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DISTANCE MODULI IN M 101 GROUP FROM BRIGHTEST STARS

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ABSTRACT. *Photometric distance moduli are defined from the brightest blue and red stars for seven companions of the galaxy M 101: NGC 5204, NGC 5238, Ho IV, NGC 5474, NGC 5477, NGC 5585, UGC 9405, and also for three foreground galaxies (NGC 4605, UGC 8508, UGC 9240). The obtained mean distance modulus of the group,* $29^{m}.09\pm0^{m}.15$, *corresponds to the Hubble parameter* $(54\pm6)\ km\cdot s^{-1}\cdot Mpc^{-1}$ *for the direction at an angle of* 23° *to the plane of the Local supercluster. The statistics of orbital parameters of the companions bears witness against the presence of large amount of dark matter around M 101 on the scale ~300 kpc.*

1. INTRODUCTION

The gigantic spiral galaxy M 101 alongside with M 81, NGC 2403 and NGC 5128 is one of the foundation-stones for almost all the methods used to define the Hubble constant value. Together with several neighbouring irregular galaxies it forms a group which is isolated from other systems. As distinct from the groups M 81, IC 342, Sculptor and NGC 5128, the group M 101 is outside the plane of the Local supercluster (SGB$\simeq23^{\circ}$). This diminishes the probability of including false members in it and makes the virial mass estimate for the group more reliable.

The opposition of adepts of the short and long scale of extragalactic distances, that lasted two decades, affected M 101 too. So, Sandage & Tammann (1974a) estimated the distance modulus to be μ_0=29.3±0.3 mag, and from de Vaucouleurs (1993) it is μ_0=28.6±0.1. It should be noted that in argument between the authors of the short and long scales rather old photometry data, possibly burdened with the systematic error, still appear. For half of the members of this group the large-scale photographs, and hence the data on the brightest stars, are lacking so far. To make up for the deficiency, we performed a CCD survey of the group M 101 in several passbands and found individual distance moduli for 11 galaxies from their brightest stars.

2. OBSERVATIONS AND DATA REDUCTION

The images of the galaxies in the region of the group M 101 were obtained with a CCD of 580×520 pixels installed in the prime focus of the 6 m telescope. The CCD pixel size is 18×24 μm and the readout noise is 20 electrons. In the maximum of the B,V,R,I bands of Kron-Cousins' system its quantum efficiency is 21, 42, 42 and 35%, respectively. During the first observing season (February-May, 1992) the CCD was used in combination with the focal reducer, which ensured a scale of 0.71″×0.53″/pixel and a field of view of 6.9′×5.1′. Since May 30, 1992 our observations have been carried out without the corrector with a field of view of 120″×80″ and a scale of 0.205″×0.154″/pixel. The information on the dates and exposures for each galaxy are tabulated in Table 1. The exposures here are given in seconds, the round and square brackets being used to mark the observations with the corrector and without it, respectively. For the photometric calibration the equatorial standards (Landolt, 1992) and the standards from the paper by Smith et al. (1991) were observed.

Table 1. Observational log

Galaxy	Date	Filter, Exposure time (sec)		
N 4605	5.05.92:	B(900),	V(600),	R(300)
N 5204	24.04.93:	B[1200],	V[600],	R[300]
U 8508	24.04.93:	B[1200],	V[600],	R[300]
N 5238	6.05.92:	B(900),	V(600),	R(300),
	30.05.92:	B[900],	V[900],	R[300]
Ho IV	11.02.92:	V(600),	R(300)	
	24.04.93:	B[1200],	V[600],	R[300]
M 101e	6.05.92:	B(900),	V(600),	R(300)
N 5474	5.05.92:	B(900),	R(300)	I(300)
N 5477	24.04.93:	B[1200],	V[600],	R[300]
N 5585	6.05.92:	B(900),	V(600),	R(300)
U 9240	25.04.93:	B[1200],	V[600],	R[300]
U 9405	30.05.92:	B[1000],	V[600],	R[300]

The reduction of images: dark frame subtraction, flat-fielding, cosmetic procedures, and stellar photometry were performed using the software package created on the basis of the library of programs PC VISTA (Treffers and Richmond, 1989) and also the programs of median smoothing (Georgiev, 1990). Stars were selected and the aperture photometry was made after the image background correction, i.e. subtracting the image smoothed by the median filter with a window of 7×FWHM.

3. PHOTOMETRY RESULTS

Apart from the obvious members of the group M 101 we have included in the observing program a few galaxies whose association with M 101 seems unlikely. The distribution of these galaxies in the equatorial coordinates is shown in Fig. 1. The underlined numbers here indicate the radial velocity of a galaxy in km/s, corrected for the Milky Way rotation. The straight lines connect M 101 with the galaxies that satisfy the group membership according to the criterion (Karachentsev, 1993). Let us consider observational data for each galaxy taken separately.

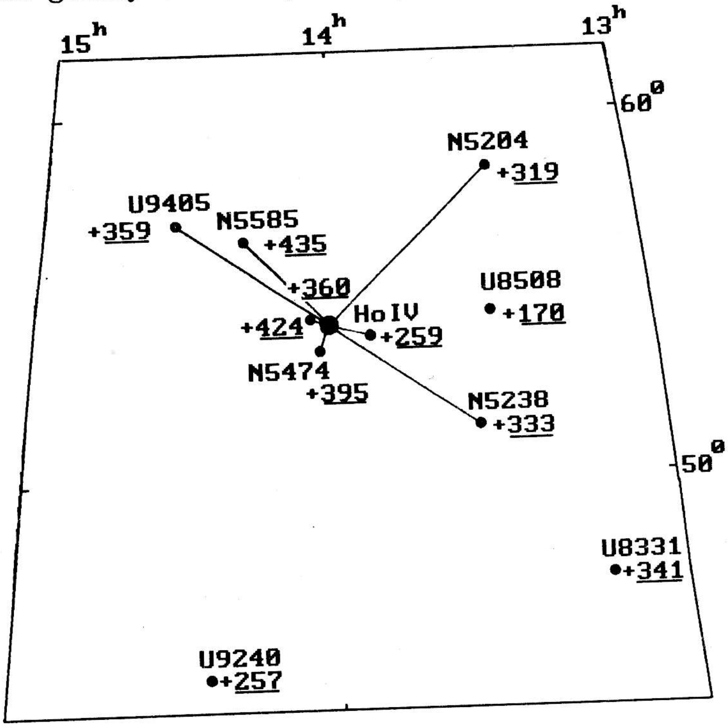


Fig. 1. *A region of the group M 101 in equatorial coordinates. The companions which satisfy conditions (3), (4) are connected to it with lines. The underlined numbers correspond to the radial velocity of the galaxy in km/s.*

3.1. NGC 4605

This bright irregular galaxy has the apparent integral magnitude B_T=10.90 and the angular diameter a=5.7′ (Paturel et al., 1992). In spite of its brightness we have failed to find in the literature indications that NGC 4605 is resolved into stars. Judging by the location (13° to NW of M 101) and radial velocity (+254 km/s) this galaxy looks like a border object between the groups M 101 and M 81. Fig. 2 reproduces the image of NGC 4605 in the R band. The outer isophotes of the galaxy are characterized by considerable asymmetry, and the central part is covered with dust lanes, which strongly hinders stellar photometry there. Using the B, V, R measurements of the brightest stars in the outer parts of the galaxy, we picked out the three reddest and one bluest stars. The results of our photometry are listed in Table 2.

Table 2. The brightest stars in NGC 4605

Star	B	V	R
R1	22.50	20.71	19.41
R2	22.80	20.78	19.35
R3	22.68	21.00	19.91
B3	20.15	19.79	19.71

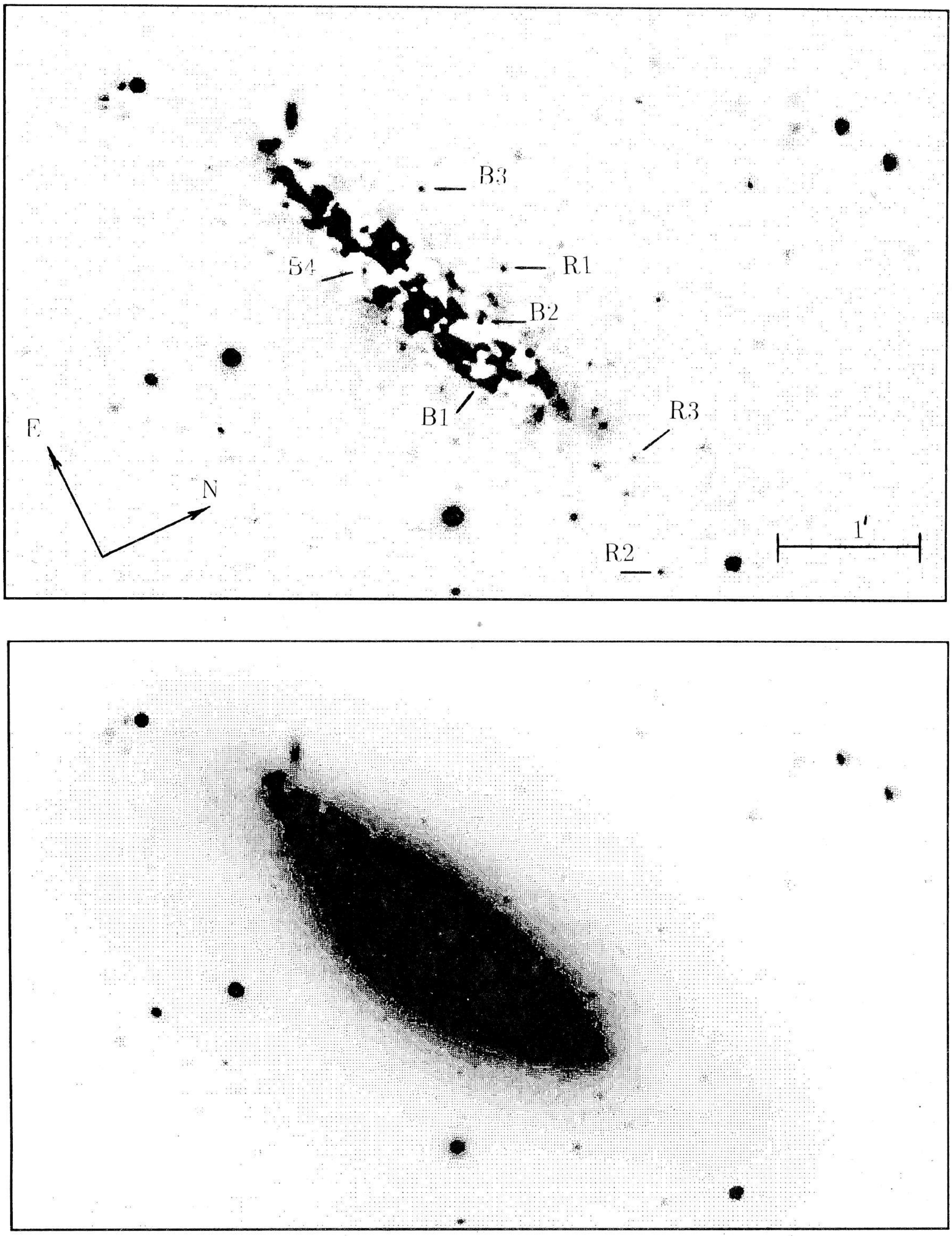


Fig.2. *A red CCD image of the galaxy NGC 4605 with (above) and without background subtraction. The brightest red and blue supergiant candidates are marked with R and B. The scale and orientation of the frame are indicated in the lower corners.*

We have taken the star R1 with the colour indices B-V=1.79 and V-R=1.30 as a candidate to the brightest red supergiants. At the absolute magnitude $M_V(R1)=-7.8$ (de Vaucouleurs, 1978: Sandage & Tammann, 1974b) and at negligibly small light absorption in this portion of the sky (Burstein & Heiles, 1984) the "red" modulus of NGC 4605 is $\mu_0^R=28.51$. Evaluating the photometric modulus from three brightest blue stars, we employed the relation

$$\langle M_B(3B)\rangle = -0.51\delta m(3B) - 4.14, \qquad (1)$$

which reflects the empirical correlation between the luminosity of the brightest blue stars and the integral luminosity of the parent galaxy. Here the argument $\delta m(3B) = \langle B(3B)\rangle - B_T$ does not depend on the galaxy distance, and the numerical parameters are calibrated by objects with the measured Cepheid moduli. This relation is valid for both normal and dwarf galaxies and has a standard deviation of $0^m.45$ (Karachentsev & Tikhonov, 1994). Having available an additional photographic plate with a high angular resolution, we have found a few more blue stars (marked in Fig.2) in the central region of NGC 4605. Three brightest blue stars have $\langle B(3B)\rangle = 19.78$, which gives us the "blue" modulus $\mu_0^B = 28^m.45$ that is in good agreement with the red one.

