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ON THE DISTANCE OF DARK CLOUDS IN THE VICINITY OF THE REFLECTION NEBULA NGC 7023 IN CEPHEUS

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Abstract. Distance to a group of dark clouds at moderate galactic latitudes Lynds 1147, 1148, 1152, 1155, 1157, 1158, 1167, 1168, 1170, 1171, 1172, 1173 and 1174 is estimated from the extinction A_V vs distance plot. This dependence is based on photometry of 79 stars down to $V = 12.5$ in the Vilnius photometric system and their two-dimensional classification. The distance of the L1147/1158 group of clouds is found to be 325±13 pc and that of the L1167/1174 or NGC 7023 group of clouds is 288±25 pc. A number of stars with peculiar energy distribution has been found.

Key words: dark clouds – Vilnius photometric system – photometric classification – interstellar extinction

1. Introduction

The investigated area within $\alpha(1950) = 20^h32^m \div 21^h07^m$ and $\delta(1950) = +66°24' - +68°15'$ contains two groups of clouds. The first group contains Lynds 1147, 1148, 1152, 1155, 1157 and 1158 (Lynds, 1962). The second group contains Lynds 1167, 1168, 1170–1174 and the reflection nebula NGC 7023 illuminated by the Herbig Ae/Be star HD 200775. Hereafter we shall call the first group as the

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L1147/1158 area and the second group as the NGC 7023 area. Both groups of dark clouds are situated at moderate galactic latitudes (l between 101°and 105°and b between 13°and 16°).

The NGC 7023 area is known as a star forming region. It contains the Ae/Be star HD 200775, some Orion variables (FU Cep, FV Cep, EH Cep), Hα emission stars and infrared sources. The area has been studied photometrically in the *UBVRI* and Vilnius systems by Krasnikov and Stalbovsky (1985), in the *uvby* system by Pfau et al. (1987) and in the *UBVRI* system by Shevchenko et al. (1989). Pfau et al. (1987) give also polarimetric observations of 9 stars. Interstellar extinction properties of the dark clouds in the area were studied by Rössiger (1971), Viotti (1976), Altamore et al. (1980), Witt and Cottrell (1980a), Walker et al. (1980), Whitcomb et al. (1981), Sandell and Johansson (1982) and Pfau et al. (1987). The extinction law for HD 200775 is found to be abnormal with very weak interstellar bands. However, extinction properties in the wider cloud surrounding this star seem to be normal.

The L1147/1158 area has been studied by Krasnikov and Stalbovsky (1985) in the *UBVRI* and Vilnius systems. However, their photometric classification of most stars is only one-dimensional and distances of stars are rather inaccurate. The Vilnius photometry which gives two-dimensional classification was not completed. Interstellar extinction in the area was also investigated by Harjunpää et al. (1991) using star counts and by Snell (1981) using the stars with *UBV* and MK data in a 20° × 20° region centered on the L1147 cloud. Snell (1981) has also found 10 infrared sources in this cloud and has measured their *JHKL* magnitudes and colours.

For determination of distances of the dark clouds different methods have been used, including extinction vs. distance relation (Snell, 1980; Krasnikov and Stalbovsky, 1985; Shevchenko et al., 1989), the distance of HD 200775 (Viotti, 1964; Strom et al., 1972; Witt and Cottrell, 1980b; Whitcomb et al., 1981), radial velocity profiles of CO clouds interpreted with differential galactic rotation (Lebrun, 1986). The distances within 250 and 600 pc have been obtained.

The Vilnius photometric system which gives two dimensional classification and interstellar reddening of stars of all spectral types, is especially useful for distance determination to dark clouds, as it has been shown in the papers by Straižys and Meištas (1980), Meištas and Straižys (1981), Straižys (1984), Černis (1987, 1990), Straižys et al. (1989a) and Černis and Straižys (1992). The same method has been applied to the group of dark clouds investigated in this paper.

