Studying of space voids at Rozhen NAO: Joint Bulgarian-German project

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Abstract. This report is devoted to the 30-year anniversary of the Rozhen NAO.In the end of 1990 an observational program was started by the Max Plank Institute of Astronomy, Heidelberg and the Institute of Astronomy of the Bulgarian Academy of Sciences. aiming to check the lack of galaxies in some regions of the cosmic space – so called "VOIDS". The idea was to use the 2-m telescope of the Rozhen NAO with its large field of 1 x 1 sqr.deg. The program list contains one comparison field – the well known cluster of galaxies A 1376 with coordinates (1950) R.: 11h 40m 54s and Dec: +20deg 07' 00" and about a dozen of voids. Using the exposure time ca. 3 hours we reach a limiting magnitude ca. B = 23 – i.e fainter than the POSS limit. The second step was detailed studies of the most interesting objects using the CCD frames. As a result more than 6000 new galaxies were found and measured in the fields 0049 + 00, 1042 + 00, 1306 + 34, +35, +36, 1600 + 18 (Hercules) and 2320 + 1339.

Key words: Voids: astrometry, photometry, cluster analysis. Large scale structure

Изследване на пространствени празнини в НАО-Рожен: Съвместен българско-германски проект

Георги Петров

Този отчет е посветен на 30-годишния юбилеюй на НАО - Рожен. В края на 1990 година започна нов изследователски проект на Института по астрономия "Макс Планк", Хайделбергс и Института по астрономия, БАН. с цел да се провери наличието или липсата на галактики в избрани области от пространството, наречени "празнини". За целта бе използван 2-м телескоп на НАО с неговото голямо поле - 1x1 кв. градуса. Програмата включваше едно поле за сравнение - добре известния куп от галактики A 1376 с координати (1950) Rec.: 11h 40m 54s и Dec: +20deg 07' 00" и около дузина празнини. При експозиции от порядъка на 3 часа бе достигната гранична зв. в-на B = 23, по–голяма от тази на Паломарския обзор. Следваща стъпка бе детайлно изучаване на по-интересните обекти със ССД-камера. В резултат на програмата са измерени повече от 6000 галактики в полетата на празнините 0049 + 00, 1042 + 00, 1306 + 34, +35, +36, 1600 + 18 (Херкулес) и 2320 + 1339.

Introduction

The presence of voids in the distribution of galaxies has been discovered in early redshift surveys of galaxies - see e.g. Chincarini & Rood (1980), Gregory & Thompson (1982). Further studies show that the largest voids are those delineated by rich clusters and superclusters of galaxies - Oort (1983), Rood (1988). Since 1992 altogether 17 long exposure plates for 10 selected voids, covering one square degree of celestial sphere each in B – color were taken with the 2-m RCC telescope of NAO "Rojhen". In Table1 the summary of the observational data for the selected voids is presented.

A brief description of the project is presented in Petrov (2006). All data used here are accessible via the WEBpage http://www.astro.bas.bg/p̃etrov/ and soon – via BGVO portal.

Table 1. Programm list and results of 'Searching for Galaxies in Voids'

Name	h m s	° ′ ″	N1	Plate N0.	Ng	Np
V1-1	00 00 00	+12 00 00	35			
V1-2	00 00 00	+15 00 00	40			
V1-3	00 00 00	+18 00 00	40			
V2-1	00 30 00	+12 00 00	30			
V2-2	00 30 00	+15 00 00	30			
V2-3	00 30 00	+18 00 00	30			
V3	00 33 00	+06 54 00	50			
V4	00 41 00	+05 00 00	45	1862		
V5-1	00 45 00	+04 00 00	45	1863, 1868		414
V5-2	00 45 00	+05 00 00	45	1864		563
V5-3	00 45 00	+06 00 00	45	1865		
V6	00 49 00	+05 00 00	45	1867	1957	568
V7	02 00 00	+13 00 00	35	2043		
V8	10 42 00	+00 00 00	50	1896, 7084CA	847	
V9	13 00 00	+35 00 00	45	1817		
V10-1	13 06 00	+34 00 00	45	1898, 7082CA	791	
V10-2	13 06 00	+35 00 00	45	1899	829	
V10-3	13 06 00	+36 00 00	45	1897	1126	
V11	13 12 00	+35 00 00	50	1890	443	
V12	16 00 00	+18 00 00	100	1830, 1831, 1818	2145	225
V13	23 20 00	+13 39 00	50	1861	279	90
V14-1	23 30 00	+12 00 00	45			
V14-2	23 30 00	+15 00 00	45			
V14-3	23 30 00	+18 00 00	45			