3.2. NGC 5204

In the Atlas of Sandage & Bedke (1988) this galaxy is well resolved into stars. According to PGC (Paturel et al., 1992) it has the integral magnitude $B_T = 11.69$ and the standard angular diameter $a_{25} = 5.0'$. Fig. 3 displays a frame of the central part of NGC 5204 taken in the R band without the focal reducer at FWHM=1.0″. The galaxy shows irregular structure outlined with complexes of bluish and diffuse condensations. The measured apparent magnitudes of the five brightest blue stars and the brightest red star are presented in Table 3. From these data using the red star we obtain the modulus $\mu_0^R = 28.56$, from three brightest blue stars with $\langle B(3)\rangle = 19.92$, $\langle B-V\rangle = 0.22$ and $\langle V-R\rangle = 0.13$ we have $\mu_0^B = 28.26$.

Table 3. The brightest stars in NGC 5204

Star	B	V	R
B1	19.64	19.50	19.44
B2	20.00	19.73	19.63
B3	20.12	19.85	19.73
B4	20.39	20.18	20.05
B5	20.70	20.46	20.32
R1	22.60:	20.76	19.98

3.3. UGC 8508 = IZw60

As in the case of NGC 4605, this galaxy had not been previously resolved into stars. Zwicky (1971) included it in the list of compact blue objects. According to PGC, U 8508 has $B_T = 14.14$ and $a_{25} = 1.7'$. Judging by the corrected radial velocity $V_0 = +171$ km/s, this dwarf galaxy is located in the foreground of the group M 101.

Fig.4 shows the U 8508 image we obtained in the V band at FWHM=0.9″. The whole body of the galaxy excellently resolves into stars. The photometry of the bluest and reddest stars is presented in Table 4. The star A of neutral colour

Table 4. The brightest stars in UGC 8508

Star	B	V	R
A	19.81	18.88	18.35
B1	20.53	20.68	20.70
B2	20.56	20.77	20.82
B3	20.66	20.78	20.81
B4	20.70	20.93	20.98
B5	20.94	21.03	21.00
B6	21.09	21.26	21.27
B7	21.32	21.34	21.32
R1	22.55	20.23	19.14
R2	22.73	20.95	20.08
R3	24.98	22.48	21.30

situated outside the galaxy has been added to them as a secondary photometric stan-dard.

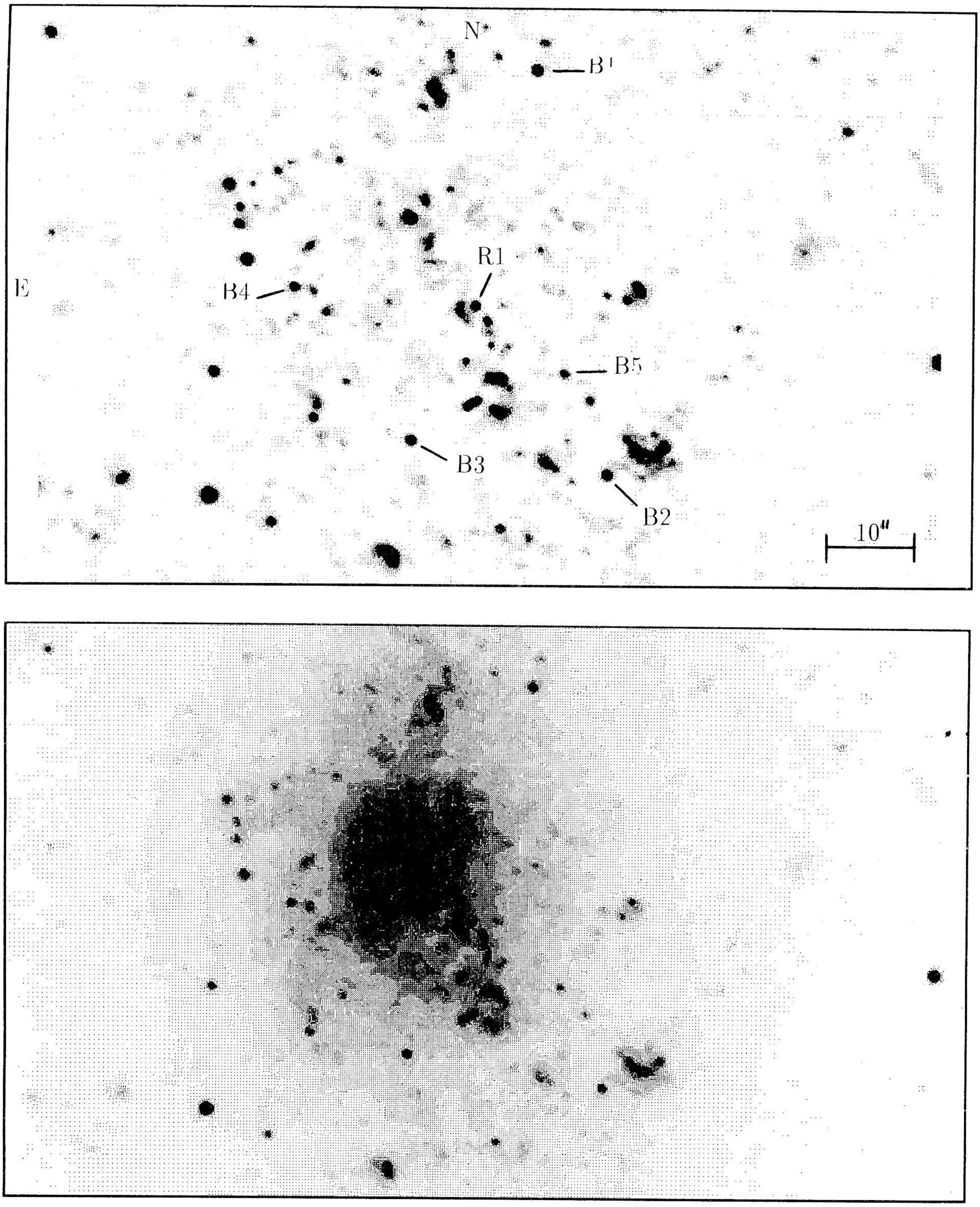


Fig.3. *The image of the galaxy NGC 5204 in the R band. Designations are the same as in Fig.2.*

Taking the star R1 with B-V=2.32 and V-R=1.09 as the brightest red supergiant, we obtain the distance modulus μ_0^R=28.03. For three brightest blue stars we have <B(3)>= -20.58, <B-V>=-0.16 and <V-R>=-0.03. With the difference in apparent magnitudes $\delta m(3B)=6\overset{m}{.}14$ the expected luminosity of blue supergiants corresponds to

$\langle M_B(3B) \rangle = -7.27$, which gives the blue modulus $\mu_0^B = 27.85$ that is in good agreement with the red modulus.

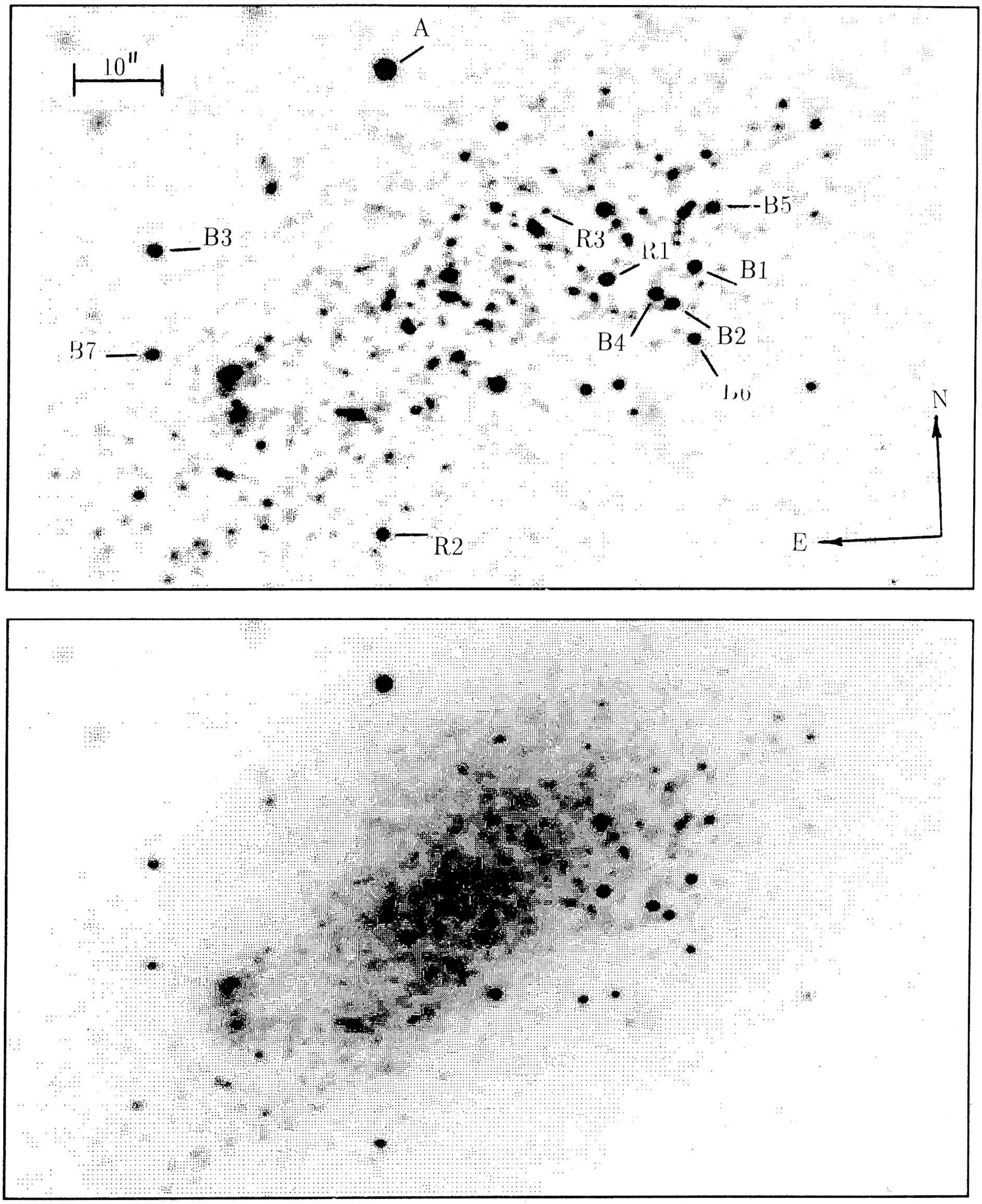
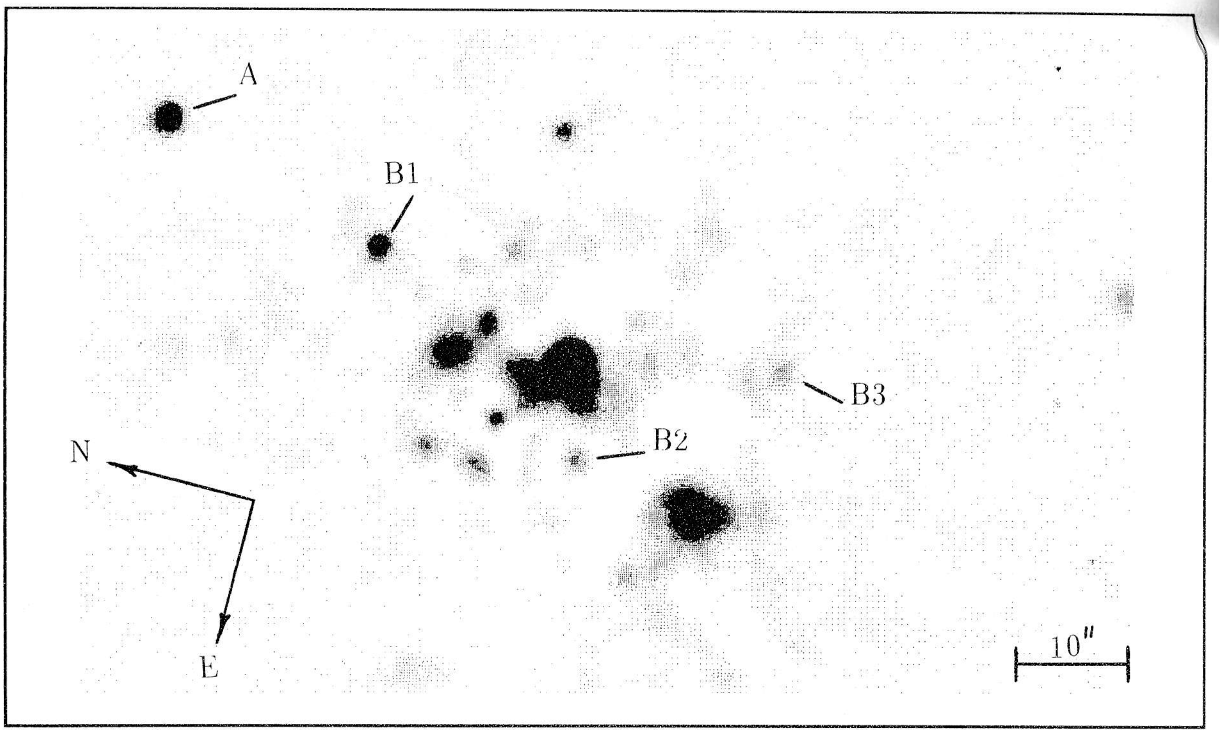


Fig.4. *A reproduction of the galaxy UGC 8508 in the V band.*

3.4. NGC 5238 = IZw64 = VV 828 = K 384

Vorontsov-Veliaminov (1977) and Karachentsev (1987) classified this galaxy as an interacting binary system. On a large-scale photograph (Karachentsev, 1987) this galaxy resolves into stars. PGC gives the integral apparent magnitude $B_T = 13.90$ and the standard diameter a_{25}=1.7′.



