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MAFFEI 2, A NEARBY GALAXY SHIELDED BY THE MILKY WAY

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ABSTRACT. *For the spiral galaxy Maffei 2, located at a latitude of 20 arcminutes from the Milky Way plane, deep CCD frames were obtained at a subarcsecond seeing. The light absorption in the direction of the galaxy is estimated as A_v=6.3±0.1 from the colour excess in the galaxy bulge and HII regions. The distance modulus of Maffei 2 found from its brightest blue stars is close to the modulus of IC 342 and makes $26\overset{m}{.}7$. As the nearby galaxies, Maffei 2 and IC 342 could markedly affect the trajectories of the Local group galaxies.*

1. INTRODUCTION

A pair of galaxies with the coordinates RA=$02^h32^m36\overset{s}{.}0$, D=+59°26′00″ and $02^h38^m07\overset{s}{.}9$, +59°23′24″ was accidentally detected by P. Maffei (1968) when searching for cometary nebulae in the Milky Way on infrared plates. The extragalactic nature of the first object (Maffei 1) was established by Spinrad et al. (1971), who measured the radial velocity, V_h=-10±50 km/s, radial velocity dispersion, σ_v=200±50 km/s and estimated the distance to this elliptical galaxy at the Milky Way light absorption $A_v=5\overset{m}{.}1\pm0\overset{m}{.}2$ to be 0.9-4 Mpc. Another spiral-type galaxy Maffei 2 was detected in HI line by Shostak & Weliachew (1971) and Bottinelli et al. (1971). According to the data of the latter authors Maffei 2 has V_h=+25±10 km/s, the rotation curve amplitude V_{max}=200 km/s and a distance between 2.0 and 5.9 Mpc. Spinrad et al. (1973) found that in the direction of Maffei 2 the interstellar absorption is $A_v=6\overset{m}{.}3\pm0\overset{m}{.}2$. Both galaxies have a very low galactic latitude: $-0\overset{\circ}{.}57$ for Maffei 1 and $-0\overset{\circ}{.}33$ for Maffei 2. They are also located in the plane of the Local supercluster (SGB, $+1\overset{\circ}{.}5$ and $+0\overset{\circ}{.}8$, respectively).

After the publications of Spinrad and coauthors there was a break in the study of these galaxies. Ten years later the investigations were continued by Buta & McCall (1983), Ho et al. (1989), Ishiguro et al. (1989), Hurt & Turner (1991), Hurt et al. (1992).

