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Microscale structure in the Norma dark cloud *

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Abstract. To investigate the structure of a standard dark cloud like that in the Norma region ($l = 325\overset{\circ}{.}6$, $b = 0\overset{\circ}{.}13$), a photometric and spectral study was undertaken. $B-V$ vs V-$3(B-V)$ diagrams (similar to the more usual E_{B-V} vs $V_0 - M_V$) were built for the stars on the spectral ranges B4–B8, B9–A3 and A4–F5. These diagrams were explained through the building of numercial models which allowed us to obtain some statistical parameters of the microclouds components of the dark region. We found that this standard dark cloud is well represented by microclouds with radii in the range 1 and 2 pc and mean excess between 0.1 and 0.15 magnitudes. The mean density is 8 10^{-3} microclouds pc^{-3}.

Key words: interstellar medium: clouds: general – interstellar medium: dust – interstellar medium: extinction – interstellar medium: general

1. Introduction

There is no doubt about the existence of small-scale structure in the interstellar dark clouds. However very little is known concerning the statistical properties of their individuals components.

Ambarzumian (1950) was the first to propose a discrete cloud model for the structure of the interstellar medium. Later, Chandrasekhar & Münch (1952) introduced the concept of angular correlation coefficient for the interstellar reddening. At the same time Münch (1952) gave illustrative values of the cloud parameters since he supposes that the radius of the clouds are so small compared with the distance between them that they can be considered like points along the line of sight and nothing can be said about their real dimensions. A few years after Serkowski (1958), Krzeminski & Serkowski (1967) and Scheffler (1967) estimated the micro scale of the oscillations in the space density of the interstellar dust. Knude (1979) studied clouds of small reddening within 400 pc from the Sun and found a mean reddening of 0.03 mag for the average cloud. After this period Clocchiatti & Marraco (1986a, b) were the first to analyze the problem of the microstructure of the dust. They used the concept of the interstellar matter structural function, already proposed by Serkowski (1958), and proved that it is an useful tool to derive the features of the interstellar dust distribution.

This paper is devoted to the study of a region inside the Norma dark cloud and it is an attempt to arrive at parameters describing the concentration of dust in this area. Using thin objective prism plates nearly 500 stars were selected in two regions, one inside the dark cloud and the other outside it and free of dust. Besides, to provide additional information about the objects already classified in the thin prism plates, BV photographic photometry for these stars was obtained and $(B-V)$ vs. V-$3(B-V)$ diagrams (similar to the more current E_{B-V} vs. $V_0 - M_V$) were built. These diagrams show anomalies in the dust distribution suggesting the possible existence of micro structure inside the cloud. To analyze this phenomenon we propose a model of the morphology of cloud structure with some free parameters and try to adjust them to the observed values of the region. The comparison between the observations and the model should give the additional information about the microstructure.

2. The Norma region

The Norma dark cloud is of basic interest as a key region for the understanding of a standard dark cloud without star formation activity.

In this direction the absorption increases strongly with distance within the first kpc. Haug & Bredow (1977) found evidence for two separate concentrations of dark material near to the Sun at less than 0.3 kpc and a third one farther at about 0.7 kpc. This is in good agreement with that observed by Haug et al. (1966), Schnur (1970) and Rydgreen (1974) in the sense that the reddening in the Norma region essentially appears in a layer of strong darkness close to 0.7 kpc from the Sun and increase gradually up to 3 kpc.

For this study we selected two zones of 1 square degree each, one inside the Norma dark cloud and chosen because it showed a nearly constant extinction and other, hereafter the comparison zone, very near to the cloud but outside it and apparently free of obscuration.

The absorption zone is centered on galactic coordinates $l = 325\overset{\circ}{.}6$ and $b = 0\overset{\circ}{.}13$. Haug & Bredow (1977) found notable "gaps" in the star distribution at $l = 325°$ suggesting probable absorption values which cannot be reached with their sample (stars of spectral types between B2 and B8).

Our absorption zone partially overlaps with area 308 from the Catalogue of dark nebulae and globules for galactic longitudes

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240 to 360 degrees by Feitzinger & Stüwe (1984) and it can be distinguished in Neckel's (1967) catalogue where he assigns to this area the presence of absorption values varying between 2.2 and 3.0 magnitudes. Besides, our zone includes area 177 from the Catalogue of southern dark clouds by Hartley et al. (1986).

