it must be located well behind the L 935 dust cloud, in a relatively transparent space where the parent dust/molecular cloud has been already destroyed.

Looking for young stellar objects (YSOs) in the NAP area, we have analyzed stars measured in different photometric systems covering a spectral range between 0.35 and 8.3 μm. We have found some stars behind the L 935 (Lynds 1962), or Tokyo 497 (Dobashi et al. 2005), dust/molecular cloud which are similar to heavily reddened O-type stars located at a distance of the nebulae. This stimulated the present search for stars which can be contributors to the ionization of the surrounding nebulae. For the investigation a $3° \times 3°$ area centered at J2000: $20^{\rm h}\,56^{\rm m}$, $+44°$ was taken.

3. MORE O-LIKE STARS BEHIND THE L 935 CLOUD

For the identification of potential ionizing stars behind the L 935 cloud in the 2MASS catalog we applied a method similar to that used by Comerón and Pasquali but with the following alterations: (1) the search area was extended along all the length of the L 935 cloud; (2) the magnitude K_s limit was changed to $K_s < 5.6 + 1.8\,(H - K_s)$; this limit includes all main-sequence O-type stars up to 550 pc and more luminous stars at larger distances; (3) according to Straižys et al. (2008), the ratio of color excesses E_{J-H}/E_{H-K_s} in the Q-parameter was taken 2.0, i.e., $Q_{JHK_s} = (J-H) - 2.0\,(H-K_s)$. The limits set to Q_{JHK_s} were the values between 0.05 and –0.15, obtained from the intrinsic Q_{JHK_s}-value of O-type stars, –0.05, taking into account the scatter of points in Figure 1 of paper Straižys et al. (2008). One more restriction was put on the accuracy of 2MASS photometry: all objects with the errors in *J, H* and K_s magnitudes (given in the catalog) larger than 0.1 mag were not considered. According to Straižys & Lazauskaitė (2008), the ratio E_{J-H}/E_{H-K_s} depends slightly on the temperatures of stars: with decreasing $T_{\rm eff}$ the ratio also decreases. The expected difference in slopes between O- and K-type stars is only about 3 %, and this effect was neglected in the present study.

The objects, satisfying the above conditions, were checked in the Simbad database, and all known stars of spectral class B and cooler were rejected. Among them quite numerous were N-type carbon stars. A few infrared objects, classified spectroscopically by Comerón & Pasquali (2005, Table 1) as carbon or AGB stars, were also excluded. We also excluded stars outside the L 935 dust cloud and the Pelican Nebula where the A_V extinction lower than 10 mag is expected (Cambrésy et al. 2002). Most probably, these objects are not heavily reddened O-stars.

The remaining 13 objects are listed in Table 1 which includes also CP05-4, the confirmed O5 V star. The star No. 12 was included in the list despite its Q_{JHK_s} = –0.22; see discussion in Section 7. All these objects hereafter will be called as 'O-like stars'. No information about them is given in the Simbad database. Their

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DSS2 magnitudes V, F and N were taken from the GSC-2.3 catalog available at Simbad. The J, H and K_s magnitudes were taken from the 2MASS Point Source Catalog; in Table 1 their values are rounded to two decimal places. For most of the objects the MSX fluxes at 8.3 μm are available and are given in Table 1. The next columns give the values of Q_{JHK_s}, maximum A_V expected (see Section 6) and the classification of the objects (see Sections 4, 5 and 7).

In Figure 1 the stars from Table 1 are plotted on a sky image, together with the nebulae and the radio continuum at 21 cm intensity isolines from the Canadian Galactic Plane Survey (Taylor et al. 2003). Figure 2 shows the positions of these stars in the K_s vs. H–K_s diagram.

Table 1. Stars in the North America and Pelican nebulae complex simulating heavily reddened O-type stars.

No.	RA (J2000)	DEC (J2000)	V	F	N (or I)	J	H	K_s	[8.3] Jy	Q_{JHK_s}	A_V max.	Possible type
1	20 49 57.23	+44 22 53.8	–	–	–	12.01	9.31	7.98	–	0.04	23.4	O–B0?
2	20 50 35.05	+44 26 29.6	–	–	16.96	9.90	7.06	5.64	0.87	0.01	24.2	carbon?
3	20 52 46.79	+44 02 30.8	–	–	–	11.99	9.21	7.85	0.15	0.06	20.5	AGB?
4	20 53 15.82	+44 32 57.0	–	–	–	11.36	8.89	7.64	–	–0.03	18.7	O9–B0?
5	20 54 13.42	+44 02 58.9	–	18.40	13.21	8.37	6.48	5.58	0.78	0.08	21.1	AGB?
6	20 54 16.26	+43 43 09.1	–	18.77	15.85	8.24	6.36	5.46	1.06	0.08	22.0	AGB?
7	20 55 25.16	+44 18 14.4	19.06	17.43	13.32	7.96	6.20	5.29	0.86	–0.05	26.6	O5?
8*	20 55 51.25	+43 52 24.6	13.24*	10.69	8.86	6.36	5.51	5.04	0.84	–0.08	28.4	O5 V
9	20 55 52.70	+43 53 24.2	–	–	17.66	10.82	8.56	7.44	0.22	0.03	28.4	O9–B0?
10	20 57 36.47	+44 04 55.9	–	–	17.77	10.63	8.57	7.48	0.22	–0.12	19.3	AGB?
11	20 58 06.73	+43 55 14.1	–	–	–	12.88	8.66	6.57	0.80	0.04	26.6	O5, AGB?
12	20 58 24.24	+43 56 38.6	–	–	–	12.69	8.88	6.87	0.61	–0.22	26.6	AGB?
13	20 58 26.22	+43 42 38.5	17.56	15.04	12.53	8.33	6.42	5.49	0.66	0.05	24.7	carbon?

Note: No. 8 = CP05-4, its V magnitude is from Laugalys et al. (2006).

The 'O-like stars' can be either O-type stars or high-luminosity stars of other spectral classes located behind the L 935 cloud, i.e. farther than 500–600 pc. All cooler main-sequence stars (including B-stars) behind the cloud are eliminated since in the K_s passband they are fainter than O-stars. Normal K and M red giants are excluded by the $Q_{JHK_s} < 0.15$ criterion. However, B-stars of higher luminosities (from IV to I), supergiants of spectral classes A–F5 and AGB stars of the latest spectral classes (M6–M10 for oxygen-rich giants and N-stars for carbon-rich giants) can intervene the J–H vs. H–K_s and K_s vs. H–K_s diagram regions used to isolate possible O-type stars.