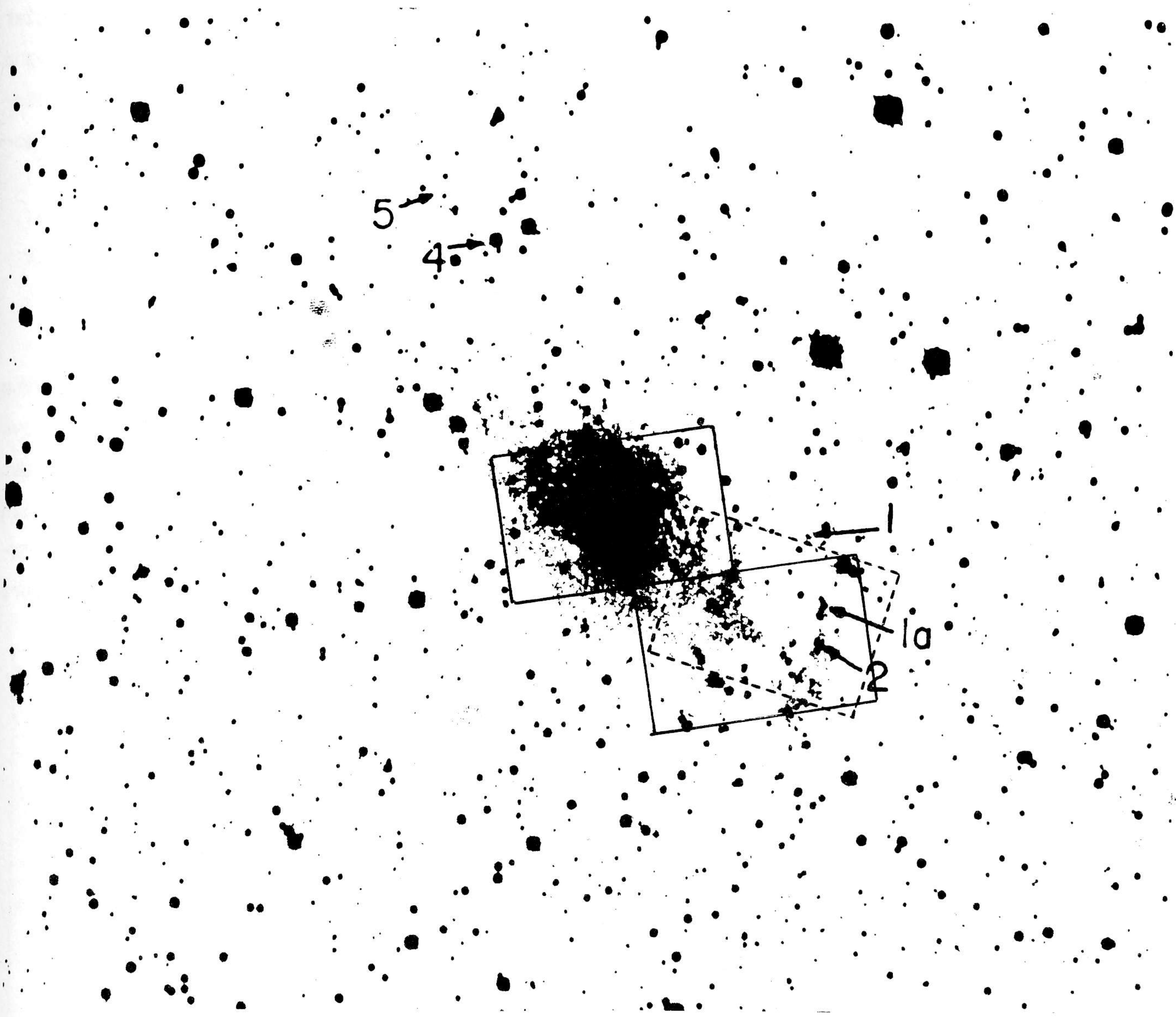

Fig. 1. *The reproduction of Maffei 2 photograph taken by Spinrad et al. (1973) on the 3 m Lick telescope with the image tube in H_α-filter. Two solid-line rectangles show the position of our CCD frames in the August 1992 observations. The dotted-line rectangle corresponds to the position of the deepest frame in the V and I passbands. The arrows indicate the HII region according to Spinrad et al. (1973).*

The last surge of interest in the pair Maffei 1+2 was initiated by the hypothesis of "Local Big Bang" (Zheng et al., 1991; Valtonen et al., 1993) according to which Maffei 1, the galaxy IC 342, close to Maffei 1 in the sky, and also M 31 were tight neighbours 4 billion years ago. Numerical experiments showed that this hypothesis is capable of explaining a number of features of the Local group of galaxies (orbits of the Magellanic Clouds and Leo I) which have been a problem in the traditional consi deration of the trajectories of the Milky Way and M 31 (Byrd et al., 1994). The ne scenario is based on the short (D≤3 Mpc) scale of distances of Maffei 1 and 2. How ever, Luppino and Tonry (1993) measured the surface brightness fluctuations fo Maffei 1 and evaluated its distance to be 4.2±0.5 Mpc. Being separated by an angula distance of only 40′ and having a small radial velocity difference, Maffei 1 an Maffei 2 seem undoubtedly a physical pair. That is why the specification of the dis tance of Maffei 2 is a task of vital importance for understanding of dynamical histo ry of the Local group of galaxies.