2. Observations and quantification of stars

79 stars down to $V \approx 12.5$ projected on both groups of dark clouds were measured in the Vilnius photometric system. The identification chart reproduced from the Papadopoulos and Scovil (1980) atlas is shown in Fig. 1. The stars were measured with a photoelectric photometer on the 1-meter telescope of our Institute at the Maidanak Observatory in Uzbekistan. The star HD 198737 ($V = 6.95$, F2 V) was used as the local standard, its magnitude and colour indices outside the atmosphere were obtained by Nikonov's method. Magnitudes and colour indices of program stars are given in Table 1. The accuracy of colour indices as a rule is of the order of ± 0.01 (m.sq.e. of one observation), except those marked by a colon. The coordinates given in Table 1 for identification purpose have been measured by us with the accuracy ± 1 time second in α and ± 0.1 arcmin in δ.

The stars were quantified in spectral types and absolute magnitudes by the following two methods: (1) by reddening-free Q, Q diagrams calibrated in terms of spectral class and M_V by Straižys et al. (1982) and (2) by the method of comparison of five reddening-free parameters Q_{UPYV}, Q_{PXYV}, Q_{XYV}, Q_{ZVYV} and Q_{VSYV} of program and standard stars in the comparison catalogue (about 5000 stars, Straižys et al., 1989b). The obtained spectral types and absolute magnitudes are given in Table 2. The accuracy of spectral types can be estimated from the quantity $\sigma_{\delta Q}$ (min) given alongside. Its definition is

$$\sigma_{\delta Q} = \left[\sum_{i=1}^{5} \frac{\delta Q_i^2}{5} \right]^{1/2} = \text{minimum} ,$$

where δQ are the differences of Q parameters of the program star and the comparison star. The minimum value of σ depends on the photometric accuracy of colour indices and on the availability of close analogues in the comparison catalogue. For the best cases σ does not exceed 0.005 mag but the values up to 0.02 mag are acceptable. For K- and M-type stars values up to 0.05 mag happen due to rapid change of colour indices in this spectral range and difficulty to find a close analogue. The value $\sigma > 0.05$ mag for early-type star means

