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THE RESIDUAL IMAGE METHOD AND SOME OF ITS APPLICATIONS

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The residual digital image is defined as a difference between the raw image and the result of its smoothing. Analysis of the residual image can give valuable information about the unwell pronounced local brightness variation of the investigated object. This method is examined to demonstrate the hot points in a solar spot, the jets in the Halley's comet, the spiral structure of the galaxies M 51, M 31, M 81 and the bridge between M 81 and M 82.

Сообщается о фортрановском пакете программ, который работает на мини-ЭВМ РДР 11-34. Пакет предназначен для получения информации из протяженных изображений и представления информации в графическом виде. Реализованы предварительные процедуры для анализа изображения и его фона, для калибровки, для сверточного и медианного сглаживания и т. п. Последующие обработки выдают фотометрические профили, изофотные карты, морфологические функции, фотометрические диаграммы, остаточные изображения и т. д. Некоторые применения, а также важнейшие результаты методики приводятся в качестве примеров.

Introduction

The isophote map gives a valuable information about the large scale structure of the digital image. Unfortunately, the local variations of the brightness are lost, because of the impossibility to use an isophote system suitable both for the whole image and for its details. Sometimes the appearance of the image can be made better by a contrast changing techniques, but the visibility of the details rests poore.

Especially in case of the high brightness gradient, this problem is very serious. Suitable example is the M 31 galaxy, where the isophote maps don't help to solve the problem about its spiral structure. So, the enhancement of the image, aiming to show its hidden features, is an important problem.

In general, it is necessary to use a method that can demonstrate the unwell pronounced variations of the brightness about its local mean value. The purpose of the present paper is to point out the existence of such a method, both simple and effective and to show some of its first appiications.

The method

The idea of the residual image method (RIM) is as follows. From the raw digital image that has the elements $V(i, k)$ we can receive a smoothed image that has the elements $\bar{V}(i, k)$. It is possible now to form the residual image with the elements

$$dV(i, k) = V(i, k) - \bar{V}(i, k).$$

The isophote map (or the grey-scale map) of the residual image shows very sensitively the hidden details of the raw image.

The most important problem in the RIM is the method of the smoothing. Usually we use a fast median filtering method with a square window. Changing the