The choice of an unreddened comparison field must be very careful because although we admit the presence of a diffuse general interstellar absorption, the effect produced by the Norma cloud has to be avoided. Moreover, the comparison field is needed to be so close as possible to the studied cloud.

Our comparison field is located at galactic coordinates $l = 327\overset{\circ}{.}8$ and $b = -2\overset{\circ}{.}36$. It coincides with a region already studied by Drilling (1968) thereby including some additional objects of his sample in our study.

3. Observations

We used thin objective-prism plates (dispersion 1360 Å/mm at Hγ) and direct BV plates kindly made available by Dr. J. C. Muzzio. These plates were obtained in 1975 with the Curtis-Schmidt telescope at Cerro Tololo Inter-American Observatory. The spectra, widened 0.2 mm, were recorded on IIIa-J emulsion backed in dry nitrogen. The exposure times were 10, 30 and 80 min. The direct visual plates were recorded on IIa-D emulsion and a GG-14 filter was used. For the blue plates a IIa-O emulsion and GG-13 filter were employed. The exposure times were 10 min both for the visual and the blue.

The thin objective-prism plates offer an excellent tool to classify rapidly a great number of stars. The spectra are shorter than usually so fainter magnitudes may be reached (the limiting magnitude is approximately $B = 15$ mag) minimizing overlapping problems. However it is possible to recognize only approximate groups of spectral types.

We applied the low-dispersion classification criteria from Martinez et al. (1980). They distinguish the following spectral type ranges: B4–B8, B9–A3, A4–F5, F6–G2, G3–K0, K1–K5 and K6–M.

The adoption of a spectral type range to carry out the study of the selected areas requires that the region under study contains enough stars of that kind. Besides it is very important to choose a narrow spectral range because, in such case, the mean absolute magnitude and the scatter around the mean are well determined.

In this case we chose stars from the range B9–A3. The stars of this "Natural Group" gather, at least, three properties which turn them into excellent objects to study the dark cloud: (i) They are intrinsically bright to penetrate the Norma cloud. (ii) There is a sufficient number of B9–A3 stars, thereby it is possible to carry out statistical studies with them. Earlier papers (Drilling 1968; McCuskey & Houk 1971; McCuskey & Lee 1976) assign the presence of a notable concentrations of such stars to be within 2 kpc. (iii) It is rather easy to classify these stars on thin objective prism plates because: (a) the strength of Balmer's lines and (b) the Ca II K line is not present allowing to distinguish them from later spectral types. Furthermore the objective prism transmits light essentially in the ultraviolet region which lets us detect easily the Balmer jump and makes it possible to distinguish more luminous A stars from earlier Main Sequence stars.

Besides the B9–A3 stars, those belonging to spectral types B4–B8 and A4–F5 were chosen to complete the sample. From the search 186 stars of the three spectral types were selected at the absorption zone and 342 at the comparison zone in addition to 35 stars from Drilling's region.

4. Observed $(B-V)$ vs. $V-3(B-V)$ diagrams

The extinction of stars versus their distance moduli for each individual spectral type was plotted in the direction of the cloud and the comparison zone. But designing $(B-V)$ vs. $V-3(B-V)$ diagrams similar to more usual E_{B-V} vs. $V_0 - M_V$. This can be explained in the following way:

$$B-V = E_{B-V} + (B-V)_0$$

$$V-3(B-V) = V - 3E_{B-V} - 3(B-V)_0$$

$$V-3(B-V) = V_0 - 3(B-V)_0$$

$$V-3(B-V) = (V_0 - M_V) + (M_V - 3(B-V)_0)$$

where $(B-V)_0$ and $M_V - 3(B-V)_0$ are constant for a given spectral type. (It is here that one sees the advantage of taking a narrow spectral range.)

Figures 1 to 6 show the obtained diagrams. Detailed information about them is given in Table 1. The two solid lines corresponds to the observed search's limits which are given by the following expressions:

$$V-3(B-V) = B-4(B-V) > B_M - 4(B-V)$$
$$V-3(B-V) = B-4(B-V) < B_m - 4(B-V)$$

where B_M and B_m are the approximate bright and faint limits respectively. The adopted values for them are 12 and 15 magnitudes for the cloud and 12 and 14 magnitudes for the comparison zone.

