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NEW PROCESSING OF SURFACE PHOTOMETRY OF MARKARIAN GALAXIES. I

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Numerical methods for processing of the surface photometry of galaxies consisting of smoothing, filtering and computation of two-dimensional correlation functions are given. Methods are adapted for the application to the photometry of Markarian galaxies. A new processing of published data for the galaxies Mrk 7, 8, 10, 11, 12, 13, 185, 186 and 190 has begun and some illustrative results are given. Results of the surface photometry of Mrk 10 for a diaphragm of $3\overset{''}{.}5\times3\overset{''}{.}5$ are presented.

1. *Introduction*. In this and in a forthcoming papers we are considering a new processing of the surface photometry of some Markarian galaxies. The interest in these galaxies is not decreasing and now a large amount of diverse observational material has been already accumulated. Regardless of the observations, many astrophysical peculiarities of Markarian galaxies are still enigmatic. But our aims are much simpler namely to apply numerical methods for processing the surface photometry of Markarian galaxies. The new information should offer a possibility to find some photometric and structural peculiarities.

We are treating nine galaxies from the first two lists of Markarian [1, 2] — Mrk 7, 8, 10—13, 185, 186 and 190, the surface photometry of which has been published by Börngen and Kalloghlian [3—5] and Börngen, Kalloghlian and Eghikian [6, 7].

Two essentially different methods have been applied to the surface photometry. The first one contains general ideas of smoothing and filtering of time series and of discrete two-dimensional (2—D) fields, which ideas have been adapted to the problem of clustering of galaxies and clusters of galaxies by Kalinkov [8, 9]. The second method offers a possibility to determine 2—D correlation functions and it is described by Kalinkov [10—13]. Both methods enable us to obtain new information for the apparent (2—D case) and for the space (3—D case) distribution of galaxies and clusters of galaxies, e. g. [8, 10—12, 14—16]. There is no reason why both methods should not work well for the case of surface photometry of Markarian galaxies as well.

In this first part of our study we give some basic data for the nine Markarian galaxies, a new photometry of Mrk 10, adapted versions of the methods which are used, and a few illustrations of the new processing. In the second part we shall give the results and the discussion.

2. *Data.* The surface photometry on Schmidt plates, taken with the two meter Tautenburg telescope, was used. The scale of the plates is 51″ mm^{-1}. The measurement method is described in [3], where the relations between Tautenburg and the standard UBV system are given. The photometry for Mrk 185, 186 and 190 is three-colour and for the rest six galaxies is four-colour, *UBVR*, as *R* is very near to the *R* of the Becker system.

Some data for the nine Markarian galaxies are listed in Table 1. The first two columns contain cross-identification among the lists of Markarian and of Zwicky [18], by NGC and IC, and according to [19] and [20]. The coordinates are from Peterson [21]. The type *T* of the galaxies is in the de Vaucouleurs system — by RC2 [22]. The morphological type is according to Kalloghlian [23], Börngen and Kalloghlian [24] and Huchra [25]. Further on are m_p — Zwicky magnitudes, V_H — Huchra *V* magnitudes and V_{BK} — integral *V* magnitude obtained in [3—7] for sizes $(D \times d)_{BK}$. For comparison we give $(D \times d)_{RC2}$, calculated from [22], which are isophotal sizes, measured at or reduced to surface brightness level $\mu_B = 25.0$ mag sec^{-2}. The major and minor axes from RC2 are very near to the corresponding axes in [20]. The radial velocity V_0 is corrected for the solar motion and is mainly from [22]. For Mrk 10 and 13 the radial velocity is according to Weedman [26] and Feldman et al. [27]; for Mrk 190, data from [27] and [28], together with RC2 are used. (In the catalogue [20] V_0 for U 04093 = = Mrk 13 is in error). The last column of Table 1 contains the linear size, corresponding to 10″ at the distance of the galaxies determined from V_0 with a Hubble constant $H_0 = 100$ km s^{-1} Mpc^{-1}. A square diaphragm of 5″ × 5″ in the series of papers is used. Therefore, applying the procedures of smoothing and filtering we are unable to say something for all characteristic lengths $l < l_{10''}$, since $l_{10''}$ is in fact the Nyquist scale length.

A new surface photometry has been carried out especially for Mrk 10 with a diaphragm of 3.″5 × 3.″5. The corresponding Nyquist

Table 1

MRK Zw N, I	MCG U	α (1950) δ	T	Type	m_P V_H	V_{BK}	D×d (BK)	D×d (RC2)	V_0 km s^{-1}	$l_{10''}$ kpc
7 7 Zw 153	12– 7–38 U 03838	$7^h22^m18^s.7$ +72°40′24″		Im	13.9 14.48	14.39	42″×30″	59″×25″	3251	1.6
8 7 Zw 156 I 2184	12– 7–41 U 03852	7 23 38.5 +72 13 50		Im	13.8 14.21	14.00	48 ×30	76 ×64	3628	1.8
10	10–11–138 U 04013	7 43 07.4 +61 03 23	3	SBbc (Sy)	14.0	13.70	60 ×36	122 ×53	8750	4.2 (3.0)
11	12– 8–11 U 04014	7 43 17.0 +74 27 30	–3	SBc S0	14.4	14.56	30 ×18	76 ×39	4056	2.0
12	12 – 8–13 U 04028	7 44 41.0 +74 29 06	5	Sc	12.7 12.82	13.09	54 ×54	79 ×66	4233	2.0
13	10–12–17 U 04093	7 51 56.8 +60 26 17	3	SBb	14.5 14.15	14.57	36 ×36	69 ×59	1630	0.8
185 N 3811	8–21–91 U06650	11 38 36.0 +47 58 13	6	SB (r) b SBcdp	13.0 12.70	12.81	54 ×54	144 ×112	3121	1.5
186 N 3870	8–22– 1 U 06742	11 43 16.9 +50 28 43	–2	SB0/a	13.2 13.25	13.40	30 ×24	77 ×61	790	0.4
190 N 3928	8–22–19 U 06834	11 49 10.1 +48 57 34	–5	S0 S0/E	13.1 12.89	12.88	42 ×42	107 ×107	1051	0.5

scale length $l_{7''}$ is also given in Table 1 (last column, in parenthesis). The *UBVR* surface photometry is presented in Table 2 in the same manner as in [3—7].