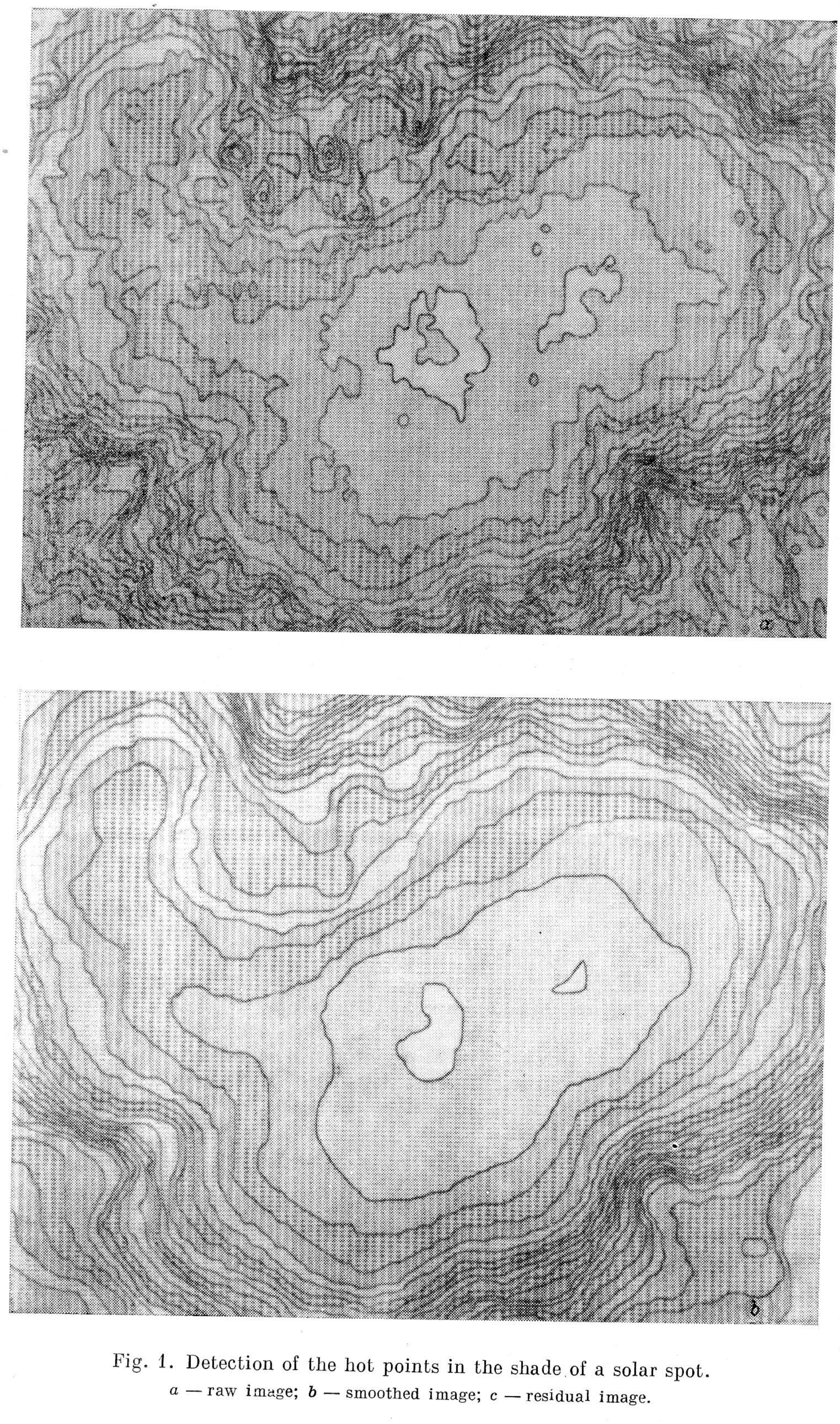

Fig. 1. Detection of the hot points in the shade of a solar spot.
a — raw image; *b* — smoothed image; *c* — residual image.

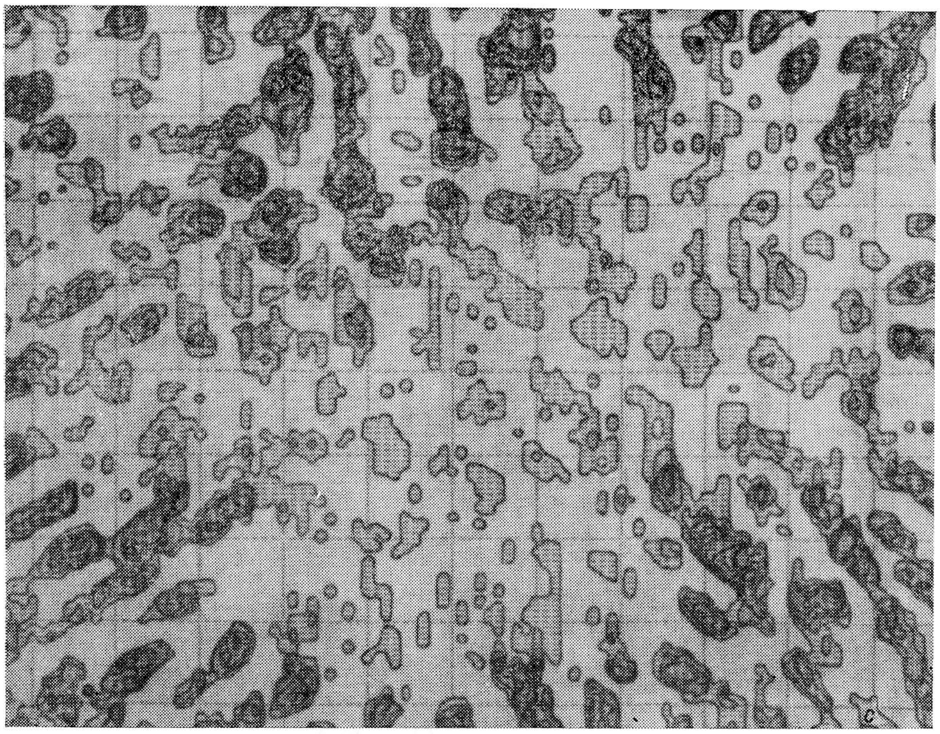

Fig. 1.

window dimention W, we can smooth the image less or more. After this we can detach in the residual image respectively smaller or bigger detailes. Such examples are given in Figs. 1—7 where the sizes of the median windows are shown by hatched squares.

Another approach, whose applying is coming in the future is the two-dimentional fitting of the image used as a smoothed one. This method is not too universal, but in cases of simple images it may be better than the median filtering.

Further on a set of expedient applications of the proposed method is shown. The information about the illustrations is collected in Table 1.