Figures 2 and 5 show the distribution for B9–A3 stars in both regions. Although the apparent magnitude faint limit is greater there is a notably smaller number of stars in the cloud region. Note that far, low excess stars are relatively less in Fig. 2 than in Figure 5.

Meanwhile Figs. 4 and 6 present a uniform distribution for B4–B8 and A4–F5 stars of the comparison region, in the cloud region only B4–B8 stars (Fig. 1) are affected by a strong absorption (the farthest) and A4–F5 (Fig. 3) are affected by a weak absorption (the nearest). However, Fig. 2 shows a great dispersion in extinction therefore it is strange to suppose the absence of B4–B8 stars with weak absorption and A4–F5 with strong absorption. It should be explained by the existence of small concentrations responsible of the dispersion observed.

The observed distribution in these diagrams is in good agreement with that obtained by various papers in the Norma region (Westerlund 1969; Drilling 1972). The darkness seems to change notably over small angular distances in the sky. Hence the color excess vs. distance diagrams should present a great dispersion unless an area small enough can be chosen.

Table 1. Detailed information about the observed $(B-V)$ vs. $V-3(B-V)$ diagrams. N is the number of stars classified on each spectral type

Figure	Zone	Spectral type	N
1	Absorption	B4–B8	50
2	Absorption	B9–A3	106
3	Absorption	A4–F5	30
4	Comparison	B4–B8	62
5	Comparison	B9–A3	240
6	Comparison	A4–F5	40

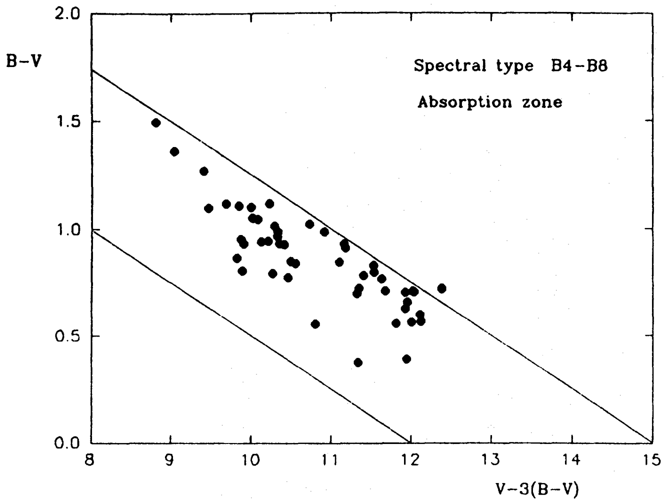

Fig. 1. The $B-V$ vs. $V-3(B-V)$ relation for the observed B4–B8 spectral type stars on the absorption zone. The two solid lines correspond to the search's limits

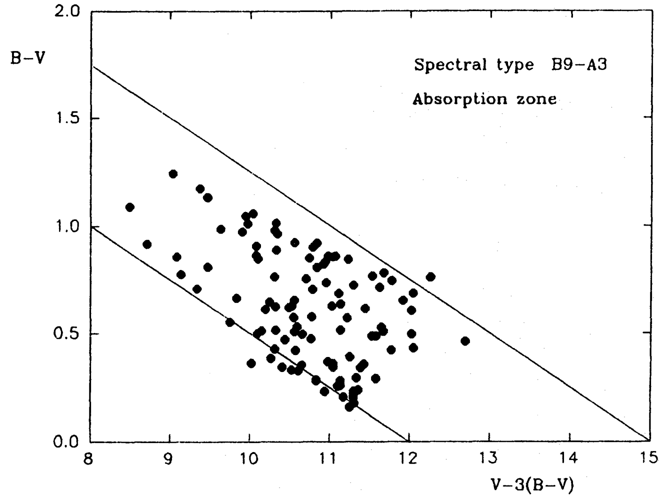

Fig. 2. The $B-V$ vs. $V-3(B-V)$ relation for the observed B9–A3 spectral type stars on the absorption zone. The two solid lines correspond to the search's limits

