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2MASS TWO-COLOR INTERSTELLAR REDDENING LINE IN THE DIRECTION OF THE NORTH AMERICA AND PELICAN NEBULAE AND THE CYG OB2 ASSOCIATION

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Abstract. The slope of the interstellar reddening line in the J–H vs. H–K_s diagram of the 2MASS survey in the direction of the North America and Pelican nebulae, the L 935 dust cloud and the Cyg OB2 association is determined. The MK types were either classified by C. J. Corbally or collected from the literature. The ratio $E_{J-H}/E_{H-K_s} = 2.0$ is obtained by taking the average for the four groups of spectral classes: O3–B1, B2–B6, B7–B9.5 and red clump giants. The obtained ratio is among the largest values of E_{J-H}/E_{H-K_s} determined till now.

Key words: ISM: extinction, clouds: individual (L 935) – ISM: H II regions: individual (North America Nebula, Pelican Nebula) – associations: individual (Cyg OB2) – stars: fundamental parameters

1. INTRODUCTION

The 2MASS survey presents all-sky photometry in the near-infrared *J, H* and K_s passbands which is useful for a variety of investigations of the Galaxy. The system has been successfully used for study of star-forming regions and search for young stellar objects (YSOs), for investigation of the interstellar extinction in dust/molecular clouds, large-scale distribution of interstellar dust, the interstellar reddening law in the infrared, spectral energy distributions, etc.

Recently, the interstellar reddening law in the infrared wavelengths was studied by Fitzpatrick & Massa (2005, 2007), Indebetouw et al. (2005) and Flaherty et al. (2007) applying the 2MASS data alone or joining them with the *Spitzer* results at longer wavelengths. In some papers regional values of the color excess ratio E_{J-H}/E_{H-K_s} were investigated (Indebetouw et al. 2005; Nishiyama et al. 2006; Lombardi et al. 2006; Djupvik et al. 2006; Naoi et al. 2006; Román-Zúniga et al. 2007). In most cases this ratio was evaluated from the statistical distribution of red giants with various reddenings in the J–H vs. H–K_s diagram. The red clump giants of early K spectral subclasses are the most abundant population in 2MASS near the Galactic plane, since they are very bright in the near infrared and, despite the interstellar extinction, have been observed at large distances – up to the Galactic central bulge and the disk edges in the direction of the 2nd and 3rd quadrants.

In the listed papers some regional variations of the E_{J-H}/E_{H-K_s} ratio or the interstellar reddening law in the infrared wavelengths have been noted. Consequently, before applying the J–H vs. H–K_s diagram for star classification or other tasks, it is important to investigate the color-excess ratio in each specific area.

To our knowledge, the ratio E_{J-H}/E_{H-K_s} in the area of the North America and Pelican nebulae (hereafter NAP), including the L 935 dust cloud, separating the nebulae, has not been determined till now. Cambrésy et al. (2002), Comerón et al. (2002) and Comerón & Pasquali (2005) in their studies, based on the 2MASS data in Cygnus, have applied a value of 1.70 which follows from the Rieke & Lebofsky (1985) interstellar extinction law. However, this ratio corresponds to the Arizona *J,H,K* system, which is slightly different from the 2MASS system. On the other hand, this extinction law was obtained by using heavily reddened stars located in various directions (five stars in the Galactic center direction, *o* Sco and Cyg OB2 No. 12). Among them, Cyg OB2 No. 12 is an emission-line B supergiant with a number of peculiarities, see discussion in Section 3.

We decided to investigate the ratio E_{J-H}/E_{H-K_s} in the NAP direction applying the classical method which determines slopes of reddening lines plotted for stars in narrow intervals of spectral classes. For this aim the most suitable are early-type stars of spectral classes O and B since these types of stars are sufficiently luminous and apparently bright to be accessible for spectral classification and sufficiently distant to be considerably reddened. A similar method has been successfully used by He et al. (1995) for reddened O–B stars in the southern Milky Way.

2. THE LIST OF O–B STARS

The starting step in composing the list of early-type stars in NAP, classified in the MK system, was the search of the Simbad database for the ALS stars (Reed 1998, 2005) in the area $3^\circ \times 3^\circ$ with the center at J2000: $20^{\rm h}\,56^{\rm m}$, $+44^\circ$. The next step was the check of the catalogs of stars measured and classified in two dimensions using the *Vilnius* seven-color photometric system (Straižys et al. 1989, 1993; Laugalys & Straižys 2002; Laugalys et al. 2006a,b, 2007). To verify the quality of photometric classifications, 37 B-stars from the Vilnius lists were classified by one of us (C.J.C.) using blue grating spectra of 2.8 Å resolution obtained with the Boller and Chivens spectrograph on the 2.3 m telescope of Steward Observatory at Kitt Peak. Part of these classifications were published in Straižys et al. (1999), the spectral types of the remaining 14 are given in Table 1 of the present paper.

Since the coincidence between spectroscopic and photometric spectral types was quite good, we have added to the list 29 B-type stars in the cluster NGC 6997 and Collinder 428 areas with reliable two-dimensional classifications obtained using the *Vilnius* seven-color photometric system (Laugalys et al. 2006a, 2007); in Table 1 their spectral classes are marked by lower-case letters.

However, for the selected B-stars in the region of the North America and Pelican nebulae the largest values of E_{H-K_s} are about 0.25 which correspond to $A_V \approx 4$ mag. To have a longer reddening line, we added O–B stars from the

Table 1. O–B stars in the vicinity of the North America and Pelican nebulae and in the Cyg OB2 association.