TABLE 1

Data about the plates and the digital images used for the illustrations

Fig. No	Object	Telescope, system		Pixel Observer[mic]		Image dimension	Win-dow W	Isophotes: Zero level	Isophotes: Inter-val	Sys-tem
1*ab*	Solar	spot.		Ondrejov obs.	50	130×150	7	0.4	0.1	*D*
2*a*	Comet	1 ZU21	pg	V. Ivanova	100	131×200	11	0.1	0.2	*D*
3*ab*	M 51	3 ZU21	*B*	G. Ivanov	150	200×332	65	24	0.5	*B*
4*a*	M 31	2 103aO	*U*	F. Borngen	300	150×520	35	0.05	0.10	*U*
4*b*	M 31	2 103aE	*R*	F. Borngen	300	150×520	35	0.02	0.10	*R*
5	M 31	2 103aO	*U*	F. Borngen	300	150×520	31	0.05	0.1	*U*
6	M 81—M 82	3 ZU21	*B*	R. Getov	100	200×235	31	0	0.2	*B*
7	M 81	1 103aO	*U*	T. Georgiev	40	180×280	15	0	0.32	*D*

The numbers of the telescopes are as follows:

1 — The Rozhen 50/70 cm Schmidt telescope; scale 120″/mm.
2 — The Tautenburg 134/200 cm Schmidt telescope; scale 51.7″/mm.
3 — The Rozhen 2-m RCC telescope; scale 12.9″/mm.

The system D in the last column means that the image is processed in densities. The information about the residual images in Fig. 1*c*, 2*b* and 3*c* is given in the text.

The applications

The very early application of the RIM was made in 1985 on a stellar spot aiming to find the hot spots in its shade [1]. They can be observed in the best photographs as small details which aren't much brighter than its surroundings. The problem, pointed by Dr. V. Dermendjiev was to find the hot points that are invisible on the photograph. The solution of this problem is illustrated in Fig. 1.

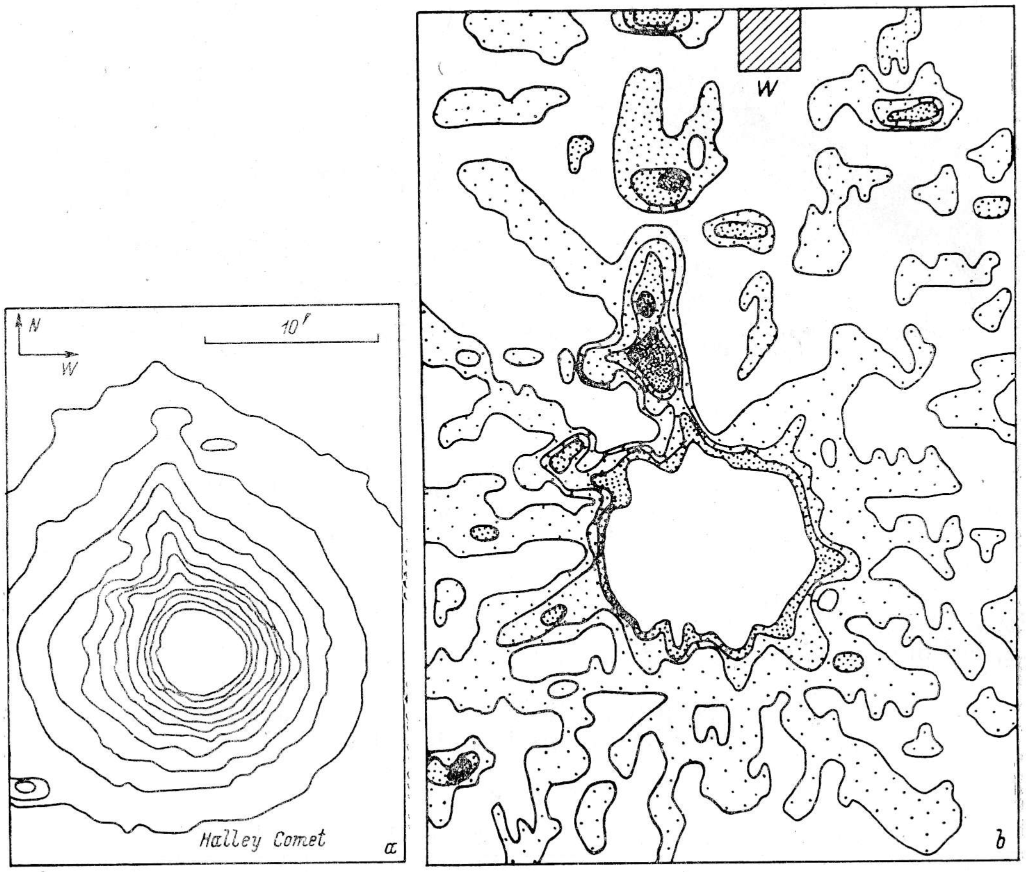

Fig. 2. Detachment of the set of jets in the coma of the Halley's comet.
a — raw image; *b* — residual image.