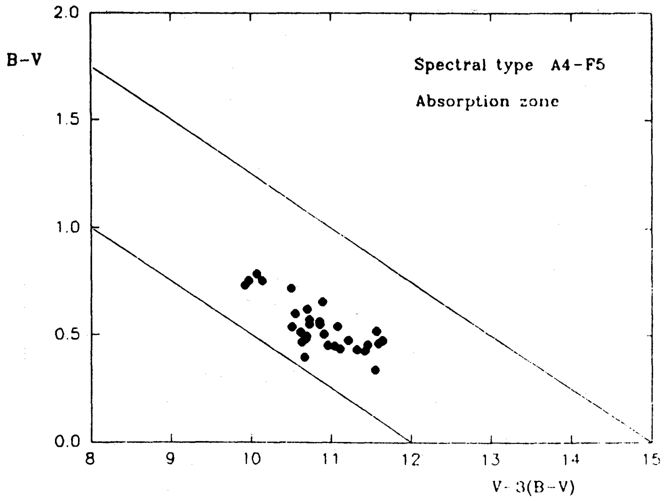

Fig. 3. The $B-V$ vs. $V-3(B-V)$ relation for the observed A4–F5 spectral type stars on the absorption zone. The two solid lines correspond to the search's limits

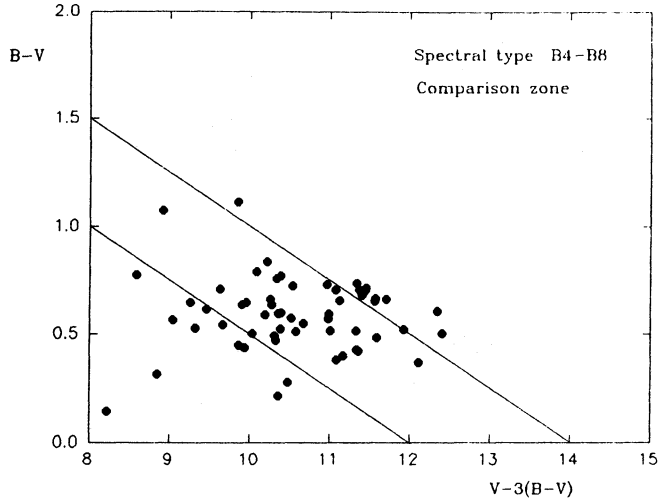

Fig. 4. The $B-V$ vs. $V-3(B-V)$ relation for the observed B4–B8 spectral type stars on the comparison zone. The two solid lines correspond to the search's limits. The apparent magnitude faint limit is one magnitude greater than in the absorption zone

The presence of H-alpha emission objects should introduce a remarkable dispersion in the observed values so a search for them was carried out but no one was found.

5. The models

To explain the observed diagrams we built a model of the interstellar dust components in the direction of the dark cloud. It is obvious that the absorbing material has concentrations. For simplicity, these concentrations of dust were chosen spherically homogeneous, we called them microclouds. Each one of these microclouds is characterized by two physical parameters: the radius and the mean excess, which are free parameters of the model.

These concentrations may be used to build bigger shape concentrations. It is necessary to point out that they must not be considered real clouds and the parameters that we obtain have sense only for a statistical purpose.

We have no previous reasons to impose a fixed distribution for the microclouds neither to the stars in the region studied. For that reason we used a uniform distribution for the cloud centers and the stars positions, that is: they were randomly located inside a given volume element. The absolute magnitude for each star was also randomly calculated following a Gaussian distribution with mean value M_V and dispersion σ_{M_V}. These numbers were taken from McCuskey (1966). He uses spectral groups in the same way as we do. His group B8–A0 (the closest to our group B9–A3) was selected and the values $M_V=0.2$ and $\sigma_{M_V}=0.5$ corresponding to it were adopted.

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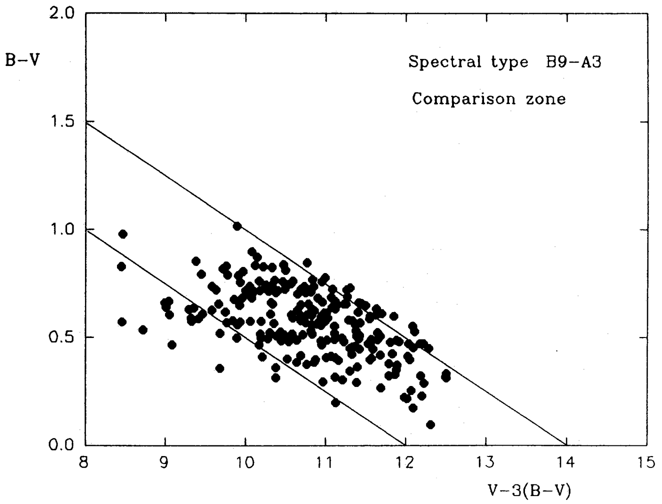