Remarks:
Name - our conditional name according to Rec.
N1 - number of galaxies in 1 sqr. degree according Shane(1975).
Ng - number of galaxies of founded on our plates.
Np - number of galaxies founded on the POSS plates.
A. - Plates No. 7082 and 7084 - 2.2-m telescope, IIIaJ + GG 385.
B. - Plates No 1818, 1868 - 2-m telescope, 103aF + R - filter.
C. - All other plates - 2-m telescope, ZU21 + B - filter.

1. Detailed study of selected galaxies in Pisces-Cetus void

The galaxy we present here was chosen because of its interesting morphology - it looks like two colliding galaxies or like two merging systems on the B CCD frame. The basic data were taken using CCD frames and CCD spectra with the 3.5 m telescope at Calar Alto.

In Fig.1 the result of detailed study of galaxy with coordinates 0058+1008 is presented. Figure 1-1 presents the dependence of the integrated magnitudes in colors R (circles) and B (crosses) from the angular diameter of the galaxy. In Fig.1-2 the dependencies of the surface brightness (mag/sq.arcsec), color index (B-R), axial ratio B/A and position angle PA from the major axis are summarized. In Fig.1-3a,b the lines of equal intensity in B and R colors respectively are presented. Fitting ellipses are overlaid - for details see Kovachev et al., (1995).

2. Astrometry and photometry of galaxies in direction of 0049+05 void

Coordinates of 2257 galaxies, all that were detected on the plate No.1867, were measured on an GLAREX machine in MPIA Heidelberg. ORWO plate ZU–21 30x30 cm^2 and Schott filter GG 385 were used to realize the standard B–system.

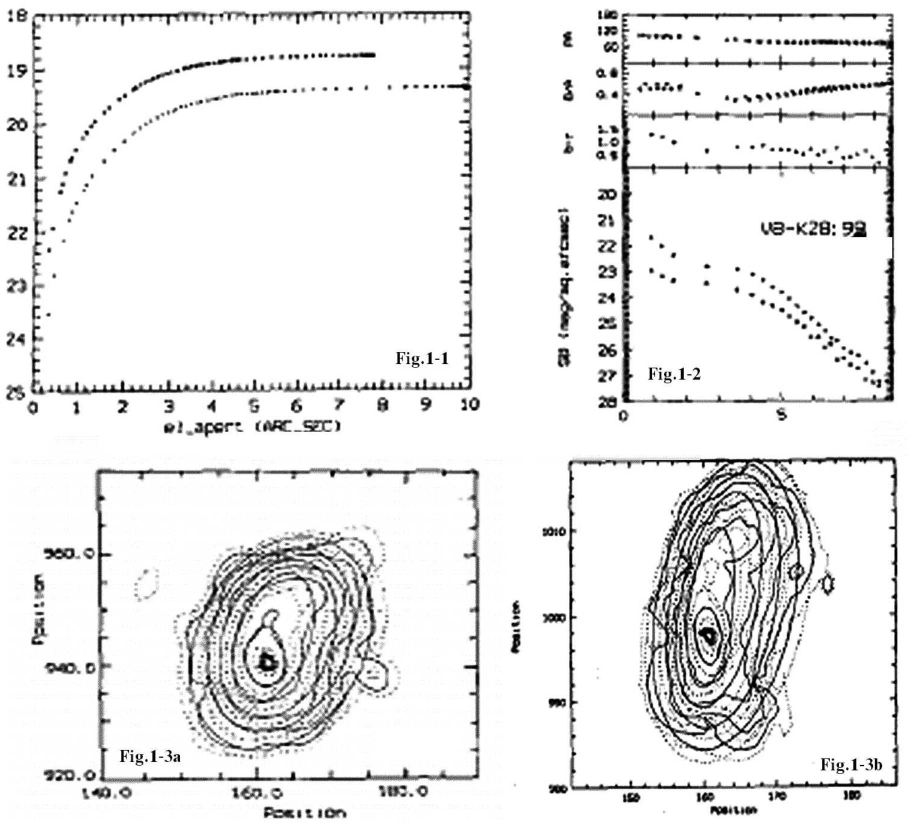

Fig. 1. Detailed study of a galaxy from Pisces-Cetus void

SAO standard stars were used as astrometric standards. Ring aperture photometry for all of them is performed. Visual magnitudes and apertures (diameters) have been determined. For details from the aperture photometry of galaxies - see Petrov et al. (2007b).

