PHOTOMETRIC INVESTIGATION OF THE
MBM 12 MOLECULAR CLOUD AREA IN ARIES.
II. CLOUD DISTANCE

V. Straižys, K. Černis, A. Kazlauskas and V. Laugalys

Institute of Theoretical Physics and Astronomy, Goštauto 12,
Vilnius 2600, Lithuania; straizys@itpa.lt, cernis@itpa.lt, algisk@itpa.lt,
vygandas@itpa.lt

Received May 25, 2002.

Abstract. Photoelectric magnitudes and color indices in the Vilnius
seven-color system for 152 stars are used to investigate the interstellar
extinction in the area of the Aries molecular cloud MBM 12, coincid-
ing with the L1454 and L1457 dust clouds. Spectral types, absolute
magnitudes, color excesses, interstellar extinctions and distances of
the stars are determined. The plot of interstellar extinction $A_V$ ver-
sus distance shows that the dust cloud is situated at a distance of
325 pc, at 180 pc from the Galactic plane, and its true diameter is
about 11 pc. The interstellar extinction law in the area is found to
be normal, typical for the diffuse dust. Ten peculiar or unresolved
binary stars and some heavily reddened stars are detected.

Key words: stars: fundamental parameters, classification – ISM:
dust, extinction, clouds – ISM: individual objects: MBM 12, L1454,
L1457

1. INTRODUCTION

A high galactic latitude molecular cloud MBM 12 (Magnani,
Blitz & Mundy 1985) in Aries at one time was considered as the
nearest to the Sun star-forming region. The molecular cloud partly
coincides with two dust clouds L1454 and L1457 (Lynds 1962). In the
same area, Lynds has distinguished two smaller clouds, L1453 and
L1458, however their identification seems to be ambiguous. Also, the
identification of the Lynds and MBM clouds, given by Magnani et al. (1985), seems to be not sufficiently correct.

The first estimate of the distance of the Aries dark clouds, done by Duerr & Craine (1982), was based on star counts on photographs of the area in the $V$ and $I$ passbands. They found evidence for two clouds at the distances of 200–300 pc and 500–800 pc.

Next estimates of the distance of MBM 12 (Hobbs, Blitz & Magnani 1986; Hobbs, Blitz, Penprase, Magnani & Welty 1988) were based on the presence or absence of the interstellar Na I lines in the spectra and the spectroscopic distances for two stars: HD 18404 and HD 18519/20 ($\epsilon$ Ari AB). The first of them was found to be at a spectroscopic distance of 60 pc, with no traces of the interstellar Na I. The second star (a visual binary) exhibited a strong Na I absorption, and its distance was accepted to be 70 pc.

Later on, Hearty et al. (2000a,b) have directed attention that the *Hipparcos* parallaxes place the star HD 18404 at much closer distance – 32 pc, while HD 18519/20 was found to be at $\sim$90 pc. Thus, the limits of the MBM 12 cloud distance were considerably widened. Additional stars closer than 100 pc were looked for the Na I absorption but none was found.

The distance of the MBM 12 cloud was reconsidered by Luhman (2001) by analyzing the data of one of the corner stars – $\epsilon$ Ari AB, which has previously provided the upper limit of the cloud distance. This binary star, consisting of A2 IV and A3 IV components, is completely unreddened, i.e., it must be in front of the dust cloud. The presence of interstellar Na lines in its spectrum was explained by the neutral gas wall associated with the Local Bubble. Luhman concluded that the star $\epsilon$ Ari AB gives only a lower limit for the distance to MBM 12. After plotting the extinction values $A_V$ for 12 stars in the immediate vicinity of MBM 12 against the *Hipparcos* distances, the author has found only a gradual increase of $A_V$ with distance up to 250 pc, with no sharp rise of extinction at the supposed distance of the cloud. The conclusion has been done that the cloud is farther away than 200–250 pc. By comparing the magnitudes of the probable foreground and background M-type dwarfs, Luhman has estimated a cloud distance of $\sim$275 pc. This value is close to distance of the first cloud of Duerr & Craine (1982).

For the determination of more exact distance to the cloud, we need reliable distances and extinctions for stars at larger distances. This information can be obtained either from MK classification of
stars combined with a two-color photometry or from multicolor photometry alone in a photometric system which is able to classify stars in two dimensions and give the interstellar reddenings of the stars. Such a system, consisting of seven medium-width passbands placed in the optimum positions for the classification of stars of all spectral types, was developed in Vilnius in the sixties of the 20th century. The system is described in detail in the Stražys (1977, 1992) monographs.

2. OBSERVATIONS, REDUCTIONS AND CLASSIFICATION OF STARS

152 Aries stars were measured in the seven passbands of the Vilnius system in 2000–2001 with the two telescopes: the 156 cm telescope of the Molėtai Observatory in Lithuania and the 150 cm telescope of the University of Arizona at Mt. Lemmon, Arizona. The area was limited by the following 2000.0 coordinates: RA = $2^h51^m - 3^h01^m$, DEC = $+18^{\circ}30' - +21^{\circ}30'$. The catalog of magnitudes and color indices and the identification chart for the measured stars are given in Kazlauskas, Černis, Stražys & Laugalys (2002, Paper I).

For the determination of spectral classes and absolute magnitudes of stars two independent methods were used.