An excellent photograph from the solar telescope of the Ondrejov observatory (CSSR) was used. About 5 hot points were visible in the original photograph. The isophote map of the raw image (Fig. 1*a*) gives much information about the morphology of the spot, but it can't demonstrate the background structure of its shade. The isophote map of the smoothed image (Fig. 1*b*) is quite poor in details and gives more full information only about the image as a whole. The isophote map of the residual image (Fig. 1*c*) shows clearly the complicate structure of the shade. It permits to find 10—20 small bright features which corresponds to the hot points. The isophotes in Fig. 1*c* are spaced by $0.032D$, starting from the zero level. So, they permit to point out the information which is invisible on the photograph. Another problem is the detachment of the jets in the coma of the Halley's comet. It was solved as it is shown in Fig. 2. One of the best photograph taken in

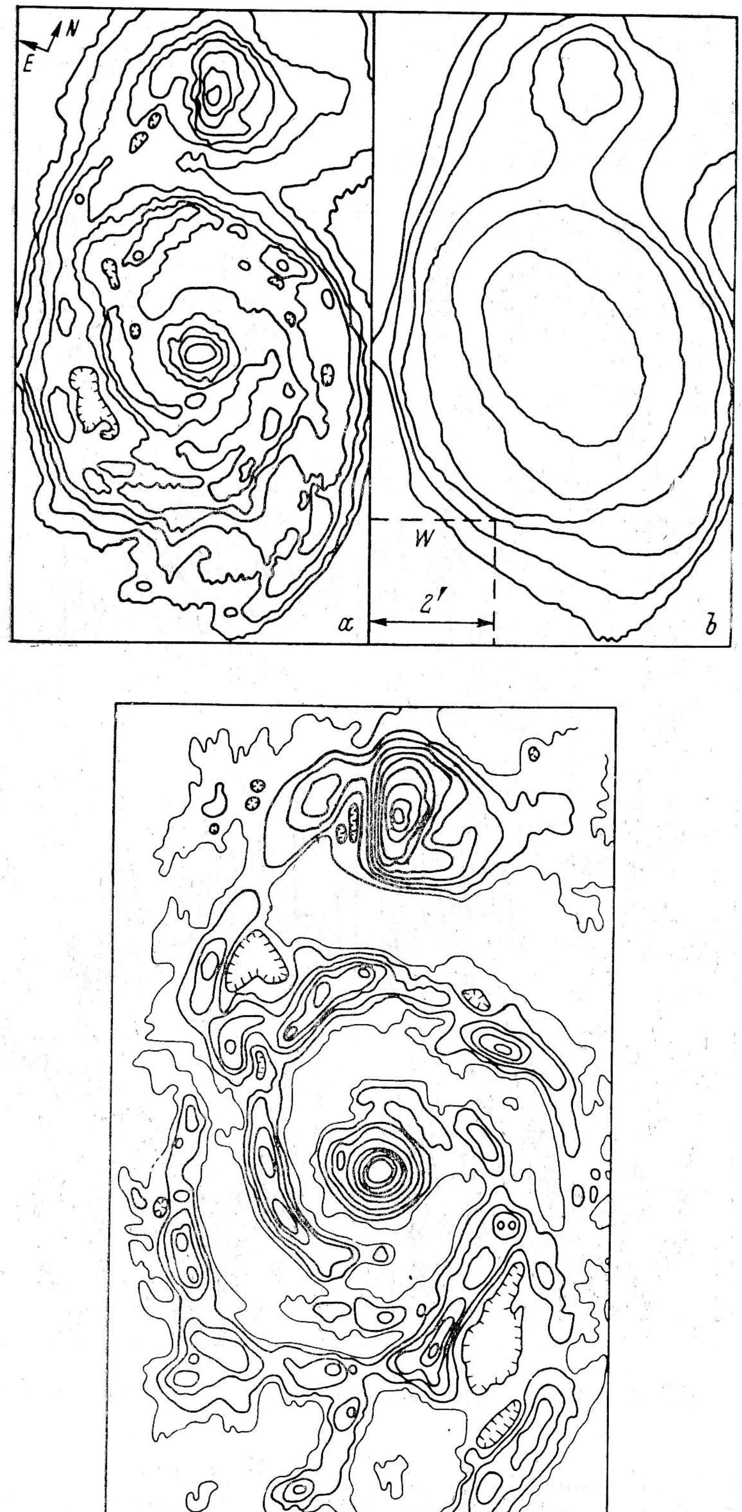

Fig. 3. A test of the method with the M 51 galaxy aiming to show clearly its spiral structure.
a — raw image; *b* — smoothed image; *c* — residual image.