Figure 2 represents the results from aperture photometry of galaxies in the direction of void 0049+05 (Petrov et al., 1997; Petrov et al., 2007b). The MIDAS cluster analysis test for all galaxies has been used to study the X–Y distribution (i.e. Alpha - Delta) of galaxies in the sample - Fig.2-1. The distribution of the magnitudes and diameters of the galaxies are compared with the LogNormal and Gauss one. The sample is full to the diameters ca. 4”

- a linear part of the relation in Fig.2-2. On the Fig.2-3 distributions of large diameters, axis-ratios and position angles of the galaxies are presented.

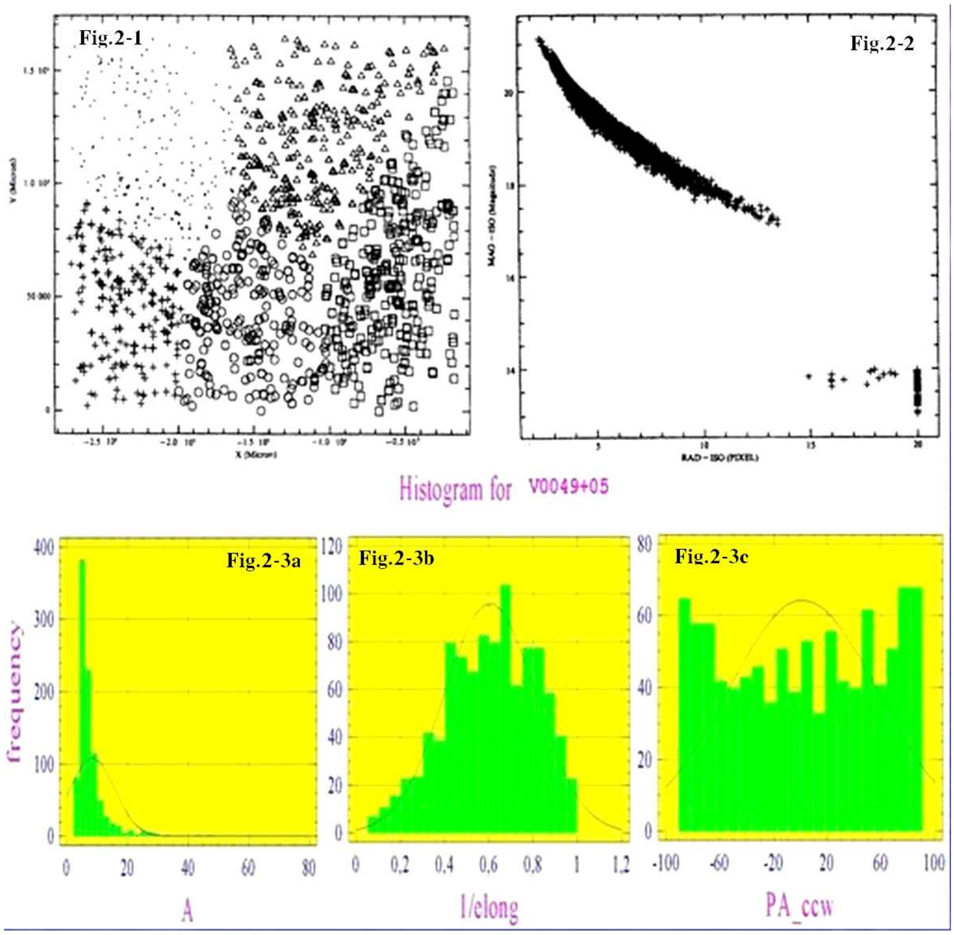

Fig. 2. Results from aperture photometry of galaxies in the direction of void 0049+05

Some results from the cluster analysis of the void are presented on the Fig.3.