Figure 3 shows the J–H vs. H–K_s diagram with the intrinsic lines of main sequence and late-type giants and the two reddening lines corresponding to red clump giants (G8–K2 III, $Q_{JHK_s} = 0.22$) and O–B stars ($Q_{JHK_s} = -0.05$). The crosses represent known N-type carbon stars (Table 2) selected in the NAP area of $3° \times 3°$ size with the center given at the end of Section 2. The blue triangles are known Mira-type variables (Table 3) selected in a larger area around the NAP nebulae, with RA between $20^{\rm h}30$m and $21^{\rm h}30$m and DEC from +41° to +46°. Most (if not all) Mira variables are oxygen-rich (M-type) giants. It is evident that the reddened carbon stars and Miras completely cover the reddening line of O-type stars. Thus, the most important task is to identify these types of objects.

4. THE I–J vs. J–H DIAGRAM

For the identification of carbon stars the $I_{\rm C}$–J vs. J–H diagram, shown in Figure 4, can be used. Here $I_{\rm C}$ is the far-red magnitude close to the Cousins

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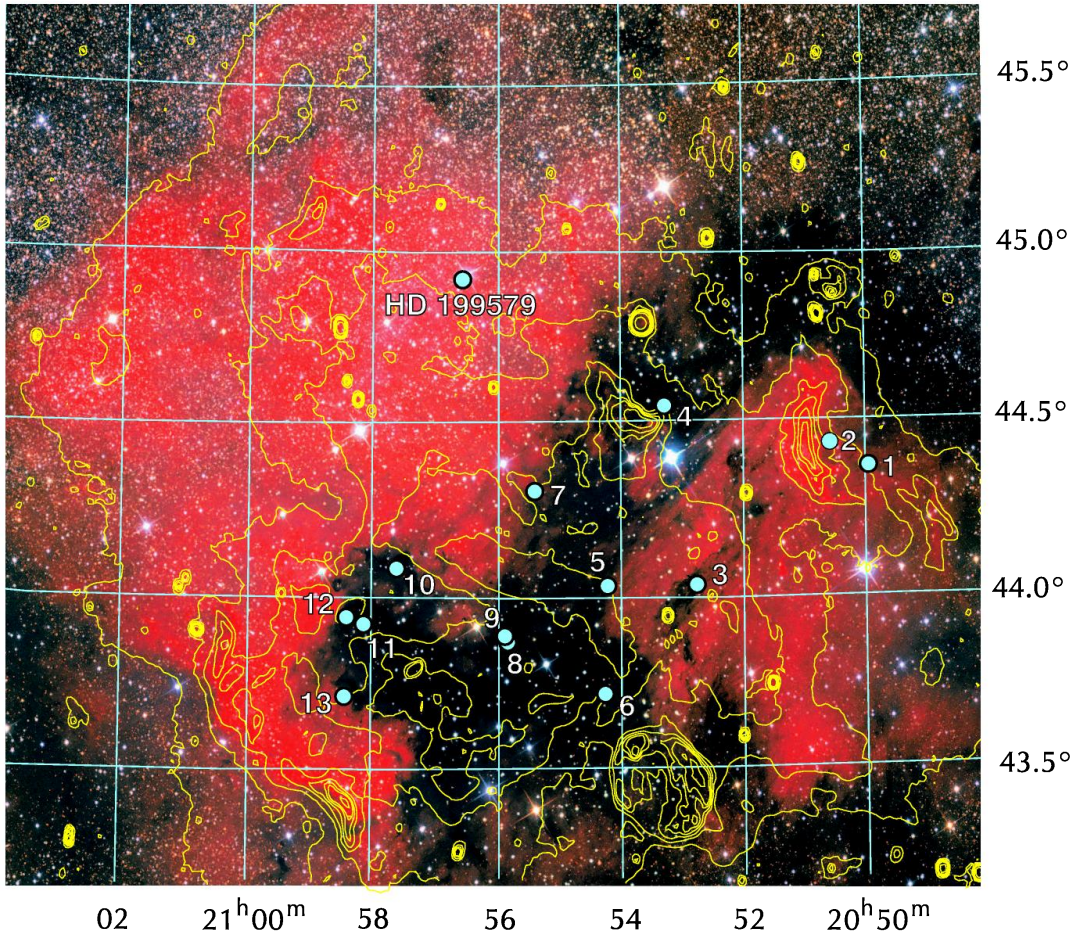

Fig. 1. The map of the NAP nebulae region with the radio continuum isolines from the Canadian Galactic Plane Survey and the stars from Table 1. The radio isolines correspond to the T_b values of 6, 8, 10, 12, 14, 16, 18, 20, 25 and 50 K. The oval feature of $15' \times 20'$ size at $20^h53.3^m$, $+43° 27'$ is the supernova remnant SNR 084.2-00.8 located at a distance of 4.5 kpc (Matthews et al. 1977; Kaplan et al. 2004). Most of other small radio sources in the area are extragalactic objects (Matthews & Goss 1980).

system. The intrinsic lines of normal main-sequence stars and cool giants were calculated in the following way. The intrinsic color indices I_C–J for main-sequence stars and K-giants were calculated from the tabulation of V–J by Koornneef (1983) and V–I_C by Straižys (1992). The same color indices for M0–M6 giants were calculated from V–J by Koornneef (1983) and V–I_C by The et al. (1990). The intrinsic color indices J–H for main-sequence stars and late-type giants were taken from Bessell & Brett (1988) after their transformation to the 2MASS system by the equations given in Carpenter (2001).

The intrinsic line of M giants was extended up to the spectral type M8 III taking its DENIS-based I–$J = 3.8$ and J–$H = 1.1$ from Glass & Schultheis (2002) and Groenewegen & Blommaert (2005). The difference between the 2MASS and DENIS systems was neglected. This value of J–H is confirmed by 2MASS results for the coolest Mira-type variables: R Cas (M6e–M10, $P = 430$ d), W And (M7-Se, S6,1e–S9,2e, $P = 397$ d) and RU Her (M6e–M9, $P = 485$ d). Their J–H values