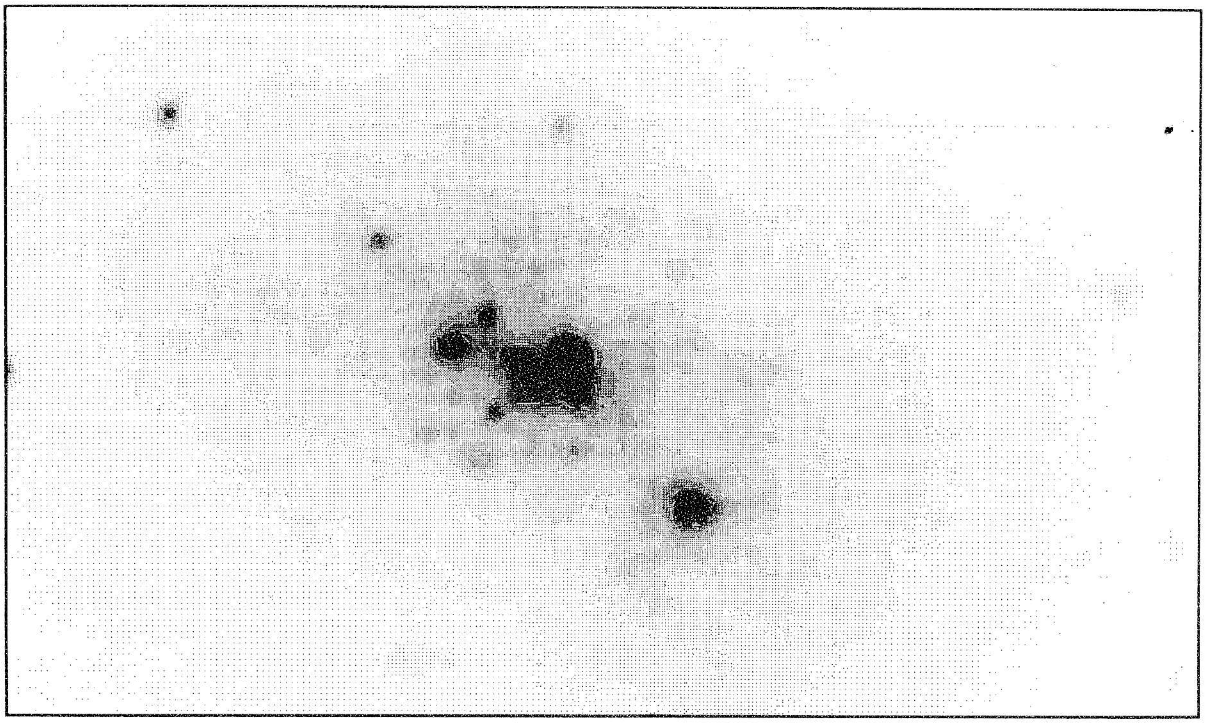


Fig.5. *The galaxy NGC 5238 in the V band.*

We observed NGC 5238 in two modes: with the focal reducer and without it, in both cases at a seeing of 2.0″-2.3″. The reproduction of the galaxy in the V band is shown in Fig.5. Two brightest condensations, judging by their emission spectra, are HII regions with the radial velocity difference 60±28 km/s. Besides these objects two dozen of stars of neutral and blue colour can be seen in the picture. Due to the absence of red stars we have estimated the galaxy distance only from three blue stars. The measured apparent magnitudes of these stars and that of the foreground star A are listed in Table 5. At $\langle B(3)\rangle = 20.83$ and $\delta m(3B) = 6.93$ the distance modulus of NGC 5238 is $28^{m}.50$.

Table 5. Blue stars in NGC 5238

Star	B	V	R
B1	20.24	20.44	20.45
B2	20.81	21.16	21.17
B3	21.45	21.35	21.27
A	20.46	19.83	19.44

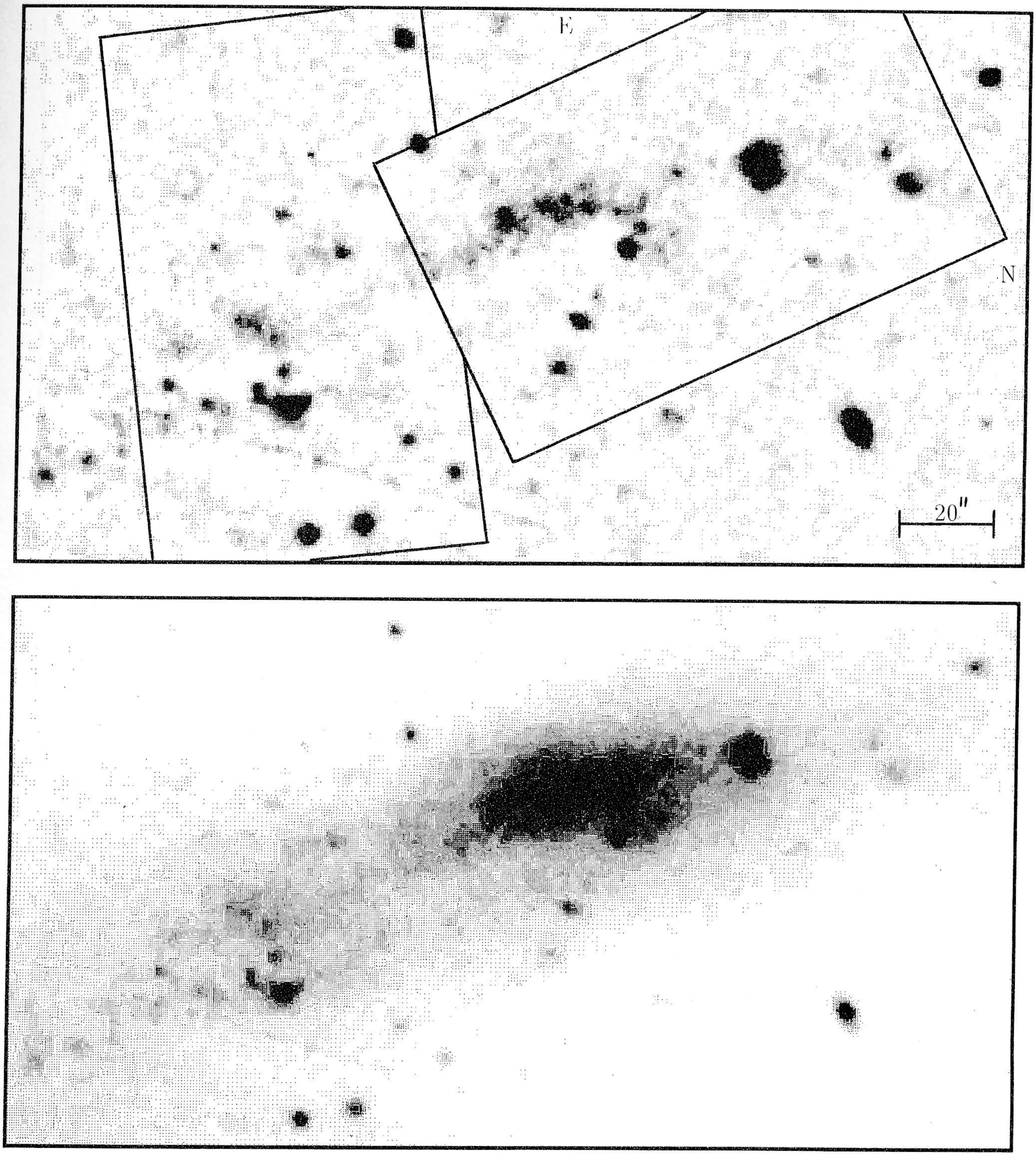
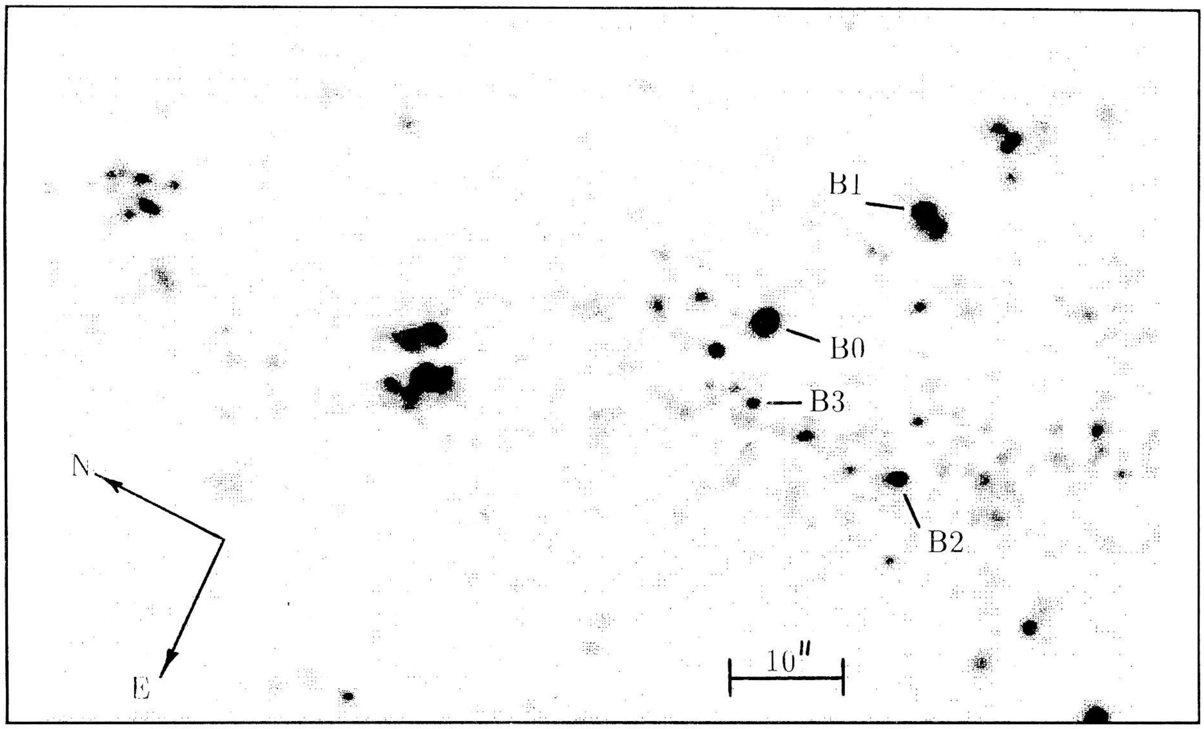
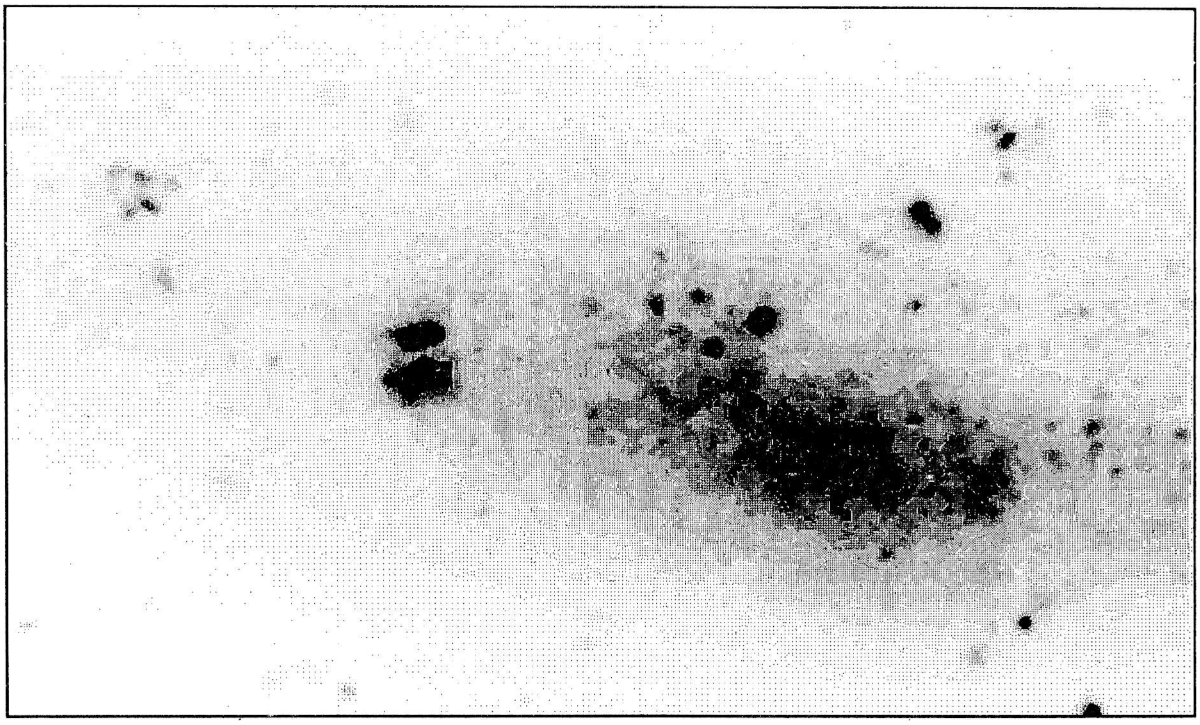