Name*	BD, HD	RA (2000)	DEC (2000)	V	Sp	J–H	H–K_s
ALS 17661	BD+45 3239	20 40 58.94	45 46 59.2	8.71	B6 III	0.078	0.050
ALS 11494	BD+42 3835	20 42 06.86	43 11 03.7	9.20	O9	0.245	0.121
ALS 11500	BD+45 3246	20 42 31.01	45 54 04.6	9.67	B1 Vn	−0.042	0.054
ALS 11525	BD+45 3260	20 45 35.28	46 21 02.1	9.06	O9 V	0.098	0.084
ALS 17656	BD+45 3264	20 45 52.34	45 46 47.5	9.35	B8 III	−0.053	−0.037
ALS 17618	BD+41 3884	20 47 09.92	42 24 35.4	7.42	B9 III	−0.095	−0.005
ALS 17619	HD 198414	20 48 26.34	45 27 07.6	7.68	B7 III	−0.029	−0.002
ALS 11565	BD+45 3290	20 48 54.99	45 37 27.2	8.57	B1 III	0.032	0.042
ALS 11566	BD+45 3291	20 48 56.29	46 06 50.9	4.83	B3 Ia	0.133	0.103
ALS 11568	BD+44 3594	20 49 11.59	45 24 39.8	9.78	B1 V:npe	0.217	0.330
ALS 11576	BD+45 3295	20 49 44.20	46 00 33.8	10.31	B3 II	0.087	−0.029
SMV89-131		20 51 40.00	44 00 02.7	10.78	B2 V*	0.250	0.084
ALS 11593		20 51 44.07	46 01 48.3	10.54	B0.5 Vn	0.091	0.093
ALS 17657	HD 198915	20 51 57.35	46 44 05.2	7.50	B6 IV	−0.111	−0.031
SMV89-140		20 52 07.65	44 03 44.4	10.52	B3 V*	0.203	0.075
ALS 11597	HD 198931	20 52 09.72	44 26 04.6	8.72	B1 Ve*	0.266	0.328
LS02-40		20 52 23.75	44 36 15.1	12.09	B2.5 Vnn**	0.337	0.146
SMV89-148	BD+43 3751	20 52 33.36	44 11 42.1	9.66	B2 Vp*	0.053	0.123
SKV2-44		20 52 46.71	43 55 43.5	11.02	B7 V*	0.178	0.058
ALS 11599	HD 199021	20 52 53.21	42 36 27.9	8.43	B0 V	0.113	0.068
SKV2-52		20 53 04.97	43 37 13.2	11.18	B2 Vn*	0.301	0.108
SMV89-159*	HD 199081	20 53 14.75	44 23 14.1	4.74	B5 V	0.148	0.002
SKV2-57		20 53 15.91	43 47 57.7	12.49	B1 V*	0.360	0.223
SMV89-163		20 53 34.19	44 09 07.0	11.45	B3 V*	0.270	0.087
SMV89-166	BD+42 3897	20 53 39.23	42 42 05.4	8.68	B8.5 V	−0.045	0.015
ALS 17620*	HD 199206	20 54 05.94	45 06 36.5	7.67	B8 II	−0.031	0.004
ALS 17658	BD+46 3097	20 54 20.74	46 42 40.8	9.12	B9.5 III	0.023	0.055
ALS 17622*	HD 199312	20 54 45.30	45 08 10.6	7.59	B8 IV	−0.045	−0.028
ALS 11618	BD+44 3627	20 54 47.47	44 50 46.5	9.85	B2 III*	0.200	0.131
LS02-209		20 54 58.87	44 54 55.6	11.58	B1 V**	0.183	0.146
SMV89-177	BD+44 3629	20 55 04.08	44 45 34.1	10.06	B8 V*	0.136	0.078
LS02-217		20 55 04.40	45 20 48.8	12.36	B4 V**	0.079	0.030
LS02-222		20 55 07.29	44 35 49.8	12.24	B0.5 III**	0.385	0.154
LS02-229		20 55 10.27	44 42 46.4	12.36	B8 III-IVp**	0.393	0.229
LS02-230		20 55 10.31	45 03 03.1	11.84	B0.5: Ve**	0.314	0.278
SMV89-184	BD+42 3909	20 55 33.07	43 32 55.6	8.65	B9.5 V	−0.048	0.019
LS02-267		20 55 35.60	45 09 00.9	11.99	B1 V**	0.078	0.043
SMV89-185*	BD+44 3636	20 55 48.10	44 47 44.7	10.39	B9 V	0.099	0.086
SMV89-188*	HD 199479	20 55 59.01	44 22 26.2	6.81	B9 V	−0.026	0.004
CP05 4		20 55 51.25	43 52 24.5	13.24	O5 V	0.849	0.466
SMV89-190		20 56 02.96	45 21 24.0	11.27	B5 IV*	0.009	0.082
LSV06-1-133		20 56 07.11	44 42 23.1	12.81	b4 V	0.236	0.091
LSV06-1-158		20 56 11.42	44 27 56.0	15.32	b7 III	0.310	0.186
LSV06-1-175		20 56 13.76	44 38 39.9	16.24	b9 V	0.445	0.144

Table 1. Continued

Name*	BD, HD	RA (2000)	DEC (2000)	V	Sp	J–H	H–K_s
SMV89-194	BD+44 3637	20 56 18.02	44 46 47.8	9.68	B8 V	−0.096	0.009
LSV06-1-203		20 56 19.27	44 40 34.5	14.92	b9 V	0.329	0.184
ALS 11628	BD+42 3914	20 56 24.09	43 07 46.5	8.43	B0 III:	0.287	0.162
SMV89-197		20 56 24.61	44 39 21.5	11.13	B5 V*	0.136	0.034
LSV06-1-242		20 56 25.66	44 38 55.8	15.72	b7 III	0.308	0.191
LSV06-1-295		20 56 32.52	44 45 27.4	16.21	b9 V	0.350	0.208
ALS 11633*	HD 199579	20 56 34.78	44 55 29.0	5.96	O6.5 III	−0.035	−0.026
LS02-691		20 56 37.18	43 55 05.5	13.88	B2 Ib**	0.483	0.249
ALS 11636	BD+45 3339	20 56 39.23	46 21 20.7	9.93	B1 IV	0.118	0.007
LSV06-1-356		20 56 42.28	44 39 16.8	14.00	b9 III	0.321	0.138
LSV06-22-35		20 56 43.74	43 53 25.3	17.62	b8 V:	0.520	0.250
LSV06-1-366		20 56 43.82	44 25 56.5	14.98	b9 IV-V	0.375	0.176
LSV06-22-47		20 56 50.09	43 56 23.8	15.46	b9.5 IV	0.437	0.212
LSV06-1-427		20 56 52.50	44 35 53.0	13.75	b5 V	0.264	0.111
ALS 11643	BD+45 3341	20 57 02.68	46 32 44.7	8.73	B1 II	0.105	0.019
LSV06-1-497		20 57 02.79	44 36 45.1	14.91	b9.5 III	0.340	0.122
LS02-401		20 57 04.12	45 12 53.3	12.16	B9 III**	0.145	0.088
LSV06-1-525		20 57 06.35	44 31 29.8	15.86	b9 V	0.318	0.162
LS02-463		20 57 49.37	44 51 27.2	12.32	B5 V He(e)**	0.163	0.064
LS02-476		20 57 54.38	44 31 38.3	12.49	B4 Vp(Si)**	0.218	0.176
ALS 11651	BD+44 3655	20 58 25.52	45 08 59.1	9.24	B1 IV*	0.074	0.060
ALS 16465	BD+41 3949	20 58 30.95	41 56 23.7	6.16	B7 III	−0.052	−0.030
LS02-537		20 58 36.57	45 05 02.6	10.92	B1 Ve**	0.282	0.311
SKV2-198		20 59 01.57	42 55 42.5	11.34	B9.5 IV-V*	0.238	0.134
LS02-584		20 59 04.72	44 06 41.2	12.90	B4 IV**	0.419	0.261
SMV89-226		20 59 14.49	44 46 57.3	10.33	B4 IIIn*	0.172	0.099
LS02-608		20 59 18.52	45 29 50.0	11.18	B0.5 Vne**	0.176	0.214
ALS 19944	HD 200030	20 59 24.62	42 19 28.1	6.48	B8 III	−0.084	−0.018
SMV89-229	HD 200042	20 59 33.11	43 03 51.5	8.01	B7 III	−0.025	0.028
SMV89-230		20 59 30.70	45 17 19.1	11.08	B4 III*	0.116	0.061
SMV89-236	BD+44 3664	20 59 55.99	45 20 13.0	10.19	B1 Vn*	0.151	0.088
SMV89-239	BD+44 3666	21 00 05.18	45 02 49.3	10.18	B1 Ve*	0.207	0.264
SMV89-242	HD 200178	21 00 28.73	43 33 40.4	8.36	B9 V*	−0.015	−0.017
ALS 11675	BD+45 3360	21 00 34.21	46 14 49.9	10.00	B3 V	0.094	0.028
ALS 17624	BD+46 3141	21 00 49.86	46 34 42.9	7.26	B5 V	−0.055	−0.044
SMV89-245	BD+42 3937	21 01 00.92	42 46 31.4	9.34	B8 III-IV*	0.183	0.010
ALS 11678	BD+45 3364	21 01 10.93	46 09 20.8	5.40	B1 V	−0.092	−0.041
SMV89-248*	HD 200311	21 01 14.32	43 43 18.4	7.66	B8p	−0.080	−0.010
SMV89-249		21 01 24.34	44 10 01.1	11.18	B5 III*	0.203	0.087
ALS 11682		21 02 12.58	46 12 37.8	10.19	B8 II	0.028	0.044
LSV07-114		21 02 41.03	44 31 54.0	13.12	b8 IV	0.194	0.063
LSV07-217		21 02 52.06	44 35 33.2	11.39	b5.5 III	0.123	0.056
LSV07-198		21 02 50.05	44 29 48.5	12.96	b9 IV-V	0.187	0.070
LSV07-201		21 02 50.42	44 37 14.7	12.36	b8 IV-V	0.182	0.019
LSV07-355		21 03 03.81	44 34 37.2	13.31	b7 IV	0.126	0.046
LSV07-464		21 03 13.95	44 45 03.7	13.54	b6 III	0.163	0.110
LSV07-357		21 03 04.38	44 34 37.6	13.97	b7 V	0.096	0.110