3. *Gaussian Smoothing and Filtering of 2—D Discrete Fields.* Let us have a table, like the Table 2, consisting of surface photometry data. Let us extend the table up to a rectangular of dimension $m \times n$, without rejection of any of the data. We use a matrix designation and we regard the element d_{ik} representing the surface brightness or the colour in a square, located at the i-th row and the k-th column of the extended table. For example, for Table 2 we have $m = 14$, $n = 26$. We shall apply 2—D Gaussian (or normal) smoothing functions (SFs) and filtering functions (FFs), which have radial symmetry supposing $\sigma_x = \sigma_y$. These functions are approximated by square discrete fields of dimension $(2r+1) \times (2r+1)$. Denoting the common element of an SF or an FF with w_{pq}, we have

$$\sum_{p=-r}^{r} \sum_{q=-r}^{r} w_{ik} = \begin{cases} 1 \text{ for any SF} \\ 0 \text{ for any FF.} \end{cases} \tag{1}$$

The smoothed or the filtered estimate $\tilde{d}_{ik}$ instead of d_{ik} is obtained by the formula

$$\bar{d}_{ik} = \sum_{p=-r}^{r} \sum_{q=-r}^{r} w_{pq} d_{i+p,\, q+q}, \tag{2}$$

$$i = r+1,\ r+2, \dots,\ m-(r+1),$$

$$k = r+1,\ r+2, \dots,\ n-(r+1).$$

But the estimate (2) is not applicable to those d_{ik} elements, for which there is no surface photometry. Besides, (2) leads to a decrease of the dimension of the smoothed or filtered field, which evidently has to be $(m-r) \times (n-r)$. To avoid these troubles we introduce an indicative field, defined as

$$z_{ik} = \begin{cases} 1 \text{ when the element } d_{ik} \text{ is measured,} \\ 0 \text{ otherwise,} \end{cases} \tag{3}$$

and extend the fields d_{ik} and z_{ik}, where the new indices are

$$\begin{aligned} i' &= 1, 2, \dots, r,\ r+1, \dots,\ r+m,\ r+m+1, \dots,\ 2r+m, \\ k' &= 1, 2, \dots, r,\ r+1, \dots,\ r+n,\ r+n+1, \dots,\ 2r+n \end{aligned} \tag{4}$$

or, which is the same,

$$i' = 1, 2, \ldots, r, r+i, r+m+1, \ldots, 2r+m, \text{ for } i = 1, 2, \ldots, m,$$
$$k' = 1, 2, \ldots, r, r+k, r+n+1, \ldots, 2r+n, \text{ for } k = 1, 2, \ldots, n. \quad (5)$$

However, for the extended parts of the field d_{ik} we shall have

$$z_{i'k'} = 0 \text{ for } \begin{cases} i' = 1, 2, \ldots, r; \ r+m+1, \ldots, 2r+m \\ k' = 1, 2, \ldots, r; \ r+n+1, \ldots, 2r+n \end{cases} \quad (6)$$

and for the original part

$$z_{i'k'} = \left.\begin{cases} 1 \text{ for measured} \\ 0 \text{ for non-measured} \end{cases}\right\} \text{elements, } \begin{matrix} i' = r+i; \ i = 1, 2, \ldots, m \\ k' = r+k; \ k = 1, 2, \ldots, n. \end{matrix} \quad (7)$$

Thus, the basic formula for the smoothed or the filtered estimate instead of d_{ik} will be given by

$$\tilde{d}_{i'k'} = \left(\sum_{p=-r}^{r} \sum_{q=-r}^{r} w_{pq} d_{i'+p,\, k'+q} z_{i'+p,\, k'+q} \right) \Big/ \left(\sum_{p=-r}^{r} \sum_{q=-r}^{r} w_{pq} z_{i'+p,\, k'+q} \right) \quad (8)$$

$$\text{for } i' = r+i; \ i = 1, \ldots, m,$$
$$k' = r+k; \ k = 1, \ldots, n.$$

Let us note that the estimates $\tilde{d}_{ik}$ for the corner elements, namely for $i, k \leqslant r$; $m-i, k \leqslant r$; $i, n-k \leqslant r$; $m-i, n-i \leqslant r$ are not good, since for their calculation a small number of weights, $\leqslant (r+1)^2$, instead of $(2r+1)^2$, are used. In general, the smoothed or filtered elements in the edge zone of the field d with a width up to r are not representative but, nevertheless they yield some information for the field structure.

We do not give here Gaussian SFs, which are used in our study. The entire SF is further denoted as [0.5].

The frequency response of a SF supplies information for the amplitude of a wave with given frequency f (or scale length $L = 1/f$) after passing through the SF. The responses of $2-D$ SFs are $2-D$ functions as well, but we shall present the responses as $1-D$ functions, because only cross-sections of circular $2-D$ Gaussian SFs will be examined. It is thus possible to plot many frequency responses on one Figure. Therefore, the response of a Gaussian SF may be written as

$$R_s(L) = \exp(-2^s a/L), \quad (9)$$
$$s = 0, 1, \ldots$$

where, let us emphasize, L is the scale length, or wave number for the $2-D$ case. Putting $a = 2(0.25\,\pi)^2$ we have for $s = 0$ the response of