2. OBSERVATIONS

Fulfilling the program of numerous determination of distances to nearby galaxie from the photometry of their brightest stars, we also undertook an attempt to resolv the spiral galaxy Maffei 2 into stars. The observations were carried out on Augus 27, 1992 in the primary focus of the 6 m telescope using a CCD of 580×520 pixels wit the pixel size 18×24 μm or 0.20″×0.15″ and a field of view of 120″×80″. In the Kron Cousins' B,V,R,I system frames of the central part of the galaxy with an exposur of 180^s each and frames of the SW portion of the spiral arm with exposures of 2×900^s(B), 600^s(V), 300^s(R) and 300^s(I) were taken at a seeing of 1.1″ (FWHM). On October 15, 1993 we added these data by frames of nearly the same region of the spiral arm at a seeing of 0.85″. The exposure time was 4×900^s in the V passband and $900+100^s$ in the I band. The disposition of our frames is shown with rectangles in Fig.1, which reproduces the H_α-filter photograph of Maffei 2 taken by Spinrad et al. (1973) on the 3 m Lick telescope with an image tube. The CCD frames were reduced using the program PC VISTA improved by Georgiev (1994). The photometric calibration was performed by the standard stars of Landolt (1992).

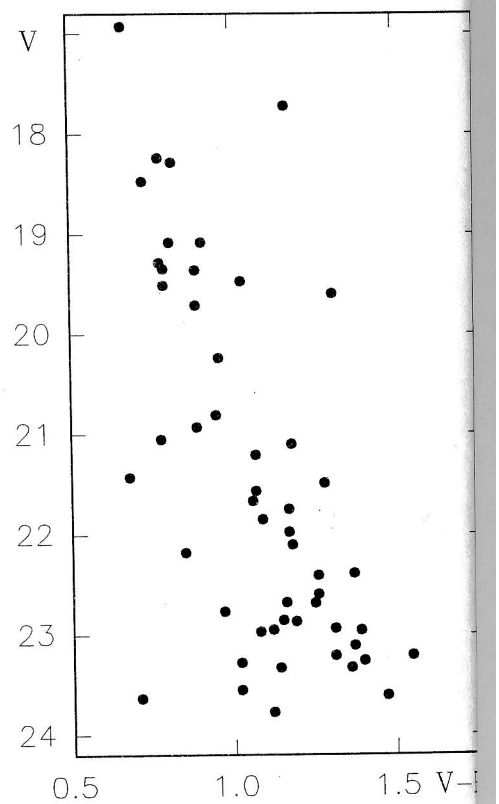

Fig.2. The colour-magnitud diagram in the V, R band for the area in the regio of the Maffei 2 spiral arm

3. DISCUSSION OF RESULTS

Let us present some final data without dwelling on the photometry details of the obtained CCD frames. Fig.2 reproduces one of the "colour-magnitude" diagrams constructed for the stars of the spiral arm region from the observations of 1992. Most of the stars on this diagram should be attributed to the Milky Way stars. On average the colour index tends to increase when switching from bright to faint stars, which is apparently due to the selective absorption of light by interstellar dust. Near the photometric limit at $V{\sim}23^m$ increased concentration of the number of stars is to be expected, possibly contributed by the supergiants of Maffei 2. A deeper diagram (Fig.3) constructed from the photometry results in the V and I bands presented in Table 1 confirms this assumption.