Table 1. Continued

Name*	BD, HD	RA (2000)	DEC (2000)	V	Sp	J–H	H–K_s
LSV07-498		21 03 16.88	44 32 59.4	14.23	b6 V	0.116	0.024
LSV07-363		21 03 05.26	44 37 14.2	14.30	b7 IV	0.151	0.108
ALS 17978	BD+44 3685	21 03 38.45	45 22 04.6	7.86	B8 II	−0.076	0.009
ALS 11699	BD+45 3384	21 03 53.80	46 19 49.9	7.81	B1 IV:p	−0.021	−0.039
LSV07-827		21 03 58.01	44 35 32.8	14.40	b9 III-IV	0.179	0.070
LSV07-479		21 03 15.67	44 41 21.2	15.79	b6 IV	0.161	0.154
LSV07-665		21 03 34.33	44 45 24.0	15.83	b9 Vp?	0.171	0.157
LSV07-447		21 03 12.27	44 37 37.7	15.98	b8 IV	0.157	0.176
LSV07-438		21 03 11.06	44 46 43.0	16.17	b3 V	0.200	0.137
LSV07-690		21 03 36.08	44 26 40.4	16.30	b7 V	0.408	0.173
ALS 17987	BD+45 3387	21 04 18.21	46 31 52.8	8.61	B8 III	−0.008	0.003
ALS 11718	BD+45 3406	21 06 32.43	45 51 31.0	9.52	B1 Iab	0.134	0.112
ALS 17980	BD+44 3710	21 07 14.94	44 40 26.7	7.38	B8 III	–	–
		Cyg OB2 association: brightest stars					
VI Cyg 1		20 31 10.55	41 31 53.5	11.06	O9 V	0.412	0.191
VI Cyg 2		20 31 22.04	41 31 28.4	10.61	B1 Ib:	0.325	0.122
VI Cyg 3	BD+40 4212	20 31 37.50	41 13 21.0	10.35	O9:	0.497	0.253
VI Cyg 4	BD+40 4219	20 32 13.83	41 27 12.0	10.07	O7 III	0.334	0.143
VI Cyg 5*	BD+40 4220	20 32 22.43	41 18 19.1	9.21	O7e	0.442	0.406
VI Cyg 12		20 32 40.96	41 14 29.2	10.40	B5 Iab:	1.155	0.808
VI Cyg 6		20 32 45.46	41 25 37.4	10.65	O8 V:	0.336	0.196
VI Cyg 9		20 33 10.75	41 15 08.2	10.78	O5 Ie	0.571	0.327
VI Cyg 7		20 33 14.11	41 20 21.8	10.50	O3 I	0.430	0.207
VI Cyg 8B		20 33 14.76	41 18 41.6	10.31	O8	0.447	0.192
VI Cyg 8A	BD+40 4227	20 33 15.08	41 18 50.5	8.99	O5.5 I	0.402	0.218
VI Cyg 8D		20 33 16.34	41 19 01.8	12.02	O8 V	0.418	0.185
VI Cyg 8C		20 33 17.99	41 18 31.1	10.08	O5 III	0.373	0.213
VI Cyg 10	BD+41 3804	20 33 46.10	41 33 01.1	9.89	O9.5 Ia	0.455	0.257
VI Cyg 11	BD+41 3807	20 34 08.50	41 36 59.2	10.08	O5 If	0.424	0.236
		Cyg OB2 association: Massey & Thompson (1991) stars					
MT91-299		20 32 38.57	41 25 13.7	10.84	O7.5 V	0.276	0.202
MT91-556		20 33 30.78	41 15 22.6	11.01	B1 Ib	0.602	0.349
MT91-601		20 33 39.10	41 19 25.8	11.07	O9.5 III	0.485	0.263
MT91-258		20 32 27.66	41 26 22.0	11.10	O8 V	0.342	0.172
MT91-259		20 32 27.74	41 28 52.2	11.42	B0.5 V	0.296	0.129
MT91-227		20 32 16.56	41 25 35.7	11.47	O9 V	0.325	0.204
MT91-145		20 31 49.65	41 28 26.5	11.52	O9.5 V	0.306	0.134
MT91-417		20 33 08.79	41 13 18.2	11.55	O4 III(f)	0.570	0.314
MT91-531		20 33 25.56	41 33 26.9	11.58	O8.5 V	0.420	0.225
MT91-339		20 32 50.02	41 23 44.6	11.60	O8.5 V	0.391	0.206
MT91-605		20 33 39.79	41 22 52.3	11.78	B0.5 V	0.333	0.264
MT91-642		20 33 47.83	41 20 41.5	11.78	B1 III-Ib	0.499	0.278
MT91-516		20 33 23.46	41 09 13.0	11.84	O5.5 V(f)	0.645	0.330
MT91-480		20 33 17.48	41 17 09.3	11.88	O7.5 V	0.465	0.240
MT91-745		20 34 13.50	41 35 02.7	11.91	O7 V	0.402	0.227