3. Astrometry and photometry of galaxies in direction of 1312+35 void

ORWO plate ZU 21 30x30 cm^2 and Schott filter GG 385 were used to realize the standard B–system. Coordinates and photometry of all 444 detected galaxies are presented in Strigachev & Petrov (1994).

Distribution of the Diameters and Magnitudes of the galaxies are presented on the Fig.4.

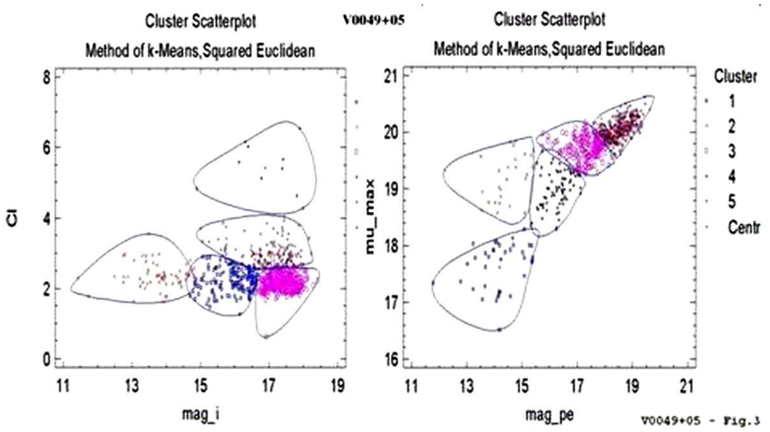

Fig. 3. Results from cluster analysis of galaxies in the direction of void 0049+05

Figure 4a (upper panel) shows the distribution of the number of galaxies according to the determined magnitude m(B). Figure 4b (lower panel) shows the similar distribution of the major diameters of the galaxies.

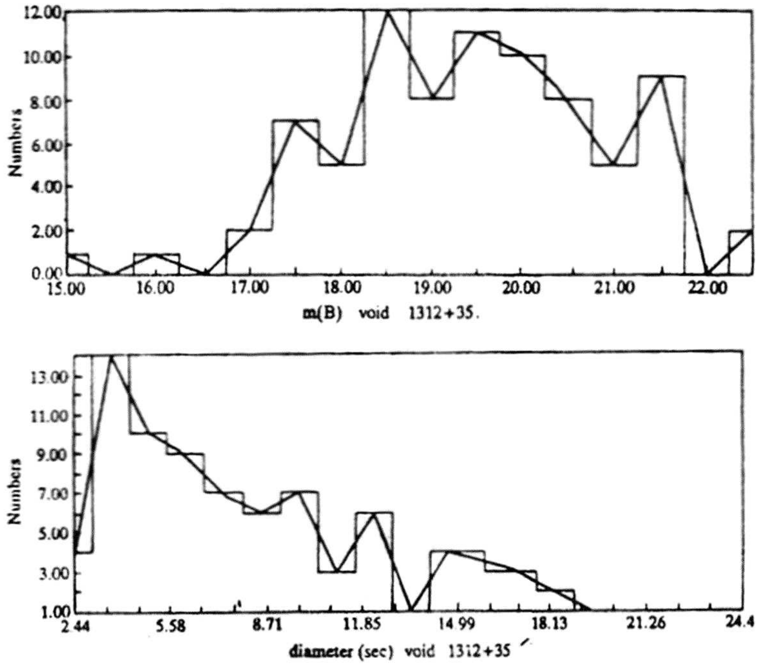

Fig. 4. Results from aperture photometry of galaxies in the direction of void 1312+35

4. Surface photometry and cluster analysis of galaxies in direction of Hercules void

Based on photographic plates obtained with 2m RCC telescope at National Astronomical Observatory Rozhen (Bulgaria) we inspected an area of $\sim$1 sq.degree in the direction of the Hercules void visually and with automatic object detection software (Kniazev et al., 2003). Ca. 1850 faint galaxies in the wide range of magnitudes $13^m \leq B \leq 21^m$ and effective surface brightnesses $16 \leq \mu_{\rm eff}(B) \leq 24$ mag arcsec^{-2} detected in a field of one square degree centered at 1600+18 (1950) (Hercules void) were reselected in this manner amongst the ca. 2150 galaxies visually selected.