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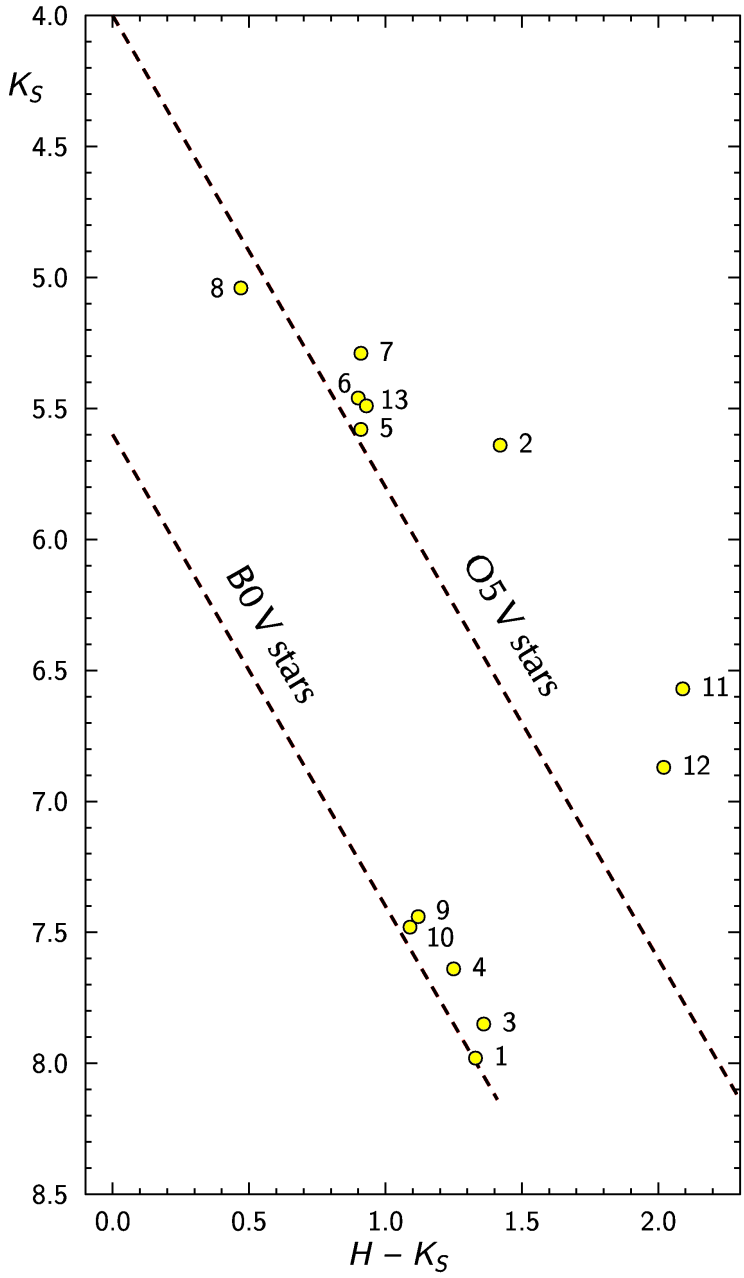

Fig. 2. Color-magnitude diagram K_s vs. H–K_s for the stars from Table 1. The two parallel lines are the interstellar reddening lines for the stars of spectral types O5 V and B0 V at a distance of 550 pc.

from 2MASS are 1.01, 1.09 and 1.01, respectively. The intrinsic line of M-giants runs almost vertically due to increasing absorption in the TiO band at 850 nm.

To define the interstellar reddening line, in Figure 4 we plotted 58 O-type stars belonging to the Cyg OB2 association and listed in Table 1 of Straižys et al. (2008). Color indices I_C–J and J–H of these stars were calculated either from the I_C magnitudes given in Droege et al. (2006) or from the DSS2 photographic N magnitudes (given in the GSC-2.3 catalog, Simbad), and the J and H

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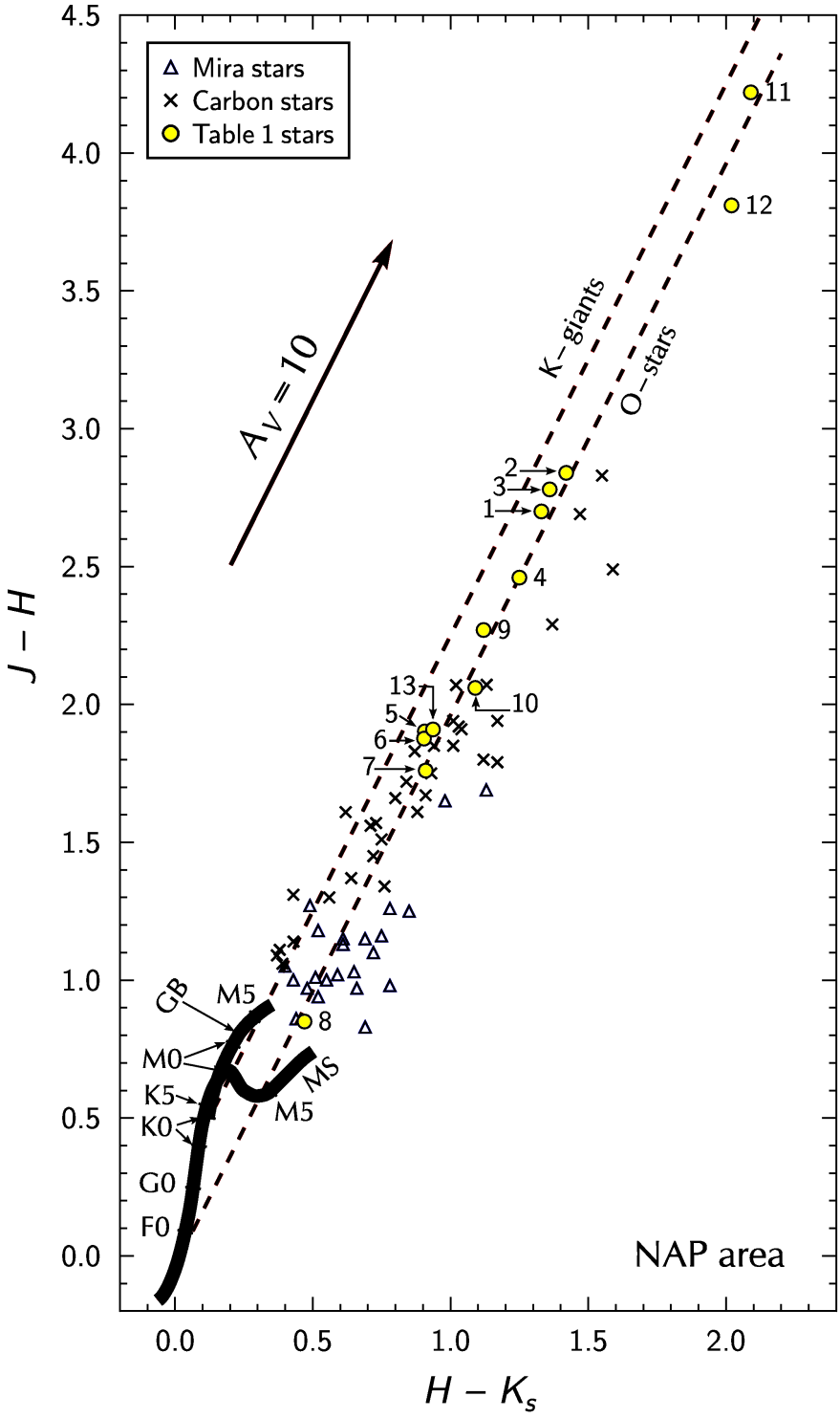

Fig. 3. The J–H vs. H–K_s diagram with the intrinsic main sequence (MS) and giant branch (GB). Two parallel broken lines (in red) are the interstellar reddening lines of O-type stars and red clump giants. Crosses designate known N-type carbon stars and blue triangles O-rich Mira variables located in the NAP area. The numbered yellow circles indicate the stars from Table 1.