(1) The $\sigma Q$-method of matching 14 different interstellar reddening-free $Q$-parameters of a program star to those of about 8400 standard stars of various spectral and luminosity classes, metallicities and peculiarity types (Stražys & Kazlauskas 1993). The reddening-free $Q$-parameters are defined by the equation:

$$Q_{1234} = (m_1 - m_2) - (E_{12}/E_{34})(m_3 - m_4), \tag{1}$$

and

$$E_{k,\ell} = (m_k - m_\ell)_{\text{reddened}} - (m_k - m_\ell)_{\text{intrinsic}}. \tag{2}$$

where $m$ are the magnitudes in four (sometimes three) passbands, $m_1 - m_2$ and $m_3 - m_4$ are the two color indices and $E_{12}$ and $E_{34}$ are the corresponding color excesses. In the medium-band Vilnius system the ratios of color excesses depend slightly on spectral and luminosity classes, and this dependence is taken into account. In calculating the $Q$-parameters, we used the color excess ratios $E_{12}/E_{34}$ corresponding to the normal interstellar extinction law (see Stražys 1992). The extinction law, i.e. the dependence of the extinction
on the wavelength, has not been investigated in the Aries dark clouds. However, studies of the extinction law in the adjacent areas in Perseus and Taurus give arguments in favor of the normal law in Aries, at least in the directions where spatial dust density is low (for a discussion see Straižys et al. 2001a,b). Lower in this section, we give an estimate of the ratio $E_{V-K}/E_{B-V}$ which also seems to be close to normal. The matching of $Q$-parameters leads to a selection of some standard stars which have a set of $Q$s most similar to those of the program star. The match quality is characterized by

$$
\sigma_Q = \pm \sqrt{\frac{\sum n \Delta Q_i^2}{n}},
$$

(3)

where $\Delta Q$ are differences of corresponding $Q$-parameters of the program star and the standard, $n$ is a number of the compared $Q$-parameters (in our case, $n = 14$). If the $\sigma_Q$ value is sufficiently small (i.e., the $Q$ differences between the program and the standard star are small), the spectral and luminosity classes of the closest star may be prescribed to the program star. For photometry of Population I stars measured with the 1% accuracy, $\sigma_Q$ is usually of the order of $\pm (0.01 - 0.02)$ mag. In most cases, for the program star we have accepted the average spectral and luminosity classes of the best fitted standard stars (from two to five).

(2) Interstellar reddening-free $Q$, $Q$ diagrams calibrated in terms of MK spectral classes and absolute magnitudes $M_V$ by Straižys et al. (1982). In the present study we applied the method (2) mostly for G8–K5 giants and subgiants for which the accuracy of determination of absolute magnitudes by the calibrated $Q_{UPY}$, $Q_{XZS}$ and $Q_{XYZ}$ diagrams is much better than by the method (1). The same method was used for some stars with rare spectral types for which no analog stars were found among the 8400 standards.

Both methods give the accuracy of spectral class $\pm 1$ decimal spectral subclass. The errors of absolute magnitudes are within $\pm 0.3$ and $\pm 0.5$ mag.

The color excesses $E_{Y-V}$ of stars were calculated as the differences between the observed $Y-V$ and the intrinsic color indices $(Y-V)_0$ for various spectral and luminosity classes, taken from Straižys (1992, Tables 66–69 and 73). The distances of stars were calculated by the equation:

$$
5 \log r = V - M_V + 5 - A_V,
$$

(4)
where $A_V = R_{YV}E_{Y-V}$. For the majority of stars the absolute magnitudes were taken from Straizys (1992) tabulation according to the spectral and luminosity classes, with a correction of $0.1$ mag, bringing the $M_V$ scale to the new distance modulus of the Hyades ($V-M_V = 3.3$, Perryman et al. 1998).

The $V$ magnitudes of the stars and the results of photometric quantification (spectral types and absolute magnitudes $M_V$) are given in Table 1. The table also contains color excesses $E_{Y-V}$, extinctions $A_V$, distances $r$ and the classification accuracy $\sigma Q$. The values of distances at $r > 200$ pc are rounded to the nearest number multiple of 10. In the column headed “Other sp. types”, the table contains spectral types of the stars collected from the literature: the data are taken from the HD, AGK 3 and PPM catalogs. The last column shows that the $\sigma Q$ values for the overwhelming majority of stars are between 0.01 and 0.02 mag, i.e., their classification accuracy is sufficiently good. The Q, Q mark in this column means that the star was classified by the $Q, Q$ diagrams, not by the $\sigma Q$ method.

For the estimation of the ratio $R_{YV}$ in the area, we have used the $V-K$ color indices measured in the 2MASS survey (Skrutskie et al. 1997). We have found 25 stars with $E_{Y-V} \geq 0.20$ for which $K$ magnitudes are available. Their spectral range is from A5 V to K5III. For these stars we calculated color indices $V-K$, taking $V$ from Table 2, and color excesses $E_{V-K}$, taking the intrinsic $(V-K)_0$ from Straizys (1992, Tables 22–24). The least square solution gives the equation (after rejection of the two reddest K5III stars):

$$E_{V-K}/E_{Y-V} = 3.229 + 0.962(Y-V)_0 \pm 0.240$$

with a correlation coefficient of 0.65. This equation is not valid for stars with $(Y-V)_0 > 0.9$, i.e. cooler than K3III. For the transformation of the ratio $E_{V-K}/E_{Y-V}$ to $E_{V-K}/E_{B-V}$ we need the ratio of color excesses in the Vilnius and $BV$ systems, $E_{Y-V}/E_{B-V}$. Due to the band-width effect, this ratio slightly depends on spectral type of a star. For A5–G5 stars the ratio is $\sim 0.80$ and for G8–K2 III stars it is $\sim 0.85$. Equation (5) and the ratio $E_{Y-V}/E_{B-V}$ lead to $E_{V-K}/E_{B-V} \approx 2.8$ for A5–G5 stars. This value is very close to that given by the normal interstellar extinction law (Straizys 1992). According to Cardelli, Clayton & Mathis (1988, 1989), the form of the extinction law in the visible and the infrared ranges, defining the ratio $R_{BV}$, is well correlated with its form in the ultraviolet. Thus, we may accept that in the Aries cloud the extinction law is normal,
i.e. it is typical for the diffuse dust. The same conclusion has been
done by Andersson & Wannier (1995) by measuring the wavelength
of maximum polarization for three stars in the area (our numbers
15, 61 and 100).

For the normal interstellar extinction law, the ratio $R_{YV} =
A_V/E_{Y-V} = 4.16$, with a very small dependence on spectral type
of the star (Straižys et al. 1996). We used this value of $R_{YV}$ to
calculate the extinctions $A_V$ and distances $r$ given in Table 1. The
expected errors for single stars are: $\pm 0.03$ mag for $E_{Y-V}$, $\pm 0.1$ mag
for $A_V$ and $\pm 15$–$25\%$ for distance (Straižys et al. 2001a).

