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Adaptive Filter Applications in Surface Photometry of Galaxies*

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Abstract

We consider the smoothing application of the adaptive filter, juxtaposed to the other most commonly used filters, in the surface photometry of galaxies. We point out the adaptive filter advantages and illustrate them with the azimuthally shrunk luminosity profiles of the Seyfert galaxy NGC 5548.

1 Introduction

Reducing noise is an outstanding problem in astronomy mainly due to the faint signals. This is especially important for surface photometry. Raw data may also contain artifacts originating from elements having abnormal properties. Such bad pixels are usually replaced by a local estimate. The main difference among filters is the different type of estimators they are based on. Filtering is a widely used tool for both replacement of artifacts and reducing the noise, thus increasing the signal-to-noise ratio (SNR) of the periphery regions of extended objects. Besides smoothing, filters may have other applications, too. Adaptive filter itself has a variety of potentialities – image restoration, pattern recognition, interfering objects removal, data compression. We will constrain only on filters' smoothing application.

One of the simplest tool for increasing the SNR is block averaging. When it is done by a pixel box, smaller than the FWHM of the point-spread function (PSF), it does not degrade the resolution appreciably (*e.g.* [13]); [1] used a fixed 2×2 pixels size of the pixel box.

Smooth filters (SFs) are peaked and they leave less sharper features in the result frame than block filters. One application of smooth filters is the running average filter (RAF).

*Based on observations collected at the Rozhen National Astronomical Observatory of Bulgaria operated by the Institute of Astronomy, Bulgarian Academy of Sciences.

In the presence of image defects (cosmic ray hits, hot/cool pixels) the median is a better estimator of the true mean level of the signal then $k\sigma$-clipping.

Median filter (MF) can only detect artifacts if they occupy less than half of the filter size. Therefore, its size must be conformable to both the sizes of the defects to be cleaned and of the objects to be preserved. [7] used a 3×3 pixels median filter in order to enhance the SNR of the outer regions of the galaxies studied.

Gaussian filter (GF) is another kind of SF. It can be performed by convolving with a circular Gaussian function of a fixed width ([3]) or with a 2D Gaussian relevant to the PSF of the image. [13] used a 2D Gaussian having FWHM equal to 3 times the seeing disk for noise reducing, low surface brightness (SB) structures enhancing and looking for sharp features. [5] smoothed the images with a GF of a few pixels of width that matched the seeing disk of the images. [4] developed a variable smoothing method, wherein the image was smoothed with a Gaussian ellipse whose size was adjusted to preserve constant signal to noise in the resulting image, with a fixed axial ratio oriented along the major axis of the galaxy.

The adaptive filtering technique (described in [6, 8, 9]) is another approach to increase the SNR. The task uses H-transform to calculate the local SNR at each point of the image as a function of the resolution and determines the size of the impulse response of the filter at this point. In places of high SNR the task uses a smaller size of response and, vice-versa, leaving more sensitive parts like the bulges of galaxies almost unchanged while filtering thoroughly in regions of low signal [10, 12}. That means, an adaptive (space variable) filter (AF) smooths extensively the background, less extensively the galaxian outskirts and not at all the highest resolution features. The filter strength, defined by the minimum SNR for the detection of a local signal, generally depends on the RMS noise level of the sky background at each scale length. Both the maximum filter size and the strength of the filter are variable. [10] found that the best results were achieved using 11×11 pixels for the maximum filter size and setting the threshold parameter to 3 times the sigma of the sky background. [12] varied the maximum filter size between 15×15 pixels and 23×23 pixels depending on the quality of the frames and the filter strength – generally between 2.0–2.5 sigma.

Before applying the AF interfering objects have to be masked out. This masking is essential for proper determination of the noise statistics used by the filter. Special care must be taken in constructing the mask frame for large filter sizes: the masks for bright objects should be large enough in order to avoid artifacts in the outskirts.

The main advantage of the adaptive filtering technique consists in recognition of the local signal resolution and adapting its own impulse response to this resolution. [2] showed that AF, implemented in Potsdam Adaptive Filtering Facility (PAFF) is bias-free – important for its use for galaxy photometry and similar applications. It is available in the ESO-MIDAS environment and in IRAF. [10] compared the resulting profiles of adaptive filtered and unfiltered galaxy images and discovered no evidence of smearing of the outer parts of the galaxy over a large area or of any kind of distortion.

2 Observations and Data Reduction

We use R_C images of Seyfert galaxy NGC 5548 to compare different filtering techniques. It was oberved on April 19, 1999. The observations were performed at Rozhen National Astronomical Observatory of Bulgaria with the 2-m Ritchey-Chrétien telescope equiped with 1024×1024 Photometrics AT200 CCD camera system (CCD chip SITe SI003AB) having 24μm pixel size that corresponds to 0.309 arcsec on the sky.