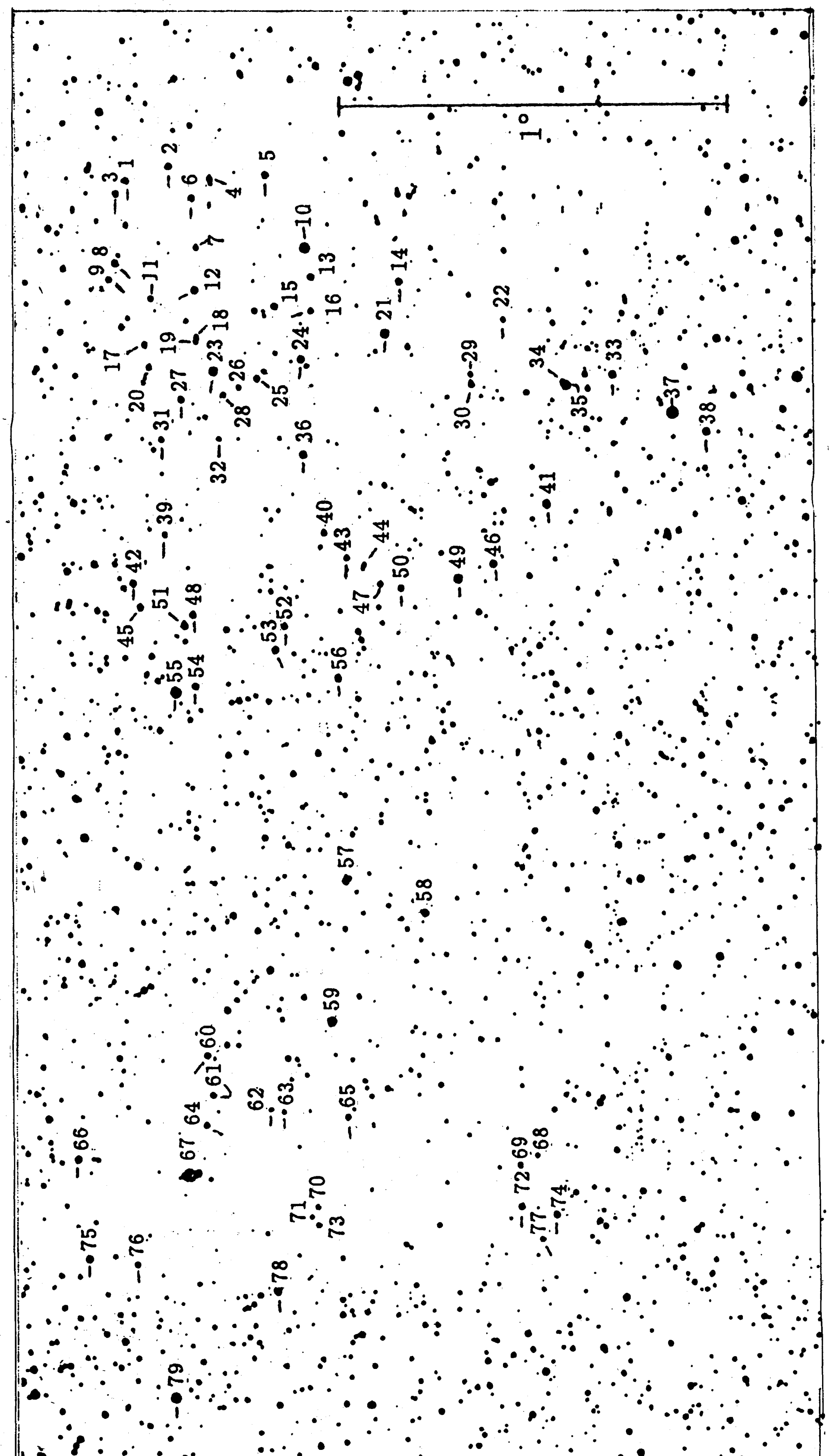

Fig. 1. The identification chart.

Table 1. Results of photometry

No.	α(1950)	δ(1950)	V	$U-P$	$P-X$	$X-Y$	$Y-Z$	$Z-V$	$V-S$	n
1.*	$20^h33^m48^s$	+67°44.′2	10.72	0.80:	1.60:	2.73	0.79	0.65	1.37	5
2.	20 33 49	67 37.5	11.24	0.75	0.91	0.67	0.36	0.20	0.45	3
3.	20 34 16	67 46.3	10.51	0.90	0.98	0.62	0.35	0.20	0.47	4
4.	20 34 22	67 31.9	11.01	0.47	0.54	0.68	0.31	0.18	0.51	4
5.*	20 34 33	67 23.5	9.84	0.60	1.20	1.89	0.51	0.39	0.86	5
6.	20 34 46	67 35.2	10.58	0.75:	1.29	2.07	0.72	0.44	1.08	4
7.	20 36 01	67 35.9	11.90	0.59:	0.80:	0.96:	0.44	0.26	0.67	2
8.*	20 36 02	67 48.4	10.30	0.67	0.76	1.00	0.53	0.30	0.78	5
9.	20 36 27	67 49.8	11.30	0.67	1.06	1.37	0.59	0.38	0.90	3
10.*	20 36 35	67 19.7	7.66	0.43	0.56	0.21	0.06	0.09	0.13	2
11.	20 37 10	67 44.1	11.55	0.69	0.78	0.84	0.46	0.26	0.66	4
12.*	20 37 09	67 37.4	9.67	0.47	0.55	0.74	0.34	0.19	0.54	6
13.	20 37 21	67 19.8	10.11	1.04	1.75	2.75	0.98	0.63	1.54	1
14.*	20 37 54	67 06.6	9.77	0.53	0.53	0.60	0.31	0.12	–	1
15.	20 37 58	67 26.1	10.51	0.47	0.70	0.85	0.34	0.25	0.59	2
16.	20 38 16	67 20.8	11.09	0.71	1.16	1.50	0.67	0.41	0.99	1
17.	20 38 23	67 46.3	11.59	0.68	0.73	0.91	0.47	0.28	0.69	2
18.	20 38 27	67 38.5	11.43	0.45	0.56	0.70	0.31	0.19	0.49	2
19.*	20 38 33	67 38.7	11.99	0.63:	1.25:	2.23	0.74	0.47	1.15	3
20.	20 39 01	67 46.3	11.58	0.35	0.80	1.43	0.36	0.25	0.63	2
21.*	20 39 13	67 10.3	8.35	0.46	0.55	0.62	0.29	0.18	0.44	7
22.	20 39 24	66 51.8	11.65	0.40:	0.73:	0.96	0.36	0.26	0.63	2
23.*	20 39 25	67 36.9	8.95	0.44	0.53	0.68	0.32	0.19	0.50	6
24.*	20 39 31	67 23.6	9.82	0.75	1.35	2.22	0.77	0.63	1.31	2
25.	20 39 50	67 30.7	11.14	0.71	1.28	2.10	0.66	0.43	1.02	2
26.	20 39 59	67 33.7	11.43	0.89	0.97	0.67	0.38	0.21	0.50	2
27.	20 40 03	67 42.4	10.33	0.51	0.60	0.65	0.29	0.17	0.46	2
28.	20 40 07	67 36.2	11.95	0.42	0.65	0.82:	0.35	0.23	0.58	2
29.	20 40 41	66 58.3	11.80	0.43:	0.67:	0.90	0.35	0.25	0.59	2
30.	20 40 57	66 58.4	10.76	0.45	0.60	0.69	0.32	0.19	0.51	2
31.	20 41 02	67 46.5	11.54	0.44:	0.71	0.89	0.36	0.23	0.60	2
32.	20 41 16	67 38.1	12.22	0.70:	1.17:	1.93:	0.71	0.45	1.05	2
33.*	20 41 19	66 36.7	9.40	0.56	0.60	0.68	0.30	0.16	0.48	12
34.*	20 41 19	66 44.4	9.09:	0.90:	1.42:	2.22	0.73	0.59	1.28	4
35.*	20 41 23	66 43.9	8.64	0.66	0.74	0.51	0.22	0.12	0.33	10
36.*	20 42 04	67 25.9	10.02	0.57	0.79	0.50	0.21	0.12	0.29	6
37.*	20 42 34	66 28.5	5.57	0.58	0.77	0.47	0.19	0.11	0.27	8
38.*	20 43 11	66 23.9	9.20	0.52	0.62	0.81	0.34	0.20	0.55	12
39.*	20 43 37	67 48.5	12.35	0.67	0.78	0.86	0.47	0.27	0.67	2
40.	20 44 14	67 24.8	11.21	0.67:	1.34	2.19	0.71	0.45	1.08	2