18 stars from our list have trigonometric parallaxes measured
by the Hipparcos orbiting observatory. Their HIC numbers are given
in the Notes to Table 1. Among them are two binary stars, not
classified photometrically. The standard deviation of the distances
for the 10 stars, which are closer than 200 pc, is only $\pm 7$ pc. Both
distance scales do not show any systematic differences.

3. INTERSTELLAR EXTINCTION AND CONCLUSIONS

The dependence of extinction vs. distance for the stars in the in-
vestigated area is shown in Figure 1. We have not tried to divide the
area into smaller regions of different run of extinction vs. distance,
since the number of stars is insufficient for a detailed study. Some
stars with low classification accuracy can be identified in Table 1 by
the absence of absolute magnitudes, color excesses and distances and
the presence of notes. These stars were not used in the extinction
study. Probably, most of them are unresolved binaries. They need
further individual investigation by spectral analysis, radial velocity
measurements, spectral energy distribution modeling, etc.

The following conclusions may be drawn from Figure 1.

(1) The non-zero extinction starts at $\sim 60$ pc and it increases
gradually up to a distance of 250 pc, reaching a mean value of 0.3
mag. This value is close to the extinction created by the general
Galactic dust layer predicted by the exponential Parenago formula
with the coefficients: $A_0 = 1.5$ mag/kpc and $\beta = 0.11$ kpc (Parenago
1945, Sharov 1963), shown in Figure 1.

(2) At distances $>250$ pc many reddened stars appear with ex-
tinctions between 0.5 and 2.0 mag. They are situated near the edges
of the dark clouds.
Table 1. Results of photometric quantification, determination of color excesses, extinctions, and distances of the stars.

| No. | GSC       | Photom. sp. type | Other sp. types | $V$   | $M_V$   | $E_{V-V}$ | $A_V$   | $r$   | $\sigma Q$ |
|-----|-----------|-----------------|----------------|-------|---------|-----------|---------|-------|------------|
| 1.* | 1227:0327 | F9 IV           | F8             | 6.62  | +2.8    | 0.03      | 0.12    | 55    | 0.01       |
| 2.  | 1227:0966 | G5 V            | G0             | 8.97  | +5.0    | 0.01      | 0.04    | 61    | 0.01       |
| 3.  | 1227:0013 | F5 IV           | F5             | 10.62 | +2.5    | 0.10      | 0.42    | 350   | 0.01       |
| 4.  | 1227:0163 | G9 III          | K0             | 9.34  | +0.9    | 0.13      | 0.54    | 380   | Q,Q        |
| 5.* | 1227:0222 | K5 II-III       | K5             | 8.36  | –1.0    | 0.16      | 0.66    | 550   | Q,Q        |
| 6.  | 1227:0280 | F5 V            |                | 11.46 | +3.5    | 0.07      | 0.29    | 340   | 0.01       |
| 7.  | 1230:0673 | G7 III-IV       |                | 11.85 | +1.6    | 0.17      | 0.71    | 810   | Q,Q        |
| 8.  | 1227:0305 | G9 IV-V         |                | 11.11 | +4.3    | 0.08      | 0.33    | 198   | Q,Q        |
| 9.  | 1230:0729 | M0 III          |                | 11.09 | –0.6    | 0.25      | 1.02    | 1360  | Q,Q        |
| 10. | 1230:0942 | K0 III          |                | 12.35 | +0.9    | 0.13      | 0.54    | 1520  | Q,Q        |
| 11.*| 1227:0649 | F8 I-II?        | F              | 9.21  |        |          |         |       |            |
| 12. | 1227:0081 | K1 III          | K0             | 9.03  | +0.7    | 0.11      | 0.46    | 370   | 0.02       |
| 13. | 1227:0136 | F8 V            |                | 12.04 | +4.0    | 0.12      | 0.50    | 320   | 0.01       |
| 14.*| 1230:0782 | G5 IV-V:        |                | 11.10 | +4.0    | 0.12      | 0.50    | 210   | 0.02       |
| 15. | 1227:0617 | K0 III          | G5, K0         | 8.83  | 0.0     | 0.17      | 0.71    | 420   | Q,Q        |
| 16. | 1227:0449 | A5 m            |                | 10.69 | +1.8    | 0.20      | 0.83    | 410   | Q,Q        |
| 17. | 1230:0814 | G8.5 IV         |                | 11.51 | +2.4    | 0.16      | 0.67    | 490   | Q,Q        |
| 18. | 1227:0550 | K0 III          |                | 11.77 | –0.3    | 0.24      | 1.00    | 1640  | Q,Q        |
| 19.*| 1230:0724 | G7 III          | G5, K0         | 8.24  | +0.8    | 0.13      | 0.54    | 240   | 0.01       |
| 20. | 1227:0469 | G9.5 III        |                | 11.34 | –0.1    | 0.17      | 0.71    | 1400  | Q,Q        |
| 21.*| 1230:0966 | A5 V            |                | 12.01 | +1.8    | 0.30      | 1.25    | 620   | 0.01       |
| 22. | 1227:0585 | G8 III          | G5             | 9.71  | +1.5    | 0.15      | 0.61    | 330   | Q,Q        |
| 23. | 1227:0457 | F5 IV           |                | 10.92 | +2.5    | 0.08      | 0.33    | 410   | 0.01       |
| 24. | 1227:0412 | K0 III-IV       |                | 12.15 | +1.8    | 0.12      | 0.50    | 930   | Q,Q        |
| 25. | 1227:0045 | K1 III          |                | 12.39 | +0.5    | 0.35      | 1.46    | 1220  | Q,Q        |
| 26. | 1227:0046 | F6 V            |                | 12.05 | +3.6    | 0.24      | 1.00    | 310   | 0.01       |
| 27. | 1227:0790 | F5 V            |                | 10.81 | +3.5    | 0.06      | 0.25    | 260   | 0.01       |
| 28.*| 1227:0725 | M4.5 III        |                | 10.96 |        |          |         |       |            |
| 29. | 1227:0231 | K0.5 V          |                | 12.18 | +6.0    | 0.07      | 0.29    | 150   | 0.02       |
| 30.*| 1227:0218 | F3 IV           | A5             | 9.05  | +2.4    | 0.05      | 0.21    | 194   | 0.01       |
| 31. | 1227:0428 | A2 V            |                | 11.75 | +1.2    | 0.14      | 0.58    | 990   | 0.01       |
| 32. | 1227:0131 | K3 V            |                | 11.74 | +6.6    | 0.04      | 0.17    | 98    | 0.02       |
| 33. | 1230:0767 | G2 V            |                | 10.15 | +4.6    | 0.05      | 0.21    | 117   | 0.01       |
| 34. | 1227:0073 | K1 V            |                | 12.23 | +6.1    | 0.05      | 0.21    | 153   | 0.02       |
| 35. | 1227:0460 | G2 V            |                | 11.53 | +4.6    | 0.06      | 0.25    | 220   | 0.01       |
Table 1 (continued)