1986 was used, where a big jet was observed. The isophote map of the coma is shown in Fig. 2*a* after a «cosmetic» smoothing. It shows the big jet and permits to suggest the existence of 2—3 more faint ones. The residual image (Fig. 2*b*) shows clearly the main jet as well as few others. It is interesting that a system of about 10 very faint radial jets is detected. The isophotes in Fig. 2*b* are spaced by 0.02*D*, starting from the zero level. Note, that the RIM can't show the structure of the image close

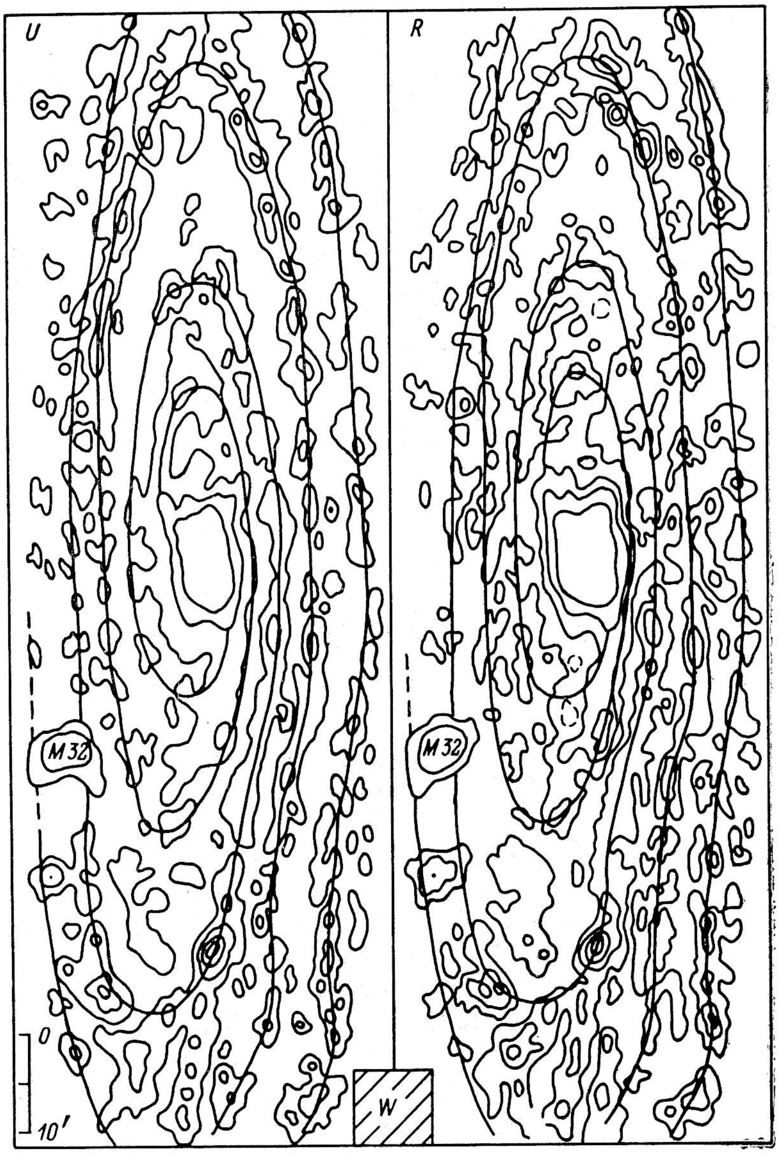

Fig. 4. Demonstration of the two-armed spiral structure of the M 31 galaxy in *U* and *R* light.

to the nucleus of the comet because in the conditions of the great density gradient its dimension is comparable with the dimension of the median window.

The detachment of the spiral structures of the galaxies is an interesting field for the RIM applying. The method testing was made on the remarkable grand design of the M 51 galaxy, as it is shown in Fig. 3 [2, 3]. A preliminary median filtering with a window of 7×7 pixels (13″×13″) was applied to remove the smallest details of the image. The isophote map of the result (used as a raw image) is shown in Fig. 3*a*. It is seen that the well pronounced spiral structure of the M 51