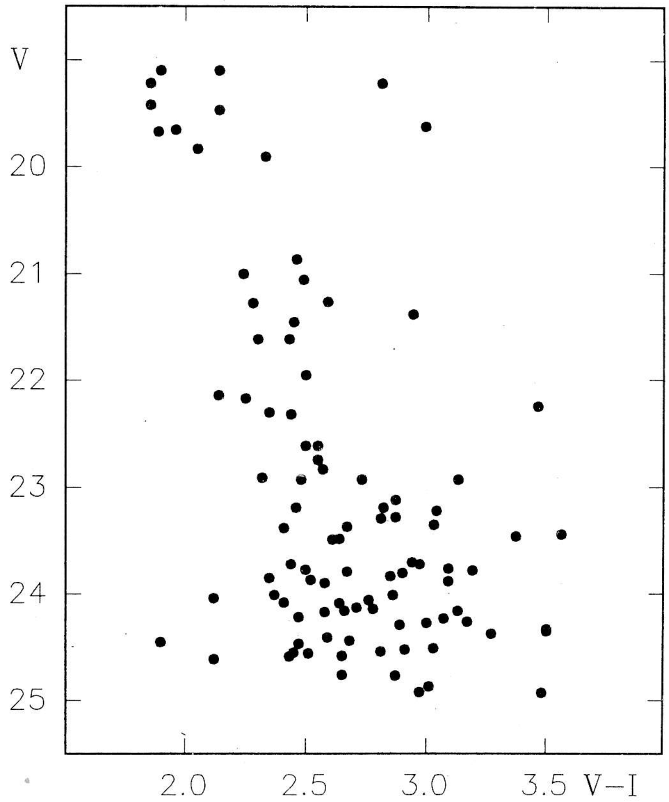

Fig.3. *The colour-magnitude diagram in the V and I bands for the region marked with the dotted-line rectangle in Fig.1.*

Table 1. Coordinates X,Y (pixels), apparent V magnitudes and colour indices V-I for 96 stars in the frame of Fig.4.

N	X	Y	V	V-I	N	X	Y	V	V-I
1	39	31	24.33	3.50	22	244	125	22.30	2.35
2	77	15	23.28	2.87	23	224	143	19.67	1.89
3	70	36	21.00	2.24	24	242	178	22.74	2.55
4	102	54	23.70	2.94	25	284	157	23.87	2.52
5	85	104	22.93	2.48	26	295	118	23.12	2.87
6	112	75	22.93	2.73	27	319	109	23.80	2.90
7	78	127	24.13	2.71	28	305	57	23.19	2.82
8	112	95	24.47	2.47	29	330	33	24.27	3.00
9	119	123	22.91	2.32	30	318	25	19.65	1.96
10	136	67	24.54	2.81	31	397	65	24.87	3.01
11	151	60	21.61	2.30	32	369	87	23.19	2.46
12	178	53	23.78	3.19	33	342	121	24.16	3.13
13	190	58	22.61	2.50	34	349	133	23.46	3.37
14	184	80	23.44	3.56	35	364	121	24.01	2.86
15	179	87	23.76	3.09	36	389	85	24.41	2.59
16	164	97	24.14	2.78	37	408	100	24.09	2.64
17	195	96	24.52	2.91	38	385	115	24.08	2.41
18	240	72	23.72	2.44	39	394	142	23.35	3.03
19	228	26	22.93	3.13	40	406	133	24.93	3.48
20	222	94	19.10	1.90	41	418	120	23.88	3.09
21	240	108	19.42	1.86	42	436	127	24.44	2.68

Table 1 (continued).