| No. | GSC       | Photom. type | Other type | $V$ | $M_V$ | $E_{V-V}$ | $A_V$ | $r$ | $\sigma Q$ |
|-----|-----------|-------------|------------|-----|-------|-----------|-------|-----|------------|
| 36. | 1227:0554 | G5 III      |            | 11.83 | 0.15 | 0.62 | 1150 | 0.01 |            |
| 37.*| 1230:1048 | K1 III      | K0         | 7.10  | 0.09 | 0.37 | 220  | Q,Q  |            |
| 38. | 1230:0999 | F5/8 II-III | G0         | 9.79  |       |       |       |      |            |
| 39. | 1230:0630 | G5 IV       |            | 11.73 | +3.4 | 0.19 | 0.79 | 320 | Q,Q       |
| 40. | 1230:1004 | F0 V        |            | 12.33 | +2.7 | 0.38 | 1.58 | 410 | 0.02      |
| 41. | 1227:0564 | M0/1 III    |            | 10.01 |       |       |       |      |            |
| 42. | 1230:0428 | F7 IV-V     |            | 11.10 | +3.4 | 0.14 | 0.58 | 260 | 0.01      |
| 43.*| 1230:0816 | K1.5 III    | K0         | 6.95  | -0.2 | 0.10 | 0.42 | 184 | Q,Q       |
| 44.*| 1227:0916 | F0 IV       | A3         | 7.00  | +2.1 | 0.01 | 0.04 | 94  | 0.01      |
| 45. | 1230:1055 | F8 V        |            | 10.88 | +4.0 | 0.04 | 0.16 | 220 | 0.01      |
| 46.*| 1230:0821 | G2 V        | F8         | 8.64  | +4.6 | 0.02 | 0.08 | 62  | 0.02      |
| 47.*| 1230:0600 | F4 V        | F2         | 8.81  | +3.3 | 0.04 | 0.16 | 117 | 0.02      |
| 48. | 1227:1316 | F5 V        |            | 10.41 | +3.5 | 0.03 | 0.12 | 230 | 0.01      |
| 49. | 1227:0447 | K5 III      |            | 10.36 | -0.7 | 0.36 | 1.50 | 820 | Q,Q       |
| 50. | 1227:0684 | G0 V        |            | 10.43 | +4.3 | 0.01 | 0.04 | 165 | 0.01      |
| 51. | 1230:0643 | F9 V        |            | 10.89 | +4.2 | 0.06 | 0.25 | 194 | 0.01      |
| 52. | 1227:0362 | F8 V        |            | 9.93  | +4.0 | 0.05 | 0.21 | 139 | 0.01      |
| 53. | 1230:0854 | F6 V        | G0         | 9.79  | +3.6 | 0.09 | 0.37 | 146 | 0.01      |
| 54. | 1227:0297 | K0 II-III   |            | 11.64 | -1.4 | 0.65 | 2.70 | 1170| Q,Q       |
| 55.*| 1230:1002 | K-M V       | K6e        | 12.21 |       |       |       |      |            |
| 56.*| 1230:0416 | G5 V        |            | 11.11 | +5.0 | 0.07 | 0.29 | 146 | 0.03      |
| 57.*| 1227:1100 | G9 V        | K0         | 9.75  | +5.8 | 0.02 | 0.08 | 59  | 0.02      |
| 58. | 1230:0854 | F6 V        | G0         | 9.79  | +3.6 | 0.09 | 0.37 | 146 | 0.01      |
| 59.*| 1227:0558 | K3/5 III?   |            | 10.73 |       |       |       |      |            |
| 60. | 1227:0087 | G0 V        |            | 11.84 | +4.3 | 0.05 | 0.21 | 290 | 0.01      |
| 61.*| 1227:0883 | F2          |            | 8.97  |       |       |       |      |            |
| 62. | 1227:0190 | G2 IV-V     |            | 11.95 | +3.4 | 0.20 | 0.83 | 350 | 0.01      |
| 63. | 1230:0797 | K5 III      |            | 12.20 | -0.5 | 0.31 | 1.29 | 1910| Q,Q       |
| 64. | 1227:1115 | K2 III      |            | 11.13 | +0.4 | 0.26 | 1.08 | 850 | Q,Q       |
| 65. | 1227:0777 | F8 V        | F5         | 9.84  | +4.0 | 0.01 | 0.04 | 144 | 0.01      |
| 66. | 1230:0458 | F5 V        |            | 11.78 | +3.5 | 0.31 | 1.29 | 250 | 0.01      |
| 67.*| 1227:1401 | F6 IV       | F5, F6 V   | 5.58  | +2.6 | 0.00 | 0.00 | 39  | 0.01      |
| 68.*| 1230:0784 | F8          |            | 11.49 |       |       |       |      |            |
| 69.*| 1227:1362 | K0.5 IV-V?  |            | 11.61 |       |       |       |      |            |
| 70. | 1230:0771 | G9 III-IV   |            | 11.63 | +1.3 | 0.24 | 1.00 | 730 | Q,Q       |
Table 1 (continued)