Table 1. Continued

Name*	BD, HD	RA (2000)	DEC (2000)	V	Sp	$J–H$	$H–K_s$
MT91-376		20 32 59.19	41 24 25.4	11.91	O8 V	0.362	0.210
MT91-473		20 33 16.34	41 19 01.7	12.02	O8.5 V	0.418	0.185
MT91-771		20 34 29.59	41 31 45.5	12.06	O7 V	0.530	0.321
MT91-485		20 33 18.03	41 21 36.6	12.06	O8 V	0.429	0.202
MT91-138		20 31 45.40	41 18 26.7	12.26	O8.5 I	0.513	0.293
MT91-793		20 34 43.58	41 29 04.6	12.29	B1.5 III:	0.498	0.415
MT91-696		20 33 59.52	41 17 35.4	12.32	O9.5 V	0.394	0.251
MT91-588		20 33 37.00	41 16 11.3	12.40	B0 V	0.515	0.239
MT91-470		20 33 15.71	41 20 17.2	12.50	O9.5 V	0.398	0.210
MT91-555		20 33 30.30	41 35 57.8	12.51	O8 V	0.546	0.271
MT91-174		20 31 56.94	41 31 47.8	12.55	B1.5 V	0.388	0.182
MT91-507		20 33 21.01	41 17 40.1	12.70	O8.5 V	0.402	0.227
MT91-611		20 33 40.86	41 30 18.9	12.77	O7 Vp	0.397	0.252
MT91-736		20 34 09.51	41 34 13.6	12.79	O9 V	0.412	0.246
MT91-455		20 33 13.69	41 13 05.7	12.92	O8 V	0.475	0.279
MT91-5		20 30 39.81	41 36 50.7	12.93	O6 V(f)	0.524	0.261
MT91-403		20 33 05.26	41 43 36.7	12.94	B1.5 V	0.432	0.230
MT91-390		20 33 02.92	41 17 43.1	12.95	O8 V	0.553	0.292
MT91-429		20 33 10.50	41 22 22.4	12.98	B0 V	0.424	0.216
MT91-70		20 31 18.33	41 21 21.6	12.99	O9 V	0.561	0.300
MT91-534		20 33 26.74	41 10 59.5	13.00	O7.5 V	0.537	0.269
MT91-292		20 32 37.02	41 23 05.2	13.08	B1 V	0.465	0.221
MT91-187		20 32 03.77	41 25 10.4	13.24	B0.5: V	0.405	0.235
MT91-248		20 32 25.49	41 24 52.0	13.36	O5.5 V	0.344	0.203
MT91-575		20 33 34.33	41 18 11.3	13.41	B1.5 V	0.679	0.572
MT91-467		20 33 15.31	41 29 56.7	13.43	B1 V	0.456	0.230
MT91-378		20 32 59.64	41 15 14.6	13.49	B0 V	0.596	0.307
MT91-716		20 34 04.86	41 05 12.9	13.50	O9 V	0.466	0.259
MT91-692		20 33 59.25	41 05 38.0	13.61	B0: V	0.421	0.266
MT91-448		20 33 13.26	41 13 28.7	13.61	O6 V(f)	0.636	0.337
		Cyg OB2 association: Comerón et al. (2002) stars					
CPR02-A4		20 31 36.25	41 22 03.2	15.0	–	1.149	0.655
CPR02-A5		20 35 09.75	41 35 29.7	16.2	–	1.040	0.611
CPR02-A6		20 32 08.33	40 25 06.9	17.5	–	1.055	0.548
CPR02-A7		20 34 42.96	40 29 30.2	17.7	–	1.072	0.541
CPR02-A8		20 33 41.61	41 47 57.0	15.5	–	1.165	0.564
CPR02-A9		20 35 32.71	41 20 55.0	17.2	–	1.019	0.498
CPR02-A10		20 34 55.11	40 34 44.3	15.6	–	0.840	0.451
CPR02-A11		20 32 31.54	41 14 08.2	12.5	O7.5 Ib-II	0.723	0.430
CPR02-A12		20 33 38.21	40 41 06.4	12.1	B0 Ia	0.734	0.425
CPR02-A13		20 33 01.24	40 32 33.7	15.1	–	0.745	0.398
CPR02-A14		20 31 18.99	42 02 55.9	14.3	–	0.768	0.402
CPR02-A15		20 31 36.90	40 59 09.2	13.0	O7 Ib(f)	0.705	0.397
CPR02-A16		20 34 36.94	40 41 01.9	15.0	–	0.737	0.386
CPR02-A17		20 32 35.34	41 14 45.4	14.5	–	0.644	0.388
CPR02-A18		20 30 07.88	41 23 50.4	14.0	~O8 V	0.658	0.374

Table 1. Continued

Name*	BD, HD	RA (2000)	DEC (2000)	V	Sp	J–H	H–K_s
CPR02-A19		20 31 25.91	41 16 02.7	14.1	–	0.659	0.341
CPR02-A20		20 33 02.92	40 47 25.4	12.0	O8 IIf	0.619	0.358
CPR02-A21		20 29 34.80	41 20 08.9	13.7	–	0.635	0.331
CPR02-A22		20 33 11.29	40 42 33.8	13.4	–	0.649	0.330
CPR02-A23		20 30 39.70	41 08 48.9	11.3	B0.7 Ib	0.600	0.348
CPR02-A24		20 34 44.10	40 51 58.4	12.7	O6.5 III(f)	0.609	0.348
CPR02-A25		20 32 38.43	40 40 44.5	13.0	∼O8 III	0.642	0.322
CPR02-A26		20 30 57.72	41 09 57.5	13.1	O9.5 V	0.579	0.316
CPR02-A27		20 34 44.71	40 51 46.5	11.4	B0 Ia	0.621	0.331
CPR02-A28		20 34 16.04	41 02 19.6	13.4	–	0.579	0.313
CPR02-A29		20 34 56.05	40 38 18.0	11.7	O9.7 Iab	0.581	0.314
CPR02-A30		20 31 22.10	41 12 02.9	13.1	∼B2 V	0.469	0.299
CPR02-A31		20 32 39.49	40 52 47.5	13.1	∼B0.5 V	0.595	0.285
CPR02-A32		20 32 30.33	40 34 33.2	12.1	O9.5 IV	0.527	0.295
CPR02-A33		20 32 34.98	40 52 39.0	13.0	B2.5 V	0.541	0.289
CPR02-A34		20 31 36.93	42 01 21.8	11.3	B0.7 Ib	0.399	0.299
CPR02-A35		20 30 55.52	40 54 54.1	12.8	∼B0 V	0.488	0.285
CPR02-A36		20 34 58.78	41 36 17.4	11.5	B0 Ibn	0.538	0.299
CPR02-A37		20 36 04.51	40 56 12.9	12.3	O5 Vf	0.600	0.283
CPR02-A38		20 32 34.86	40 56 17.4	13.1	O8 V	0.524	0.294
CPR02-A39		20 32 27.34	40 55 18.4	11.9	B2 V	0.466	0.277
CPR02-A40		20 35 13.66	40 55 25.0	12.5	–	0.608	0.257
CPR02-A41		20 31 08.38	42 02 42.2	12.4	O9.7 II	0.536	0.269
CPR02-A42		20 29 57.01	41 09 53.8	12.3	B0 V	0.417	0.250
CPR02-A44		20 31 46.05	40 43 24.6	–	B0.5 IV	0.426	0.227
CPR02-A45		20 29 46.66	41 05 08.3	11.9	B0.5 Vn	0.397	0.179
CPR02-A46		20 31 00.19	40 49 49.7	11.3	O7 Vf	0.362	0.190

Notes:

ALS = Reed (1998, 2005);
CP05 = Camerón & Pasquali (2005);
CPR02 = Camerón et al. (2002);
MT91 = Massey & Thompson (1991);
SMV89 = Straižys et al. (1989);
SKV93 = Straižys et al. (1993);
LS02 = Laugalys & Straižys (2002);
LSV06-1 = Laugalys et al. (2006a);
LSV06-22 = Laugalys et al. (2006b, Table 2);
LSV07 = Laugalys et al. (2007);
VI Cyg = numbers of the Cyg OB2 association stars from Johnson & Morgan (1954) and Morgan et al. (1954). VI Cyg is the former name of the Cyg OB2 association.
SMV89-248 = V2200 Cyg (B9p, α^2 CVn type);
VI Cyg 5 = V729 Cyg, EB;
ALS 11633, SMV89-159 and SMV89-188 – spectral binaries;

ALS 17620, ALS 17622 and SMV89-185 – visual binaries.