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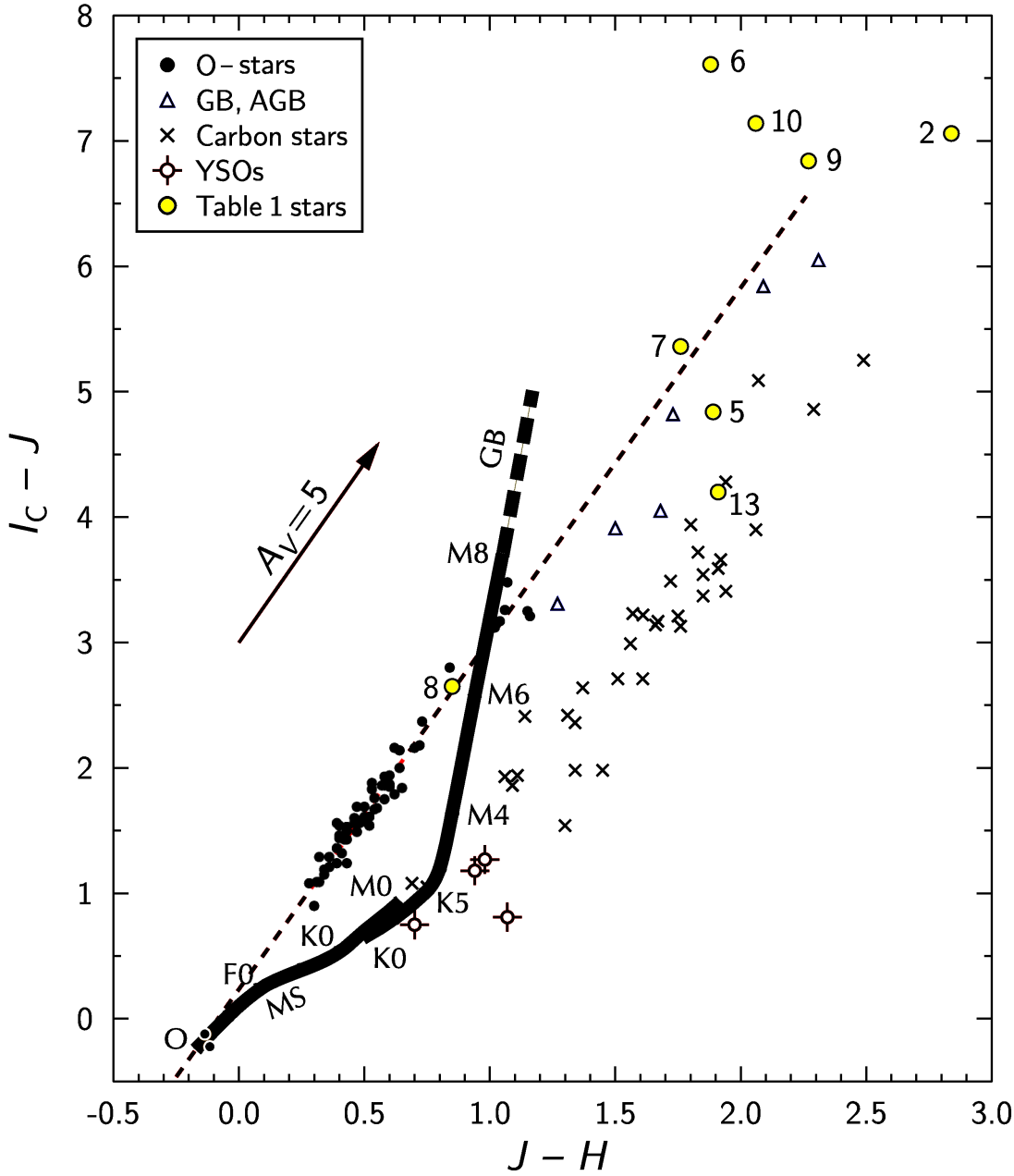

Fig. 4. The I_C–J vs. J–H diagram with the intrinsic main sequence (MS) and red giant branch (GB) (thick orange and yellow lines). Dots are O–B1 stars in the NAP and Cyg OB2 association areas, defining the interstellar reddening line. Crosses designate known N-type carbon stars in the NAP area and blue triangles designate GB and AGB stars classified by Comerón & Pasquali (2005). The numbered yellow circles indicate the stars from Table 1.

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Table 2. Color indices of carbon stars in the $3^\circ \times 3^\circ$ NAP area (rounded to two decimal places).

CGCS	N–J	J–H	H–K_s	CGCS	N–J	J–H	H–K_s
4982	4.28	1.94	1.01	5049	3.14	1.66	0.80
4986	1.93	1.06	0.39	5058	3.23	1.57	0.73
4992	1.05	0.75	0.17	5061	1.86	1.09	0.37
4993	5.09	2.07	1.02	5071	3.94	1.80	1.12
4996	3.59	1.91	1.04	5075	2.99	1.56	0.71
4998	3.49	1.72	0.84	5084	2.64	1.37	0.64
5002	3.90	2.06	1.11	5085	1.81	1.79	1.17
5003	3.13	1.76	0.91	5091	1.94	1.11	0.38
5007	3.66	1.92	1.03	5095	3.17	1.67	0.91
5010	3.54	1.85	0.94	5099	2.41	1.14	0.43
5014	3.41	1.94	1.17	5105	1.98	1.45	0.72
5017	2.71	1.61	0.88	5110	1.98	1.34	0.76
5020	3.72	1.83	0.87	5124	2.71	1.51	0.75
5021	3.37	1.85	1.01	5135	1.54	1.30	0.56
5027	1.08	0.69	0.22	CP05-10	4.86	2.29	1.37
6876*	3.21	1.75	0.93	CP05-16	–	2.69	1.47
5033	2.42	1.31	0.43	CP05-18	5.25	2.49	1.59
5035	3.22	1.61	0.62	CP05-19	–	2.83	1.55

Note: CGCS 6876 = CP05-6.