| No. | GSC    | Photom. sp. type | Other sp. types | $V$  | $M_V$ | $E_{V-V}$ | $A_V$ | $r$  | $\sigma Q$ |
|-----|--------|-----------------|-----------------|------|-------|-----------|-------|------|------------|
| 71. | 1227:0818 | G8 V            |                 | 10.94| +5.5  | 0.05      | 0.21  | 111  | 0.02       |
| 72.*| 1230:0302 | F0 V            | A5              | 8.76 | +2.7  | 0.04      | 0.16  | 151  | 0.01       |
| 73. | 1227:0157 | G9 IV           |                 | 12.28| +2.4  | 0.23      | 0.96  | 610  | Q,Q         |
| 74.*| 1230:0286 | G6-K1 III-IV?   |                 |      |       |           |       |      |            |
| 75. | 1227:0917 | F5 V            |                 | 10.88| +3.5  | 0.12      | 0.50  | 240  | 0.01       |
| 76. | 1230:0446 | G8 II           |                 | 12.13| -2.0  | 0.55      | 2.29  | 2340 | Q,Q         |
| 77. | 1230:0993 | K0.5 III        |                 | 12.16| -0.1  | 0.29      | 1.21  | 1620 | Q,Q         |
| 78. | 1227:0036 | F2 V            |                 | 11.45| +3.0  | 0.16      | 0.66  | 360  | 0.01       |
| 79. | 1230:0404 | K0 III          |                 | 13.28| -0.6  | 0.34      | 1.41  | 3110 | Q,Q         |
| 80. | 1227:0205 | K1 III          |                 | 10.12| +0.7  | 0.31      | 1.29  | 420  | Q,Q         |
| 81.*| 1230:0905 | F8 II-III       |                 |      |       |           |       |      |            |
| 82. | 1230:0907 | G0 V            | G0              | 10.68| +4.3  | 0.07      | 0.29  | 165  | 0.01       |
| 83. | 1230:0910 | G2 V            |                 | 12.19| +4.6  | 0.06      | 0.25  | 290  | 0.01       |
| 84.*| 1227:0620 | F2/5 IV-V       | F5              | 9.81 |       |           |       |      |            |
| 85. | 1227:0437 | K2 III          |                 | 12.20| -0.3  | 0.15      | 0.62  | 2380 | Q,Q         |
| 86.*| 1227:0769 | G-K?            |                 | 12.16|       |           |       |      |            |
| 87. | 1230:0510 | G3 V            |                 | 11.55| +4.7  | 0.08      | 0.33  | 200  | 0.01       |
| 88. | 1230:0665 | G4 V            | G5              | 9.92 | +4.9  | 0.03      | 0.12  | 95   | 0.01       |
| 89. | 1227:0115 | K0 III          |                 | 11.29| +0.7  | 0.16      | 0.66  | 970  | Q,Q         |
| 90. | 1230:0888 | F6 III          |                 | 11.80| +2.0  | 0.36      | 1.50  | 460  | Q,Q         |
| 91. | 1230:0783 | F6 V            |                 | 10.31| +3.6  | 0.06      | 0.25  | 196  | 0.01       |
| 92. | 1230:0664 | G8 V            |                 | 12.17| +5.5  | 0.09      | 0.37  | 181  | 0.02       |
| 93. | 1227:0481 | G0 IV-V         |                 | 11.36| +3.4  | 0.21      | 0.87  | 260  | 0.01       |
| 94. | 1230:0616 | G0 V            |                 | 10.63| +4.3  | 0.08      | 0.33  | 158  | 0.01       |
| 95. | 1230:0552 | F9 V sd?        |                 | 11.40| +4.2  | 0.05      | 0.21  | 250  | 0.02       |
| 96.*| 1230:0400 | F8 V            |                 | 11.37|       |           |       |      |            |
| 97.*| 1230:1425 | F5 V            | F0, F5 IV       | 5.73 | +3.5  | 0.00      | 0.00  | 28   | 0.01       |
| 98. | 1227:0363 | G9 III          |                 | 11.55| +0.7  | 0.16      | 0.66  | 1090 | Q,Q         |
| 99.*| 1230:0850 | G?              |                 | 11.78|       |           |       |      |            |
| 100.| 1230:0432 | F6 V            |                 | 9.47 | +3.6  | 0.09      | 0.37  | 126  | 0.01       |
| 101.| 1227:0003 | K1 V            |                 | 12.21| +6.1  | 0.05      | 0.21  | 152  | 0.02       |
| 102.| 1230:0332 | G8 V            |                 | 13.02| +5.5  | 0.08      | 0.33  | 270  | 0.01       |
| 103.| 1227:1330 | K2 V            |                 | 10.53| +6.4  | 0.03      | 0.12  | 63   | 0.03       |
| 104.*| 1230:0744 | K2 V?           | K4e             | 12.06|       |           |       |      |            |
| 105.| 1227:0870 | K0 II-III       |                 | 11.34| -0.9  | 0.41      | 1.71  | 1280 | Q,Q         |
| No.  | GSC   | Photom. sp. type | Other sp. types | V  | $M_V$  | $E_{V-V}$ | $A_V$ | r  | $\sigma Q$ |
|------|-------|-----------------|-----------------|----|--------|------------|-------|----|-----------|
| 106  | 1227:0986 | K0 III | | 10.80 | +1.3 | 0.18 | 0.75 | 560 | Q,Q |
| 107.* | 1227:0210 | K0 II-III | | 12.05 | -1.7 | 0.85 | 3.54 | 1100 | Q,Q |
| 108  | 1227:0342 | C9 III | | 10.94 | +0.2 | 0.27 | 1.12 | 840 | Q,Q |
| 109  | 1230:0713 | G6 IV G5 | | 10.15 | +3.0 | 0.10 | 0.42 | 220 | 0.01 |
| 110.* | 1230:0520 | A-F | | 12.16 | | | | |
| 111.* | 1227:0771 | G2 V G0 | | 8.77 | +4.6 | 0.00 | 0.00 | 68 | 0.01 |
| 112  | 1227:0860 | F6 V | | 12.11 | +3.6 | 0.11 | 0.46 | 410 | 0.01 |
| 113  | 1230:0862 | K1 V | | 12.00 | +6.1 | 0.08 | 0.33 | 130 | 0.02 |
| 114  | 1230:0511 | G3 V | | 11.40 | +4.7 | 0.07 | 0.29 | 191 | 0.01 |
| 115  | 1230:0550 | G9 V G5 | | 9.74 | +5.8 | 0.01 | 0.04 | 60 | 0.03 |
| 116.* | 1230:0970 | M1 III M0 | | 8.83 | -0.8 | 0.47 | 1.96 | 340 | Q,Q |
| 117.* | 1230:0240 | A5 A3 | | 6.70 | | | | |
| 118.* | 1227:0642 | G8 III K0 | | 8.24 | +0.4 | 0.16 | 0.67 | 270 | Q,Q |
| 119  | 1230:0723 | F0 IV | | 11.24 | +2.1 | 0.41 | 1.70 | 310 | 0.02 |
| 120  | 1227:0116 | K4.5 II-III | | 9.25 | -1.7 | 0.14 | 0.58 | 1180 | Q,Q |
| 121  | 1227:0160 | F6 V | | 10.96 | +3.6 | 0.06 | 0.25 | 260 | 0.01 |
| 122  | 1227:0891 | F8 V | | 10.98 | +4.0 | 0.04 | 0.16 | 230 | Q,Q |
| 123.* | 1227:0027 | F2 V F0 | | 7.32 | +3.0 | 0.00 | 0.00 | 73 | 0.01 |
| 124  | 1227:0494 | F0 IV-V | | 10.91 | +2.4 | 0.12 | 0.50 | 400 | Q,Q |
| 125  | 1230:0576 | G3 V | | 10.94 | +4.7 | 0.12 | 0.50 | 140 | 0.02 |
| 126  | 1227:0820 | F0 V | | 10.57 | +2.7 | 0.19 | 0.79 | 260 | 0.02 |
| 127  | 1230:0853 | A7 V A2 | | 9.32 | +2.2 | 0.09 | 0.37 | 220 | 0.02 |
| 128  | 1230:1044 | G2 V | | 12.06 | +4.6 | 0.08 | 0.33 | 270 | 0.01 |
| 129  | 1230:0987 | G9 III | | 11.25 | -0.4 | 0.33 | 1.38 | 1130 | Q,Q |
| 130  | 1227:0744 | F9 V | | 12.16 | +4.2 | 0.12 | 0.50 | 310 | 0.01 |
| 131.* | 1230:0772 | F7 V | | 10.07 | | | | |
| 132  | 1227:0232 | G8 IV | | 11.36 | +2.9 | 0.16 | 0.66 | 360 | Q,Q |
| 133  | 1230:0655 | G3 V | | 12.11 | +4.7 | 0.11 | 0.46 | 240 | 0.01 |
| 134  | 1230:0722 | G7 V | | 10.55 | +5.4 | 0.00 | 0.00 | 107 | 0.02 |
| 135  | 1230:0852 | G9.5 III | | 12.46 | +0.7 | 0.23 | 0.96 | 1440 | Q,Q |
| 136  | 1230:0742 | F5 V | | 10.74 | +3.5 | 0.09 | 0.37 | 240 | 0.02 |
| 137  | 1230:0867 | K0 III | | 12.05 | +0.4 | 0.25 | 1.04 | 1320 | Q,Q |
| 138.* | 1227:1178 | B9.5 V A0 | | 6.73 | | | | |
| 139  | 1230:0679 | G7 III | | 10.08 | +1.4 | 0.25 | 1.04 | 340 | Q,Q |
| 140  | 1230:0735 | M2 III | | 12.06 | -1.0 | 0.31 | 1.29 | 2260 | 0.02 |
Table 1 (continued)