	42"	38.5	35	31.5	28	24.5	21	17.5	14	10.5	7	3.5	0"
21"					24.96 −0.89 — —	24.63 — 0.86 0.17	24.29 −0.53 0.54 0.32	24.61 — 0.99 0.47	23.98 — 0.53 —	24.71 −1.41 1.02 0.37	— — — —	24.94 — 1.37 —	24.88 — — —
17.5			24.64 — 0.75 0.60	24.32 — 0.50 0.47	23.98 — 0.50 0.36	24.20 — 0.70 0.21	24.06 −0.55 0.76 —	24.37 — 0.98 0.26	24.06 — 0.85 0.23	24.52 — 1.16 0.29	23.91 0.11 0.52 0.09	23.94 −0.32 0.66 0.03	23.94 −0.47 0.82 0.00
14		24.61 — 0.86 0.37	24.28 −0.27 0.80 0.45	24.17 −0.37 0.82 0.40	24.00 −0.39 0.42 0.71	24.00 −0.29 0.69 0.33	24.05 −0.01 0.80 0.20	24.43 — 1.33 0.27	24.41 — 1.27 0.20	24.19 −0.12 1.18 0.15	23.57 −0.20 0.28 0.26	23.58 −0.28 0.52 0.15	23.66 −0.26 0.70 0.05
10.5	24.30 — — —	23.68 −0.20 0.21 0.35	23.63 0.07 0.44 0.05	23.58 0.17 0.63 0.02	23.77 0.20 0.55 0.10	24.18 −0.11 0.93 0.34	23.76 — 0.72 0.10	23.85 0.39 0.97 0.17	23.66 0.19 0.76 0.38	23.23 0.44 0.68 0.00	23.19 0.05 0.58 0.13	23.06 −0.11 0.60 0.30	23.02 −0.06 0.70 0.23
7	24.55 — 0.85 —	24.06 — 0.78 —	23.74 — 0.42 0.39	24.02 — 0.70 −0.02	23.56 — 0.50 0.55	23.47 0.26 0.62 0.28	23.11 0.23 0.60 0.22	22.81 0.07 0.60 0.27	22.62 0.13 0.62 0.28	22.65 0.11 0.72 0.23	22.49 0.11 0.67 0.30	22.43 0.02 0.63 0.12	22.38 0.09 0.64 0.23
3.5		24.41 — 0.95 —	24.23 — 1.02 0.08	24.16 — 1.06 —	23.72 0.25 0.72 0.19	23.08 −0.02 0.55 0.52	22.54 −0.07 0.51 0.35	22.39 0.19 0.67 0.30	22.27 0.30 0.76 0.13	22.18 0.38 0.86 0.29	21.93 0.16 0.94 0.19	21.62 0.04 0.44 0.37	20.97 −0.28 0.46 0.29
0"		24.40 — 0.79 —	23.97 — 0.51 0.23	24.07 −0.28 0.96 0.10	23.78 −0.16 1.08 0.03	23.22 0.10 0.90 0.32	22.77 0.12 0.72 0.25	22.64 0.02 0.95 0.14	22.20 0.38 0.83 0.14	22.05 0.78 0.89 0.29	21.77 0.33 1.01 0.25	20.55 −0.22 0.33 0.55	19.23 −0.75 0.37 —
3.5			— — — —	24.15 — 1.19 0.23	24.03 — 1.17 −0.05	23.80 −0.58 1.05 0.08	22.91 0.10 0.69 0.16	22.58 0.00 0.74 0.14	22.48 0.16 0.78 0.14	22.35 0.20 0.82 0.23	22.20 −0.05 1.01 0.21	21.58 −0.18 0.83 0.25	20.89 −0.26 0.68 0.34
7			24.45 — 0.97 —	23.85 −0.34 0.85 0.02	23.76 0.06 1.00 0.03	24.06 −0.10 1.02 0.17	23.73 0.31 0.88 0.41	23.53 −0.39 1.15 0.28	23.01 0.03 0.86 0.20	22.67 −0.15 0.78 0.14	22.50 0.11 0.75 0.06	22.50 0.07 0.88 0.05	22.51 0.03 0.84 0.21
10.5				24.01 — 0.48 —	23.93 — 0.86 0.33	24.01 — 0.88 0.18	23.87 — 0.69 0.44	23.69 0.23 0.79 0.32	23.77 0.01 1.04 0.51	23.29 −0.29 0.91 0.32	23.16 −0.07 0.91 0.07	23.17 0.11 0.91 0.25	23.17 −0.02 0.88 0.10
14							24.39 — 0.84 —	24.17 −0.16 0.65 0.19	24.05 0.18 0.93 —	23.77 0.34 0.75 0.18	24.02 −0.04 0.82 0.09	23.69 0.18 0.64 −0.02	23.54 — 0.70 0.01
17.5							24.72 — 0.69 —	24.46 — — —	24.30 — 0.30 —	24.41 — 0.53 —	24.32 — 0.36 —	24.39 −0.49 0.77 0.49	23.98 — 0.49 0.25
21													
24.5"													