The stars with spectral types marked by asterisks are classified in MK system by C. J. Corbally: one asterisk – published in Straižys et al. (1999), two asterisks – published in the present table. Here are notes on the spectra of individual stars (IS means the interstellar band at 443 nm). Interstellar extinction values A_V are from Laugalys & Straizys (2002).

LS02-40: IS band slight;

LS02-209: IS band moderate, $A_V = 2.9$;

LS02-217: IS band slight, He slightly strong, $A_V = 2.3$;

LS02-222: very strong IS band, quite strong IS Ca K, $A_V = 4.2$;

LS02-229: sharp hydrogen line cores, moderate IS band, Hg-Mn, Cr-Sr;

LS02-230: emission in H and He, with normal decrement, spectral class is an estimate from H wings and He I D-series, IS band moderate, $A_V = 2.5$;

LS02-267: IS band strong, $A_V = 2.2$;

LS02-401: IS band slight, IS Ca K quite strong, $A_V = 1.9$;

LS02-463: all He lines are filled in by emission, $A_V = 1.9$;

LS02-476: IS band moderate; $A_V = 2.7$;

LS02-537: IS band moderate, $A_V = 2.2$;

LS02-584: IS band moderate, IS Ca K line strong, $A_V = 3.9$;

LS02-608: Balmer line decrement weak, IS band slight, IS Ca K line moderate, $A_V = 1.8$;

LS02-691: noisy spectrum, IS band strong, $A_V = 5.2$.

Cyg OB2 association located behind the Great Cygnus Rift, 4° from the NAP nebulae. Investigations of the extinction law in Cygnus discussed in our earlier paper (Straižys et al. 1999) do not show any significant differences in extinction properties between various directions in Cygnus. Table 1 lists 95 OB-type stars from the NAP region and 98 O–B1 stars from the Cyg OB2 association. We list only those Cyg OB2 stars which were used for plotting the reddening line. They include 15 brightest stars from Johnson & Morgan (1954) and Morgan et al. (1954), 45 stars from Massey & Thompson (1991) and 42 stars from Comerón et al. (2002). The last list contains stars having 'featureless' infrared spectra and considered as the candidate O-type stars. Hanson (2003) and Negueruela et al. (2008) have classified 27 of them in MK and confirmed that they indeed are O–B0 type stars. The stars with blended images have been excluded. We also excluded two stars from the Massey & Thompson list (575 and 793) which show a considerable deviation from the reddening line of other O–B1 stars. The reddest star in the NAP region is the CP05 4 star with spectral type O5 determined by Comerón & Pasquali (2005). The J–H and H–K_s color indices given in the table were calculated from the 2MASS J, H and K_s data.

3. INTRINSIC COLOR INDICES

Despite a wide use of the 2MASS photometric system, intrinsic color indices $(J–H)_0$ and $(H–K_s)_0$ of stars of different spectral and luminosity classes are unknown. Usually they are being obtained by transformation from the Koornneef (1983) or Bessell & Brett (1988) tabulations with the Carpenter (2001) equations. Since these transformation equations for O and B stars are rather uncertain, we decided to determine their intrinsic color indices directly in the 2MASS system by dereddening relatively bright stars with small interstellar reddening.

For determining the intrinsic color indices for O- and B-type stars we took some little reddened stars listed in Table 2. The three O-stars are the least reddened field stars. The B5–B6 and B8–B9 stars were selected in the vicinity of the NAP nebulae from our Table 1 and from the Fehrenbach et al. (1961) catalog of stars in the Kapteyn Selected Area 40. For each star color excesses E_{B-V} were transformed to E_{J-H} and E_{H-K} by the equations given by Bessell & Brett (1988). Since the reddenings are small, $E_{H-K} \approx E_{H-K_s}$. After that color indices were dereddened for all stars individually taking differences of the observed color indices and the corresponding color excesses:

$$(J-H)_0 = (J-H) - E_{J-H} \ , \tag{1}$$

$$(H-K_s)_0 = (H-K_s) - E_{H-K_s}. \tag{2}$$

Then dereddened color indices were averaged to obtain the intrinsic color indices $(J–H)_0$ and $(H–K_s)_0$ for O8, B5.5 and B8.5 stars listed in Table 3.

4. EQUATIONS OF THE REDDENING LINES

Table 1 stars were divided into three spectral groups: O–B1, B2–B6 and B7–B9.5, neglecting their luminosity classes. However, we excluded all emission-line B-stars which exhibit excesses of $H–K_s$ at constant $J–H$. For each spectral group we have plotted the $J–H$ vs. $H–K_s$ diagram shown in Figures 1–3. Figure 1 shows that O–B1 type stars in the NAP region and in the Cyg OB2 association exhibit the same slope of the reddening line. The CP05 4 star at $H–K_s = 0.47$ (the uppermost dot) lies also together with the association stars. Two Cyg OB2 stars, No. 5 (O7e) and No. 12 (B5 Iab), deviate downwards from the reddening line considerably, imitating the presence of circumstellar thermal emission in the dust or electron free-free transitions. Peculiarities of star No. 12 were widely discussed by Massey & Thompson (1991); they find Hβ line in emission. In the direction of these two stars condensations of CO have been discovered (Scappini et al. 2002; Casu et al. 2005). These two stars were rejected from the reddening line solutions. After the listed rejections, we have 118 O–B1 stars, 29 B2–B6 stars and 46 B7–B9.5 stars.

The least-square solutions for Figures 1–3 have been made with the fixed intrinsic positions of O–B1, B2–B6 and B7–B9.5, respectively. The following equations were obtained:

$$J-H = 2.004(\pm 0.016)(H-K_s) - 0.050 \ , \tag{3}$$

$$J-H = 1.876(\pm 0.105)(H-K_s) - 0.014 \ , \tag{4}$$

$$J-H = 2.106(\pm 0.094)(H-K_s) - 0.039 \ . \tag{5}$$

These equations show the slope of the reddening line, E_{J-H}/E_{H-K_s}, for O–B stars is between 1.9 and 2.1. Probably, the average value 2.0 can be accepted for future analysis of the distribution of reddened stars in the 2MASS two-color diagram. Zero-points of the equations mean the points on the $J–H$ axis at which the reddening lines cross the line $H–K_s = 0.0$. They are the same as the values of the interstellar reddening-free Q_{JHKs} parameters:

$$Q_{JHK_s} = (J-H) - E_{J-H} \,/\, E_{H-K_s}(H-K_s) \ . \tag{6}$$

Table 2. Color excesses of little reddened O–B stars used in the determination of intrinsic color indices.

Name	Spectral type	E_{B-V}	E_{J-H}	E_{H-K_s}
O-type stars				
S Mon	O7 Ve	0.09	0.033	0.017
68 Cyg	O8e	0.26	0.096	0.050
10 Lac	O9 V	0.11	0.041	0.021
B5–B6 stars				
BD+45 3242	B5 V	0.19	0.073	0.036
BD+45 3279	B6 V	0.25	0.092	0.048
HD 198915	B5 V	0.10	0.037	0.019
BD+44 3579	B5 V	0.30	0.111	0.057
BD+46 3141	B5 V	0.06	0.022	0.011
B8–B9 stars				
HD 197374	B9 V	0.00	0.000	0.000
HD 197391	B8 V	0.15	0.055	0.028
HD 199121	B8 V	0.00	0.000	0.000
HD 199417	B9 V	0.10	0.037	0.019
BD+45 3247	B9 V	0.12	0.044	0.023
BD+43 3701	B9 V	0.08	0.030	0.015
BD+45 3256	B8 V	0.09	0.033	0.017
BD+45 3264	B8 III	0.14	0.052	0.027

Table 3. Intrinsic color indices of stars in the 2MASS system.