N	X	Y	V	V-I
43	476	93	24.56	2.51
44	453	65	19.47	2.14
45	437	46	19.10	2.14
46	489	26	24.22	2.47
47	518	42	24.04	2.12
48	540	54	24.45	1.90
49	525	97	23.83	2.85
50	548	86	24.37	3.27
51	523	163	22.61	2.55
52	518	184	22.83	2.57
53	558	218	24.58	2.65
54	544	266	24.01	2.37
55	522	317	24.35	3.50
56	504	357	22.17	2.25
57	470	351	22.25	3.46
58	423	336	23.48	2.64
59	407	302	21.38	2.94
60	385	386	23.29	2.81
61	387	327	24.55	2.45
62	369	324	24.59	2.43
63	371	270	24.17	2.58
64	408	196	21.61	2.43
65	381	157	23.77	2.50
66	339	164	21.95	2.50
67	356	228	23.37	2.67
68	345	295	24.51	3.03
69	322	273	21.27	2.28
70	315	242	23.38	2.41
71	296	289	24.61	2.12
72	310	304	24.92	2.97
73	308	324	24.77	2.87
74	287	338	23.49	2.61
75	265	371	19.22	2.81
76	272	311	21.05	2.49
77	232	261	19.22	1.86
78	218	373	24.29	2.89
79	208	339	24.06	2.76
80	188	352	23.85	2.35
81	194	370	22.14	2.14
82	153	308	22.32	2.44
83	183	267	24.26	3.17
84	174	222	19.62	2.99
85	198	200	23.22	3.04
86	123	196	21.45	2.45
87	92	258	23.79	2.67
88	123	295	23.90	2.58
89	119	366	23.72	2.97
90	97	356	19.83	2.05
91	58	375	24.23	3.07
92	48	340	24.16	2.66
93	76	313	21.26	2.59
94	36	299	19.90	2.33
95	33	340	20.86	2.46
96	29	100	24.76	2.65

Note: the objects No.7, 8, 16, 50, 62, 79 and 83 are not quite stellar-like.

The reproduction of I band frame in Fig.4 shows that the distribution of the faintest stars in the frame's field is not homogeneous. A lot of them are concentrated along the spiral arm. The diffuse objects marked by Spinrad on the H_α-photograph as HII regions seem readily resolved into separate stars immersed in a common nebula. The reasoning presented gives grounds to believe that we have succeded in resolving the galaxy into stars and can use the photometry of the brightest stars in Maffei 2 to define its distance.

3.1. The galactic reddening

We have evaluated the absorption in the direction of Maffei 2 in several independent manners. Having made photometry of the central part of Maffei 2, we obtained colour indices B-V=+2.83 and V-I=+3.64 in the diaphragm of 2.4″ in size. According to de Vaucouleurs & Longo (1988) the bulges of spiral galaxies of Sbc type have the mean colour indices $(B-V)_0=+0.85$ and $(V-I)_0=+1.21$, which yields the colour excess E(B-V)=+1.98 and E(V-I)=+2.43. We have made another estimate of reddening from photometry of HII regions picked out on the H_α-photograph. Since the main contributors to the luminosity of these complexes are young hot stars, we can adopt $(B-V)_0\simeq0$ and $(V-I)_0\simeq0$ as their typical colour indices. From our measurements four HII regions, marked in Fig.4, have $\langle B-V \rangle=+1.92$ and $\langle V-I \rangle=+2.57$. According to Dean et al. (1978) for early-type stars the relation $E(V-I)=1.25\ E(B-V)$ is valid. Taking it into account we derive the mean value of reddening $\langle E(B-V) \rangle=+1.97\pm0.03$. With the standard relation between the general and selective absorption $A_V/E(B-V)=3.2$ (Crawford & Mandwewala, 1976) the absorption value in the V band makes $A_V=6^m.30\pm0^m.10$. Note good agreement of this estimate with $A_V=6.3\pm0.2$ obtained by Spinrad et al. (1973) from a comparison of energy distribution $I(\lambda)$ in the nuclei of Maffei 2 and M 31.