The images were debiased, flat-fielded and co-added by means of ESO-MIDAS procedures. Sky background was determined approximating it by a surface created from a 2-dimensional polynomial of first order using the least-squares method (FIT/FLATSKY task). The resulting background fit was subtracted from the frame. All frames were independently smoothed by a MF, RAF, GF and AF. The sizes of the MF, RAF and GF were chosen to be less than the FWHM of the PSF of the images. Both the size and the strength of the AF varied. We used programs from the Astrophysical Institute of Potsdam (AIP) package [6, 11, 12] under ESO-MIDAS for adaptive filtering and topological operations with masks.

3 Discussion

We have tested different smoothing filters on a set of galaxies and have concluded that AF is the optimal one for our purposes. In this paper we illustrate this with the Seyfert galaxy NGC 5548. We present the azimuthally shrunk surface brightness profiles (SBPs) for NGC 5548 in ADU per square arcsec units. The SBPs of the running average filtered images (RASBPs), of the median filtered images (MSBPs), of the Gaussian filtered images (GSBPs) and of the adaptive filtered images (ASBPs) are overplotted on the unfiltered SBP. The size of the X-axis is almost twice as the galaxy size. We aim to explore the effect of the filters both on the galaxy and on the background. Careful examination of the given filtered SBPs in the low intensity levels shows that the AF is the most extensive filter, followed by the GF, RAF and MF. There is not a substantial difference among the last three filters. Figure 1 gives the GF (white dots), RAF (light-grey dots) and MF (dark-grey dots) overplotted on the unfiltered SBP (black dots) at low intensity levels. One can see that RAF and MF have almost one and the same filtering power, whereas GF is better then both of them. Figure 2 gives the AF (white dots) overplotted on the most extensive of the GF, RAF and MF filters, namely, the GF (gray dots) and on the unfiltered SBP (black dots) at low intensity levels. Now it is obvious that AF is better than GF. It is explicitly seen that AF strongly reduces the noise of the background. As a consequence the galaxy could be traced to fainter limits.

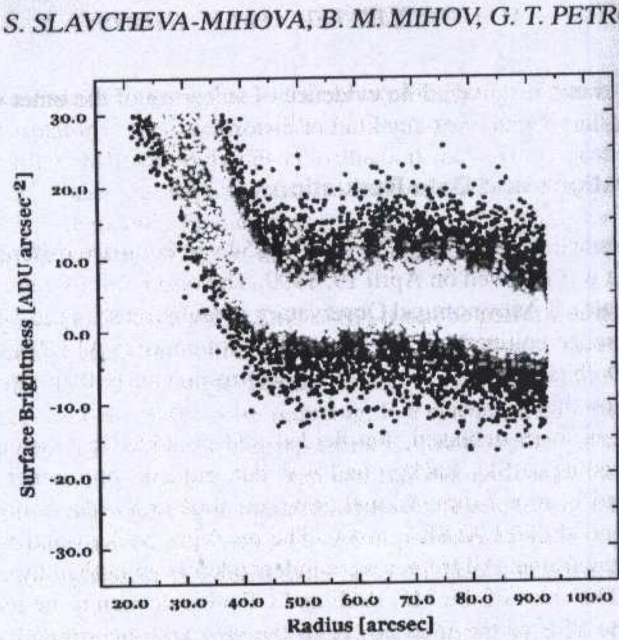

Figure 1. Azimuthally shrunk R_C surface brightness profiles for the Seyfert galaxy NGC 5548 at low intensity levels. The different profiles are denoted as follows: unfiltered – black dots; MF – dark-grey dots; RAF – light-grey dots; GF – white dots.

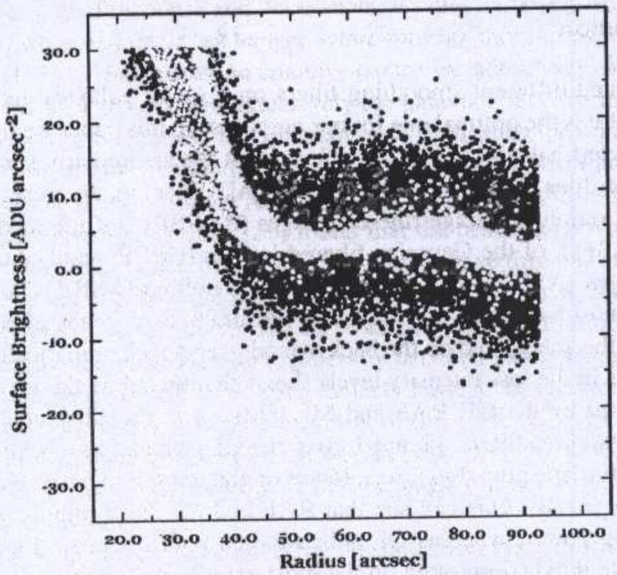

Figure 2. The same as Figure 1 but now the profiles are: unfiltered – black dots; GF – grey dots; AF – white dots.