Color index	O8	B5.5	B8.5
$(J–H)_0$	–0.164	–0.081	–0.062
$(H–K_s)_0$	–0.058	–0.035	–0.009

Equations (3), (4) and (5) show that the Q_{JHK_s} values for the three spectral classes are –0.050, –0.014 and –0.039. The maximum absolute deviations of individual values from the mean are 0.015, and this means that all O–B stars lie practically on one line which coincides with the reddening line (Figure 4). Thus, we may solve the least square equation using all 193 stars together (with the intrinsic position of an O8-type star):

$$J - H = 2.024(\pm 0.018)(H - K_s) - 0.048 \ . \qquad (7)$$

5. THE REDDENING LINE OF RED GIANTS

We have one more possibility to find the reddening line slope in the $J–H$ vs. $H–K_s$ diagram. In Figure 5 we show the plot of this diagram for 99 000 stars in the $3° \times 3°$ area with the center given in Section 2. These stars were selected from the 2MASS database with an error limit of < 0.05 mag for the three magnitudes. The stars form a comet-like crowding in which we show approximate intrinsic positions of the main sequence and K–M giants. The interstellar reddening vector is shown,

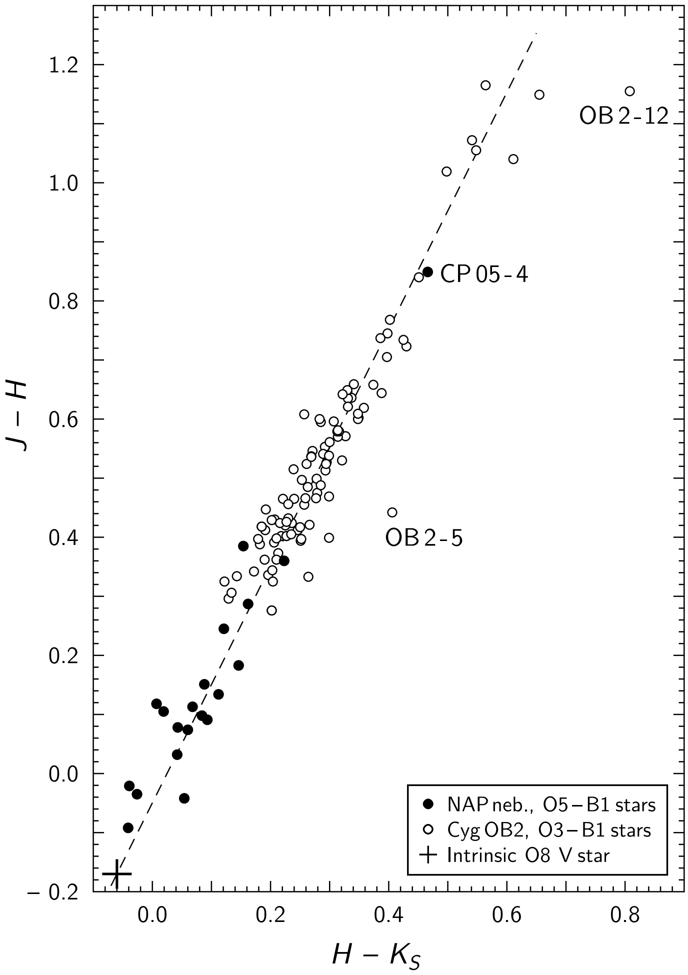

Fig. 1. Interstellar reddening line for O–B1 stars in the NAP nebulae region and the Cyg OB2 association. The broken line is the least-square solution for all 118 stars with the fixed intrinsic colors $J–H = -0.17$, $H–K_s = -0.06$. The Cyg OB2 stars Nos. 5 and 12 are rejected.

its slope is 2.0 and its length corresponds to the extinction $A_V = 10$ mag. The tail of the 'comet' is composed of normal reddened stars, mostly of red clump giants of early K subclasses (the discussion see in López-Corredoira et al. 2002). This means that the stars at the upper end of the tail are reddened K-type red clump giants with $A_V \approx 30$ mag. The comparison of their colors with the intrinsic colors of red giants may be used to estimate the slope of the reddening line. However, we need to know the intrinsic position of red clump giants in the $J–H$ vs. $H–K_s$ diagram.

For determining the intrinsic position of red clump giants we used the old open cluster M 67 which is very suitable, as the cluster is practically unreddened and its stars have solar chemical composition. Seven clump stars with V at 10.5 and $B–V$

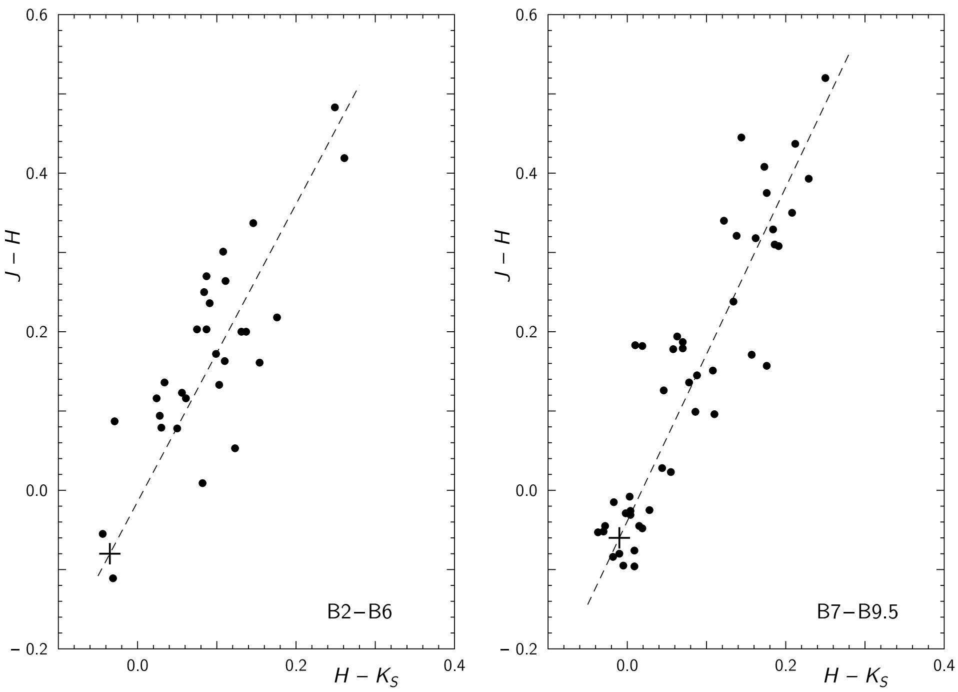

Fig. 2. Interstellar reddening line for B2–B6 stars in the NAP nebulae region. The broken line is the least-square solution for 29 stars with the fixed intrinsic colors $J–H = -0.08$, $H–K_s = -0.035$.