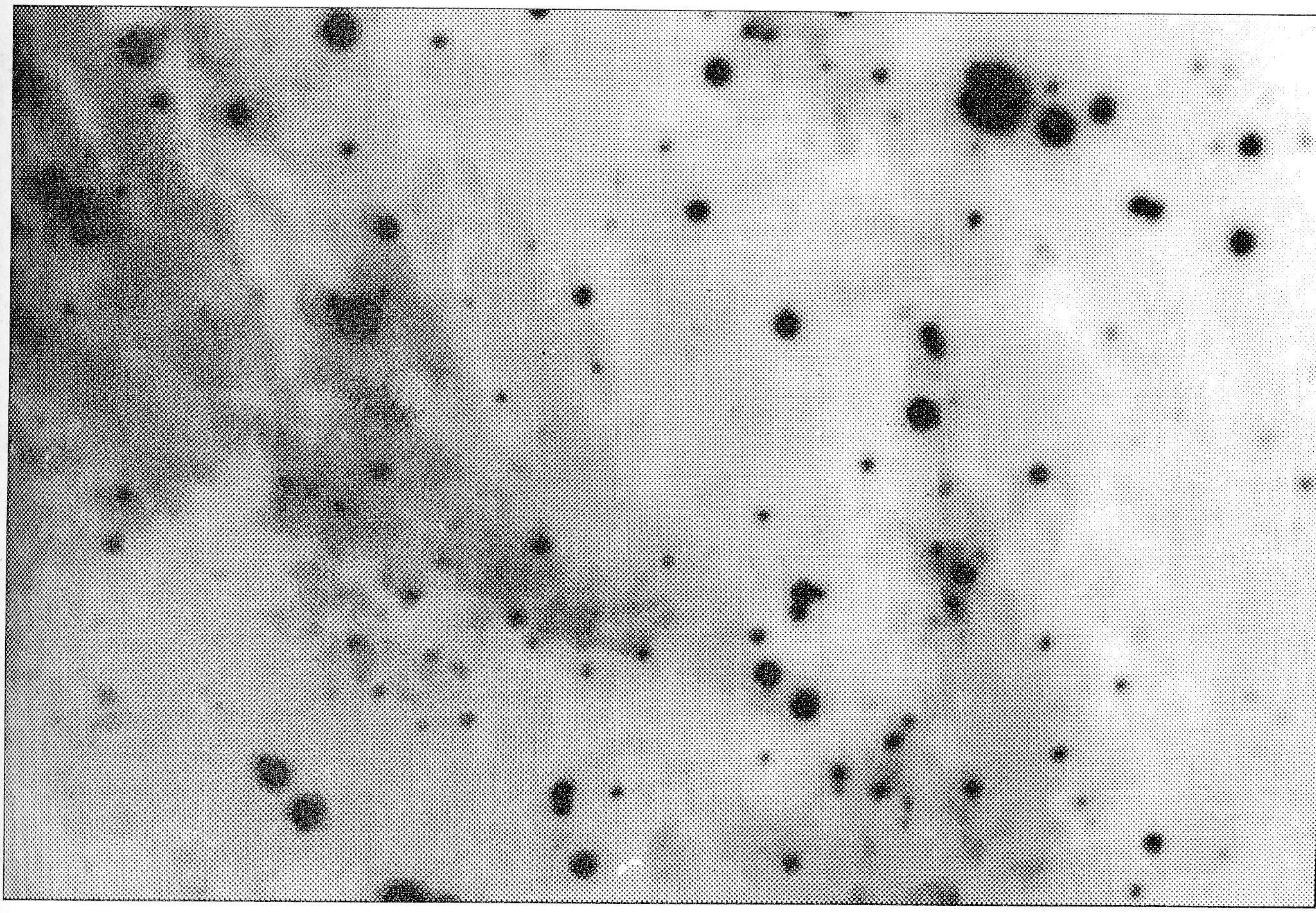

Fig.4 a) *The reproduction of a CCD frame in the I band, obtained with an exposure of 900^s at FWHM=0.85".*

3.2. Distance to Maffei 2

Not far from Maffei 2 at the galactic latitude $b=10^\circ.6$ another galaxy, IC 342, is located. A comparison of visibility of the brightest stars in the two galaxies allows rough evaluation of the distance to Maffei 2. As can be seen from Fig.3, the distribution of the number of stars according to apparent magnitude, N(V), shows a local rise at $V_* \simeq 23.8$ caused by the presence of brightest stars in Maffei 2. From the data of Karachentsev & Tikhonov (1993) a similar bend is observed in IC 342 at $V_* \simeq 19.0$. With the allowance for the smaller absorption value in the direction of IC 342, $A_V=1.95$, we obtain the difference between distance moduli in the two galaxies,