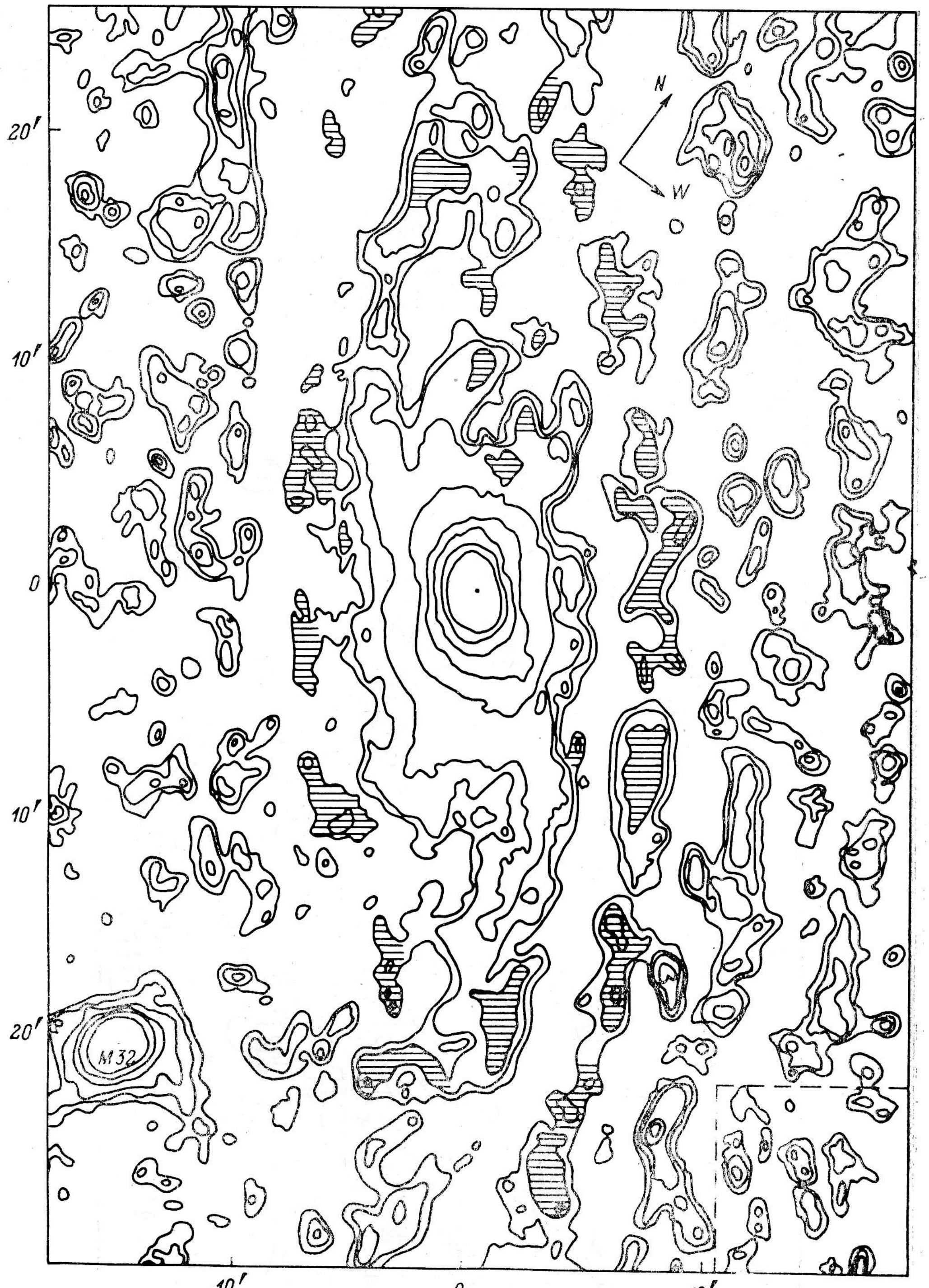

Fig. 5. Detection of unknown star complexes (marked by hatching) in the bright part of the M 31 galaxy image.

galaxy is not well appeared in its isophote map. Further on a median filtering with a window of 65×65 pixels is applied. The dimension of the image is 200×332 pixels and the processing time on the PDP 11—34 minicomputer is about 16^m.