| No. | GSC     | Photom. sp. type | Other sp. types | \( V \)  | \( M_V \)  | \( E_{V-V} \) | \( A_V \)  | \( r \)  | \( \sigma Q \) |
|-----|---------|-----------------|-----------------|--------|----------|-------------|----------|--------|-------------|
| 141. | 1230:1017 | G0 V         |                 | 11.97  | +4.3     | 0.09        | 0.37     | 290    | 0.01       |
| 142. | 1230:1010 | F2.5 IV A5   |                 | 9.90   | +2.3     | 0.08        | 0.33     | 280    | 0.02       |
| 143.* | 1230:0434 | M0/2 III     |                 | 11.48  |          |             |          |        |            |
| 144. | 1230:0696 | G8.5 IV K0   |                 | 9.98   | +2.7     | 0.09        | 0.37     | 240    | Q,Q        |
| 145. | 1230:0694 | G7 IV        |                 | 12.07  | +3.1     | 0.18        | 0.75     | 440    | 0.01       |
| 146. | 1230:0786 | F4 V         |                 | 12.16  | +3.4     | 0.25        | 1.04     | 350    | 0.01       |
| 147. | 1230:0997 | K3 V         |                 | 11.58  | +6.6     | 0.02        | 0.08     | 95     | 0.02       |
| 148. | 1231:1650 | F1 IV F0     |                 | 9.17   | +2.2     | 0.04        | 0.16     | 230    | 0.02       |
| 149. | 1231:1230 | F6 V         |                 | 12.14  | +3.6     | 0.30        | 1.25     | 290    | 0.01       |
| 150. | 1228:1069 | F5 IV        |                 | 10.42  | +2.5     | 0.08        | 0.33     | 330    | 0.01       |
| 151. | 1228:1624 | F0 V F0      |                 | 9.49   | +2.7     | 0.08        | 0.33     | 196    | 0.01       |
| 152.* | 1228:1051 | F0 V F2      |                 | 9.00   | +2.7     | 0.10        | 0.42     | 150    | 0.02       |

NOTES:

1. HD 17659 (F8) = HIC 13269.
5. HD 17768 (K5) = HIC 13337.
11. HD 17834 (F)
14. Classification uncertain: photometry of low accuracy.
19. HD 17870 (G5) = HIC 13418
21. According to B.-G. Andersson (personal communication) its spectral type is B7 V-III. Further verification is necessary.
28. Uncertain absolute magnitude.
30. HIC 13496.
37. HD 18019 (K0) = HIC 13532.
43. HD 18066 (K0) = HIC 13571.
44. HD 18091 (A3) = HIC 13579.
46. HD 18106 (F8) = HIC 13589, standard star.
47. HD 18090 (F2).
55. Classification uncertain. T Tauri type star (Hearty et al. 2000a, Jayawardhana et al. 2001).
56. Low accuracy of classification due to larger \( U-V \) and \( P-V \) errors.
57. HIC 13631.
59. Classification uncertain: low accuracy observations of \( U-V, P-V \) and \( X-V \).
61. HD 18190 (F). Binary WDS 02558+1909, \( \rho = 0.5'' \), \( \Delta m = 1.1 \) mag.
67. HD 18256 (F5) = HIC 13702, \( \rho \) Ari.
68. Classification uncertain. Binary?
69. Classification uncertain. Carbon-rich?
72. HD 18283 (A5) = HIC 13723.
74. Classification uncertain: low accuracy of $U-V$, $P-V$ and $X-V$.
81. Classification uncertain. Binary?
84. Classification uncertain.
86. Classification uncertain: low accuracy of $U-V$.
96. Binary WDS 02580+2124, $\rho=4.6''$, $\Delta m=0.1$ mag.
97. HD 18404 (F0) = HIC 13834.
99. Classification uncertain. Binary?
104. Classification uncertain. T Tauri type star (Hearty et al. 2000a, Jayawardhana et al. 2001).
107. The most reddened star in our sample.
110. Classification impossible. Binary?
111. HIC 13855.
116. SAO 75669. The star has been analyzed by Bhatt et al. (1994).
Polarization 3.7% (Bhatt & Jain 1992).
117. HD 18484 (A3) = HIC 13892. Binary WDS 02589+2137, $\rho=0.5''$, $\Delta H_p=0.2$ mag.
118. HD 18485 (K0) = HIC 13893.
123. HD 18508 (F0) = HIC 13913.
131. Binary WDS 02597+2013, $\rho=5.3''$, $\Delta m=0.3$ mag.
138. HD 18654 (A0) = HIC 14021, 50 Ari. Binary WDS 03005+1800, $\rho=2.2''$, $\Delta H_p=3.0$ mag.
143. Classification uncertain. Binary?
152. HIC 14201.

(3) The three most reddened stars, found in the area, are 107 (K0 II-III, $A_V=3.54$ mag), 54 (K0 II-III, $A_V=2.70$ mag) and 76 (G8 II, $A_V=2.29$ mag). All the three are very distant objects ($r > 1$ kpc), being seen through a lane of lower extinction near the +20° declination circle, separating the L1454 and L1457 dust clouds. The star 76 is seen only at 5′ distance from the well-known T Tauri type star WY Ari. Other four T Tauri type stars are in the same lane.

(4) There are 21 stars with distances >1 kpc in our sample, including the three stars described above. All these stars are seen through more transparent cloud sections, exhibiting extinction values between 0.5 and 3.5 mag. At these distances, the stars with larger extinctions are too faint to be detected with the present limiting magnitude.
Fig. 1. The extinction $A_V$ plotted as a function of the distance $r$ in parsecs. The solid line shows the extinction run according to the Parenago formula for the $-34^\circ$ Galactic latitude. The broken line is the limiting curve for stars of $V_{\text{lim}} = 12$ mag and $M_V = +1$ mag. Above this curve a strong selection effect is present. For more details see the text. The circle with the error bar is shown at the estimated distance of the dust cloud.

(5) Figure 1 also shows the curve, corresponding to a limiting apparent magnitude of $V = 12$ mag and the absolute magnitude $M_V = +1.0$. This value of $M_V$ corresponds to K-type giants, which are most numerous absolutely brightest stars in the area. Above the limiting curve, a strong selection effect takes place: K giants, as well as absolutely fainter stars, with larger extinctions are too faint to be included in the present program. Above the curve only some stars of fainter apparent brightness or absolutely brighter than $M_V = +1.0$ are present.

We confirm Luhman’s (2001) conclusion that the Aries cloud cannot be closer than 200–250 pc. In this distance range there is only a gradual increase of extinction related to the general Galactic
dust layer. Only a small hump of extinction from 0.2 to 0.4 mag at 140–160 pc may be suspected. It may be related to an extension of the Taurus dark cloud complex to the Aries area. The first considerably reddened stars start to appear at 250 pc. However, this does not mean that the dust cloud begins there. The reddened stars at this distance may appear due to accidental negative distance determination error: at 310 pc the rms error is about ±60 pc. Consequently, the dust cloud may be situated at 310 pc distance or even farther.

Another estimate of the dark cloud distance is the distribution of stars with low reddening. The stars near the Parenago exponential curve disappear at ∼410 pc, what means that the dust cloud rises their positions in Figure 1 upward at a distance of 410 − 70 = 340 pc, here 70 pc is the distance rms error at 340 pc. This distance is not very different from the value obtained from the considerably reddened stars discussed in the previous paragraph.

Consequently, our study gives evidence that the dark cloud distance is between 310 and 340 pc. As a preliminary value, the distance 325 pc may be accepted. Since the angular diameter of the dust cloud is about 2°, at this distance the true diameter is ∼11 pc. Probably, its radial extent is of the same order. The distance from the Galactic plane at $b = −34^\circ$ is ∼180 pc. These values should be considered as preliminary, since it is not excluded, that in future some reddened stars at the distances closer to the Sun will be found.

Zimmermann & Ungerechts (1990), Pound et al. (1990) and Moriarty-Schieven et al. (1997) from the observed equivalent widths of radio lines of $^{12}$CO and $^{13}$CO molecules have determined the mass of the Aries cloud, which ranges between 30 and 200 $M_\odot$, assuming a cloud distance of 65 pc. If we place the cloud 5 times farther, it becomes much more massive, 750–5000 $M_\odot$. Even this new mass is still too small in comparison with the virial mass estimated by the same authors, assuming virial equilibrium between the gravitational potential and the kinetic energy. This means that the mass of the whole cloud is not sufficient to bind it gravitationally. A considerable fragmentation is found in the cloud with different clumps having different velocities.