Table : v1600+18 selected galaxies !For demonstration purpose

Seq	LARGE_D	AX_RA	POS_A	ra	dec	B_msk	eB_msk	RB_ef	SBB_ef	B_t	eB_t	RB_50	SBB_50
1	10.77	0.789	64.5	239.9728	17.7849	19.83	0.289	1.88	23.41	19.82	0.28	2.34	23.25
2	28.42	0.545	-21.1	239.9759	17.7767	18.60	0.184	3.15	22.29	18.59	0.18	4.42	23.58
3	17.82	0.984	64.6	239.9766	17.7437	19.06	0.216	2.71	22.98	19.05	0.21	2.84	22.90
4	13.87	0.857	54.4	239.9790	17.4893	19.20	0.224	2.19	22.58	19.20	0.22	2.10	22.23
5	26.29	0.350	-22.1	239.9850	17.6762	20.10	0.324	2.48	22.82	20.05	0.31	4.27	25.16
1846	23.41	0.828	-62.6	241.0851	17.7976	18.50	0.224	2.83	22.61	18.50	0.22	2.97	22.85
1847	18.13	0.868	84.5	241.0880	17.6810	18.87	0.262	2.03	22.39	18.87	0.26	2.00	22.37
1848	22.05	0.808	83.4	241.0909	17.7620	18.62	0.236	1.85	21.71	18.61	0.23	1.29	21.16
1849	63.42	0.306	-71.9	241.0912	18.1387	16.92	0.114	4.05	21.90	16.92	0.11	5.83	22.74
1850	27.16	0.929	-14.9	241.0929	18.0259	17.84	0.171	3.18	22.17	17.84	0.17	2.97	22.20
1851	19.41	0.947	28.2	241.0950	17.8298	18.95	0.273	1.95	21.95	18.95	0.27	1.02	21.00
1852	35.43	0.821	84.8	241.0961	17.8785	15.90	0.073	3.35	20.50	15.90	0.07	3.26	20.46

Seq	RB_90	SBB_90	C	RA_2000	DEC_2000	SDSS_like_NAME	RB_25	B_25	eB_25
1	4.20	24.17	1.791	15:59:53.52	+17:47:05.64	J155953+174705	3.67	20.34	0.32
2	7.32	24.27	1.657	15:59:54.24	+17:46:36.12	J155954+174636	7.65	18.80	0.18
3	4.91	23.76	1.728	15:59:54.48	+17:44:37.32	J155954+174437	5.64	19.22	0.21
4	4.98	23.94	2.375	15:59:54.96	+17:29:21.48	J155954+172921	4.99	19.45	0.23
5	6.92	25.67	1.620	15:59:56.40	+17:40:34.32	J155956+174034	3.43	21.24	0.43
1846	6.32	23.85	2.249	16:04:20.40	+17:47:51.36	J160420+174751	5.57	18.67	0.24
1847	5.65	23.99	2.874	16:04:21.12	+17:40:51.60	J160421+174051	4.46	19.11	0.29
1848	4.23	23.10	3.687	16:04:21.84	+17:45:43.20	J160421+174543	3.61	18.78	0.25
1849	14.28	24.05	2.441	16:04:21.84	+18:08:19.32	J160421+180819	11.96	17.14	0.13
1850	8.06	23.73	2.832	16:04:22.32	+18:01:33.24	J160422+180133	7.03	18.05	0.19
1851	5.85	24.15	7.743	16:04:22.80	+17:49:47.28	J160422+174947	2.23	19.41	0.33
1852	9.37	22.11	3.168	16:04:23.04	+17:52:42.60	J160423+175242	11.97	15.91	0.07

Fig. 5. Results from automatic selection and reduction of galaxies in the direction of Hercules void 1600+18

Their coordinates (2000), magnitudes m(B), diameters, position angles surface brightness and some morphological parameters have been determined and studied using cluster analysis technique. Nearest and Furthest neighbor, Centroid, Median, Group, K_means and Ward's methods were tested and K_means method were used to determine the substructures in the distribution of faint galaxies. The distance metric in all the cases is squared Euclidean distance.

