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ASTRONOMIE

Monte Carlo Simulations Of The Distribution Of Galaxies In The Direction Of Hercules Void (1600 +18)

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The intention of this paper is to compare the real and simulated distribution of galaxies in direction of Hercules Void (coordinates Alpha-Delta 1600 +18) and to check if there is a substructure of any significance in this distribution. For this purpose Monte Carlo simulations and Lee statistics were used.

Observations. Three plates were taken of the void 1600 +18 with the 2-m RCC telescope at NAO Rozhen in 1991 – two blue and one red – in relatively good observing conditions, seeing 1.5 arcsec approximately. Plate No 1830 with deepest limiting magnitude was measured as basic and second blue plate was used as a control one. All three plates were measured using GLAREX XY machine in MPIA – Heidelberg, Germany. SAO standard stars were used as primary standards using program OVERLAY on VAX. As a second standard 67 stars were measured in the region of 1×1 sq. deg. around the center of the plate. AMETRY program was used to estimate parameters of the plates and coordinates of measured objects. Resulting difference between coordinates of objects are not more than 1-2 arcsec. In "A Catalogue of Principal Galaxies" [1] there are only 21 galaxies in this field. On the POSS plate we found 225 objects and on plate No 1830 we identified 1835 objects. Position angles of galaxies were measured with accuracy up to ≈5 deg. Objects near the edge of the plate were not included. Simple statistic of these galaxies is presented in Table 1.

Theory. We used a statistical method based on the maximum likelihood for the determination of substructure in distribution of galaxies. This method is described in details in Fitchet [2] and is presented here in brief. It is based on Lee statistics [3]. Galaxies are allocated to the relevant subgroup and statistical significance is assigned to the splitting. It is shown that this method is very powerful for the analysis of two-dimensional data.

Lee' s method searches through all the contiguous partitions. Basically the data is projected on to a line, a

Table 1. Statistics of galaxies measured on plate No 1830

Diameters	Luminosity	Morphology
1 - 90	B - 369	R - 1078
2 - 807	N - 610	L - 501
3 - 539	L - 836	I - 232
4 - 243	? - 13	S - 115
5 - 138		? - 16
? - 11		

Remark: Diameters: 1<1.9, 2<3.6, 3<5.4, 4<5.7, 5>5.7 arcsec. Luminosity: B-bright, N-normal, L-low. Morphology: R-ring, L-lens, I-irregular, S-spiral.

measure of clumping is evaluated and the line is rotated in the *p*-dimensional space of observations. This procedure is repeated over and over again and one searches for the line that maximizes the degree of clumping in the projected data. This procedure is exactly equivalent to the likelihood ratio test and computation requirements are much more reasonable.

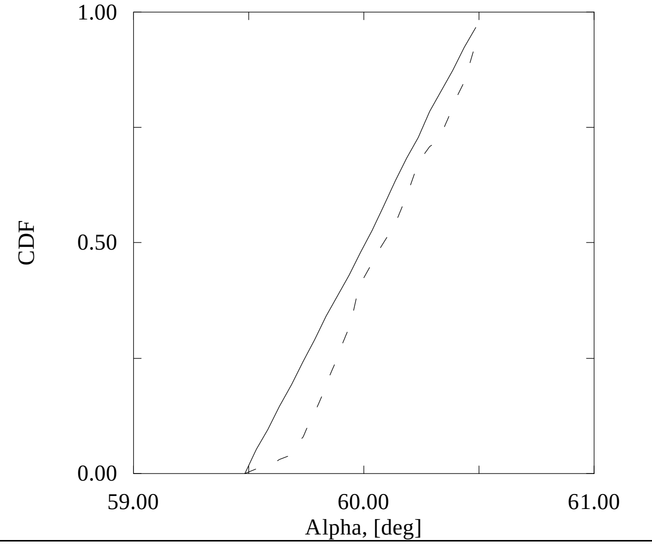
The procedure gives a function $L(\phi)$ where ϕ is the angle between the line on to which the data is projected and the horizontal ($\phi=0$). This function $L(\phi)$ can be plotted against ϕ and the angle at which the maximum occurs, ϕ_{max}, defines the line along which structure may be significant. The maximum separation along this line corresponds to the most likely dividing point between any structure present.