Fig.6 a) *The R image of the galaxy Ho IV obtained with the reducer. Rectangles show the position of two frames without the reducer.*



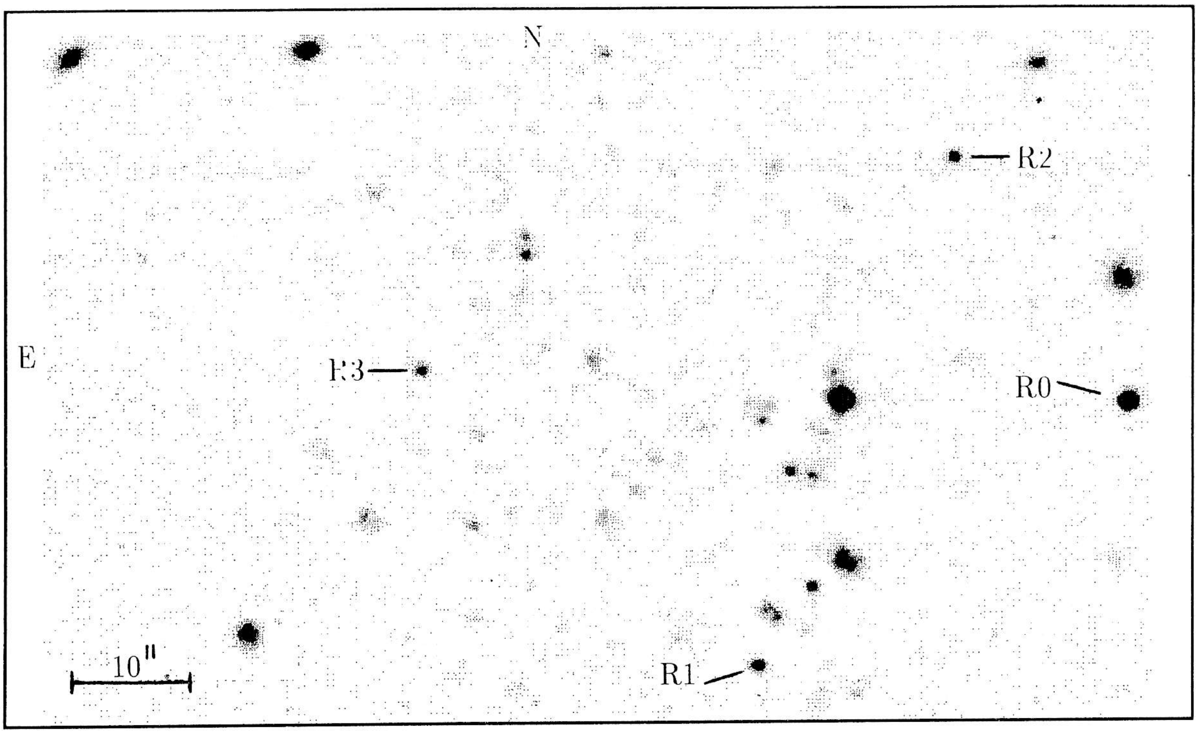


ig.6 b) *The fragment of the northern region of Ho IV in the V band.*

3.5. Ho IV = DDO 185 = UGC 8837

This bluish asymmetric galaxy was noted by Holmberg (1964) as a probable companio M 101. According to PGC its integral apparent magnitude is $13^{m}.79$, and the standar gular diameter a_{25}=4.2′. We have not found large-scale photographs of this galax the literature.

Fig.6a represents the general view of Ho IV from a CCD frame taken in the R ban with the focal reducer. The reproduction confirms the extreme asymmetry of this dwarf system caused by the presence of several stellar complexes.



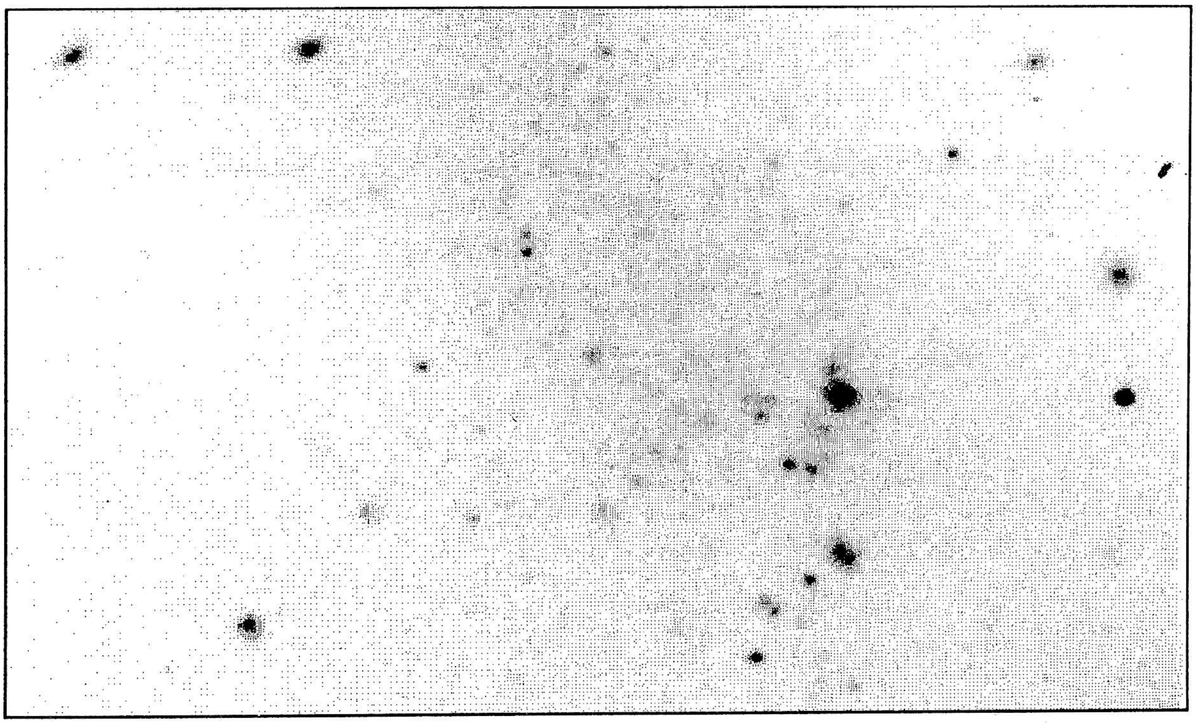


Fig.6 c) *The fragment of the southern region of IV in the R band.*

The two rectangles show the position of the CCD frames taken without the corrector at a seeing of 1.1″. On these shots (Fig.6 b,c) the galaxy is confidently resolved into stars. The photometry results of the brightest blue and red stars are presented in Table 6. From the red stars with V-R>1.0 we excluded R0 as a likely foreground star. Using R1 for evaluating the red modulus, we obtain μ_0^R=29.59. Among the blue stars the brightest, B0, is almost two magnitudes brighter than the rest of the stars. Although its image looks quite stellar (FWHM=1.0"), we suspect that this is not a single star. Except B0 for the following brightest blue stars we obtain <B(3B)>=21.52, <B-V>=+0.09, <V-R>= -0.01, which yields the distance modulus μ_0^B=29.60. At this modulus the stellar-like object B0 has a luminosity comparable with the luminosity of a blue association.

Table 6. The brightest blue and red stars in Ho IV

Star	B	V	R
B0	19.22	19.24	19.28
B1	21.16	20.85	21.01
B2	21.23	21.27	21.29
B3	22.17	22.15	21.99
R0	-	20.18	19.14
R1	-	21.79	20.65
R2	-	21.88	20.59
R3	-	21.91	20.81

3.6. M 101

In comparison with the angular size of this galaxy, a_{25}=28.6', the field of view of our CCD camera is too small to survey the brightest stars. Therefore we restricted ourselves to the observations of only one area on the eastern side of M 101, which contains a sequence of photoelectric standards of Sandage & Tammann (1974a). In the selection of the brightest blue and red stars we relied on the data of the survey made by Sandage (1983).

A reproduction of the CCD frame of the eastern part of M 101 in the V band is presented in Fig.7. The bright condensation in it corresponds to the fragment of the spiral arm, NGC 5462. The stars with the photoelectric measurements of Sandage & Tammann (1974a) are marked with letters. The results of the CCD photometry are tabulated in Table 7. Comparing our measurements with the data of Sandage & Tammann, we reveal a systematic difference: <B(ST)-B(CCD)>=-0.17±0.04 and <V(ST)-V(CCD)> = -0.33±0.02.

Table 7. The photometric sequence in M 101

ST'Star	B	V	R
F	16.36	15.99	15.66
H	17.41	16.49	15.90
K	18.32	17.00	15.72
J	18.14	18.27	18.28
L	19.05	18.27	17.62
M	19.65	18.58	17.83
O	19.97	19.46	19.29

Amongst the 7 candidates to red supergiants picked out by Sandage (1983), using the condition B-V>1.9, some stars turned out foreground judging from their spectral properties and JHK-photometry (Humphreys et al., 1986). From the rest of them, R1 is not a quite red object according to our data (V=20.62, B-V=1.11, V-R=0.68). Adopting as the brightest red supergiant the star R7 with V=20.58, B-V=2.7 and introducing the correction ΔV=+0.33 we derive the distance modulus μ_0^R=28.71. Spectral observations by Humphreys & Aaronson (1987) led to removal of a few multiple and foreground stars with negative radial velocities from Sandage's list of brightest blue stars. Amongst the rest of the candidates to blue supergiants Sandage's stars B2, B7 and B8 turn out the brightest. With the allowance of our correction to the zero-point of Sandage and Tammann (1974a) we take for these stars <B(3B)>=19.38 and <B-V>=-0.11. Then at the integral apparent magnitude of M 101 B_T=8.24 and <M_B(3B)>=-9.82 we obtain the distance modulus μ_0^B=29.20. This value is in good agreement with the modulus estimate for M 101 (Sandage & Tammann, 1974a) from the dimensions of HII regions, 29.26±0.13 and fits the distance from two Cepheids (Cook et al., 1986).