Table 2

AND U—B, B—V AND V—R COLOURS FOR MRK 10

3″.5	7	10.5	14	17.5	21	24.5	28	31.5	35	38.5	42	45″.5
24.23	24.21	24.17	24.72									
—	−0.64	—	—									
0.27	0.71	—	—									
0.19	—	—	—									
23.89	23.98	23.74	23.82	24.57								
−0.48	−0.39	−0.45	−0.47	−0.88								
0.73	0.63	0.42	0.22	—								
0.20	0.16	0.48	0.45	—								
23.69	23.56	23.07	22.95	23.10	23.67	24.04	24.32					
−0.37	−0.65	−0.34	−0.22	−0.33	−0.29	—	—					
1.02	0.83	0.20	0.31	0.12	0.46	0.67	—					
0.04	−0.07	0.33	0.21	0.33	0.13	—	—					
23.10	22.94	22.94	23.03	22.77	22.76	23.52	24.31	24.58	24.60			
0.18	0.14	−0.77	0.08	−0.09	−0.09	0.34	—	—	—			
0.79	0.60	1.56	0.61	0.48	0.48	0.84	1.04	0.66	0.95			
0.32	0.22	0.23	0.03	0.15	0.21	0.06	—	—	—			
22.49	22.54	22.72	22.80	23.01	22.58	22.73	23.16	24.36	—	24.35	—	24.54
0.21	0.28	0.07	0.12	−0.17	−0.02	−0.26	−0.27	−0.44	—	—	—	—
0.77	0.64	0.73	0.70	0.60	0.30	0.48	0.50	1.11	—	0.62	—	0.88
0.12	0.16	0.09	0.07	0.17	0.17	0.07	−0.02	0.18	0.32	—	—	—
21.57	22.13	22.19	22.30	22.81	22.64	22.57	23.36	24.15	24.51	24.45	23.98	24.16
0.53	0.35	0.19	0.12	0.03	0.00	0.14	−0.45	—	—	—	—	—
0.63	0.94	0.85	0.62	0.76	0.52	0.61	0.72	0.82	0.66	0.46	0.24	0.77
0.24	0.14	0.16	0.29	0.23	0.42	0.21	0.23	0.44	0.53	0.54	—	—
20.49	22.00	22.18	22.12	22.78	22.70	22.93	23.27	23.91	24.25	23.83	23.88	24.44
−0.19	0.26	0.28	0.35	0.01	0.10	−0.17	0.08	—	—	—	—	—
0.42	1.06	0.96	0.73	0.99	0.72	0.83	0.66	0.76	1.02	0.38	0.45	0.69
0.21	0.22	0.30	0.32	0.28	0.21	0.16	0.03	−0.02	—	0.24	0.18	—
21.46	22.28	22.43	22.63	23.13	22.92	23.13	23.68	23.66	23.95	23.51	23.60	24.58
0.42	0.01	0.26	0.29	0.12	0.07	−0.04	0.10	—	0.00	0.10	0.15	—
0.78	0.94	0.83	0.78	1.15	0.56	0.77	0.91	0.78	0.90	0.54	0.44	0.86
0.27	0.18	0.15	0.23	0.07	0.03	0.02	0.05	0.19	0.10	0.02	0.01	—
22.70	22.74	23.18	23.23	23.60	23.55	23.46	23.64	23.62	23.93	23.77	24.22	
0.08	0.19	0.33	0.71	−0.06	0.36	0.39	0.22	—	−0.20	—	—	
0.89	0.78	0.91	0.58	1.00	0.95	0.57	0.48	0.48	0.79	0.26	0.62	
0.12	0.10	0.02	0.30	0.38	−0.01	−0.07	0.00	−0.02	0.09	0.39	—	
23.43	23.40	23.54	23.29	23.52	23.27	23.47	23.67	23.99	24.06	24.25		
−0.42	−0.13	0.11	0.79	0.24	0.15	—	—	—	0.02	—		
0.92	0.76	0.97	0.35	0.58	0.46	0.42	0.77	0.67	0.82	0.54		
0.25	0.29	0.19	0.16	0.44	0.11	0.20	0.08	—	—	—		
23.68	23.99	23.84	23.80	23.54	23.75	23.79	23.82	24.82				
—	0.10	−0.32	0.10	0.50	—	—	—	—				
0.70	1.00	0.78	0.81	0.53	0.86	0.38	0.37	1.32				
0.06	0.15	0.05	0.21	0.15	1.01	0.15	0.18	—				
24.27	24.37	24.10	23.87	23.82	23.82	24.04	24.25					
—	—	—	−0.41	−0.22	0.39	—	—					
0.87	1.35	0.78	0.92	0.80	0.96	1.00	0.85					
0.14	0.19	0.40	0.11	0.16	−0.03	0.00	0.09					
	24.38	24.28	24.19	24.18	—	23.70						
	—	—	—	—	—	—						
	0.30	0.42	0.80	1.43	—	1.08						
	—	—	—	0.00	—	0.09						
			24.69	24.43	—	24.33						
			—	—	—	—						
			—	0.87	—	1.17						
			—	—	—	—						

our generating SF; for $s = 0, 2, 4, 6,$ the SFs are denoted as [0.25], [0.5], [1,2]. The responses by (9) are normalized, because $R_s(\infty) \to +1$. All the responses for $s = 0, 1, 2, \dots, 6$ are presented on Fig. 1. The units of L are in observational intervals, while the scale lengths above are for diaphragms $5'' \times 5''$ and $3.''5 \times 3.''5$.

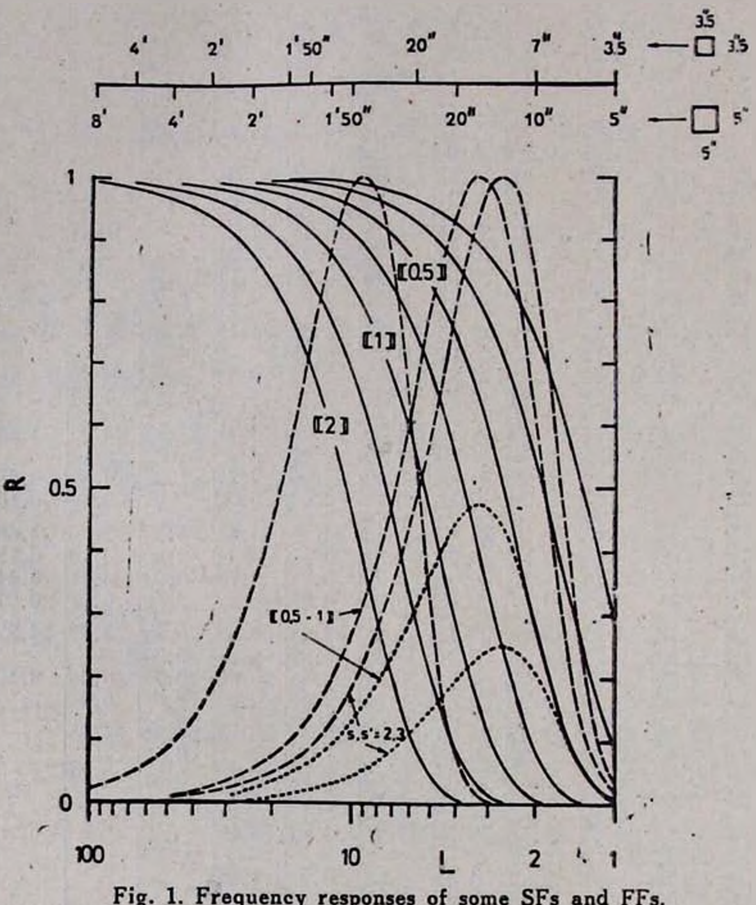

Fig. 1. Frequency responses of some SFs and FFs.