Table 3. Color indices of Mira variables in the NAP area (rounded to two decimal places).

Name	J–H	H–K_s	Name	J–H	H–K_s
BH Cyg	0.97	0.48	V603 Cyg	1.69	1.13
BL Cyg	0.83	0.69	V607 Cyg	0.94	0.52
DG Cyg	1.27	0.49	V780 Cyg	1.15	0.69
V506 Cyg	1.26	0.78	V1223 Cyg	1.16	0.75
V528 Cyg	1.25	0.85	V1225 Cyg	1.00	0.43
V580 Cyg	1.03	0.65	V1232 Cyg	1.00	0.55
V584 Cyg	1.02	0.59	V1234 Cyg	1.13	0.61
V593 Cyg	0.97	0.66	V1242 Cyg	1.18	0.52
V596 Cyg	0.86	0.44	V1243 Cyg	0.98	0.78
V597 Cyg	1.15	0.61	V1480 Cyg	1.05	0.40
V600 Cyg	1.10	0.72	V1660 Cyg	1.65	0.98
V601 Cyg	1.01	0.51			

magnitudes from 2MASS.[1] Additionally, we plotted two O-type stars with small interstellar reddening (S Mon and 10 Lac) and the O5-type star CP05-4 located in the background of the L 935 dust cloud (Comerón & Pasquali 2005). The slope of the reddening line is E_{I_C-J} / E_{J-H} = 2.84 which is considerably larger than the value 1.78 calculated from the A_λ / E_{B-V} ratios given by Fitzpatrick (1999, Table 2). The reason for this disagreement probably is related to deviations of the

[1] We assumed that the far-red magnitude systems of I_C and N coincide. This assumption may not be strictly correct as the response curves of both magnitude systems and their mean wavelengths are slightly different (806 nm for I_C and 840 nm for N, see the *Asiago Database on Photometric Systems*, Fiorucci & Munari (2003). However, the positions of reddened O-stars do not differ systematically when using either I_C from Droege et al. (2006) or N from GSC-2.3.

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Droege et al. (2006) and the DSS2 far-red systems from the standard $I_{\rm C}$ system, which itself has a poor definition and a number of versions.

Due to the band-width effect the ratio $E_{I_{\rm C}-J}$ / E_{J-H} depends slightly on the temperature of stars (Straižys & Lazauskaitė 2008): for K-type stars the ratio is by 3 % *larger* than for O-type stars. However, taking into account a very poor knowledge of response functions of the far-red passbands (I or N), this effect in Figure 4 is too small to be significant.

In Figure 4 we also plotted known N-type carbon stars selected in the NAP $3^\circ \times 3^\circ$ area (Table 2). Their far-red $I_{\rm C}$ magnitudes were taken mostly from the GSC-2.3 (i.e., DSS2 N magnitudes). For three stars we used the magnitudes from Droege et al. (2006) and for one star (CGCS 4996) from the *INT Photometric Hα Survey of the Northern Galactic Plane*, IPHAS (Drew et al. 2005; González-Solares et al. 2008). The response curve of the IPHAS far-red magnitude i is shifted blueward from $I_{\rm C}$, and has a mean wavelength of 774 nm. The i magnitude was transformed from the IPHAS system by the equation $N = i - 1.10$ obtained from a comparison of six other carbon stars with both N and i magnitudes available.

It is evident that the reddening line of carbon stars is more or less parallel to the reddening line of O–B1 type stars but lies about 1.4 mag lower. This makes possible to identify carbon stars even at the level of relatively low accuracy of the photographic DSS N magnitudes. A considerable scatter of carbon stars around their mean line may be the result of low accuracy of their photographic far-red magnitudes, possible variability and the intrinsic peculiarities in their spectral energy distributions.

However, the $I_{\rm C}$–J vs. J–H diagram is almost useless for the separation of O-type stars from oxygen-rich giants of spectral types M6 III and cooler. In Figure 4 we plot three GB and three AGB stars (triangles) classified by Comerón & Pasquali (2005), their N magnitudes being taken from GSC-2.3. All of them lie between the O-type reddening line and the carbon star sequence. Cooler AGB stars with the TiO-dominated spectra (Mira variables) in Figure 4 should cover both the reddening line of O-stars and the region above it.

To exhibit the location of YSOs, we plotted in Figure 4 two known T Tauri type stars and two Hα emission stars which lie in the Gulf of Mexico (red crossed circles). With increasing reddening, these stars can overlap carbon-rich stars but will not be mixed with O-type stars.

The O-like stars in Figure 4 are plotted as yellow circles, with their numbers from Table 1. Their far-red N magnitudes (when available) are taken from GSC-2.3. Of these stars only CP05-4 has another source of the far-red magnitude: $I_{\rm C}$ = 9.00 in Droege et al. (2006). Other three stars (3, 7 and 13) were observed in the IPHAS project (González-Solares et al. 2008). For the sake of uniformity, we have opted to use the N magnitudes for these stars, too.

Figure 4 shows that only two stars from Table 1, Nos. 7 and 9, lie almost on the extension of the reddening line of O-stars. They are the best candidates for O-type stars. Probably, stars Nos. 2 and 13 are carbon stars, while Nos. 5, 6 and 10 are oxygen-rich AGB stars (M-type Miras or other M-type long-period variables). Although their belonging to O-type stars is doubtful, they should remain in the list for future verification of spectral types by spectroscopic means. Photometric classification of stars 1, 3, 4, 11 and 12 is impossible at this moment since they have no measured far-red magnitudes. They remain in the list of suspected O-type stars.

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2008BaltA..17..143S

5. SPECTRAL ENERGY DISTRIBUTIONS

With the aim to find further evidence that at least some of the selected stars belong to early-type stars, we calculated their spectral energy distributions (SEDs) between 0.8 and 8.3 μm using the data given in Table 1. The values of log λF_λ for the N (or I_C), J, H and K_s magnitudes and the MSX 8.3 μm flux were obtained as described in Straižys & Laugalys (2007, p. 341–342).