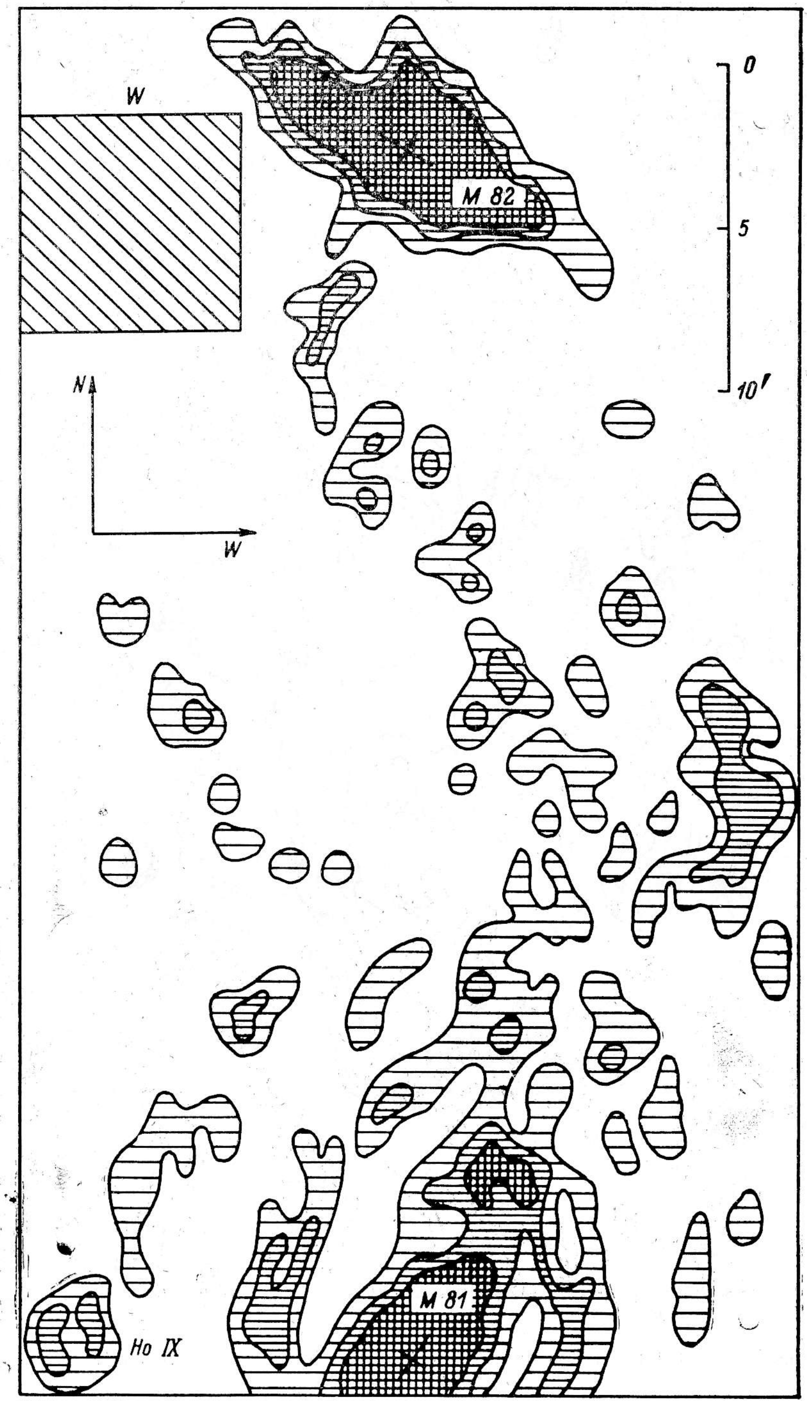

Fig. 6. Discovering of the faint bridge between the M 81 and M 82 galaxies.

The result, shown in Fig. 3*b* is a strong smoothed image, without any remains of the spiral structure. The corresponding residual image is shown in Fig. 3*c*, where the isophotes are spacing by 0.2 m/□″. The spiral structure of the M 51 galaxy