Table 2. Results of quantification

No.	Sp	M_V	E_{Y-V}	A_V	r, pc	σ, mag
1.*	R?					0.10
2.	A5 V	+2.2	0.31	1.40	340	<0.01
3.	A3 IV	+1.0	0.33	1.48	400	0.01
4.	F7 V	+4.0	0.00	0.00	250	0.01
5.	K5 II	−3.0:				0.05
6.	K5 I					0.04
7.	G2 IV	+2.9	0.14	0.63	470	0.01
8.*	G0 IV	+2.7	0.30	1.35	180	0.01
9.	G9 III-IV	+1.8	0.26	1.17	460	<0.01
10.	B9 V	+1.0:	0.01	0.04	210	0.02
11.	F2 V	+3.2	0.32	1.44	240	0.01
12.	F8 V	+4.1	0.02	0.09	125	0.01
13.	M1 III	−0.8:				0.13
14.	F8 IV:					
15.	G2 V	+4.7	0.03	0.14	136	0.01
16.	K0 III	+0.8	0.31	1.40	600	0.01
17.	F8 IV	+2.6	0.24	1.08	380	0.01
18.	F8 V	+4.1	0.00	0.00	290	<0.01
19.*	K4-5 III (C-rich?)					0.08
20.*	K2 III: (C-rich?)					0.06
21.	F6 V	+3.8	0.00	0.00	81	<0.01
22.	G8 V	+5.6	0.01	0.04	160	0.01
23.	F7 V	+4.0	0.02	0.09	94	<0.01
24.	K3 III					0.05
25.	K5 I					0.04
26.	A5 IV	+1.5	0.34	1.53	480	0.01
27.	F6 V	+3.8	0.00	0.00	200	<0.01
28.	G2 V	+4.7	0.02	0.09	270	0.01
29.	G5 V	+5.1	0.03	0.14	200	<0.01
30.	F7 V	+4.0	0.02	0.09	220	0.01
31.	G6 V	+5.2	0.00	0.00	185	<0.01
32.	K2 II	−3.2				
33.	F8 IV:					0.01
34.	K5 III	+0.2	0.24	1.08	360	0.02
35.	A8 IV	+2.1	0.04	0.18	190	<0.01
36.	A6 V	+2.5:	0.06	0.27:	280	0.01
37.	A6 V	+2.5:	0.03	0.14	38	0.01
38.	G1 IV	+2.9	0.00	0.00	180	0.01
39.*	F5 V	+3.6:	0.28:	1.26:	310:	0.01
40.	K5 III					0.07