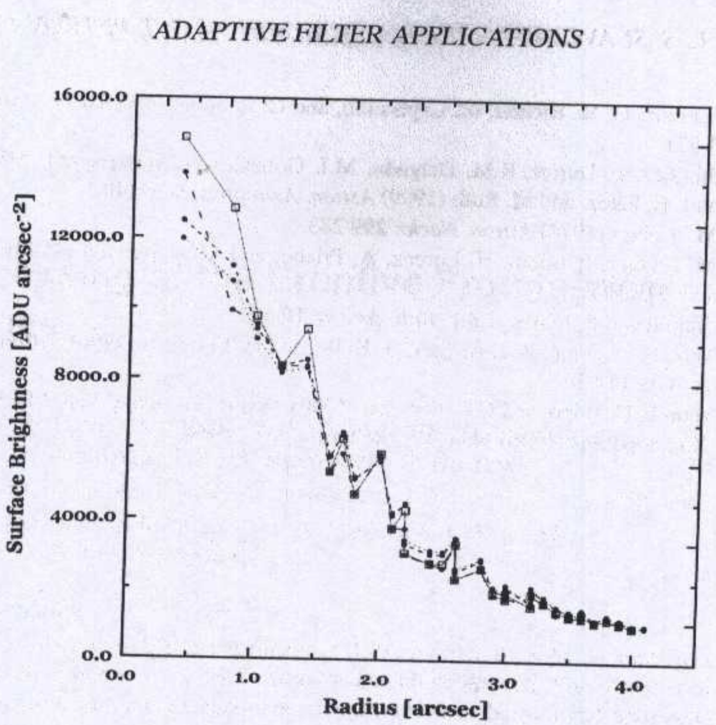

Figure 3. Azimuthally shrunk R_C surface brightness profiles for the Seyfert galaxy NGC 5548 at high intensity levels. The different profiles are denoted as follows: unfiltered – open squares; AF – solid line; MF – long-dashed line; RAF – short-dashed line; GF – dotted line. Note, that AF profile strictly follows the unfiltered one.

Figure 3 gives overplots of the MF, RAF, GF and AF, respectively, on the unfiltered SBP at high intensity levels (see figure captions for details). AF is the only one used that strictly follows the intensity values in the innermost region and leaves these high resolution features unchanged. All the other four used filters redistribute the flux and therefore they degrade the image resolution and/or mask the true flux levels at the central part of the object image.

In fine, AF has two main advantages over the others – it leaves the high-resolution regions of the galaxies unchanged and treats extensively the background. As a result the periphery galaxy parts could be better traced and the SNR in them is enhanced.

References

[1] L.M. Cairós, N. Caon, J.M. Vilchez, J.N. González-Pérez, and C. Muñoz-Tuñón (2001) *Astrophys. J. Sup.* **136** 393

[2] M. Capaccioli, E.V. Held, H. Lorenz, G.M. Richter, and R. Zeiner (1988) *Astron. Nachr.* **309** 69

[3] E.T. Chatzichristou (2001) *Astrophys. J.* **556** 676

[4] J.J. Dalcanton and R.A. Bernstein (2000) *Astron. J.* **120** 203

[5] V. Doublier, A. Caulet, and G. Comte (1999) *Astron. Astrophys. Sup.* **138** 213

[6] H. Lorenz, G. M. Richter, M. Capaccioli, and G. Longo (1993) *Astron. Astrophys.* **277** 321.

[7] I.Márquez, F. Durret, R.M. Delgado, M.I. González, J. Masegosa, J. Maza, M. Moles, E. Pérez, and M. Roth (1999) *Astron. Astrophys. Sup.* **140** 1.

[8] G.M. Richter (1978) *Astron. Nachr.* **299** 283.

[9] G.M. Richter, P. Bohm, H. Lorenz, A. Priebe, and M. Capaccioli (1998) *Astron. Nachr.* **312** 345.

[10] A. Tamm and P. Tenjes (2001) *Balt. Astron.* **10** 599.

[11] J. Vennik, U. Hopp, B. Kovachev, B. Kuhn, and H. Elsaesser (1996) *Astron. Astrophys. Sup.* **117** 261.

[12] J. Vennik, U. Hopp, and C.C. Popescu (2000) *Astron. Astrophys. Sup.* **142** 399.

[13] E. Xanthopoulos (1996) *Mon. Not. R. Astron. Soc.* **280** 6.