Fig. 3. Interstellar reddening line for B7–B9.5 stars in the NAP nebulae region. The broken line is the least-square solution for 46 stars with the fixed intrinsic colors $J–H = -0.06$, $H–K_s = -0.01$.

Table 4. Red clump giants in the M 67 cluster.

Star	V	$B–V$	$J–H$	$H–K_s$
MMJ 6485	10.48	1.11	0.485	0.133
MMJ 6492	10.59	1.12	0.528	0.146
MMJ 6494	10.48	1.10	0.506	0.153
MMJ 6503	10.55	1.12	0.494	0.114
MMJ 6506	10.58	1.10	0.504	0.118
MMJ 6512	10.55	1.10	0.513	0.125
MMJ 6516	10.47	1.12	0.485	0.164
		Average	0.502	0.136

at 1.1 were selected from the Montgomery et al. (1993) catalog and are listed in Table 4.

The straight line connecting the center of red clump stars with the end of the 'comet' tail at $J–H = 3.1$ and $H–K_s = 1.4$ has the slope 2.06. This value in good agreement with the values obtained for O- and B-stars in Section 4.

In Figure 6 we show a similar diagram for 66 000 stars selected in the association

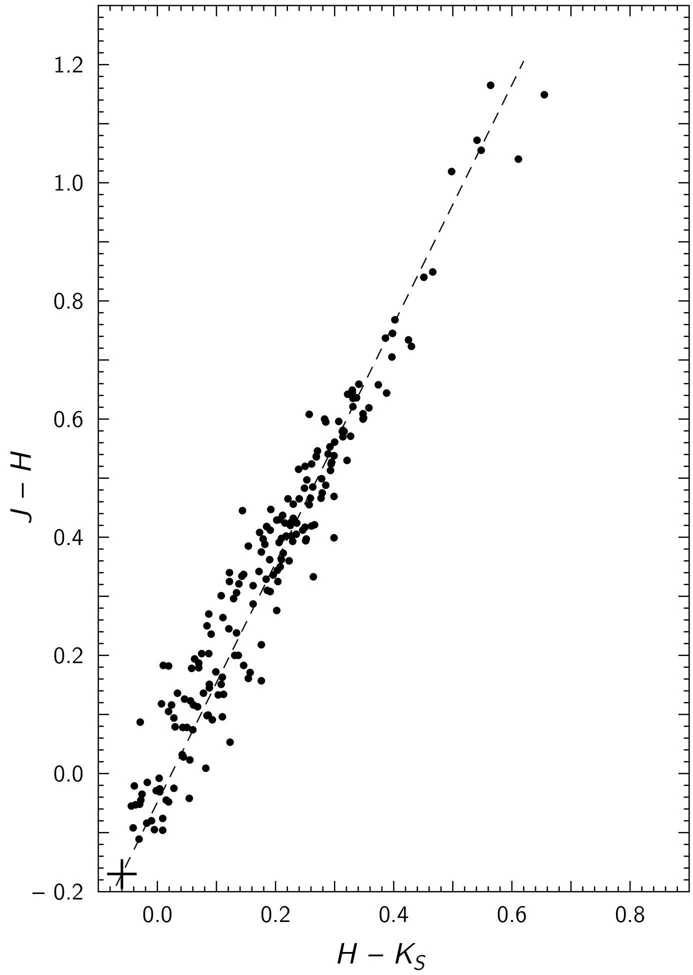

Fig. 4. Interstellar reddening line in the NAP nebulae region and the Cyg OB2 association for O–B9.5 stars together. The broken line is the least-square solution for all 193 stars with the fixed intrinsic colors J–H = −0.17, H–K_s = −0.06.

Cyg OB2 area. The area is of 3° × 3° size and its center is at $20^{\rm h}\,33^{\rm m}$, $+41°\,20'$ (J2000). The straight red line joins the intrinsic position of the red clump giants and the upper end of the 'comet' tail at J–H = 3.65 and H–K_s = 1.56. The slope of the reddening line, drawn by eye, is $E_{J-H}\ /\ E_{H-K_s}$ is 2.02, in perfect agreement with the NAP area.

6. DISCUSSION AND CONCLUSIONS

The ratios E_{J-H}/E_{H-K_s} determined so far in the 2MASS system in various Milky Way areas exhibit quite a wide range of values, between 1.6 and 2.1, the average value being close to 1.8. Our slopes of reddening lines in the NAP area and the Cyg OB2 association area both for O–B stars and K giants are near the upper limit of this range. Only for Globule 2 in the Coalsack Racca et al. (2002) in the

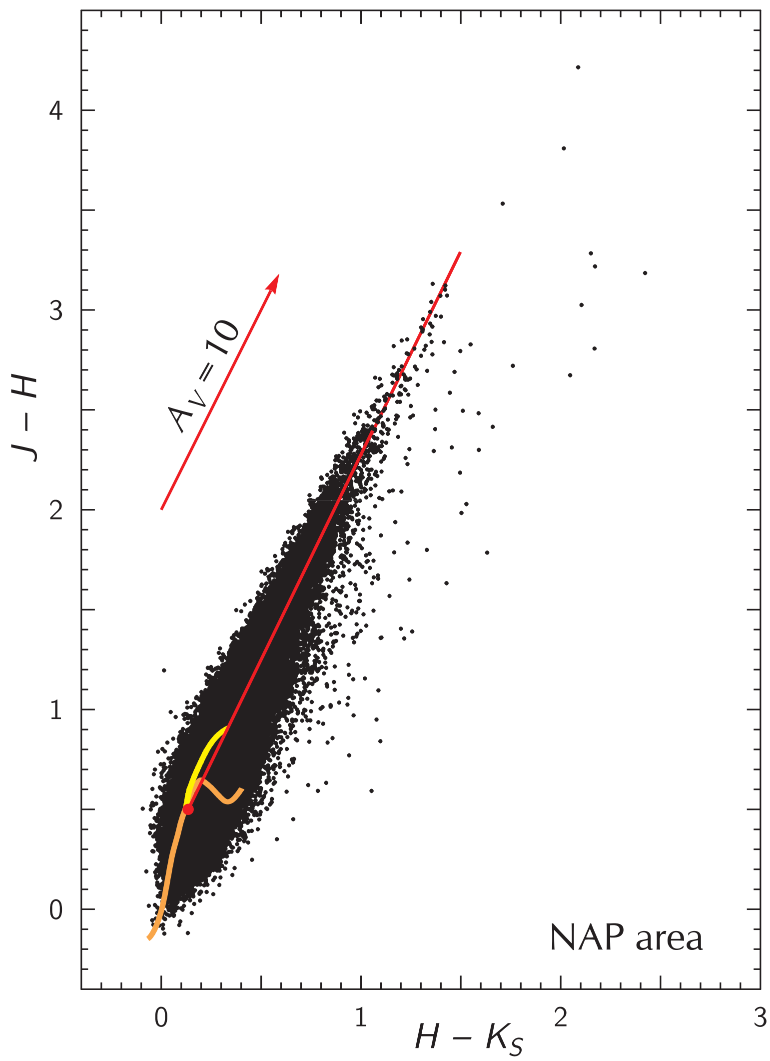

Fig. 5. Two-color diagram for the NAP nebulae area of 3° × 3° size. The orange and yellow curves are intrinsic sequences of luminosity V and III stars. The red dot is the intrinsic position of the red clump giants, whose interstellar reddening is shown by the straight red line. The red line with an arrow is the reddening vector, its slope is $E_{J-H}\,/\,E_{H-K_s} = 2.0$ and its length corresponds to the extinction $A_V = 10$ mag.