Fig. 5. The $B-V$ vs. $V-3(B-V)$ relation for the observed B9–A3 spectral type stars on the comparison zone. The two solid lines correspond to the search's limits. The apparent magnitude faint limit is one magnitude greater than in the absorption zone

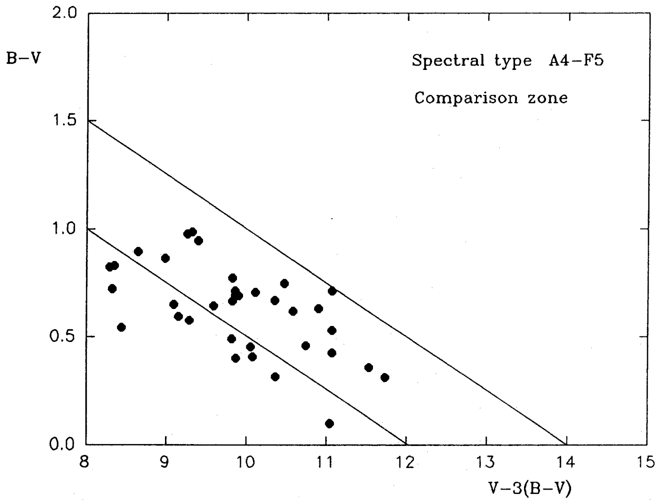

Fig. 6. The $B-V$ vs. $V-3(B-V)$ relation for the observed A4–F5 spectral type stars on the comparison zone. The two solid lines correspond to the search's limits. The apparent magnitude faint limit is one magnitude greater than in the absorption zone

For the intrinsic colour $(B-V)_0$ and the ratio of total to selective interstellar extinction R_V we used 0.0 mag and 3.0 respectively. The $\sigma_{(B-V)_0}$ is 0.05. The existence of a normal value for R_V between galactic longitudes 320° and 332° was corroborated by Waldhausen & Marraco (1982).

To build in a fast and effective way our models a combination of Simplex algorithm and χ^2 statistical test was adopted. Simplex is a direct and rapid way to find the values which maximize or minimize (the least is this case) a given function $f(x,y)$ starting from three initial pairs of values. χ^2 test is a statistical means of testing the agreement between observation and hypothesis.

All of the models were run at least twice in order to avoid the possible dependence with the "seed number" used to generate the random series.

To build a model following the ideas described above, we simulated a low density background absorption medium and another shallow region of microclouds superposed to it (like an absorbing "screen"). The light path of each star is affected by a certain number of microclouds. The absorption produced by each cloud is proportional to the path of starlight inside the cloud. All the paths calculated were converted into excesses and also the $V-3(B-V)$ for each star was estimated. Later all those stars that fell into the area of the diagrams between the observed search's limit for the dark zone were selected and a value of χ^2 was calculated. The process iterated automatically until a local minimum of χ^2 was found. The resulting set of clouds parameters and positions of clouds and stars was called a model of the region.

The values corresponding to the "standard cloud" model of Spitzer (1978) were adopted as initial values for E_m and R, the colour excess in $B-V$ and radius of each microcloud, they are $E_m = 0.05$ mag and $R = 1$ pc.

Preliminary models for the comparison region were run using values between 1 and 8 pc for the radius R of each microcloud and 0.05 and 0.10 magnitudes for the excess E_m. The set of parameters that got the best agreement with the observed distribution was employed to start the Simplex. We concluded that the best fitting to the observed $(B-V)$ vs. $V-3(B-V)$ diagrams is reached by the models characterized by microclouds with radii in the range 1 and 2 pc and mean excesses E_m between 0.10 and 0.15 mag (Figs. 7 and 8).

Then, having fixed the values of the radius ($R = 1.5$ pc) and excess ($E_m = 0.10$ mag) of the standard clouds, we turned over the dark region.

The position of the absorbing screen that causes the obscuration of the dark region was changed between 0.5 and 1.0 kpc and no definite conclusion was obtained: it can be as close as 0.65 kpc or perhaps slightly further than 1 kpc. Since the line of sight is not directed towards any particularly privileged direction we can reasonably believe that the shape of the cloud is spherical and the depth is about the same as the projected width and height thus the adopted depth of the screen is 50 pc.