Table 2 (continued)

No.	Sp	M_V	E_{Y-V}	A_V	r, pc	σ, mag
41.	K1 III	+1.3	0.00	0.00	320	0.01
42.	K3.5 II	−2.6				0.05
43.	F6 V	+3.8	0.02	0.09	310	0.01
44.	K3 II	−3.5				0.06
45.	K1 III	+0.5	0.14	0.63	760	0.01
46.	F7 V	+4.0	0.00	0.00	122	0.01
47.	F0 V	+2.8	0.20	0.90	360	0.01
48.	A1 III	−0.2	0.21	0.94	300	0.01
49.	K3 II	−2.5				0.03
50.	K4 V	+7.0	0.03	0.14	45	0.02
51.	A1 V	+1.2	0.22	0.99	340	<0.01
52.	K-M III					0.11
53.	A3 V	+1.5	0.13	0.58	330	0.01
54.	K5-M0 II-III					0.05
55.	F2:V	+3.1	0.03	0.14	55	0.01
56.*	F4 V	+3.5	0.16	0.72	160	<0.01
57.	K5 III	+1.0	0.10	0.45	300	<0.01
58.	A2 V	+1.4	0.23	1.04	300	0.01
59.	K3 III	+0.2	0.07	0.32	270	0.02
60.	F5 V	+3.6	0.02	0.09	280	0.01
61.	A5 V	+2.0:	0.53	2.38	230	0.01
62.	F5 III	+2.0	0.31	1.40	680	0.01
63.	K2 IV	+3.5	0.24	1.08	350	0.02
64.	F5 V	+3.6	0.03	0.14	280	0.01
65.	F8 V	+4.1	0.10	0.45	210	0.01
66.	G9 V	+5.7	0.00	0.00	79	0.01
67.	B3 Ve	−1.7:	0.41	1.84	275	–
68.	F5 V	+3.6	0.32	1.44	290	0.01
69.	F7 V	+4.0	0.07	0.32	190	0.01
70.	K2 V	+6.5	0.00	0.00	115	0.01
71.	K0 IV	+4.0	0.32	1.44	280	0.02
72.	F8 V	+4.1	0.01	0.04	170	0.01
73.	G6 V	+5.2	0.02	0.09	190	0.01
74.	F8 V	+4.1	0.03	0.14	120	<0.01
75.	A5-F0 V					0.02
76.	F5-G2 V					0.02
77.	F8 V	+4.1	0.02	0.09	300	0.01
78.	F8 V	+4.1	0.00	0.00	95	0.01
79.	A2 III	0.0	0.04	0.18	210	0.01

* Remarks see at the end of Table 1.

that the intrinsic energy distribution of that particular program star is rather peculiar. Spectral classification and colour excess determination for such stars are uncertain.

With the help of calibrated Q, Q diagrams, we usually obtain spectral classes and absolute magnitudes of program stars. However, in some cases luminosity V stars lie slightly off calibration network and for M_V determination the isolines should be extrapolated. In these cases the average M_V for a given MK type is ascribed to the stars.

The accuracy of M_V determination is rather difficult to estimate. In our previous works it was concluded that M_V absolute errors larger than ± 0.5 mag are hardly expected.

Interstellar extinctions and distances of the stars were obtained in the following way:

$$A_V = 4.5\Big[(Y-V)_{\rm obs} - (Y-V)_0\Big],$$

$$\log r = \frac{V - M_V + 5 - A_V}{5}.$$

Here A_V is interstellar extinction in the V bandpass of the UBV system normalised to the B0 V star. The coefficient 4.5 corresponds to the normal interstellar extinction law giving $R_{BV} = 3.15$. The absolute errors of A_V are expected not to exceed $\pm$ 0.1 mag and the absolute distance errors are $\pm$ 25%.

In classification of stars and in distance determinations, the interstellar extinction law was considered to be normal. This argument is based on the results by Rössiger (1971) and Pfau et al. (1987) which indicate a normal value of R from two colour star counts and from the wavelength of maximum polarization.

The results of determination of spectral types, M_V, E_{Y-V}, A_V and r are given in Table 2. The distances $r > 150$ pc are rounded to the nearest number multiple to 10.