The operation filtration may be realized in two ways: (*i*) by consecutive application of two SFs on one and the same field and the filtered estimate is $\bar{d}_{ik} - \tilde{\tilde{d}}_{ik}$, where $\tilde{\tilde{d}}_{ik}$ is "the smoother" value: (*ii*) by one FF, the weights of which are the differences between the weights of two SFs.

Responses of some FFs are given also in Fig. 1. But generally, the responses are non-normalized because they are directly calculated by

$$R_{s,s'}(L) = \exp(-2^s a/L^2)] - \exp(-2^{s'} a/L^2). \quad s' > s. \tag{10}$$

The normalization we are accomplishing here is according to the point L^0 of maximum transmission, i. e. $\max R = R(L^0)$ where

$$L^0_{s,s'} = [a(2^s - 2^{s'})/\ln 2^{s-s'}]^{1/2}, \quad s' > s \tag{11}$$

and the normalized response of any FF will be given by

$$R(L) = R(L)/R(L^0). \tag{12}$$

Fig. 1 contains the normalized responses of FFs as well.

The scale lengths $L^0_{s,s'}$ for maximum transmission for diaphragm 5″ × 5″ are given in Table 3. If there is a need to construct a filtered map from surface photometry with the diaphragm 5″ × 5″, having maximum transmission around 16″, we have to apply the FF [0.5—1]. For diaphragm 3.″5 × 3.″5 all data in Table 3 must be multiplied by the factor 3.5/5 = 0.7. Using the last column of Table 1, it is easy to determine the true physical size (in kpc), which corresponds to the scale lengths from Table 3.

Table 3

SCALE LENGHTS $L^0_{s,s'}$ FOR MAXIMUM TRANSMISSION OF FFs. DIAPHRAGM 5″×5″

s \ s'	1	2	3	4	5	6
0	7″	8″	10″	13″	17″	22″
1		9	12	14	18	23
2			13	16	20	26
3				19	23	29
4					27	33
5						38

There are many other ways to smooth or filter the 2—D discrete fields — with exponents, polynomials, running means, medians..., which are in use in galaxy surface photometry. Nevertheless, the described procedure has some advantages: many possibilities to choose the desired SFs and FFs, easy and simple application and clear presentation of the corresponding frequency responses. However, a caution especially for the response plots is required, since the digital SFs and FFs have true responses, which slightly differ from the analytical expressions (9) and (12).

4. *Correlation Functions of 2—D Discrete Fields.* Let us take again the rectangular discrete field of a dimension $m \times n$, with elements d_{ik} and the corresponding indicative field z_{ik} by (3), $i = 1, \ldots, m$; $k = 1, \ldots, n$. We define the normalized autocorrelation function on the field of deviations from the mean, namely

$$c_{ik} = d_{ik} - \bar{d}, \tag{13}$$

where

$$\bar{d} = \sum_{i=1}^{m} \sum_{k=1}^{n} d_{ik} z_{ik} / \sum_{i=1}^{m} \sum_{k=1}^{n} z_{ik}. \tag{14}$$

Then

$$R(r) = \Big(\sum_i \sum_k c_{ik} z_{ik} c_{i+\Delta i, k+\Delta k} z_{i+\Delta i, k+\Delta k} \Big) \Big/ \Big/ \Big(\sum_i \sum_k c_{ik}^2 z_{ik} \sum_i \sum_k c_{i+\Delta i, k+\Delta k}^2 z_{i+\Delta i, k+\Delta k} \Big)^{1/2} \tag{15}$$

and there are three possible cases

$$\begin{aligned} &(i) && \Delta i = \Delta k = q, \quad r = q\sqrt{2}, \quad q = 1, 2, \ldots, \\ &(ii) && r = q = \begin{cases} \Delta i \text{ for } \Delta k = 0, \\ \Delta k \text{ for } \Delta i = 0, \end{cases} \quad q = 1, 2, \ldots, \\ &(iii) && r = (\Delta k^2 + \Delta i^2)^{1/2}, \quad \Delta i \neq \Delta k; \ \Delta i, \ \Delta k = 1, 2, \ldots \end{aligned} \tag{16}$$

All necessary formulae are given in [11—12], but without the indicative field, which is specially introduced for this paper. Actually the estimate (15) of the autocorrelation function $R(r)$ is a function of the shift r, which is defined not only at the integers but for $r = 0, 1, \sqrt{2}, 2, \sqrt{5}, \sqrt{8}, 3, \sqrt{10}, \ldots$ Naturally, $R(0) = +1$.

Moreover, the normalized autocorrelation function may also have a 2—D presentation, $R(\Delta k, \Delta i)$, depending on the components of the shift r on the axis X which is Δk, and on the axis Y which is Δi. Using the symmetry, $R(\Delta k, \Delta i) = R(-\Delta k, -\Delta i)$ and $R(-\Delta k, \Delta i) = R(\Delta k, -\Delta i)$, it is quite sufficient to plot the 2—D autocorrelation function on a semiplane, say for $\Delta i \geqslant 0$.

If we have two 2—D discrete fields altogether, or more precisely two different realizations of one field (e. g. surface photometry of Mrk 12 in B and V), it is possible to define a cross-correlation function. In this case the formulae are more complicated and they are given in [13], where two indicative fields are used. It is clear that there is no

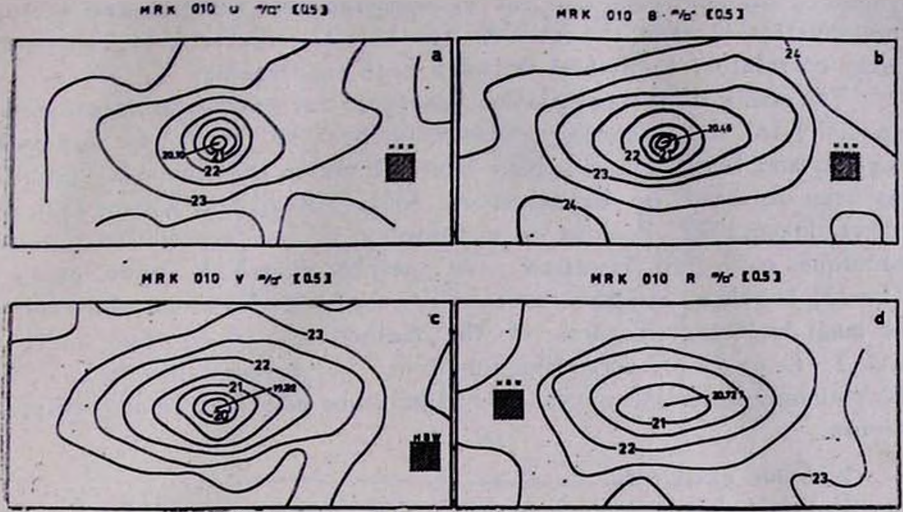

Fig. 2. Smoothed *U*, *B*, *V* and *R* maps for Mrk 010.