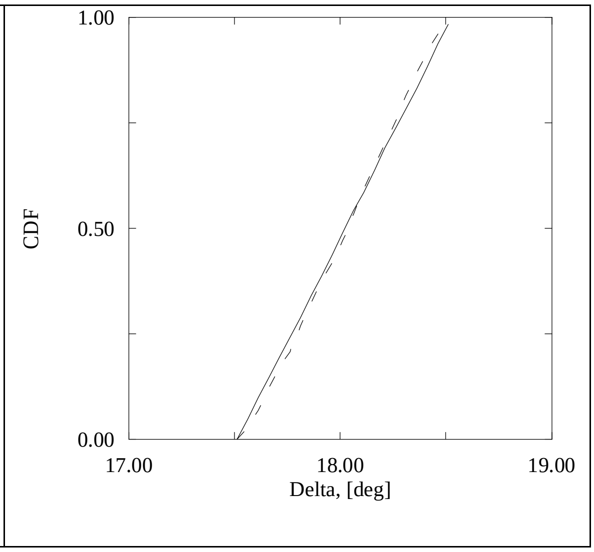
Calculations. We used Monte Carlo simulation method described in [4] to generate 1728 points randomly and uniformly distributed in the range $x, y \in [0, 15\,000]$. This interval is because of the following: the dimensions of the plate with objects is 30×30 cm. With resolution ≈20 μm we have ≈15 000 points. This makes a picture that represents a plate of 1×1 sq. deg. with randomly and uniformly distributed objects. It includes position angles and coordinates and is used to be compared with the real one. The necessary programs were written in Turbo Pascal 5.5.

Table 2. Lee-function for the galaxies measured on Plate No 1830 and for the Monte Carlo simulations

ϕ [deg]	L (Plate)	L (Monte Carlo)
0	2.9988	2.9531
10	2.8432	2.7831
20	2.6228	2.495
30	2.3833	2.2238
40	2.298	2.0245
50	2.3072	2.0391
60	2.3395	2.3019
70	2.5877	2.7058
80	2.7344	3.048
90	2.8259	3.1624
100	2.6383	3.0444
110	2.5323	2.7506
120	2.4212	2.389
130	2.2485	2.1507
140	2.1677	2.1755
150	2.2712	2.3483
160	2.5208	2.6242
170	2.8122	2.887
180	2.9988	2.9531

Cumulative distribution functions for belonging to the same extraction in distribution of Position Angles, Alpha and Delta are shown on Fig.1a, 1b, 1c.





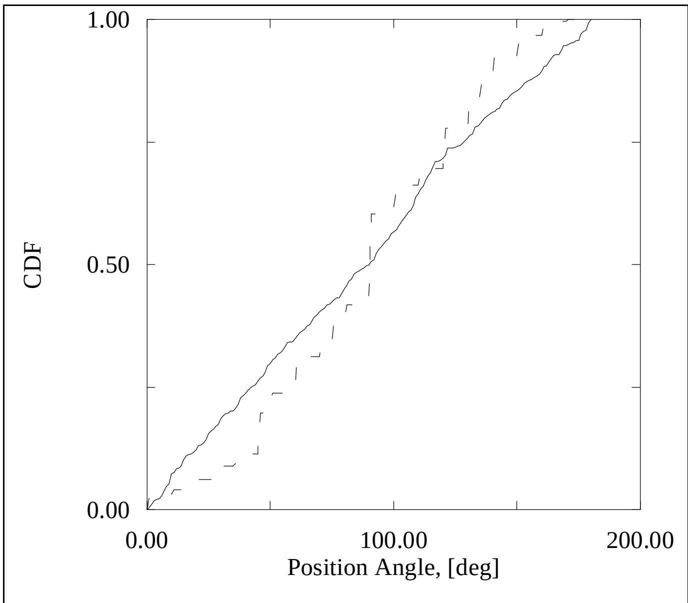


Fig. 1(a) Cumulative Distribution Function of Alpha for Monte Carlo simulated field (solid line) and for Plate No 1830 (dashed line)
Fig. 1(b) Cumulative Distribution Function of Delta for Monte Carlo simulated field (solid line) and for Plate No 1830 (dashed line)
Fig. 1(c) Cumulative Distribution Function of Position Angles for Monte Carlo simulated field (solid line) and for Plate No 1830 (dashed line)