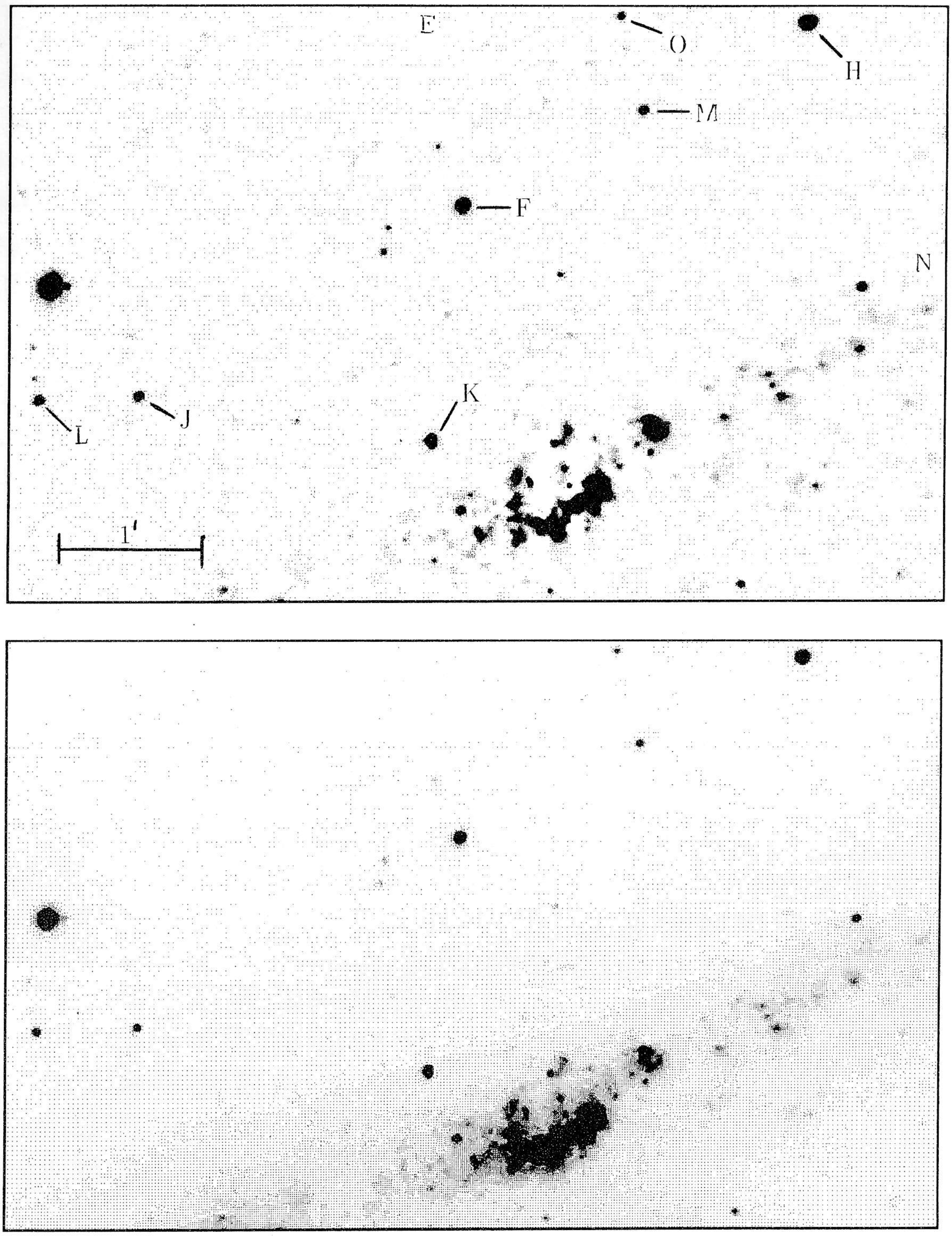


Fig.7. *A fragment of the eastern spiral arm of M 101 in the region of NGC 5462. The photoelectric standards ST(1974) are marked with letters.*

3.7. NGC 5474=VV 344=Arp 26

This galaxy with the apparent magnitude B_T=11.34 and angular diameter a_{25}=4.8′ has a very asymmetric spiral pattern, which, evidently, points to the tidal perturbati it undergoes from M 101. The CCD frames of NGC 5474 were obtained in the B, R, bands at a seeing of 2.5″. The R frame is reproduced in Fig.8.

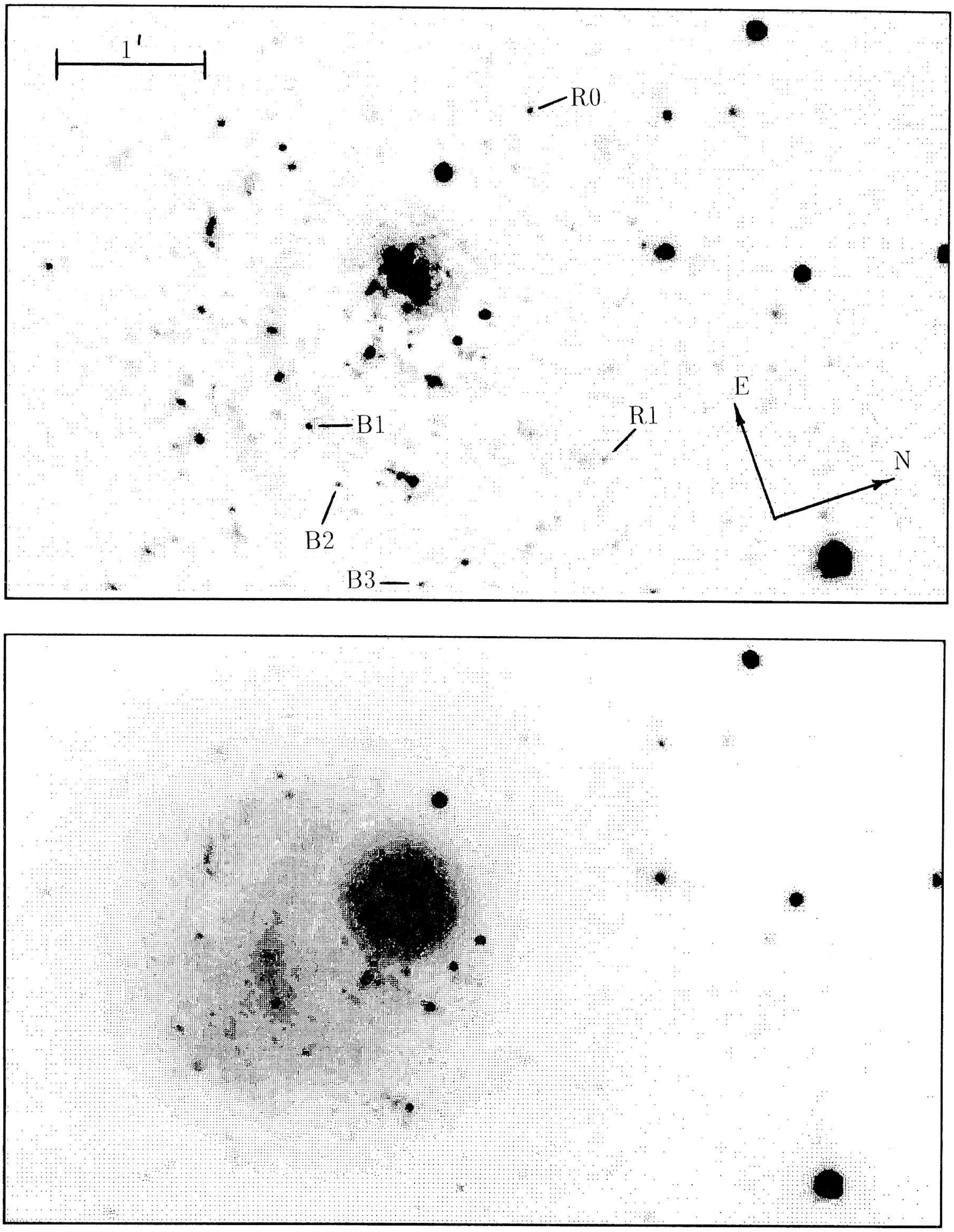


Fig.8. *A red CCD frame of NGC 5474.*

Table 8 contains our photometry data for several brightest blue and red stars. Sinc the V frame of the galaxy had been lost we estimated V magnitudes of stars from thei B and R magnitudes using the empirical relation V-R=0.35(B-R)+0.01 deduced from th standard stars by Landolt (1992) in the range -0.3<B-V<1.0. We believe the star R with V=21.46 and B-R=3.22 to be a suitable candidate to M-supergiants out of two red stars (R0 and R1). In this case the distance modulus of NGC 5474 corresponds to $29^{m}_{.}26$. For three brightest blue stars we obtain <B(3B)>=20.36, which is somewhat brighter than the previous photographic estimate of Hubble ($20^{m}_{.}6$) presented by Sandage & Tammann (1974a). At δm(3B)=9.02 this yields the modulus μ_0^B=29.10. Note the small difference between the obtained distances for NGC 5474 and M 101, which was to be expected in view of apparent signs of interaction.

Table 8. Photometry of stars in NGC 5474

Star	B	(V)	R	I
B1	19.98	19.67	19.49	19.24
B2	20.44	20.48	20.49	20.54
B3	20.66	20.31	20.11	20.02
R0	22.15	20.44	19.52	18.78
R1	23.54:	21.46	20.33	19.67

3.8. NGC 5477=DDO 186=VV 561

Being the nearest companion of M 101, this dwarf blue galaxy with B_T=14.30 and a_{25}=1.7′ resembles a knot of a spiral arm or a superassociation. On the photograph in the Atlas of Sandage & Bedke (1988) it is quite resolvable into stars. We observed NGC 5477 at a seeing a little better than 1″. A reproduction of the V frame is displayed in Fig.9. Results of search for and photometry of the brightest blue and red stars are presented in Table 9. On the basis of these data we define the distance moduli μ_0^R=29.60 from R 1 and μ_0^B=29.33 from three brightest blue stars.

Table 9. The brightest blue and red stars in NGC 5477

Star	B	V	R
B1	21.43	21.24	21.10
B2	21.46	21.59	21.70
B3	21.63	21.60	21.52
B4	21.63	21.58	21.38
R1	23.61	21.80	20.77
R2	24.40	22.47	21.19
R3	24.54	22.56	21.67

3.9. NGC 5585

According to PGC the galaxy has the integral magnitude B_T=11.32 and the angular diameter a_{25}=5.7′, being the second member of the group as to its size and luminosity. Its spiral structure is confidently resolved into stars (Sandage & Bedke, 1988), however, the photometry of the brightest stars is so far presented by the estimate <B(3B)>=20.9 from the old Hubble collection of plates (Sandage & Tammann, 1974a). This estimate is essentially different from our data. On the red CCD frame of NGC 5585 (Fig.10) that we have taken at a seeing of 2.0″ several candidates to the brightest supergiants can be seen. Their apparent magnitudes are presented in Table 10. From the star R 1 we estimated the modulus of the galaxy μ_0^R=28.78. Excluding B0 as not quite a stellar-

Table 10. Brightest stars in NGC 5585

Star	B	V	R
B0	19.26	19.10	19.02
B1	19.76	19.62	19.78
B2	20.11	19.94	19.83
B3	20.19	20.03	19.74
R1	23.13	20.98	19.56

like object, for the other three brightest stars we have <B(3B)>=20.02, <B-V>=+0.16 and <V-R>=+0.07. At $\delta m(3B)=8.70$ the blue distance modulus is $\mu_0^B=28.60$ in accordance with the previous estimate.