3. Discussion

The majority of program stars have very good accuracy of classification which is indicated by small values of σ given in Table 2. This means that despite considerable reddening, it is easy to find for them good photometric analogues among the normal comparison stars. Most of such program stars are the main sequence stars of

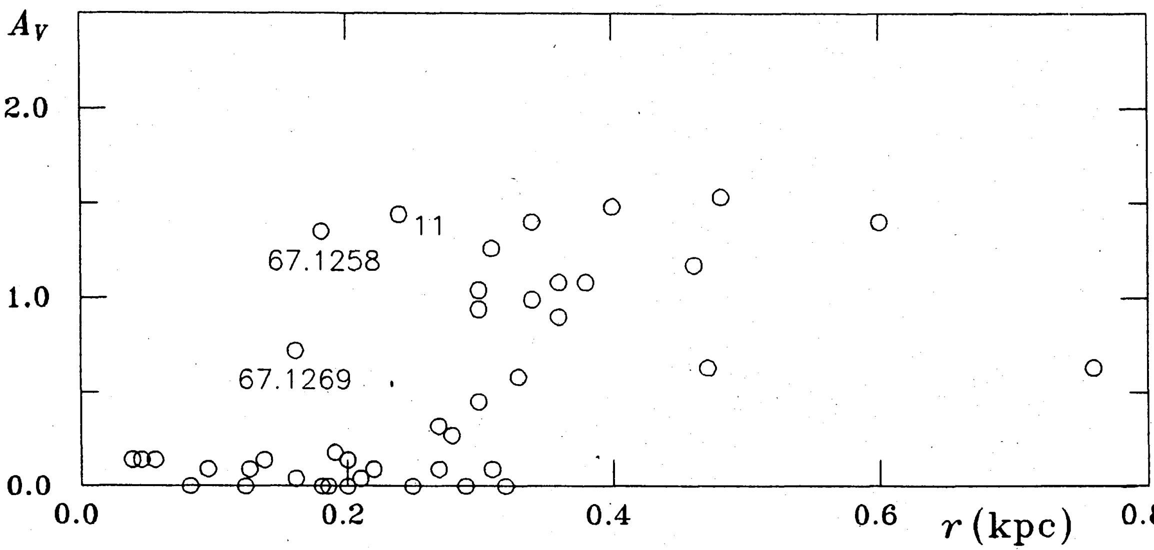

Fig. 2. Dependence of interstellar extinction on distance in the L1147/1158 area.

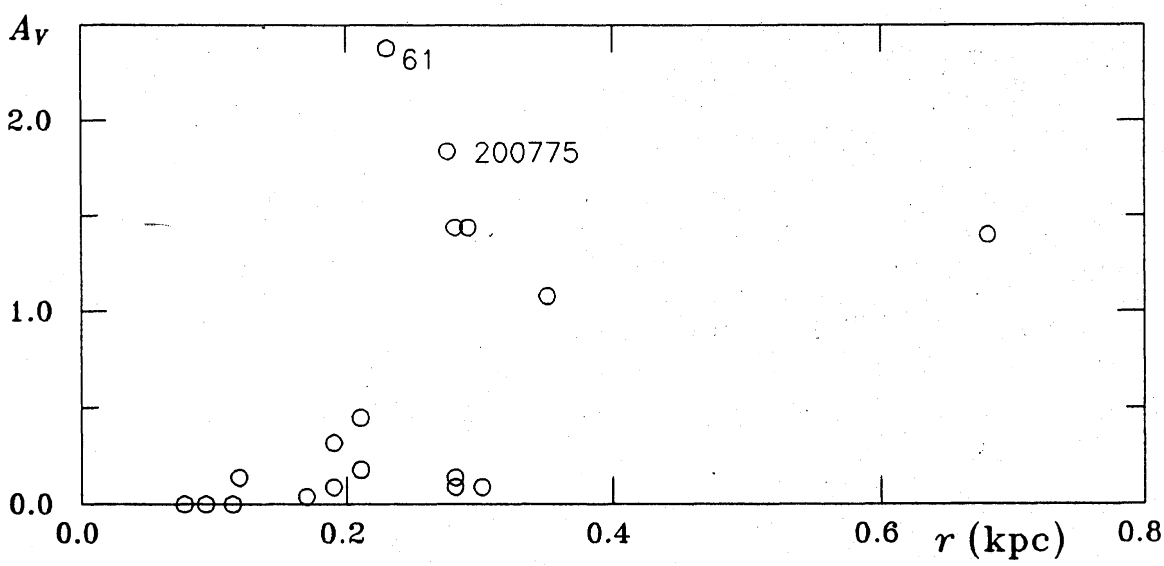

Fig. 3. Dependence of interstellar extinction on distance in the NGC 7023 area.

spectral types A–F–G and K giants. These stars with $\sigma \leq 0.02$ mag were used in the A_V versus distance plot shown in Figs. 2 and 3 for the L1147/1158 and NGC 7023 areas.