μ(Maffei 2)-μ(IC 342)=(23.8-6.3)-(19.0-1.95)$\leq$+$0\overset{m}{.}45$. Here the inequality sign accou for the fact that the distribution N(V) refers in IC 342 to nearly the whole appare area of the galaxy, while in Maffei 2 only to a spiral arm fragment. For a comp rable spiral arm fragment of IC 342 Madore & Freedman (1992) give the value V_*=19. which levels the difference of moduli in the two galaxies and yields μ_o(Maff 2)=$26\overset{m}{.}65$.

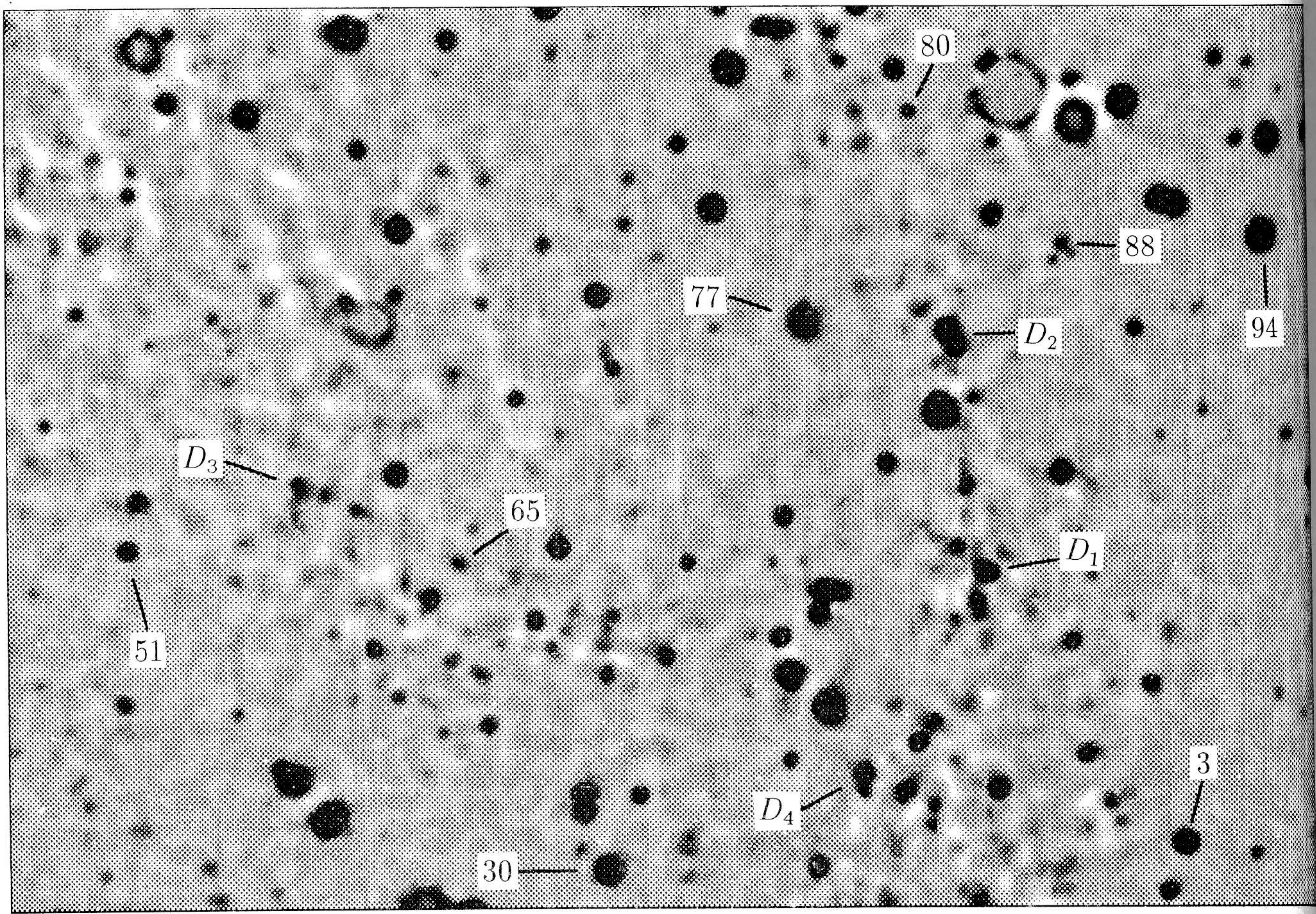

Fig.4 b) *The same frame after subtracting the image smoothed with a window of pixels. The letters D1...D4 mark the diffuse HII regions. The three brightest bl supergiant candidates are labelled with numbers 65, 80 and 88.*

Following the standard scheme, we have estimated the distance modulus of Maffei from the luminosity of three brightest blue stars. The three blue supergiant ca didates have been chosen on the basis of three conditions: $V \simeq V_*$, V-I<2.7, and loc tion on the spiral arm crest. These three stars are labelled in Fig.4 as 65, 80 a 88. Their mean apparent magnitude is <B(3)> = $25\overset{m}{.}82$ at the average colour ind <B-V>=<V-I>/1.25=1.98. According to Karachentsev (1993) the galaxy has the integr magnitude B_T=16.0. Since the luminosity of the three brightest stars and the lumin sity of their parent galaxy follow the empirical relation M(3B)=0.51(B_T-<B(3)>)-4. (Karachentsev & Tikhonov, 1994), then at M(3B)=-9.15 and A_B=8.2 we obtain the di tance modulus μ_0=$26\overset{m}{.}77$ or D=2.26 Mpc.

4. CONCLUSION