The SED curves obtained are shown in Figure 5: probable O-type stars in panel (a) and probable AGB stars in panel (b). The star numbers in the inserts correspond to Table 1. All probable O-stars have their SED maxima at 2.2 μm (K magnitude), except of the CP05-4 star which has maximum at H magnitude. The reddest is No. 4 but it has not been measured in the MSX band at 8.3 μm. The form of the SED curves suggests that the 'O-like' stars have no infrared excesses at >2.2 μm, i.e., they do not belong to YSOs or AGB stars with dust envelopes.

SEDs of the suspected AGB stars (Figure 5, panel b) are not very different from those given in panel (a). At such high interstellar reddenings the intrinsic differences of SEDs between O-type stars and late M-type stars without circumstellar dust envelopes in the 1–3 μm range become negligible if the photometric passbands do not contain strong TiO or H_2O bands. The CO bands longward of 1.56 and 2.32 μm, C_2 bands longward of 1.77 μm and H_2O bands at 1.3–1.5 and 1.7–2.0 μm, present in the spectra of AGB stars, are too faint to create a measurable photometric effect in the broad-band J–H and H–K_s color indices. However, these spectral features are easily observable in infrared spectra at a resolution of $\lambda/\Delta\lambda = 240$ (Comerón & Pasquali 2005).

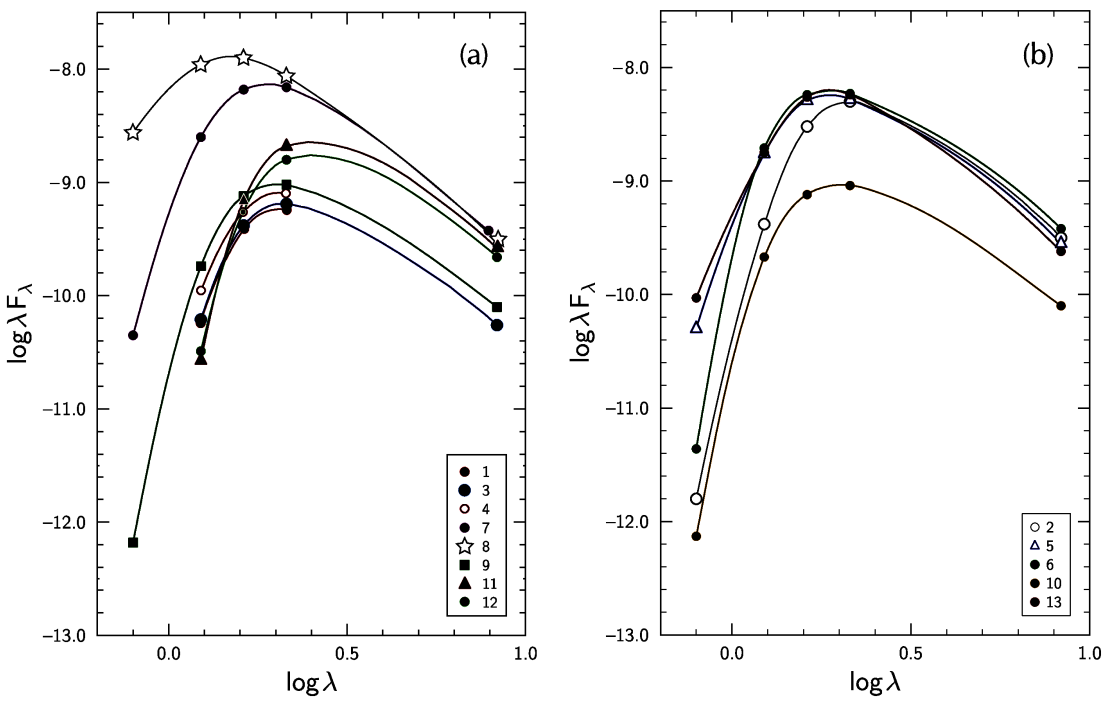

Fig. 5. Spectral energy distributions of the O-like stars between 0.8 and 8.3 μm. Here λ is in μm and F_λ is in erg $\times$ cm^{-2} $\times$ s^{-1} $\times$ μm^{-1}. Panel (a) shows the stars which are the candidates to O-type stars and panel (b) the candidates to AGB stars.

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2008BaltA..17..143S

6. INTERSTELLAR EXTINCTION IN THE DIRECTION OF O-LIKE STARS

The most detailed and deep investigation of interstellar extinction in the direction of the NAP complex was published by Cambrésy et al. (2002) who applied the method based on star counts in K_s magnitude and on statistical color excesses E_{H-K_s}. The angular resolution of the extinction map is 4–7′ in the high extinction areas with A_V between 20–30 mag. This means that smaller areas with high extinction cannot be resolved.