In both areas the stars can be clearly divided into foreground stars, background stars and the stars which might be within the cloud. The foreground stars exhibit extinction close to zero and they extend up to 300–320 pc in both areas. The problem is, which stars may be considered being immersed into the cloud. In the L1147/1158 area the nearest to us strongly reddened star is No. 8 (+67°1258) at 180 pc but this distance can hardly be considered as the beginning of the cloud, since unreddened stars are found as far as 320 pc. The largest concentration of reddened stars is at 300–330 pc and the real distance of the cloud should be there. The expected absolute error ($\pm$ 0.5) of M_V at 300 pc distance gives distance errors +80 pc and –60 pc. There are 10 stars with $A_V \geq 0.45$ mag within 240 and 380 pc. Their mean distance is 325 ± 13 pc (m.sq.e.). If we add two more stars from both sides at 180 and 400 pc (which are slightly behind the absolute error limits), then the mean distance is 319 ± 18 pc (m.sq.e.), which is not very different from the previous value. Consequently, this distance may be considered as a distance of the dark clouds L1147/1158.

The strongly reddened star No. 8 (+67°1258) as well as less reddened star No. 56 (+67°1269) seem to be too close to the Sun for their reddening values. In both cases this cannot be explained by classification errors: the star +67°1258 within $\sigma = \pm 0.010 - 0.015$ mag has five analogues of spectral types F8–G0 IV and the star +67°1269 within $\sigma = \pm 0.008$ mag has five analogues of spectral types F3–F6 V. Anomalous position of these stars in the A_V, r plot may be the result of either their shading by the closer dark clouds, or their unresolved duplicity with both components of very close spectral types. An increase of their luminosity by 0.75 mag (if both components are of the same brightness) shifts the point of +67°1258 to 260 pc and that of +67°1269 to 235 pc, i.e. the contradiction between A_V and r vanishes.

Passing on to the NGC 7023 region (Fig. 3) we have a similar situation. The most reddened star No. 61 (A5 V) with $A_V = 2.38$ mag is at 230 pc distance, while close to it in the sky unreddened stars Nos. 60 and 64 are at 280 pc. However, all of them are within distance errors. The mean distance of considerably reddened stars Nos. 61, 71, 68 and 63 is 288±25 pc (m.sq.e.), which within error limits superposes with the distance of the L1147/1158 dark clouds.

The star HD 200775, illuminating the NGC 7023 nebula, would be the best indicator of its distance. However, the star is peculiar and its luminosity is known with insufficient accuracy. According to Viotti (1964) its MK type is B3 III-IVe but Baschek et al. (1982) find B3 Ve. The corresponding M_V values from the M_V, MK table (Straižys and Kurilienė, 1981) are −2.6 and −1.7 and this leads to distances 417 and 275 pc. The second value is very close to the value found from the reddened stars around the NGC 7023 nebula.

Except for those stars for which we find very close analogues and which can be considered normal, there are 16 stars which do not have close photometric analogues in our catalogue of 5000 comparison stars (values $\sigma \geq 0.05$ mag). Part of these stars probably are K4–M giants. For them close analogues cannot be found in our comparison catalogue because not all variety of spectral types is represented in this spectral region. These stars have been approximately classified by Q, Q diagrams and their spectral types are given in Table 2. Extinction values and distances for them were not calculated. Some stars with great σ values can be peculiar objects. For three of them carbon-rich property based on the Q_{UPYV}, Q_{XZS} diagram has been assigned. These stars will be a subject of a special investigation by photometric and spectroscopic methods.

The height of the L1147/1158 group above the galactic plane is 87 pc and for NGC 7023 it is 66 pc. Consequently, both groups of dark clouds belong to the disk population.

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