The groups of Low surface brightness galaxies (Primeval galaxies ?) as the ones with High Surface Brightness were detected in such manner in the direction of the void. Distribution of Concentration index (a parameter outlined morphology of the object) give us some idea for separating of galaxies of spiral and elliptical ones. For details see Petrov et. al.(2005, 2006, 2007a).

The output data consist of a MIDAS table that contains all information about the detected galaxies: accurate positions (X, Y, $\alpha(2000)$, $\delta(2000)$), total fluxes and integrated magnitudes with their uncertainties, effective radii ($R_{\rm eff}$; in arcsec), effective surface brightnesses ($\mu_{\rm eff}$; in mag arcsec^{-2}), radii of the regions containing 50% and 90% of the integrated flux (R_{50}, R_{90}; in arcsec), concentration indices $C = R_{90}/R_{50}$, position angle (PA), axial ratio (b/a). exponential fits for the central surface brightnesses ($\mu_{\rm E,0}$; in mag arcsec^{-2}) and total magnitudes, integrated out to 25 mag arcsec^{-2} with their uncertainties.

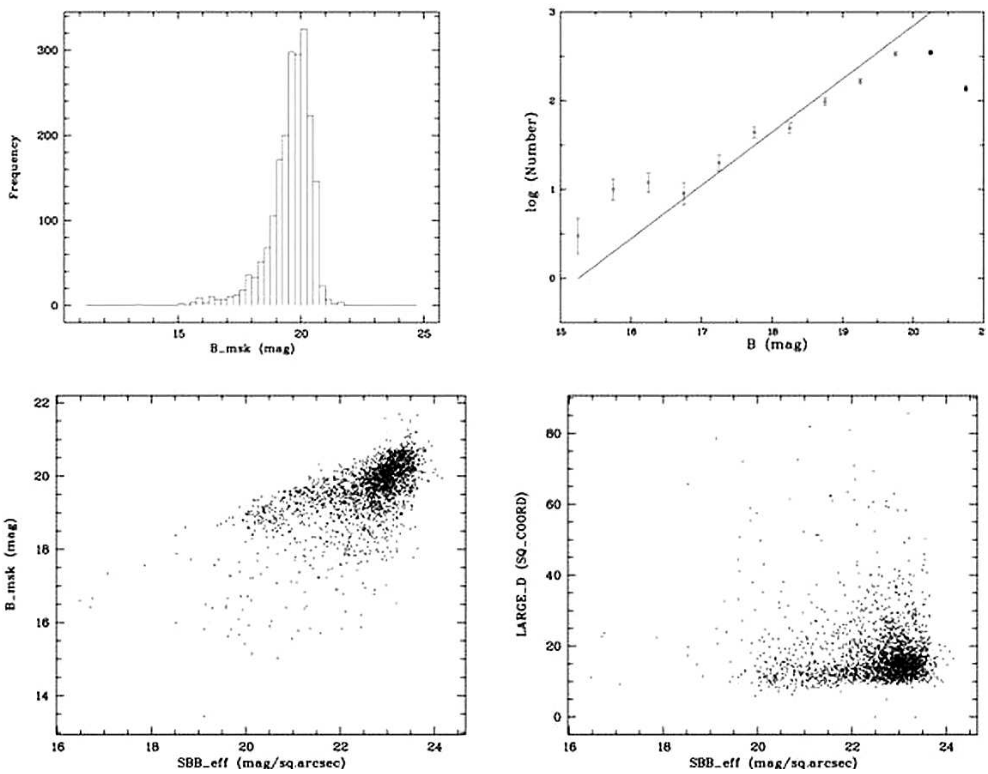

Fig. 6. Upper left panel: Distribution of apparent magnitudes for all galaxies detected with our programs. Upper right panel: Number counts of all galaxies detected with our programs as a function of apparent magnitude. The errors bars on the galaxy counts are Poissonian. The line shows the count-magnitude relation expected for a homogeneous galaxy distribution in a universe with "Euclidean" geometry: $N(B) = A_B \cdot 10^{0.6B}$. Lower left panel: Relation between the effective surface brightnesses and integrated magnitude. Lower right panel: Relation between the effective surface brightnesses and major diameter of galaxies.

The data for all 1851 galaxies in the field – coordinates, aperture and surface photometry, position angles, diameters, axis ratio and concentration are presented in Tabl.2 below - Fig.5 and are available on-line in the WEB–page of the author http://www.astro.bas.bg/p̃etrov.