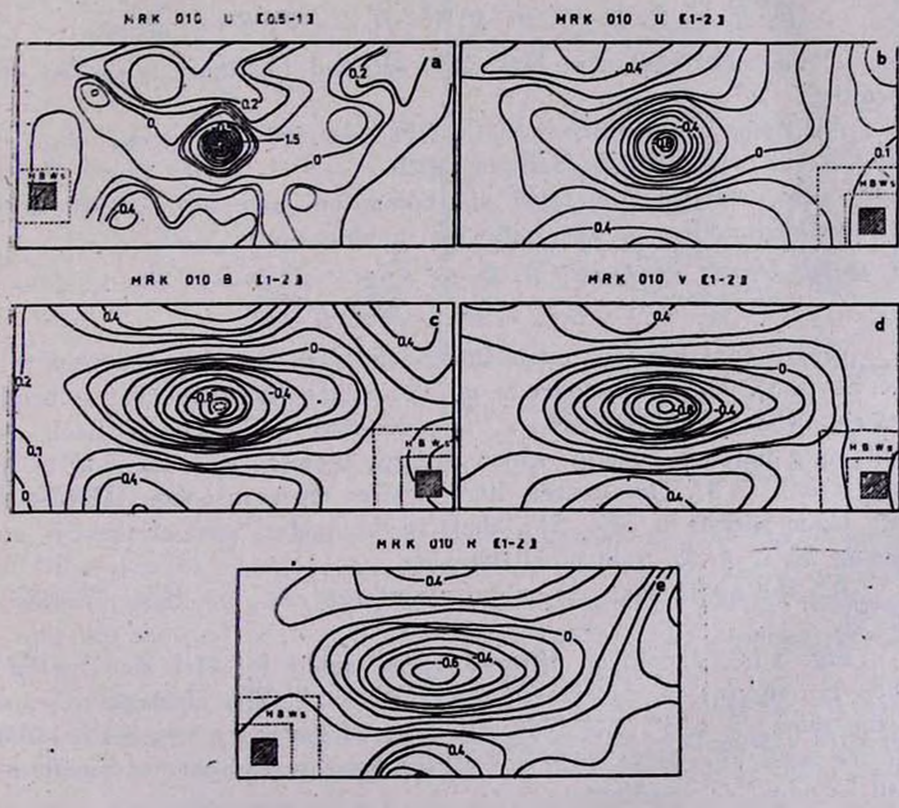

Fig. 3. Filtered *U*, *B*, *V* and *R* maps for Mrk 010.

symmetry for any values of the cross-correlation function and when a normalization is made, the estimate for $\Delta i = \Delta k = 0$ has to be the simple linear correlation coefficient between both realizations.

The using of the correlation functions for extragalactic problems, especially for the clustering problem, go back to the pioneer papers of Neyman and Scott [29, 30]. New informations on the clustering problem has been obtained by Karachentsev [31], Totsuji and Kihara [32] and others. From 1973, Peebles is developing a new correlation function technique, e. g. [33]. However, the method sketched above, given in [11—13], is unique in many respects. For the case of surface photometry, the most important features of the method are: (*i*) an opportunity to have 1—D or 2—D correlation functions; (*ii*) a possibility to calculate the standard deviation of R; (*iii*) to find some relations among different colours.

5. *Some examples.*

For each Markarian galaxy with $UBVR$ photometry we examine the following 2—D discrete fields:

$$U,\ B,\ V,\ R,\ U-B,\ B-V,\ V-R,\ U-V,\ B-R,\ U-R.$$

Let us remember that for Mrk 185, 186 and 190 there is no red photometry.

All fields are smoothed with SFs, defined with $s = 1, 2, \dots, 6$, and filtered with all FFs, defined with $s = 0, 1, \dots, 6$; $s' > s$. For all fields autocorrelation functions are computed, together with the cross-correlation functions of the following combinations:

$$U, B;\ B, V;\ V, R;\ U, V;\ B, R;\ U, R;\ U-B, B-V;\ B-V, V-R;$$
$$U-B, V-R;\ U-V, B-R.$$

Fig. 2 contains four maps for the Seyfert Mrk 10, smoothed with the SF [0.5]. The isophots are in $m/\square''$ and the smoothed central brightnesses, where the nucleus is, are denoted with arrows. Each map contains a hatched square, which is the elementary area and in this case it is $5'' \times 5''$. The dotted line square represents the HBW — the half beam width of the SF, that is the central part of the SF, containing 50 % of the sum of all weights.

All the maps have the same orientation as the basic Tables in [3—7].

Fig. 3 is a block of filtered maps again for Mrk 10. The FF is [0.5—1] only for U, and [1—2] for U, B, V, R. The elementary square is the same, $5'' \times 5''$, but for the filtered maps we give both HBWs for the used FFs. Note, that the filter procedure generates positive as well as negative amplitudes.

For Mrk 185 smoothed maps are given in Fig. 4 — SF [0.5] is applied.