CIT system obtained $E_{J-H}/E_{H-K} = 2.08$. If the ratio of colors in both systems given by Carpenter (2001) is valid also for color excesses, the ratio E_{J-H}/E_{H-K_s} in the 2MASS system should be 1.05 times larger, i.e., in the Coalsack it can be close to 2.2.

It is obvious that the variations of color-excess ratios in the infrared are related to sizes and compositions of dust grains. Most authors agree that between ~ 0.9 μm and ~ 5 μm the extinction curve can be approximated by a power law, $A_\lambda \propto \lambda^{-\beta}$. The most widely used is the value $\beta = 1.8$, representing the so-called 'universal'

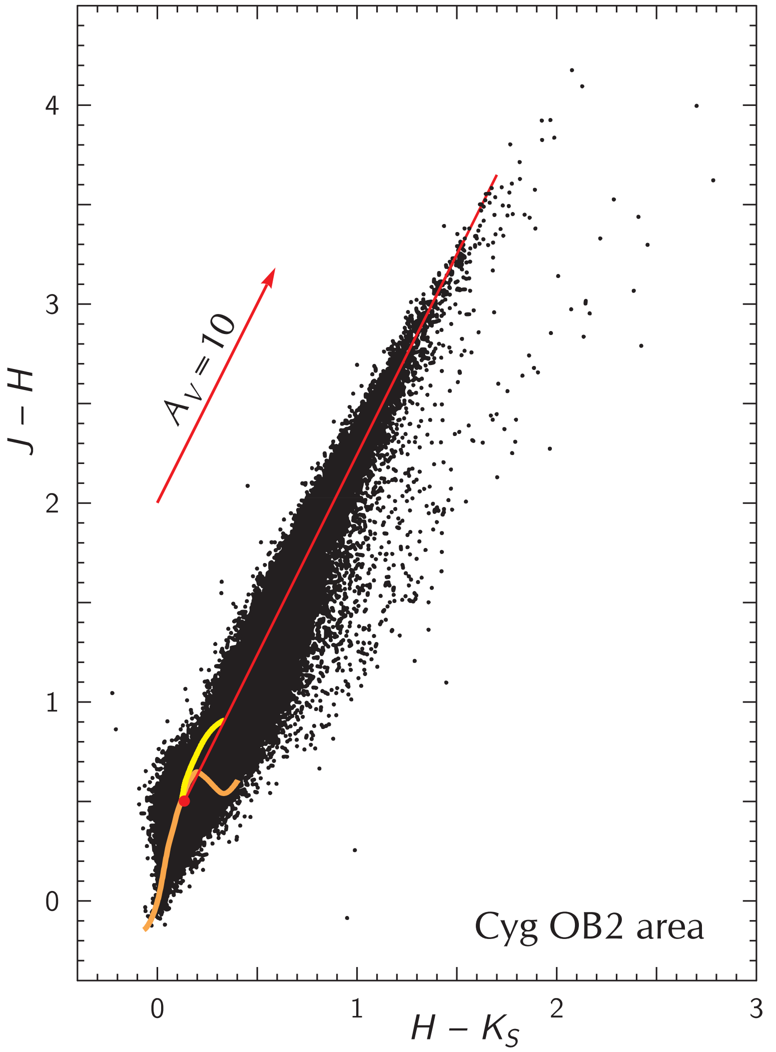

Fig. 6. The same as in Figure 5 but for the Cyg OB2 association area of 3° × 3° size and the center $20^{\mathrm{h}}\,33^{\mathrm{m}}$, $+41^\circ\,20'$ (J2000).

extinction curve in the infrared (Martin & Whittet 1990). However, in the last decade it was realized that β is not universal but has different values between 1.6 and 1.8 (see Draine 2003; Indebetouw et al. 2005; Flaherty et al. 2005; Froebrich & Burgo 2006; Froebrich et al. 2007). Since

$$\ln(A_1/A_2) = \beta \ln(\lambda_2/\lambda_1), \tag{8}$$

for the effective wavelengths of the passbands J, H and K_s we can calculate the approximate relation between β and the ratio of color excesses. Convolving the response functions given by Cutri et al. (2006) and Skrutskie et al. (2006) with spectral energy distributions of Kurucz models we obtain that λ_{eff} values for different temperatures are not very different, thus we took the values of 1.24, 1.64 and 2.14 μm corresponding to solar-type stars. In this case

$$\beta = 2.045(E_{J-H}/E_{H-K_s}) - 1.722. \tag{9}$$

For the NAP area, where $E_{J-H}/E_{H-K_s} = 2.0$, we obtain $\beta = 2.37$. This value of β gives a relatively steep interstellar extinction curve in the 1–2 μm range of wavelengths. A similar value of β was recently obtained by Larson & Whittet (2005) for high Galactic latitude clouds. Whittet (2008) estimates that such a value of β suggests smaller than average grain sizes, compared with the 'typical' value of $\beta = 1.8$. The curvature of the near IR segment of the extinction curve is a reflection of the fact that even the larger grains have sizes which are smaller than λ. In the small particle limit one would expect $\beta = 4.0$ (Rayleigh scattering). On the other hand, for larger grains (e.g., with dimensions ~ 2 μm) one would expect $\beta \approx 1.0$. It is not really possible to estimate average grain sizes from β but it should certainly follow the trend: larger β, smaller grains.

On the other hand, according to our earlier investigations, the dust in L 935 and the surrounding NAP area exhibits other peculiarities. Earlier we have obtained that the extinction law in the vicinity of NAP exhibits a smaller 'knee' in the blue part of the spectrum (Straižys et al. 1999) which is also consistent with smaller grains responsible for the extinction in the range of wavelengths covered by the B and V passbands.

To summarize, the following results of the present investigation may be listed.

1. A list of 95 O- and B-type stars with MK classifications, supplemented by the 2MASS J–H and H–K_s color indices, is compiled in the 3° × 3° area covering the North America and Pelican nebulae and including the L 935 dust cloud. For 37 stars spectroscopic MK types and for 40 stars photometric types are determined by the authors. The list is supplemented by 98 O–B1 type stars from the Cyg OB2 association.

2. Intrinsic color indices $(J–H)_0$ and $(H–K_s)_0$ are determined for spectral classes O8, B5.5 and B8.5 by dereddening bright stars with small interstellar extinction.

3. Interstellar reddening lines are calculated for stars of the three spectral groups: O–B1, B2–B6 and B7–B9.5. The slopes of the reddening lines, 2.00, 1.88 and 2.10, are obtained for the three groups.

4. The mean intrinsic colors J–H and H–K_s of seven red clump giants of spectral types G8–K2 III in the open cluster M 67 are determined. For areas of both the NAP nebulae and the Cyg OB2 association, joining the positions of the unreddened clump giants and the most heavily reddened stars in the J–H vs. H–K_s diagram, we obtain the reddening line slope of 2.06 and 2.02, respectively, which are in a good agreement with the slopes for O–B stars.

5. The mean ratio of color excesses $E_{J-H}/E_{H-K_s} = 2.0$ may be recommended for the North America and Pelican nebulae region, as well as for the Cyg OB2 association. This value is somewhat larger than the ratios which are usually in use in the Cygnus direction.

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