Results to applying Lee-function for finding a statistically significant substructure for the plate data and for the Monte Carlo simulated galaxies are presented in Table 2 and plotted on Fig. 2.

Discussion: Distribution of coordinates is random and uniform and this is well seen on Fig.1(a) and 1(b). Maximum deviation in Alpha is 0.0613426 and in Delta 0.163194. Both distributions – real measured and randomly generated – are from identical statistical extraction. It looks as if there is a small null-point difference in measured and generated coordinates. This is well seen on both figures and does not influence the main conclusion.

Randomly calculated and really measured distributions of position angles are also from identical extraction. This is seen on Fig.1(c). There is a change of sign at the point PA=90° – it is an artificial effect: some orientations may be more preferable when viewed and measured by eye. So observed position angles of galaxies measured in Hercules Void are randomly distributed in space.

The same result is also seen in Table 2 and on Fig. 2. Comparing the Lee function for the Monte Carlo

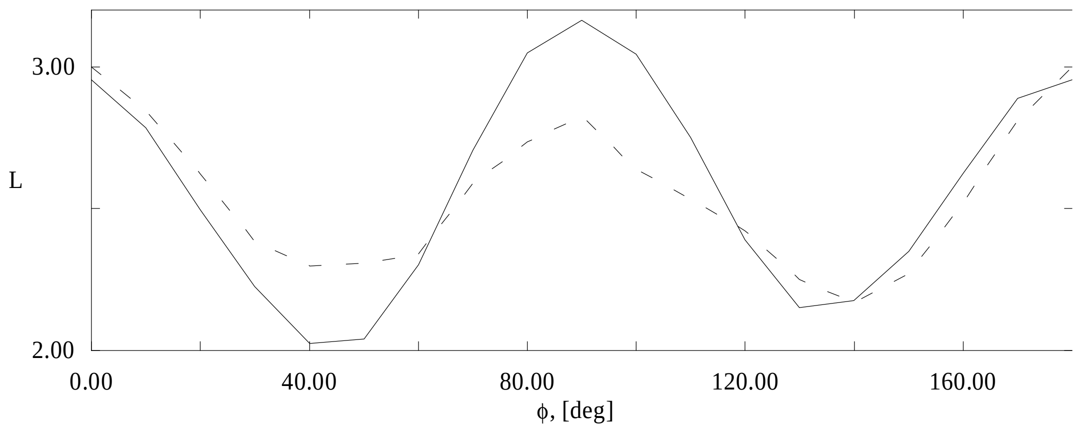


Fig. 2 Lee-function for Monte Carlo simulations (solid line) and for the galaxies measured on Plate No 1830 (dashed line)

simulated points and for the real galaxies we see that there is not a great difference between them. The shape of the function is the same – in both cases there is no substructure of any significance. So the galaxies are randomly distributed – there is no significant substructure in *2D* distribution. This is also seen from the approximate constancy of the Lee function on Fig. 2.

The main result of this paper is: *coordinates alpha-delta and position angles of galaxies observed in Hercules Void (1600 +18) are randomly and uniformly distributed in 2D space that is there is no evidence for a substructure of any kind in the investigated region.*

References:

[1] Paturel G., Fouque P., Bottinelli L., Gouguenheim L., A Catalogue of Principal Galaxies. [2] Fitchet, M., MNRAS, 1988, v.230, 161-181. [3] Lee, K.L., 1979, J. Am. Statist. Ass., v.74, No.367, 708. [4] Random Number Generators: Good Ones Are Hard To Find, Park and Miller, Communications of the ACM, Oit 1988, Vol.31, No 10, 192.

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