Apart from the search for the brightest blue supergiants, possibilities of employing other methods to evaluate the distance moduli for Maffei 2 look rather limited. So, at a particular distance and absorption the brightest red supergiants have typical apparent magnitudes: 29.0(B), 25.3(V), 22.8(R) and 20.3(I), and the brightest globular clusters have $V \simeq 24^m$. The hope of finding such objects is highest in the red spectral region.

With the apparent modulus $\mu^B=35.0$ the integral absolute magnitude of the galaxy is -19.0. To define the standard diameter of Maffei 2 is rather difficult since the light absorption diminishes its apparent diameter by about a factor of 5. According to the IRAS survey data (Assendorp, 1994), at $\lambda=100$ μm the angular diameter of Maffei 2 mounts up to 9′. The rotation curve of the galaxy extends to the distance $2R(HI) \simeq 16'$ in the 21 cm line (Hurt, 1994). Conforming to the typical structural parameters of Sbc galaxies, the standard linear diameter of Maffei 2 can be estimated as $A_{25} \simeq 13$ kpc. The amplitude of the rotation curve $V_m=170$ km/s measured by Hurt (1994) harmonizes with the luminosity and diameter of this normal (not giant) spiral. By the global parameters Maffei 2 most closely resembles the southern galaxy NGC 253 ($M_T=-18.8$, $A_{25}=13$ kpc, $W_{50}=410$ km/s) located at the same distance from us, D=2.2 Mpc.

Thus, the distance to Maffei 2 we have estimated, D=2.26 Mpc, coincides within the errors with the distance D=2.1±0.3 Mpc for the spiral IC 342 (Karachentsev & Tikhonov, 1993) and also its companion UGCA 86 (D=1.86 Mpc). Probably, all these galaxies together with Maffei 1 form a unified group located in the nearest neighbourhood of the Local system of galaxies.

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