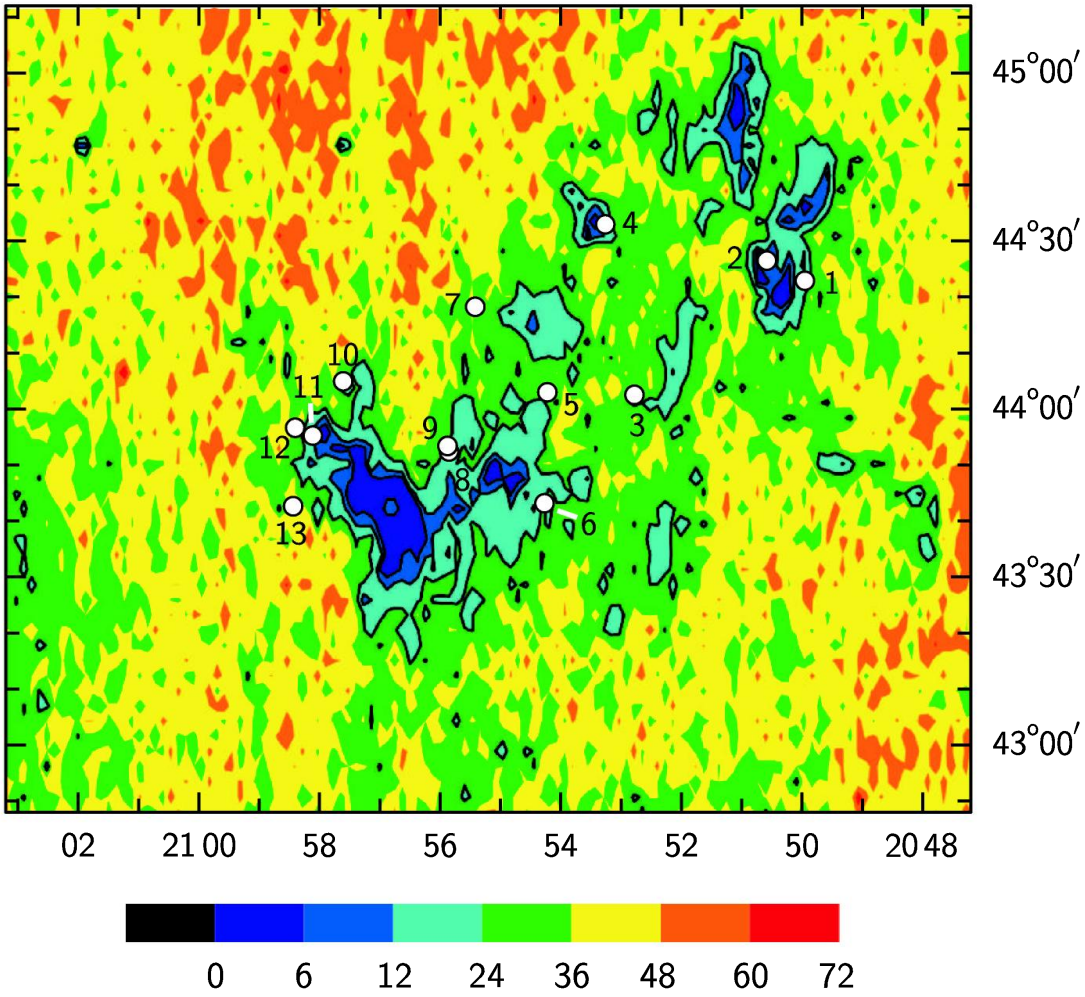

Fig. 6. The map of star counts in the K_s magnitude in $2' \times 2'$ cells. The scale below the map indicates numbers of stars. The numbered white circles show the locations of the O-like stars from Table 1.

To examine the extinction distribution in greater detail we have applied star counts in K_s within $2' \times 2'$ cells. 500 000 stars with the indication of photometric uncertainty $\sigma < 0.25$ were used. The number of stars falling in each cell varied from zero to ~ 70. The resulting star density map for RA $20^{\rm h}48^{\rm m}$ – $21^{\rm h}02^{\rm m}$ and DEC 43° – 45° is shown in Figure 6. It exhibits more details and broader boundaries of large extinction than the Cambrésy et al. (2002) map. Since we have no calibration of star counts in extinctions, the map can be used only for a qualitative estimate of the extinction in the NAP complex in the direction of O-like stars listed in Table 1.

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2008BaltA..17..143S

We also applied another method to estimate the maximum extinctions in the vicinities of O-like stars, based on the reddenings of the background red-clump giants. From the J–H vs. H–K_s diagrams, plotted for the areas of 20′ diameters around these stars, the maximum values of J–H were read out taking into account only stars close to the reddening line with the slope $E_{J-H}/E_{H-K_s} = 2.0$, originating from the intrinsic position of red clump giants, i.e., J–$H = 0.50$, H–$K_s = 0.14$ (see Straižys et al. 2008). Possible pre-main-sequence stars, identified by the criterion $Q_{JHK_s} < 0.0$, were excluded from consideration. Distances to 10 stars with maximum extinctions in each direction were calculated, accepting their $M_K = -1.7$ and the extinctions determined from E_{J-H}. Most of these stars are located between 0.6 and 2 kpc, i.e., belong to the Local arm. We accept that their extinction originates mainly in the NAP complex, since no more distant dense clouds are known in this direction. The maximum values of A_V calculated by the equation:

$$A_V(\mathrm{max}) = E_{J-H} \ / \ 0.12 = (J - H - 0.50) \ / \ 0.12.$$

are given in Table 1.

7. COMMENTS ON INDIVIDUAL STARS

1 = 2MASS J20495723+4422538

The star is one of the reddest objects in Table 1. For it only 2MASS photometry is available. If the star is of O-type, its extinction A_V must be 22.7 mag. This is in agreement with the maximum extinction value of the background red giants given in Table 1. Its proximity within $\sim 10'$ to the bright radio E-rim (Matthews & Goss 1980) and to the Pelican Nebula hot spot (Bally & Scoville 1980) makes it a good candidate for the ionizing source of the upper part of the Pelican head. Its position in the K_s vs. H–K_s diagram (Figure 2) is consistent with what we expect for a star of spectral class close to B0 V at a distance of 550 pc. If the star is more distant, its spectral type can be earlier.

2 = 2MASS J20503505+4426296

Bally & Scoville (1980) suspected that this star (called as IRS 4 in their paper) is responsible for the hot spot of the Pelican Nebula discovered in CO maps. However, the I_C–J vs. J–H diagram (Figure 3) suggests that the star is probably a carbon-rich object. In the color-magnitude diagram (Figure 2) it lies about 1 mag above the reddening line of O5 V stars. Presumably, the star can be matched with the IRAS 20487+4415 source. Consequently, this star probably is not related to the Pelican Nebula hot spot.

3 = 2MASS J20524679+4402308

Both in the color-magnitude diagram (Figure 2) and in the J–H vs. H–K_s diagram (Figure 3) this star lies very close to star No. 1. Their spectral energy distributions are also very similar. On the sky the star is located in the emission opening below Pelican's beak. If the star is of spectral type near O9–B0, its extinction A_V must be about 23 magnitudes. This seems to be too high taking into account the maximum value of $A_V = 20.5$ given in Table 1 and the absence of a dense dust condensation in this direction (Figure 6). Therefore, we cannot exclude that the star is a heavily reddened carbon- or oxygen-rich AGB object. For the verification the far-red magnitude I of the star would be important.

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2008BaltA..17..143S

4 = 2MASS J20531582+4432570

This star is located in a dense dust cloud within only a few arcminutes from the radio-bright J-rim discovered by Matthews & Goss (1980). A bright point-like radio source seen $\sim 15'$ north of the rim, is not related to the NAP complex – it is a distant H II region in the Perseus arm (Wendker et al. 1983; Heske & Wendker 1985). If the star is of spectral class O, its A_V must be 21.3 mag, which is in contradiction to the expected maximum extinction (18.7 mag) given in Table 1. The latter value of extinction may mean that accidentally no background red giant is seen in the direction of a small dust condensation which covers star No. 4 and gives the extinction close to 21 mag. In the color-magnitude diagram (Figure 2) the star lies close to the reddening line of O9–B0 V type stars. Consequently, if the star belongs to the NAP complex at a distance of 500–600 pc, its ionizing possibility is not great. However, the star may be responsible for the creation of the dense ionized rim of the dust cloud. If the complex distance is 550 pc, the projected distance between the rim center and the star is 0.8 pc only. Its SED (Figure 5a) is not very informative, since the star has not been observed both in I and MSX passbands. However, the SED in the J, H and K_s passbands seems to be quite similar to SEDs of stars Nos. 1 and 3.