In our earlier paper (Straižys et al. 2001b), we have plotted a polar diagram “distance versus galactic latitude” for the Galactic anticenter direction with positions of the investigated dust clouds in Taurus, Perseus and Aries. The Aries cloud in this diagram was plotted at the wrong distance from Hobbs et al. (1986), relating it
to the Taurus complex. In reality, the Aries cloud is so distant from the Galactic plane, that it hardly can be related both to the Taurus and to the Perseus dust layers. Its radial velocity, determined from radio lines of CO, is also different (Ungerechts & Thaddeus 1987).

In a distance range of 250–400 pc, i.e., within the error box of the cloud distance, the following 11 stars have extinctions $A_V$ larger than 0.8 mag: 66 (F5 V), 93 (G0 IV-V), 126 (F0 V), 149 (F6 V), 119 (F0 IV), 26 (F6 V), 39 (G5 IV), 116 (M1 III), 139 (G7 III), 62 (G2 IV-V), and 146 (F4 V). These stars are candidates to populate either the dust cloud or the close vicinity behind it. It is important to find their precise distances by increasing the accuracy of their absolute magnitudes. Also, these stars should be verified carefully for the presence of secondary components. In this respect, radial velocity measurements would be helpful.

On the other hand, a more exact determination of the cloud distance may be obtained by increasing the number of investigated stars, i.e., by shifting the limiting magnitude of the program to fainter stars. The program also should include more stars projected onto the dark cloud.

Additionally, in the present study we have detected about ten stars with unusual photometric properties. Due to peculiar energy distribution, they cannot be classified from their photometric $Q$-parameters. Short information about these stars is given in the Notes to Table 1. Probably, the majority of them are unresolved binaries. However, in some cases other causes of their peculiarity may be responsible. For example, the star No. 16 seems to be a metallic-line star, No. 69 photometrically is most similar to a R-type carbon star, and No. 95 may be a F subdwarf.

Additional information on the amount of dust in the cloud and its properties can be obtained by polarization studies of the stars. Andersson (2002) has made polarimetry in the $R$ passband for almost all stars of Table 1. Smaller number of stars has been measured earlier by Bhatt & Jain (1992), Leroy (1993) and Andersson & Wannier (1995). The stars of our sample with the largest color excesses exhibit the largest polarization (up to 3.7%). The heavily reddened stars found in the study may be used in future for more careful investigation of interstellar reddening and polarization law in the dust cloud.
ACKNOWLEDGMENTS. The investigation is partly supported from the AAS Chretien Grant of 2000. We are grateful to the Arizona University telescope time allocation committee for the observing time on Mount Lemmon, to the Vatican Observatory community for their help and hospitality during the observing run, to B.-G. Andersson (The John Hopkins University, Baltimore) for the proposal of the present study and useful discussions, to A. G. Davis Philip (Union College and the Institute for Space Observations, Schenectady) for reading the manuscript and for important comments. We acknowledge the use of the Simbad database of the Strasbourg Stellar Data Center.

REFERENCES

Andersson B.-G. 2002, in preparation
Andersson B.-G., Wannier P. G. 1995, ApJ, 443, L49
Bhatt H. C., Jain S. K. 1992, MNRAS, 257, 57
Bhatt H. C., Sagar R. et al. 1994, A&A, 289, 946
Cardelli J. A., Clayton G. C., Mathis J. S. 1988, ApJ, 329, L33
Cardelli J. A., Clayton G. C., Mathis J. S. 1989, ApJ, 345, 245
Duerr R., Craine E. R. 1982, AJ, 87, 408
Hearty T., Neuhäuser R., Stelzer B., Fernandez M., Alcalà J. M., Covino E., Hambaryan V. 2000a, A&A, 353, 1044
Hearty T., Fernandez M., Alcalà J. M., Covino E., Neuhäuser R. 2000b, A&A, 357, 681
Hobbs L. M., Blitz L., Magnani L. 1986, ApJ, 306, L109
Hobbs L. M., Blitz L., Penprase B. E., Magnani L., Welty D. E. 1988, ApJ, 327, 356
Jayawardhana R., Wolk S. J., Navascues D. B., Telesco C. M., Hearty T. J. 2001, ApJ, 550, L197
Kazlauskas A., Černis K., Laugalys V., Straižys V. 2002, Baltic Astronomy, 11, 219 (Paper I, this issue)
Leroy J. L. 1993, A&AS, 101, 551
Luhman K. L. 2001, ApJ, 560, 287
Lynds B. T. 1962, ApJS, 7, 1
Magnani L., Blitz L., Mundy L. 1985, ApJ, 295, 402
Moriarty-Schieven, Andersson B.-G., Wannier P. G. 1997, ApJ, 475, 642
Parenago P. P. 1945, AZh, 22, 129
Perryman M. A. C., Brown A. G. A., Lebreton Y. et al. 1998, A&A, 331, 81
Pound M. W., Bania T. M., Wilson R. W. 1990, ApJ, 351, 165
Sharov A. S. 1963, AZh, 40, 900 = Soviet Astronomy, 7, No. 5
Skrutskie M. F., Schneider S. E., Stiening R., Strom S. E. et al. 1997, in
The Impact of Large Scale Near-IR Sky Surveys, eds. F. Garzon et al.,
Kluwer Publishing Company, Dordrecht, p. 25
Straižys V. 1977, Multicolor Stellar Photometry, Mokslas Publishers,
Vilnius, Lithuania
Straižys V. 1992, Multicolor Stellar Photometry, Pachart Publishing
House, Tucson, Arizona
Straižys V., Černis K., Bartasųtė S. 2001a, Baltic Astronomy, 10, 319
Straižys V., Černis K., Bartasųtė S. 2001b, A&A, 374, 288
Straižys V., Černis K., Bartasųtė S. 1996, Baltic Astronomy, 5, 125
Straižys V., Kazlauskas A. 1993, Baltic Astronomy, 2, 1
Straižys V., Kurilienė G., Jodinskienė E. 1982, Bull. Vilnius Obs., No.
60, 3
Ungerechts H., Thaddeus P. 1987, ApJS, 63, 645
Zimmerman T., Ungerechts H. 1990, A&A, 238, 337