The comparison region was best fitted by generating approximately 2700 clouds. The screen at 0.65 kpc is well represented when is composed by an average of 50 clouds. The models cover 1° × 1° over the sky. The densities resulting from these numbers then represents 16 10^{-4} clouds pc^{-3} for the general background in the comparison region and 8 10^{-3} clouds pc^{-3} within the absorbing screen.

All the values above were obtained by trial and error (inspecting the χ^2 test fit).

It may be argued that the absorbing screen can be built using a different kind of "standard clouds". This is absolutely possible, but we decided to keep the same kind of clouds in both cases for the sake of simplicity. We considered also the low number of clouds in the screen that precludes to obtain a reasonable well determined value for these *new* free parameters.

6. Conclusions

The general interstellar medium in the neighborhood of the galactic plane is reasonably represented by microclouds of 3 pc in diameter, giving an absorption of 0.1 mag when seen across their diameters. The average number density of these clouds is 16 10^{-4}

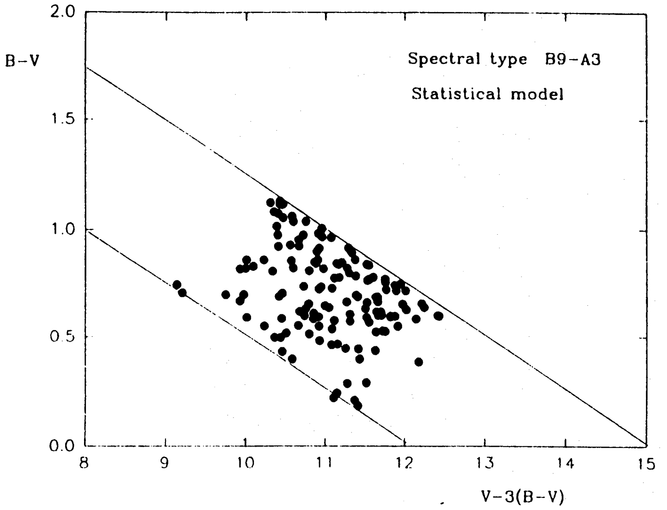

Fig. 7. One of the two best fitting models for the absorption region obtained using data from B9 A3 stars

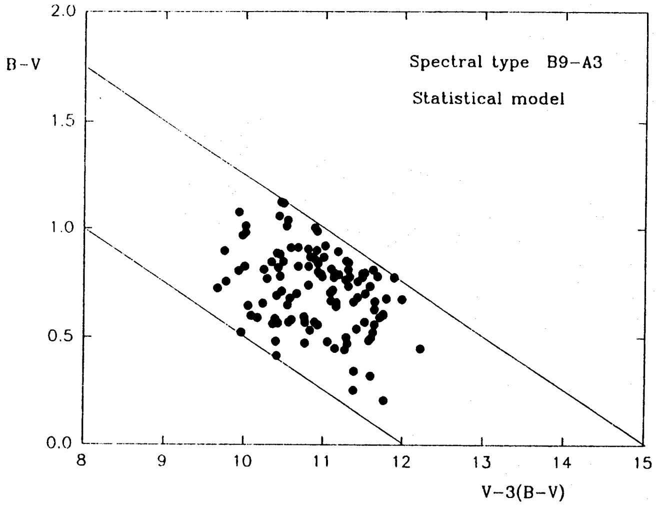

Fig. 8. The same than Fi.g 7 for the second best fitting model

clouds pc^{-3}. The cloud filling factor results 0.022 in very good agreement with the average diameter and filling factor of the local interstellar medium obtained by Knude (1981).

A standard dark cloud, like the Norma dark cloud, is well represented by the same kind of microclouds but increasing five fold the number density over the general interstellar medium to 8 10^{-3} clouds pc^{-3}.

These general conclusions apply to the Norma region but the fact that the interstellar matter is discrete, as proposed by Ambarzumian (1950), is once more confirmed for this particular region.

We confirm the distance of the Norma cloud at 650 pc.

Assuming for the Norma cloud an spherical shape of 50 pc diameter, we get, using the same arguments at Clocchiatti & Marraco (1986b) a total mass of approximately 3 10^4 solar masses.

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