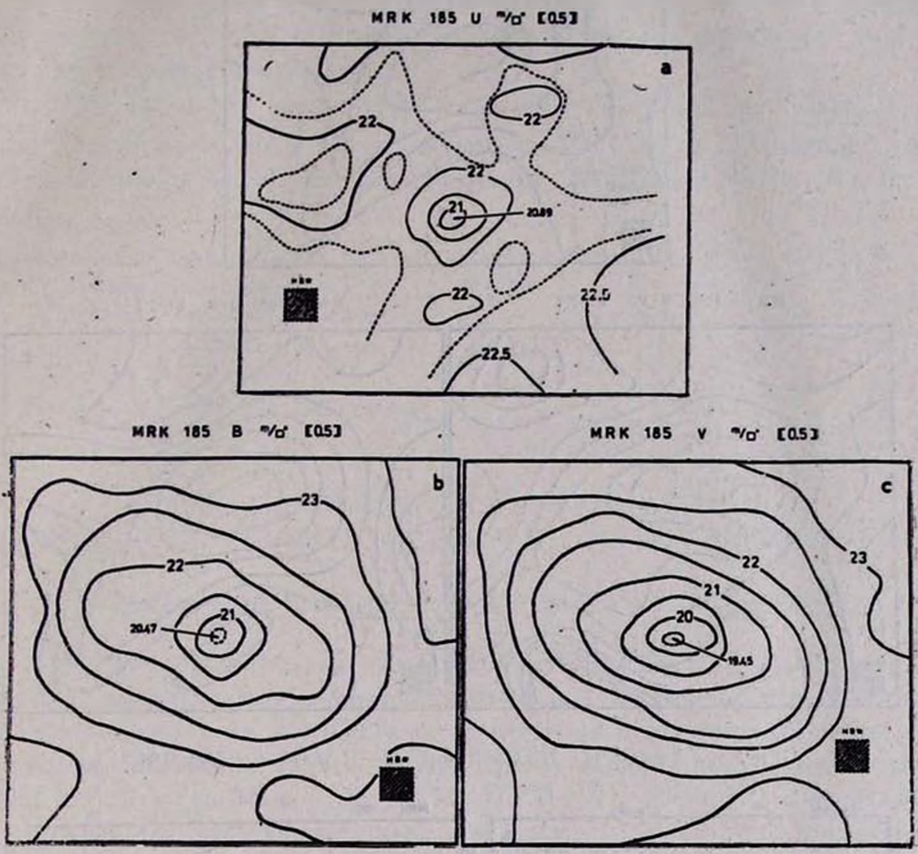

Fig. 4. Smoothed U, B and V maps for Mrk 185.

Fig. 5 contains filtered maps for the $U-B$, $B-V$ and $U-V$ colours of Mrk 185.

It is impossible to present here even a small part of the smoothed and filtered maps which we constructed for the nine Markarian galaxies. We are not giving any 2—D presentation of the autocorrelation functions, but we are showing on Fig. 6 some examples for the cross-correlation function (Mrk 10, with a diaphragm of 3."5 × 3."5).

The first example is for the U and B fields, and in fact it is an isocross-correlation map where the curves connect the points with one and the same correlation (normalized, of course). The components of the shift are given with Δi and Δk, in units of 3."5 × 3."5.

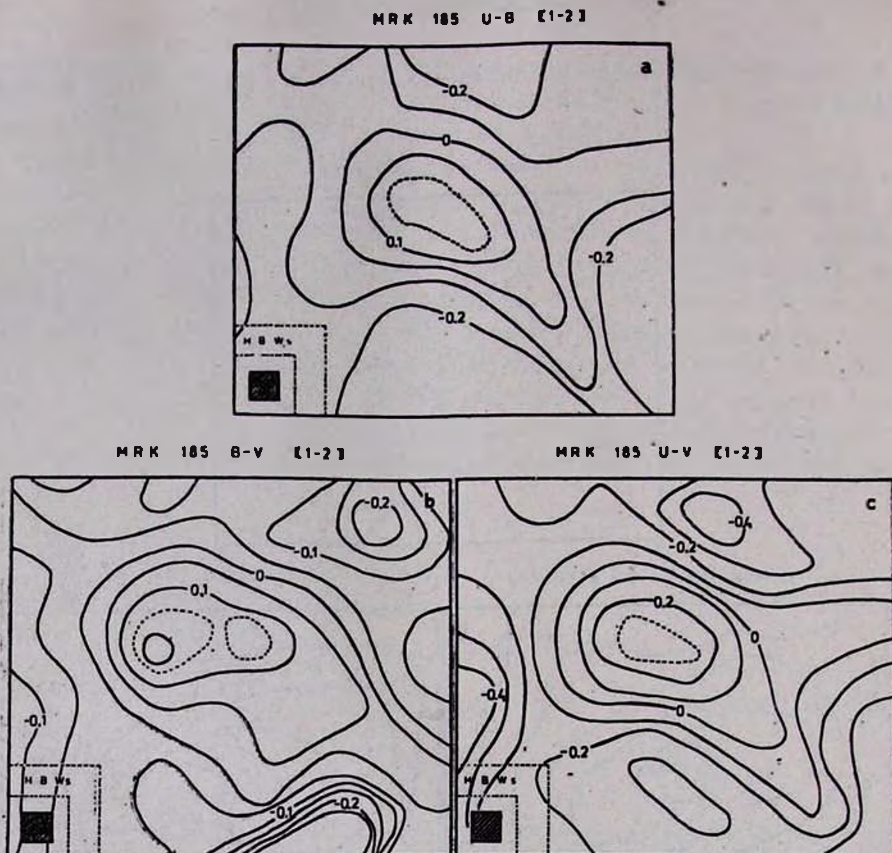

Fig. 5. Filtered $U-B$, $B-V$ and $U-V$ maps for Mrk 185.