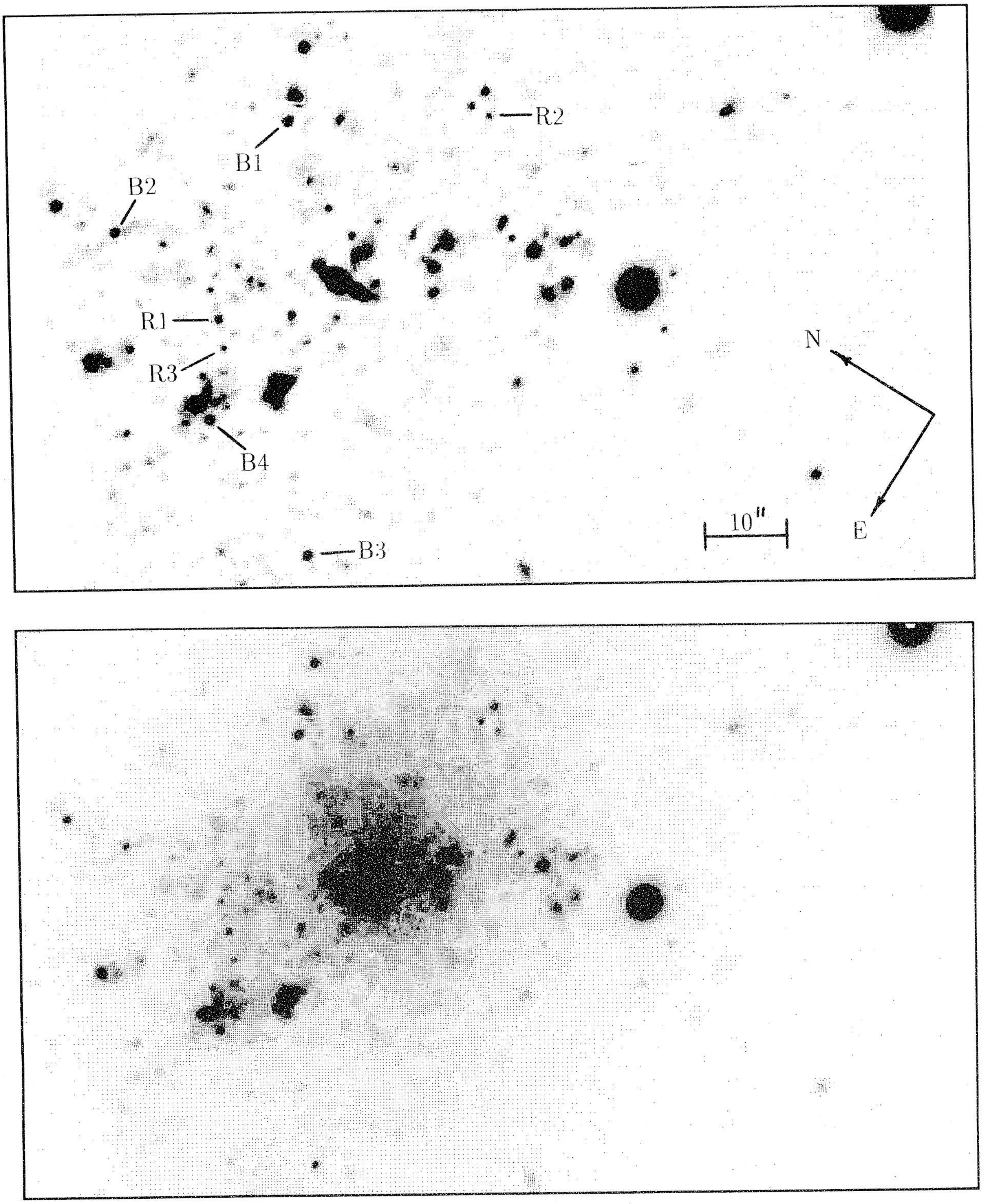


Fig.9. *The galaxy NGC 5477 in the V band.*

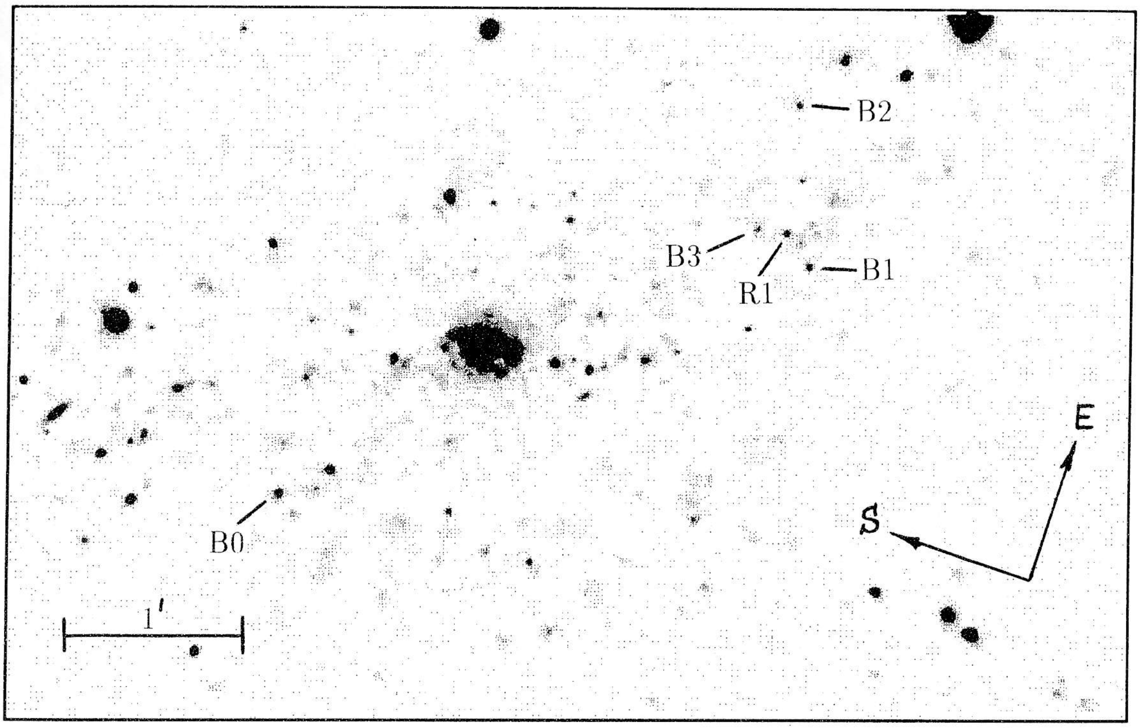
3.10. UGC 9240=DDO 190=IZw87

We observed this galaxy with $B_T=13.35$ and $a_2=1.8'$ at a seeing of 1.0" (FWHM). It was easily resolved into stars. Its reproduction in the V band is shown in Fig.11.

Table 11 contains the results of search for and photometry of the brightest blue and red stars. Taking the star R 1 as the distance indicator, we obtain μ_0^R=28.22. For the three brightest blue stars we have <B(3B)>=20.60, <B-V>=+0.12 and <V-R>=-0.14. Such a brightness of blue supergiants at δm(3B)=7.25 corresponds to the distance modulus μ_0^B=28.44, which is in good agreement with the red estimate.

Table 11. Candidates to supergiants in UGC 9240

Star	B	V	R
B1	20.49	20.34	20.50
B2	20.56:	20.48:	20.60:
B3	20.74	20.61	20.76
B4	20.81	20.66	20.81
B5	20.94	20.98	21.15
B6	21.61	21.53	21.55
R1	22.85	20.42	19.53



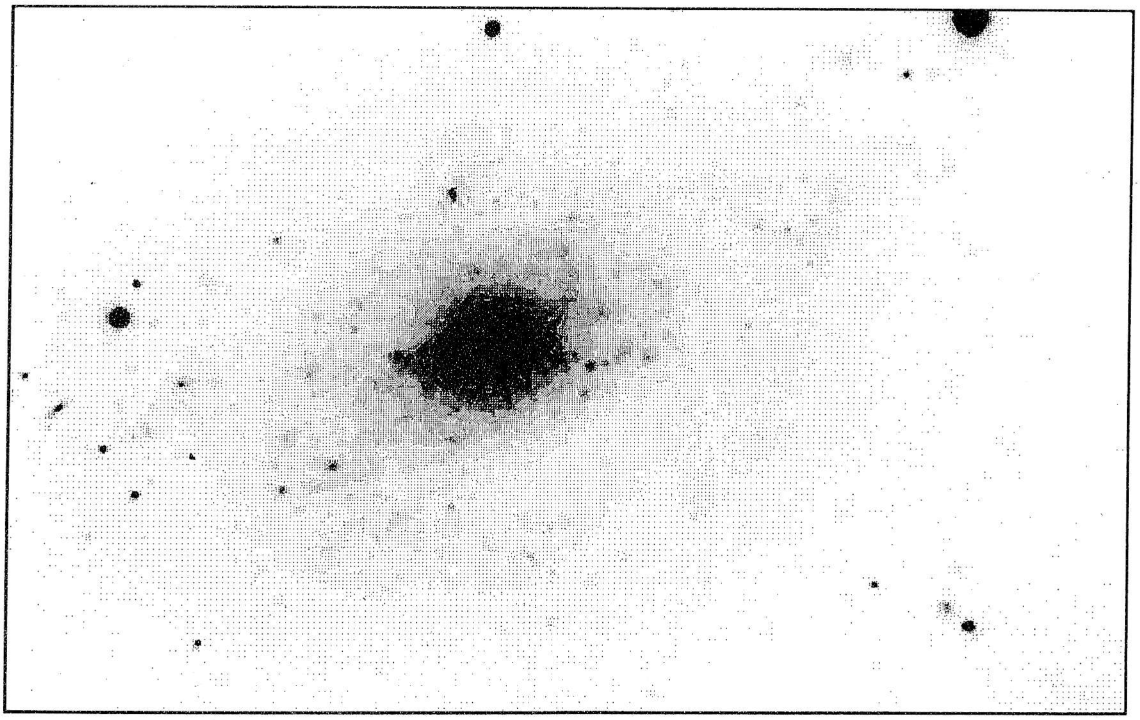


Fig.10. *The red CCD frames of the galaxy NGC 5585.*

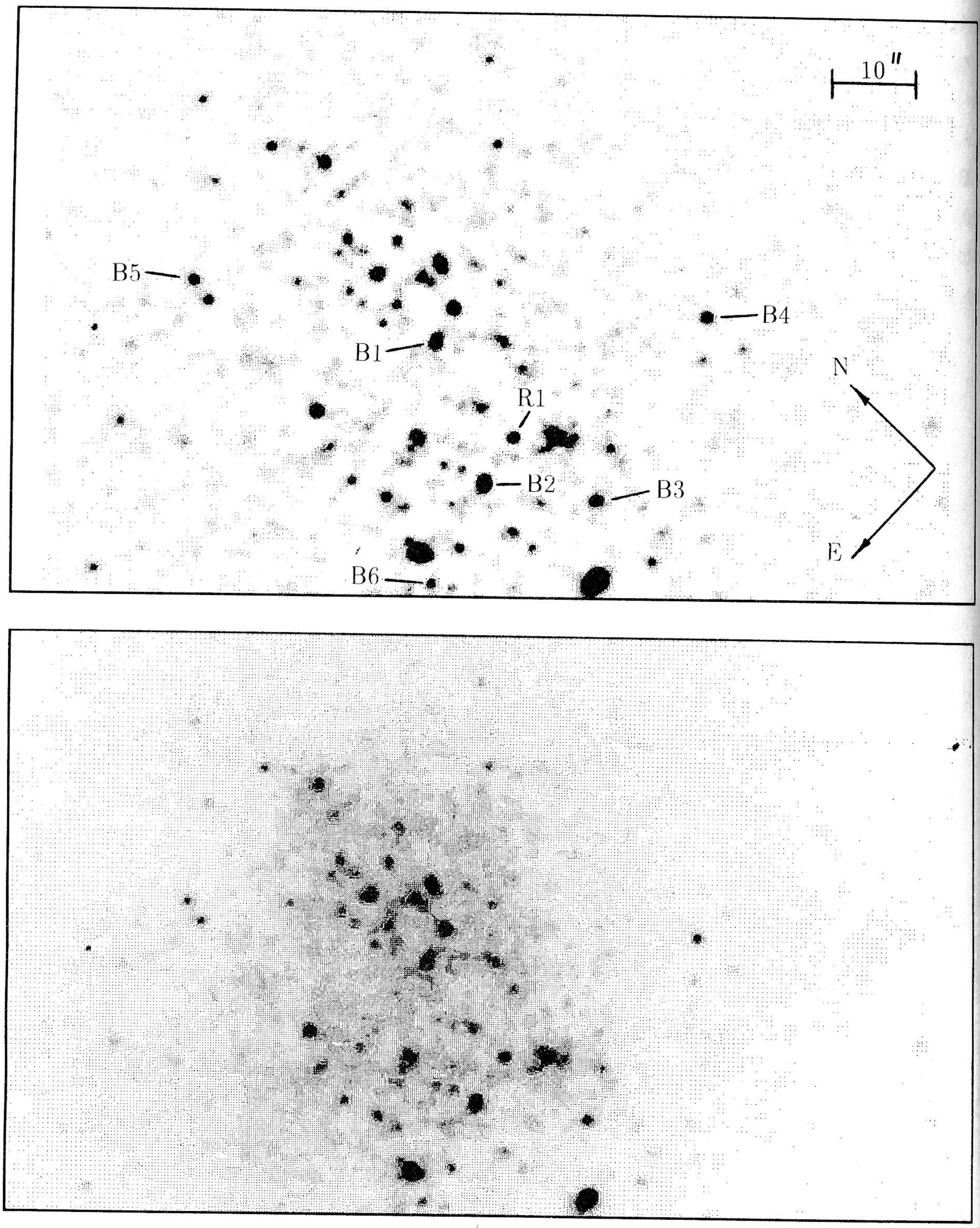


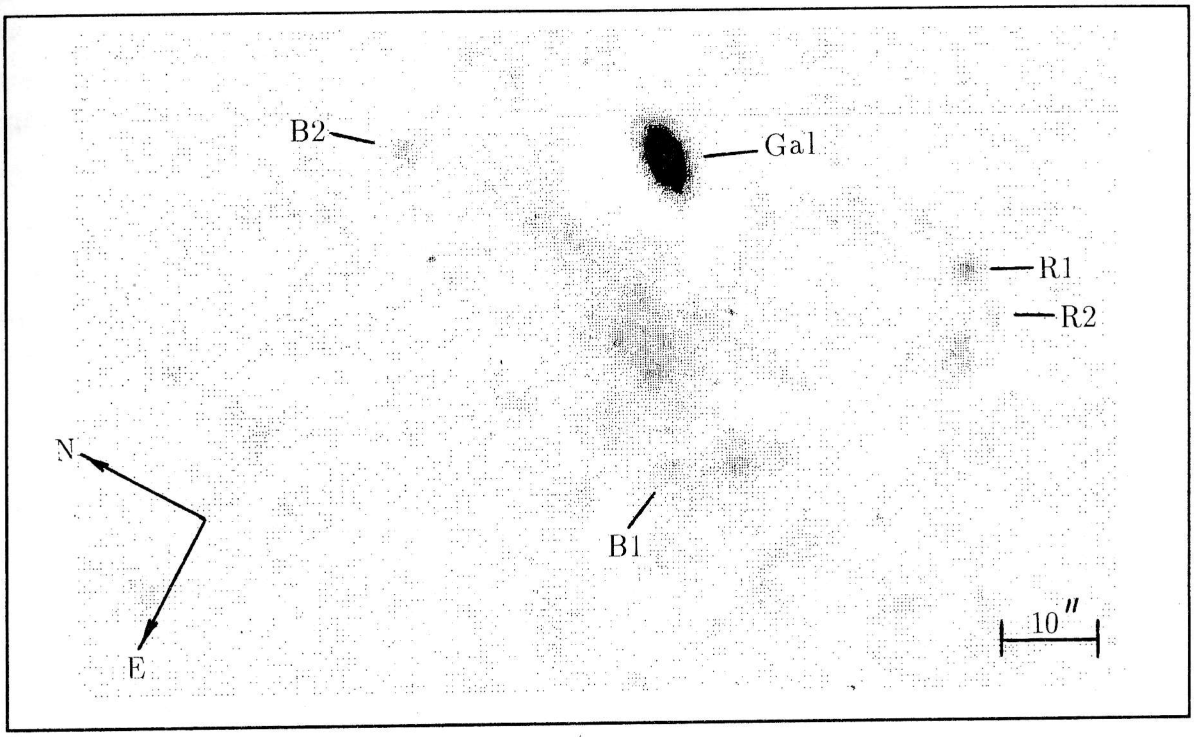
Fig. 11. *The V frame of the galaxy UGC 9240.*

3.11. UGC 9405=DDO 194

As different from the foregoing objects, this galaxy has a low surface brightnes and rather regular shape. From our evaluation its integral apparent magnitude i B =15.4±0.3, which is markedly different from B_T=16.8 from PGC. On the reproductio of the CCD frame in the V band at FWHM=2.1″ (Fig.12) only a few details are visibl in the structure of UGC 9405. Besides the projected distant galaxy we have measured apparent magnitudes of two blue and two red stars. The data are presented in Table 12. The distance modulus estimates from them seem highly unreliable. Identifying R 1 with a red supergiant, we obtain μ_0^B=29.64.