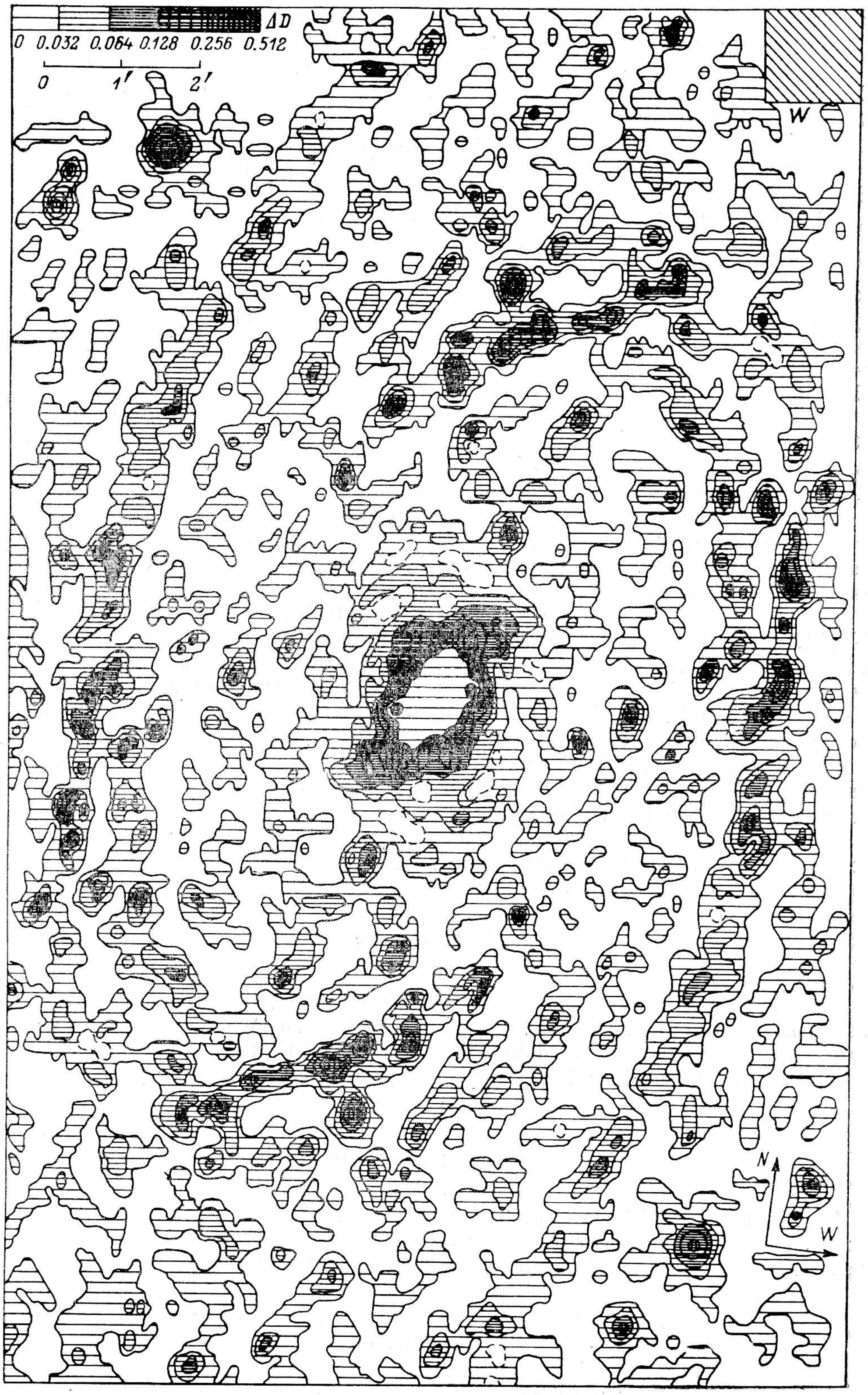

Fig. 7. The residual image of the M 81 galaxy bulge oin U-light (see the text).

appears remarkable. Note that the satellite NGC 5195 (classified by de Vaucouleurs as an irregular galaxy) has also a two-armed spiral structure.

The very difficult problem about the spiral structure of the M 31 galaxy was solved easy by the RIM [2, 3]. The residual images in U and R light, obtained after the suitable processing of Tautenburg plates, are shown in Fig. 4. The median window here is 31×31 pixels ($8' \times 8'$). The processing time on PDP 11-34 for each of this images with dimension of 150×520 pixels is about 4^m. The clear result is that M 31 galaxy has two-armed spiral structure of trailing type. Lately the geometrical parameters of its spiral arms were investigated by means of the RIM [4].

One more detailed investigation of the M 31 galaxy bulge by the RIM permits to detach 30 star complexes as an addition to the van den Bergh's list [5]. The cen ral part of the residual image in U-light is shown under about $30''$ resolution in Fig. 5. The star complexes unknown till now are hatched. It is interesting to note that this complexes just help to draw clearly the spiral arm S2—N3—S4 and to receive undoubted picture of the spiral pattern in the inner part of the M 31 galaxy.

The RIM helps us to demonstrate the existence of a low brightness bridge between the M 81 and M 82 galaxies [6]. This formation corresponds to the bridge known from the radio observations. We used two B-plates taken with the 2-m telescope at Rozhen with exposure times of 1^h and 2^h. The calibrated and averaged images with dimension of 200×230 pixels ($43' \times 50'$) were smoothed by median filtering with a window 31×31 ($6.7' \times 6.7'$). The residual image is shown in Fig. 6. An additional investigation shows that the brightness of the most faint part of the bridge is B 27 $m/\square''$.

The last example is on the image of the central part of the M 81 galaxy in U-light. It is interesting to find the continuations of the spiral arms in the bulge, as it was made in the case of M 31 4. The residual image here was superposed with the same residual image, but turned on 180° around the center. This procedure enhances the bright details which are simmetrically situated towards the center and help us to see the general shape of the spiral structure.

The result, given in Fig. 7 shows the complicated structure of the bulge. It is possible to trace the continuations of the spiral arms around the center about one turnover more, than it was known till now. It seems also that the spiral structure of this galaxy is more complicated, and may be it is four-armed. This problem must be solved in the future investigations.

Final remarks

The RIM is a part of the image processing package created in the Rozhen National Astronomical Observatory of the Bulgarian Academy of Sciences [7]. Its first application mentioned in this paper shows that by this manner we can receive useful information about the hidden properties of the astronomical images.

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