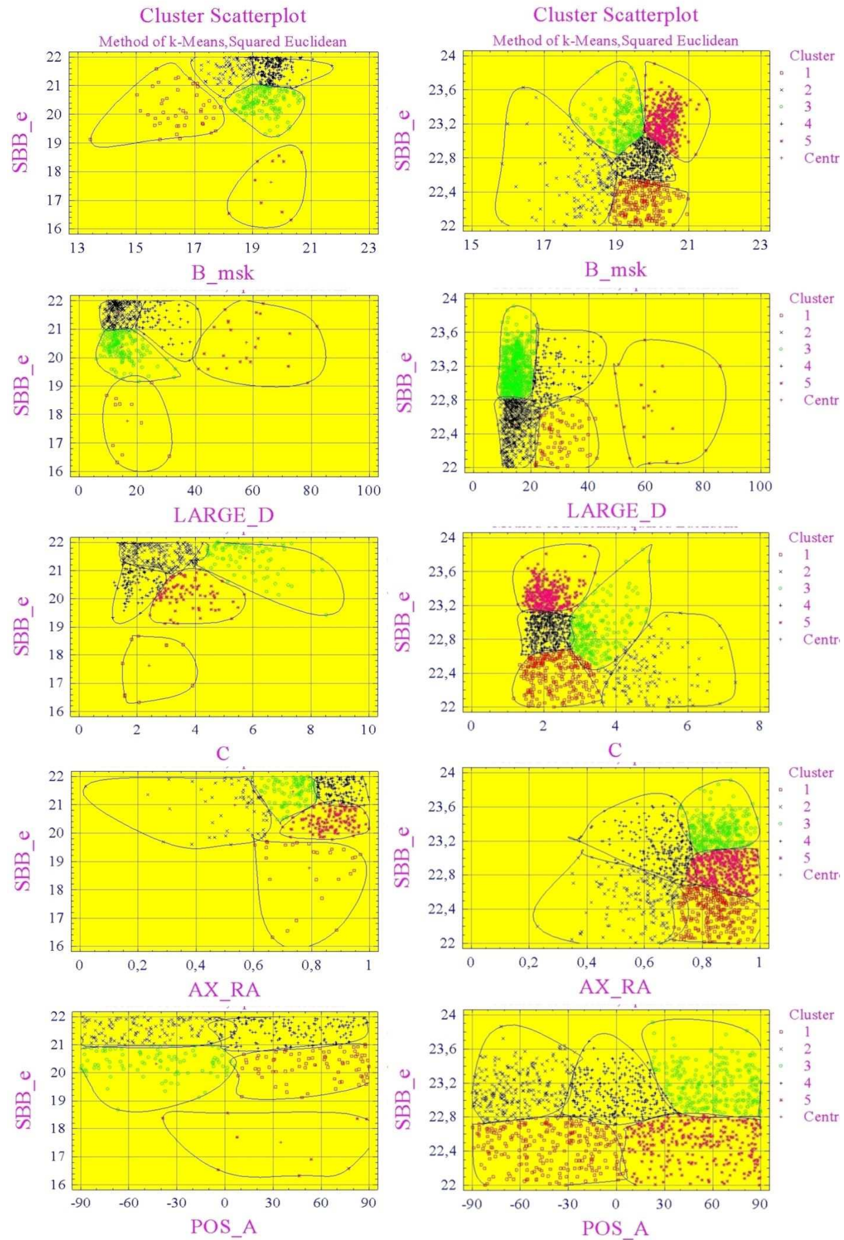

Fig. 7. Cluster analysis of: Surface Brightness against Total magnitude, Diameters, Index of Concentration, Axis Ratios and Position angle distributions for HSBG (right panels) and LSBG (left panels)

The number counts of galaxies as a function of magnitude is one of the classical cosmological tests. We did it for our data and the result is plotted on the upper right panel of Fig.6. Galaxy number counts are shown in 0.5 mag bins. The errors bars correspond to Poisson noise. The line in Figure shows a fit to the galaxy counts-magnitude relation expected in a homogeneous universe assuming Euclidean geometry for three-dimensional space. The observed galaxy counts are quite consistent with this line for $17^m \leq B \leq 20^m$ and even fainter up to B=20.5 mag. It means that we have complete data up to this magnitudes. With our data we found big excess of bright galaxies ($B<17.0^m$).The histogram of the magnitude distribution is shown on the upper left panel on the same figure. The lower panel shows the relations between the effective surface brightnesses and the integrated magnitude and the effective surface brightnesses and major diameter of galaxies.