Table 12. Photometry of some stars in UGC 9405

Star	B	V	R
Gal.	19.50	18.51	17.88
R1	23.49	21.84	20.45
R2	24.95:	23.20	21.55
B1	22.68	22.90	22.73
B2	22.66	22.28	22.38



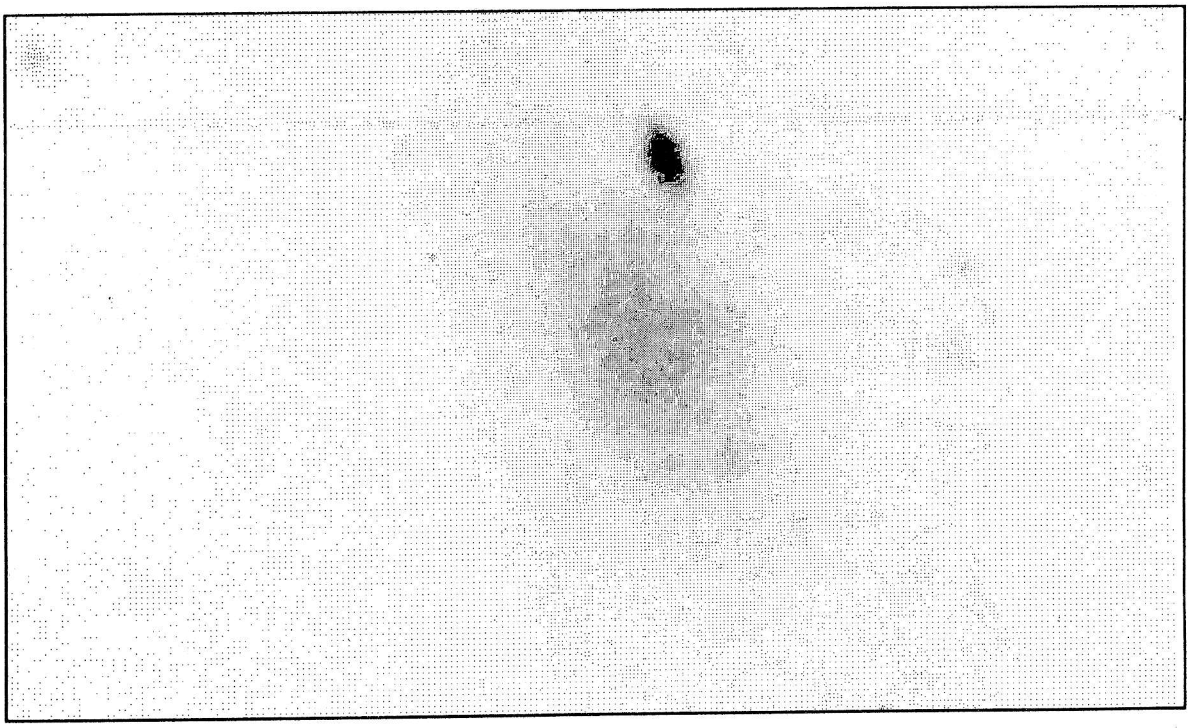


Fig.12. *UGC 9405 in the V band.*

The modulus estimate from blue stars yields $\mu_0^B \geqslant 30.6$. It should be noted that UGC 9405 bears resemblance in its structure to the galaxies Sex B, DDO 210, WLM, Phoenix and LGS-3, which, evidently, stay at the intermediate (between irregular dwarfs and spheroidal systems of Sculptor type) evolutionary stage. Judging by the radial velocity, V_0=+359 km/s, UGC 9405 is an undoubtful member of M 101. To define its modulus from giant branch stars, essentially deeper CCD frames are needed.

4. DISCUSSION

Some global parameters of the galaxies considered above are tabulated in Table 13. Its columns contain:

(1) - Name of galaxy.
(2) - Morphological type.
(3) - Angular diameter measured on the level $25^m/\text{arcsec}^2$.
(4) - Apparent axes ratio.
(5) - Integral apparent magnitude in the B band.
(6) - HI line width (km/s) measured at a 50% level from maximum.
(7) - Radial velocity (km/s) corrected for the Sun motion in the Galaxy in the IAU standard (de Vaucouleurs et al., 1991): $V_0 = V + 232 \cdot \sin l \cdot \cos b + 9 \cdot \cos l \cdot \cos b + 7 \cdot \sin b$.
(8) - Mean apparent B magnitude of three brightest blue stars.
(9) - Mean colour index of the brightest blue stars.
(10) - Apparent V magnitude of the brightest red star.
(11) - Distance modulus from the three brightest blue stars.
(12) - Distance modulus from the brightest red star.
(13) - Mean distance modulus.
(14) - Adopted distance in Mpc.

Table 13. General properties of galaxies

Name	T	a_{25}	b/a	B_T	W_{50}	V_0	<B(3B)>	<B-V>	V(R1)	μ_0^B	μ_0^R	$\langle\mu\rangle$	D
(1)	(2	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
N 4605	5	5.7	.38	10.90	333	254	19.78	.28:	20.71	28.45	28.69	28.57	5.18
N 5204	9	5.0	.61	11.69	110	319	19.92	.22	20.76	28.26	28.67	28.46	4.92
U 8508	10	1.7	.60	14.44	49	170	20.58	-.16	20.23	27.85	27.81	27.83	3.68
N 5238	8	1.7	.84	13.90	36	333	20.83	-.15	-	28.50	-	28.57	5.18
Ho IV	10	4.2	.31	13.79	77	259	21.52	.09	21.79	29.60	29.59	29.60	8.32
M 101	6	28.6	.93	8.24	143	360	19.38	-.11	20.91	29.20	29.18	29.19	6.88
N 5474	6	4.8	.90	11.34	40	395	20.36	.21	21.46	29.10	29.47	29.28	7.18
N 5477	9	1.7	.79	14.30	52	424	21.51	.03	21.80	29.33	29.55	29.44	7.73
N 5585	7	5.7	.64	11.32	146	435	20.02	.16	20.98	28.60	28.95	28.78	5.70
U 9240	10	1.8	.99	13.35	45	257	20.60	.12	20.42	28.44	28.13	28.28	4.53
U 9405	10	1.7	.38	15.40	84	359	22.70:	-	21.84:	-	29.48:	29.41:	7.62:

The following reservation should be made as refers to the distance moduli given in columns (12) and (13). When determining the distance modulus from the brightest red star, we based on the constancy of $M_V(R1)=-7.8$ for galaxies of both high and low luminosity. However, a comparison of V(R1) and B_T shows the presence of weak correlation between them for the group members located at approximately the same distance. In order to remove this drift, we have introduced a correction

$$\Delta\mu_R=0.10(\Delta m(R1)-8.0), \qquad (2)$$

where the quantity $\Delta m(R1)=V(R1)-B_T$, independent of the galaxy distance, was chosen as the argument. The necessity to allow for the weak effect of luminosity of the parent galaxy is in quantitative agreement with the data of Piotto et al. (1992) and Karachentsev & Tikhonov (1994). The maximum value of this correction is associated with M 101. The other cosmetic correction refers to the mean modulus in column (13). Since for the galaxies the average difference between the red and the blue moduli is $\langle\mu_R-\mu_B\rangle=+0.14\pm0.08$, we took account of this small difference in two cases (NGC 5238 and UGC 9405) where the second modulus estimate was lacking.

4.1. Group membership and virial mass

The group M 101 is one of the few nearby groups, where the membership of this or that galaxy does not cause discord. Probably, this is due to the fact that the group M 101 is located above the plane of the Local supercluster. Sandage & Tammann (1974a) ranked the galaxies NGC 5204, NGC 5474, NGC 5477, NGC 5585, and Ho IV with the companions of M 101. For the group of such composition they obtained the virial mass-to-integral luminosity ratio $M_{vir}/L_B\simeq10\ M_\odot/L_\odot$, which corresponds to the balance between the kinetic and potential energy of the group without involving dark matter. Similar conclusion was drawn by Allen et al. (1978) and Davies et al. (1980), who added to the group members UGC 9405 and NGC 5238, having measured their radial velocities in HI line.

The eight galaxies mentioned above were picked out by Vennik (1984) as the group members with the hierarchical clustering method. According to Vennik the group M 101 has the effective linear radius in projection 150 kpc, the mean square peculiar velocity along the line of sight 58 km/s and the virial mass-to-luminosity ratio 26 $M_\odot/L_\odot$. A similar criterion of hierarchical clustering was applied also by Tully (1987). Besides the 8 galaxies considered by Vennik, Tully included in the group UGC 8508 too, which increased the dispersion of radial velocities up to 82 km/s. From the estimate of Tully the virial mass-to-luminosity ratio in the group M 101 is 117 $M_\odot/L_\odot$, which points to the presence of dark matter. Another high quantity, $M_{vir}/L_B=80$, was obtained later by Nolthenius (1993), who isolated the same group members (except for UGC 9405 and UGC 8508) with the use of the improved clustering algorithm of Geller and Huchra. Note that the estimates of M_{vir}/L_B for M 101 group by

Tully and Nolthenius are little different from the median values for the sample of the nearby groups they investigated. That is why the group M 101 may be regarded as an object suitable for the reasons of the virial mass excess in small aggregates of galaxies to be analysed.

In the approach suggested by Bahcall & Tremaine (1981) and Karachentsev (1993) a group of galaxies is looked upon as being a system of companions travelling on Keplerian orbits round the most massive body. Such a planetary model is ideally suited to M 101 group. According to the criterion (Karachentsev, 1993) around a galaxy with mass M_1 and radial velocity V_1 other galaxies with mass M_K and radial velocity V_K are selected as companions, if they satisfy the conditions

$$g_{1K}=(V_1-V_K)^2\cdot R_{1K}/2G\cdot(M_1+M_K) < 1, \quad (3)$$

$$t_{1K}=H\, R_{1K}^{3/2}/[G(M_1+M_K)]^{1/2} < 1. \quad (4)$$

Here R_{1K} is the projection of the linear distance between galaxies, G, gravitational constant, and H, the Hubble parameter. The upper line expresses the condition of negative total energy of the pair, the lower one implies that its orbital period does not exceed the age of the Universe.

Applying criteria (3), (4) to M 101, we have an ensemble of its companions the data on which are presented in Table 14. In this case for evaluating the total mass we have used the expression

$$M=\varkappa(8G)^{-1}W_0^2\, A_{25}, \quad (5)$$

where W_0 is the HI line width with a correction for the inclination, A_{25} is the linear diameter measured on the standard isophote, and the dimensionless parameter $\varkappa=A_{max}/A_{25}$ denotes the typical length of the flat rotation curve. Following the observational data of Wevers (1984) and Begeman (1987) we adopted, as the mean for spiral galaxies, the value

$$\varkappa=2.5. \quad (6)$$

In other words, we believe that 40% of the total mass of each galaxy is concentrated, on average, within its standard radius. Individual total mass-to-total blue luminosity ratios of galaxies are given in the fourth column. In the cases when a galaxy has a small inclination to the line of sight (b/a>0.80), its mass estimate by (5) turns out unreliable, and we determined the total mass from the luminosity, having assumed that

$$M/L = \varkappa\cdot(8-0.4T)\cdot(M_\odot/L_\odot), \quad (7)$$

where T is the morphological type of a galaxy from RC3. Such values are marked in Table 14 with a colon.