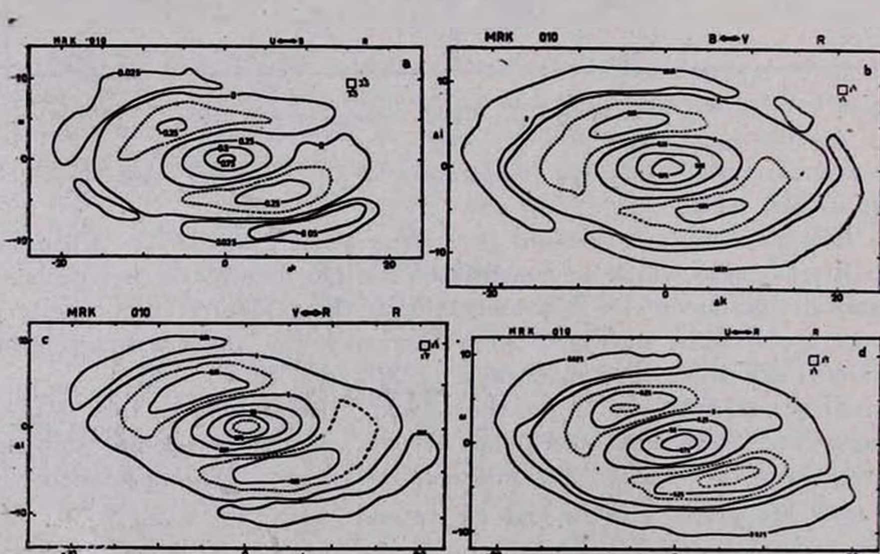

Fig. 6. Crosscorrelation functions between the fields. U and B, B and V, V and R, and U and R, for Mrk 10.

The following examples are for B and V, V and R, and finally, for U and R.

All illustrations in this paper definitely show, that it is possible to construct photometric models for each Markarian galaxy with four— or three-colour photometry.

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НОВАЯ ОБРАБОТКА РЕЗУЛЬТАТОВ ПОВЕРХНОСТНОЙ ФОТОМЕТРИИ ГАЛАКТИК МАРКАРЯНА. I

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Описаны численные методы обработки (сглаживание, фильтрация и вычисление двумерных корреляционных функций) данных поверхностной фотометрии галактик. Методы адаптированы для применения к фотометрии галактик Маркаряна. Начата новая обработка уже опубликованных данных для галактик Марк 7, 8, 10, 11, 12, 13, 185, 186 и 190 и приведены некоторые иллюстративные результаты. Даны результаты фотометрии Марк 10, проведенной с диафрагмой 3.″5 × 3.″5.

REFERENCES

1. *Б. Е. Маркарян*, Астрофизика, 3, 55, 1967.
2. *Б. Е. Маркарян*, Астрофизика, 5, 443, 1969.
3. *Ф. Бёрнген, А. Т. Каллоглян*, Астрофизика, 10, 159, 1974.
4. *Ф. Бёрнген, А. Т. Каллоглян*, Астрофизика, 11, 5, 1975.
5. *Ф. Бёрнген, А. Т. Каллоглян*, Астрофизика, 11, 617, 1975.
6. *Ф. Бёрнген, А. Т. Каллоглян, А. Г. Егикян*, Астрофизика, 13, 233, 1977.
7. *Ф. Бёрнген, А. Т. Каллоглян, А. Г. Егикян*, Астрофизика, 12, 13, 1976.
8. *M. Kalinkov*, C. r. Acad. Bulg. Sci., 26, 855, 1973.
9. *M. Kalinkov, I. Kuneva, B. Tomov, K. Vlahova, K. Yanev*, C. r. Acad. Bulg. Sci., 29, 453, 1976.
10. *M. Kalinkov*, C. r. Acad. Bulg. Sci., 26, 1155, 1973.

11. *M. Kalinkov*, Proc. First Europ. Astron. Meet., 1972. Springer Verlag Berlin, 3, 142, 1974.
12. *M. Kalinkov*, Mem. Soc. astron. Ital., 45, 637, 1974 (1976).
13. *M. Kalinkov*, C. r. Acad. Bulg. Sci., 33, 1029, 1980.
14. *M. Kalinkov, K. Stavrev, I. Kuneva, V. Dermenjiev*, In "Proc. Third Europ. Astron. Meet.", Tbilisi, 1976, p. 309.
15. *M. Kalinkov, K. Stavrev, I. Kuneva, V. Dermenjiev, K. Rudnicki*, In "Proc. Third Europ. Astron. Meet.", Tbilisi, 1976, p. 321.
16. *M. Kalinkov*, in "Highlights of Astronomy", ed. by E. Müller, Reidel, Vol. 4, Part I, 1977, p. 279.
17. *M. Kalinkov, V. Dermenjiev, B. Staikov, I. Kuneva, B. Tomov*, In "The large Scale Structure of the Universe", ed. by M. S. Longair and J. Einasto, Reidel, 1978, p. 276.
(Крупномасштабная структура Вселенной, пер. с англ., Москва, 306, 1981).
18. *F. Zwicky*, Catalogue of Selected Compact Galaxies and of Post-Eruptive Galaxies, 1971.
19. *Б. А. Воронцов-Вельяминов, А. А. Красногорская*, Морфологический каталог галактик, Москва, 1962.
20. *P. Nilson*, Uppsala General Catalogue of Galaxies, Uppsala, 1973.
21. *S. D. Peterson*, Astron. J., 78, 811, 1973.
22. *G. de Vaucouleurs, A. de Vaucouleurs, H. G. Corwin*, Second Reference Catalogue of Bright Galaxies, Univ. Texas Press, 1976.
23. *А. Т. Каллоглян*, Астрофизика, 7, 521, 1971.
24. *Ф. Бёрнген, А. Т. Каллоглян*, Астрофизика, 11, 369, 1975.
25. *J. P. Huchra*, Astrophys. J. Suppl. Ser., 35, 171, 1977.
26. *D. W. Weedman*, Astrophys. J., 183, 29, 1973.
27. *F. R. Feldman, D. W. Weedman, V. A. Balzano, L. W. Ramsey*, Astrophys. J., 256, 427, 1982.
28. *V. A. Balzano*, Astrophys. J., 268, 602, 1983.
29. *J. Neyman, E. L. Scott*, Astrophys. J., 116, 144, 1952.
30. *J. Neyman, E. L. Scott*, Astron. J., 60, 33, 1955.
31. *И. Д. Караченцев*, Астрофизика, 2, 307, 1966.
32. *H. Totsuji, T. Kihara*, Publ. Astron. Soc. Japan, 21, 221, 1969.
33. *P. J. E. Peebles*, The Large-Scale Structure of the Universe, Princeton Univ. Press, 1980 (Структура Вселенной в больших масштабах, пер. с англ., М., 1983).