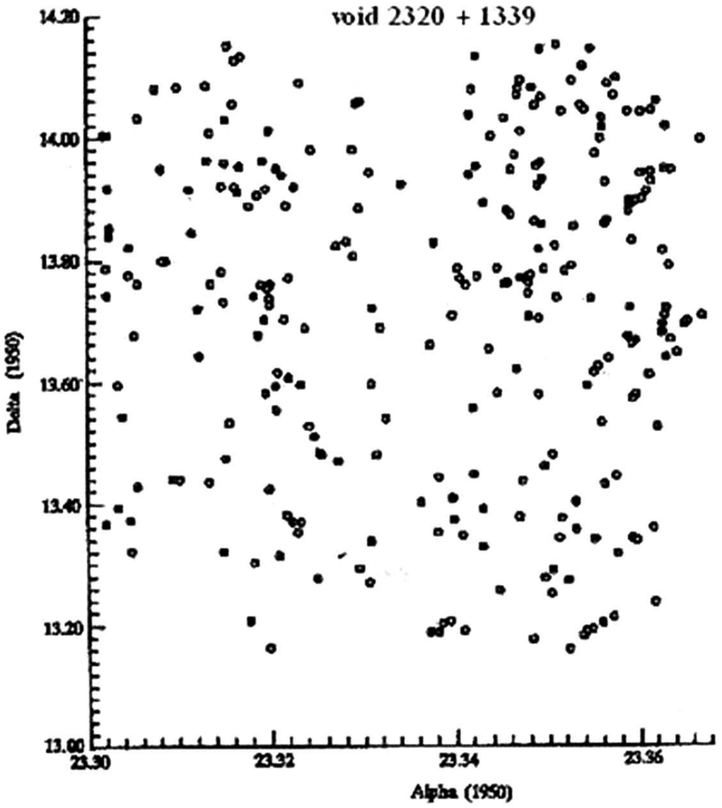

Fig. 8. Distribution of galaxies in the direction of the void 2320+39

Cluster analysis: Data Mining - this is the process of determination of new or unknown objective laws or regularities in the raw data. A popular data mining technique involves the construction of decision trees, based on decision rules which define a partition of a dataset by splitting on key variables. Cluster analysis is an exploratory data analysis tool for solving classification problems. Multivariate statistics are briefly reviewed in an astronomical context by Feigelson & Babu (2003) and are more thoroughly described by Murtagh (2002).

As a result of cluster analysis of surface brightness, magnitudes, diameters, concentration index, position angles and axis ratio of the galaxies, one can split all the objects in two main groups - 463 High Surface Brightness Galaxies (HSBG) - i.e. $SBB_{eff} \geq 22.0$ mag arcsec^{-2} and 1388 Low Surface Brightness Galaxies (LSBG) - i.e. SBB_eff<22.0 mag arcsec^{-2}.

On the Fig.7 results from the cluster analysis – the dependences of effective surface brightness from Index of concentration is presented. While by K_means and Ward's methods the groups of E/S0 galaxies is well outlined (C $\sim$5.5), SB–Sd galaxies (C $\sim$ 2.3) even grouped well by K_means clustering, are mixed amongst different surface brightness.

5. Void 2320+1339

Only a part of this large void was investigated. Here we present the distribution of galaxies measured in on 1x1 sqr.deg. field (see tab.1) - Fig.8 (Petrov et al., 1994).

Conclusion

1. Astrometric and photometric parameters for ca. 6000 galaxies are determined
2. A big excess of bright galaxies (B<17.0^m) co. to the galaxy counts-magnitude relation expected in a homogeneous universe assuming Euclidean geometry for three-dimensional space in Hercules void was found.
3. Cluster analysis method for morphological classification of galaxies and HSB_group , LSB_ group separation is presented.
4. A method for selecting of so-called giant LSB was tested and presented.

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