5 = 2MASS J20541342+4402589

The star is located in the dark cloud near the tip of Pelican's beak. In the color-magnitude diagram (Figure 2) the star lies almost on the interstellar reddening line of O5 V stars at a distance of 550 pc. As it was shown in Section 4, the star dos not seem to be of spectral class O; probably it is an asymptotic giant branch object.

6 = 2MASS J20541626+4343091

The star is located in the dark cloud below the tip of Pelican's beak. In the color-magnitude diagram (Figure 2) and the J–H vs. H–K_s diagram (Figure 3) the star lies very close to star No. 5. The diagram I_C–J vs. J–H (Figure 4) shows that both of them are AGB objects, but No. 6 is much cooler. This is confirmed also by their SEDs shown in Figure 5b.

7 = 2MASS J20552516+4418144

As it was shown in Section 4, the star satisfies all our criteria for being an O-type star. In the color-magnitude diagram (Figure 2) it lies 0.5 mag above the interstellar reddening line of O5 V stars for a distance of 550 pc. This means that the star is either more luminous than the main-sequence stars or is located closer to the Sun than 550 pc. If the star is of spectral class O, its A_V should be about 16 mag. The star is located near the edge of the L 935 dust cloud at the North America Nebula coast. In this direction the expected maximum extinction is more than sufficient to give $A_V = 16$. There is one more argument in favor of our suggestion that star No. 7 may be of spectral class O5: its SED looks like the additionally reddened SED of the known O5 V type star, CP05-4, described in Section 2. Luminosities of both stars coincide in the MSX passband at 8.3 μm where the interstellar extinction is close to zero.

8 = 2MASS J20555125+4352246

The Comerón and Pasquali star, CP05-4, described in Section 2.

9 = 2MASS J20555270+4353242

This star is located very close to CP05-4, in projection they are separated

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2008BaltA..17..143S

only by 62″. The star lies in the domains of reddened O-type stars in the three diagrams discussed above: the color-magnitude diagram K_s vs. H–K_s (Figure 2) and the two-color diagrams, J–H vs. H–K_s (Figure 3) and I_C–J vs. J–H (Figure 4). However, in the color-magnitude diagram it exhibits lower luminosity than its neighbor, CP05-4; if the star is at 550 pc, its spectral type must be around O9–B0 V, and the interstellar extinction $A_V = 19.3$ mag. This value does not rise a problem with the expected extinction in this direction (Table 1).

10 = 2MASS J20573647+4404559

The star is located at the northern coast of the Gulf of Mexico. Figure 4 shows that the star probably is an AGB star of late M spectral class.

11 = 2MASS J20580673+4355141

The star is located at the left coast of the Gulf of Mexico. In the J–H vs. H–K_s diagram it lies almost exactly on the reddening line of O-type stars, at H–$K_s = 2.09$. Since the star is not seen in the DSS far red images, it has no N (or I) magnitude available. Consequently, we had no possibility to verify whether it is a non-carbon star. In the color-magnitude diagram K_s vs. H–K_s (Figure 2) the star lies ~ 1 mag above the reddening line of O5 V stars. The SED curve of the star in J, H and K_s shows a heavy reddening but in the MSX passband at 8.3 μm its intensity almost coincides with the O5 V star CP05-4. This means that the star could be of O5-type with the extinction $A_V = 35.2$ mag. Such value of the extinction is considerably too large for this direction (see Table 1). However, the star can be heavily obscured by a small dust condensation which does not contain background red giants which would increase the value of A_V given in Table 1. Other alternative is to assume that we have here a very distant AGB star (of M or N type) which is so luminous that its apparent brightness at 8.3 μm is equal to that of CP05-4 located at 550 pc.

12 = 2MASS J20582424+4356386

The star is only 3.5′ from No. 11 and $\sim 1'$ from the suspected cluster of infrared sources ([CBJ2002] 3a in Cambrésy et al. 2002). The SEDs of both stars are quite similar (Figure 5a), but No. 12 is either slightly warmer or has a lower extinction in its direction. Its H–$K_s = 2.015$ and $Q_{JHK_s} = -0.22$, i.e. it is outside the range accepted for O-type stars. The star has no excess at 8.3 μm (MSX), so it is not YSO. Probably, this star is a distant AGB object located far behind the NAP complex.

13 = 2MASS J20582622+4342385

The star is located at the southern coast of the Gulf of Mexico. Although in the K_s vs. H–K_s diagram (Figure 2) the star is close to the reddening line of O5 V stars, in the I_C–J vs. J–H diagram (Figure 4) the star lies among carbon stars.

8. CONCLUSIONS

1. In the area of the North America and Pelican nebulae we identified thirteen stars simulating heavily reddened O-type stars at a distance of the complex, 550 pc (Table 1). The stars were selected using the J–H vs. H–K_s and K_s vs. H–K_s diagrams based on 2MASS data. One of these stars is CP05-4 classified as O5 V by Comerón & Pasquali (2005). This set of stars may contain O-type stars, B-type stars of luminosities higher than V, A–F supergiants and cool AGB stars (both

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2008BaltA..17..143S

oxygen- and carbon-rich).

2. For eight stars of the set, far-red magnitudes I (including DSS2 N magnitudes) were collected from the literature. Applying the I–J vs. J–H diagram, two carbon-rich and three oxygen-rich AGB stars were identified.

3. Spectral energy distributions, based on the I, J, H, K_s and MSX photometry, give additional information about the selected stars.

4. To estimate the maximum interstellar extinction in the direction of the 'O-like' stars located behind the dark clouds of the NAP complex, we used the J–H vs. H–K_s diagrams for the supposed background K-type giants. The star count map in the K_s passband was also constructed and used to estimate the interstellar extinction in small areas of the NAP complex.

5. Considering all the observational data together, we conclude that two stars in our set, Nos. 1 and 4, possibly are stars of late O subclasses responsible for the creation of the ionized radio rims E and J discovered by Matthews & Goss (1980).

6. Other two stars, Nos. 7 and 9, also have a considerable probability of being O-type stars. They both satisfy all photometric criteria for O-stars at a distance of the NAP complex with the A_V extinctions of 16 and 19 mag. Star No. 11 is also a probable O-star of early subclass.

7. The remaining stars in Table 1 can be heavily reddened cool AGB stars located at different distances in the background of the NAP complex. However, we cannot rule out the possibility that some of them still may be hot stars related to the complex. Only spectroscopy and photometry of these stars in the near and middle infrared can give the final answer.

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2008BaltA..17..143S

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