Note that Cote et al. (1991) investigated the velocity field in NGC 5585 in

HI line and constructed a dynamic model of this galaxy. From the author's data the rotation curve for NGC 5585 extends to $\varkappa$=2.5, and the total mass-to-luminosity ratio, 13 $M_{\odot}/L_{\odot}$, is in good agreement with the quantity given in Table 14.

Table 14. M 101 and its companions

Name	ΔV_{1K} km/s	R_{1K} Kpc	$(M/L)_K$ $(M/L)_{\odot}$	M_K $10^{10} M_{\odot}$	g_{1K}	t_{1K}
(1)	(2)	(3)	(4)	(5)	(6)	(7)
N 5204	-40	710	7.2	1.20	0.29	0.99
N 5238	-26	590	12.0:	0.22	0.11	0.76
Ho IV	-101	151	9.0	0.30	0.40	0.10
M 101	-	-	14.0:	45.4	-	-
N 5474	35	85	14.0:	2.7	0.03	0.04
N 5477	64	40	12.1	0.16	0.04	0.01
N 5585	75	380	11.4	2.6	0.52	0.39
U 9405	-1	615	23.4	0.16	10^{-4}	0.80

The Keplerian approach we have adopted allows us to check up if the group volume contains a large quantity of dark matter. From the sixth column of Table 14 we find the median value of the potential factor $\langle g_{1K} \rangle_{MED}$=0.11. According to Karachentsev (1993) at random orientation of orbits of companions with the orbit eccentricity e=0 the expected median value is 0.10 with quartils [0.04,0.25]. With the mean eccentricity e=0.6 the median decreases to 0.06. Comparing these values, we derive the estimate of the dark matter excess in the group

$$DM/\Sigma M_K \simeq (0 \div 1). \qquad (8)$$

That is, the statistics of radial velocities for companions of M 101 admits the presence of only a small amount of dark matter on a scale of about 300 kpc within fluctuations of the projection factor and uncertainty in the type of orbital motions. This result is inconsistent with the statement of Zaritsky et al. (1993) that spiral galaxies possess extended coronae whose masses and dimensions exceed the apparent mass of the galaxy by one order.

4.2. Peculiarities of the group M 101

Among the nearby groups of galaxies the group M 101 is distinguished by the great contrast in luminosity between the first and the rest of the members, $\Delta B_{1K} > 3^m$. Probably this is due to a peculiarity of formation of the group at a large distance from the plane of the Local supercluster (SGZ=2.6 Mpc). Judging by the data of Table 14, the mass of M 101 exceeds the total mass of its companions by more than a factor of 6, which supports the application of Keplerian approach to estimating the total mass of the group.

A domination of M 101 among the rest of the companions allows us to expect that it is located near the dynamical centre of the group. Indeed, the radial velocity difference between M 101 and centroid of its companions is (+1±24) km/s. From our estimate the distance modulus of M 101, $29^m.19$ is almost coincident with the mean modulus, 29.09±0.15, obtained from all the group members. In projection onto the sky M 101 does not occupy eccentric position relative to its companions either.

Attention is drawn to the morphological uniformity of the group members. It does not contain a single galaxy of a structural type earlier than Sc. It will be recalled that galaxies of early types occur in other nearby groups (LG, M 31, M 81, Cent A). A special survey revealed no dwarf spheroidal systems of Sculptor type in M 101 group either.

Judging by the data of Table 14 a characteristic "crossing time" in the group is rather large. The median of cyclic Keplerian periods t_{1K} is 0.39. In this sense the group M 101 may be regarded as rather a friable system that has not yet reached the virial balance. If the group, as a whole, contracts, the galaxies at the nearer border must have greater radial velocities than at the farther border. The distance moduli we have measured are not definitely indicative of such an effect. However, at the maximum radius of the group ~700 kpc the expected difference between the moduli is only $\sim 0^m.25$, which is comparable with the measurement errors.

4.3. On the value of Hubble parameter

The group M 101 seems to be a suitable object to define the value of the Hubble constant. It is distant enough to disregard a peculiar velocity of the Galaxy caused by the effect of M 31 and other neighbours. On the other hand, at the distance to M 101 a velocity correction due to coherent motions in the Local supercluster is not large.

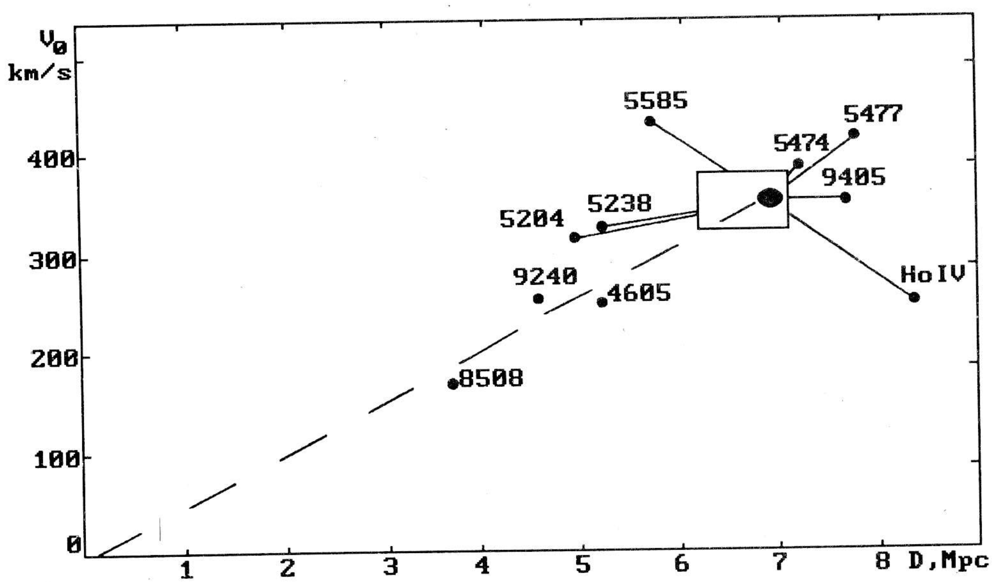


Fig.13. *The Hubble diagram for 11 galaxies with the measured distances. The members of the group M 101 are connected to it with lines. The rectangle shows the box of errors of the mean for the centroid of the group. The dashed line refers to the Hubble parameter* $H=54\ km\cdot s^{-1}\cdot Mpc^{-1}$.

Fig.13 shows the location of the galaxies we have measured on the Hubble diagram "radial velocity-distance". The centroid of the group is depicted with a rectangle whose sides correspond to the standard error of the mean. The regression line, drawn through the centroid of the group, three foreground galaxies and our Galaxy, gives the local value of the Hubble constant $H=(54\pm6)$ $km\cdot s^{-1}\cdot Mpc^{-1}$. This value coincides with the old estimate $H=(55\pm9) km\cdot s^{-1}\cdot Mps^{-1}$ obtained 20 years ago by Sandage & Tammann (1974a). Note that the scatter of foreground galaxies with respect to the regression line is not large (20 km/s) and is actually due to measurement errors of their distances. Considering the obtained value of the Hubble parameter as an argument in favour of a long scale of distances, one should, however, take into account that its value may depend on the direction relative to the Local supercluster plane (Karachentsev, 1993). To check up the suspected local anisotropy of the Hubble parameter a great number of distance modulus measurements for galaxies at high supergalactic latitudes are needed. Such a program is being carried out on the 6 m telescope.

5. CONCLUSION

Using B, V, R frames taken with the CCD camera on the 6 m telescope we undertook a search for the brightest blue and red stars in 11 galaxies of the group M 101 and its neighbourhood. From the results of photometry of candidates for blue and red supergiants distance moduli of these galaxies have been found. Three galaxies (UGC 4605, UGC 8508, UGC 9240) seem to be the foreground objects of the group. Photometric distances of the other eight galaxies agree with their membership in the group M 101 by the criterion of Karachentsev (1993). The mean distance modulus for the group members from our data is 29.09 ± 0.15.

Considering the group as the aggregate of companions travelling on Keplerian orbits round M 101, we obtain for it the following median characteristics: peculiar radial velocity of 40 km/s, projection of the linear distance from the centre, 380 kpc, and the system crossing time, $0.39\ H^{-1}$. The mean mass estimate of the group only slightly exceeds the sum of individual masses of galaxies. Under the assumption of strictly circular orbits the mass excess is about 10%. For the orbits with the eccentricity $e=0.6$ it becomes ~70%. The "orbital" mass excess value itself is comparable with the fluctuation of the projection factor. The model of massive extended halo (Zaritsky et al., 1993) does not correspond to the dynamics of the group M 101.

The obtained mean modulus of the group, as well as the moduli measured for the three foreground galaxies yield the estimate of the Hubble parameter $H=(54\pm6)$ $km\cdot s^{-1}\cdot Mpc^{-1}$ that is in agreement with the previous estimate of Sandage & Tammann (1974a). We draw attention to the necessity of observational check of possible anisotropy of the Local volume expansion, attracting for this purpose the measurements of distances of galaxies at high supergalactic latitudes.

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REFERENCES

Allen R.J., van der Hulst J.M., Goss W.M., Huchtmeier, W.: 1978, *Astron. Astrophys.*, **64**, 359.

Bahcall J.N., Tremaine S.: 1981, *Astrophys.J.*, **244**, 805.

Begeman K.: 1987, *HI Rotation Curves of Spiral Galaxies*, Dissertation, Univ. of Groningen, 1-133.

Burstein D., Heiles C.: 1984, *Astron.Astrophys.Suppl.*, **54**, 33.

Cook K.H., Aaronson M., Illingworth G.: 1986, *Astrophys.J.*, **301**, L45.

Cote C., Carignan C., Sancisi R.: 1991, *Astron.J.*, **102**, 904.

Davies R.D., Davidson G.P., Johnson S.C.:1980, *Mon.Not.R.Astron.Soc.*, **191**, 253.

de Vaucouleurs G.: 1978, *Astrophys.J.*, **224**, 14.

de Vaucouleurs G.: 1993, *Astrophys.J.*, **415**, 10.

de Vaucouleurs G., de Vaucouleurs A., Corwin H.G., Buta R.J., Paturel G., Fouque P.: 1991, *Third Reference Catalogue of Bright Galaxies*, Springer-Verlag, N.Y, (RC3), 1-430.

Georgiev Ts.B., 1990, *Astrofiz.Issled. (Izv.SAO)*, **30**, 127.

Holmberg E.: 1964, *Arkiv fur Astronomi.*, **3**, 387.

Humphreys R.M., Aaronson M.: 1987, *Astron.J.*, **94**, 1156.

Humphreys R.M., Aaronson M., Lebofsky M., McAlary Ch.W., Strom S.E., Capps R.W.: 1986, *Astron.J.*, **91**, 808.

Karachentsev I.D.: 1987, *Binary Galaxies*, Moscow, Nauka, 1-248.

Karachentsev I.D.: 1993, *Criterion for bound groups of galaxies. Application to the Local Volume*, Preprint Special Astrophys.Obs., No.100.

Karachentsev I.D., Tikhonov N.A.: 1994, *Astron. Astrophys.*, **286**, 718.

Landolt A.U.: 1992, *Astron.J.*, **104**, 340.

Nolthenius R.: 1993, *Astrophys.J.Suppl.*, **85**, 1.

Paturel G., Bottinelli L., Fouque P., Gouguenheim L.: 1992, PGC-ROM 1992, Lyon-Meudon Extragalactic Database (PGC).

Piotto G., Capaccioli M., Bresolin F.: 1992, *Mem. Soc. Astron. Ital.*, **63**, 465.

Sandage A.: 1983, *Astron.J.*, **88**, 1569.

Sandage A., Bedke J.: 1988, *Atlas of galaxies useful for measuring the cosmological distance scale*, NASA, Washington, 1-95.

Sandage A. & Tammann G.A.: 1974a, *Astrophys.J.*, **194**, 223.

Sandage A. & Tammann G.A.: 1974b, *Astrophys.J.*, **191**, 603.

Smith P.S., Jannuzi B.T., Elston R.: 1991, *Astrophys.J.Suppl.*, **77**, 67.

Treffers R.R., Richmond M.W.: 1989, *Publ.Astron.Soc.Pac.*, **101**, 725.

Tully R.B.: 1987, *Astrophys.J.*, **321**, 280.

Vennik J.: 1984, *Tartu. Astron. Obs. Publ.* **73**, 1.

Vorontsov-Vel'yaminov B.A.: 1977, *Astron.Astrophys.Suppl.*, **28**, 1.

Wevers B.M.: 1984, *A study of Spiral Galaxies,* Dissertation, Univ. of Groningen, 1-210.

Zaritsky D., Smith R., Frenk C.S, White S.D.M.: 1993, *Astrophys.J.*, **405**, 464.

Zwicky F.: 1971, *Catalog of Selected Compact Galaxies and Post-Eruptive Galaxies,* Pasadena, 1-383.

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