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# Finding LSBs from pixels

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**Abstract.** We have developed a specific approach devoted to the detection of low surface brightness galaxies on astronomical images. We use a multi-scale detection, we take into account sources of incompleteness and check selection functions both analytically and with simulations. We give a summary of the main points and some examples. Notwithstanding bottlenecks from huge data flows, we also plan to exploit a GRID approach to this problem because several different regions of the sky (images) can be treated separately but identically.

**Key words.** Galaxies: abundances – Galaxies: luminosity – Cosmology: observations

## 1. Introduction

The capital importance of surface brightness selection effects in galaxy detection was brought to attention for the first time by Disney (1976) who argued that the knowledge of galaxies had been heavily biased by the sky background brightness. Indeed the detection of low surface brightness galaxies (LSBGs) is typically strongly penalised by these effects. Since, the number of specific studies searching for this kind of objects has increased significantly and the interest on the subject is still strong (e.g see Kniazev et al (2004) and Haberzettl et al (2007) for recent work). Different surveys have used different methods for the detection of LSBGs and are therefore subject to different selection effects, completeness function and contamination. This often makes quite difficult to compare results in the literature even in same regions in the sky. Here we briefly illustrate an on going work (Scaramella and Sabatini (2008)) to improve a dedicated package aimed at the detection of LSBGs on digital images, with a reasonably good control of systematics and incompleteness of the obtained galaxy catalogues. In the long term we plan to apply this method to surveys of different depths and environments in a consistent and homogeneous way. We plan also to try a GRID approach. In fact, the method is very apt to distributed processing by splitting sky areas and processing them in equal fashion, the only bottleneck being the amount of data to be shuffled back and forth to each processing node.

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## 2. Method

### 2.1. Overview

So far the detection algorithm has been applied to both digitized POSS plates and CCD mosaics and its structure can be summarized as follows: every image is first background subtracted and then cleaned from standard objects, that are detected by means of SExtractor (Bertin et al. (1996), hereafter SE); we then use a convolution technique to enhance the signal of extremely low surface brightness objects in the masked image. The convolution is performed with a stack of digital kernels of different scale lengths. This produces a list of detected candidates for each scale, which is then pruned for multiple detections according to significance, yielding an estimate of the scale length and a significance index for each candidate. The luminosity profiles of the candidates matching our search criteria are then fit to an exponential profile to have direct estimates of structural parameters like scale length, $\alpha$, and central surface brightness, $\mu_0$. The various steps of the process are described in the following sub-sections.

We remark that the algorithm presented here is tailored to detect only objects that are possible LSBG candidates. It is well known that one of the major difficulties in this is given by the fact that often a LSBG is fragmented by standard detection algorithms that use the approach of searching for connected pixels above a threshold. We therefore widely use such methods (SE in particular) only for the cleaning process (flat-field, background and bright sources subtraction), since they are highly reliable, fast and flexible in producing catalogs from easily customizable parameters. We check that all the faint objects detected by SE with typical parameters are also detected by our algorithm. The converse is not always true and it is mainly due to the use of convolution over a stack of kernels rather than with a single one as it is done in standard SE.

### 2.2. Image cleaning and flat-fielding

For handling purposes, each original image is divided in footprints of size $2048 \times 2048$ pixel, with a small overlap between adjacent footprints (usually 100 pixels), in order to properly handle the objects falling at the border of each footprint. An image (i.e. a footprint of a CCD mosaics or a plate scan) needs two preliminary steps before object detection. First we need a good estimate of the sky background. Second, we need an objective criterion to select and remove all the bright objects present on the image. We adopted a two stage pass for a robust background estimate. All the detected objects after a run with SE are masked in the image with random noise patches of level $\sigma_{sky}$. On this masked image we run SE again and obtain a background map that is then used to " flat-field" the raw image. This procedure yields a sky-subtracted image that is ready to be analysed.

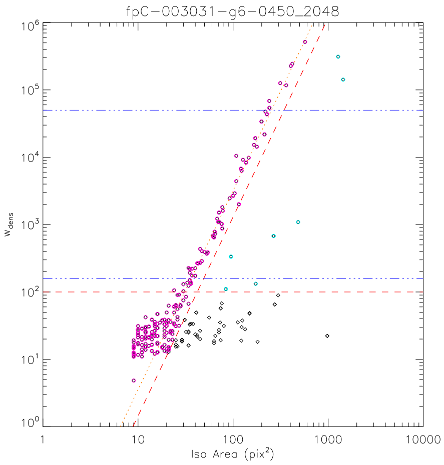


Fig. 1: Object distribution on the ($W_{dens}\,A_{iso}$) plane for a single SDSS footprint. The stellar locus is on the diagonal line. Large bright galaxies and faint ones and/or possible tips of LSB candidates occupy the region to the right of the stellar locus.

After background subtraction we also need to discard objects that are not interesting for our investigation, i.e. stars, bright galaxies, plate/CCD defects, etc. For this purpose we use the SE output catalogue and select and mask those objects in the following way. We a plane defined by isophotal areas and magnitudes, where it is relatively easy to discriminate among objects of different nature and trace the stellar locus. In particular we use a ($W_{dens}$, $A_{iso}$) plane (see Fig.1), where $W_{dens}$ is defined as $W_{dens} = f_{max}\,\langle f\rangle/\sigma^2_{sky}$ and $\sigma_{sky}$ is the pixel sky variance, $f_{max}$ is the peak flux above the background, $\langle f\rangle = f_{iso}/A_{iso}$ is the av-

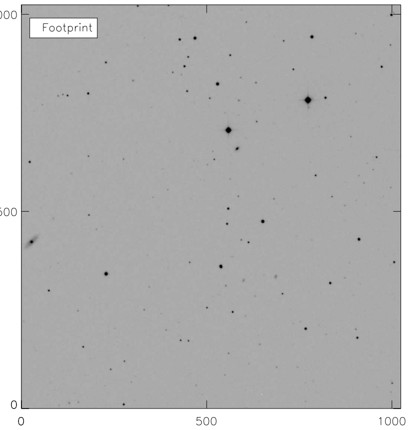


Fig. 2: An image footprint

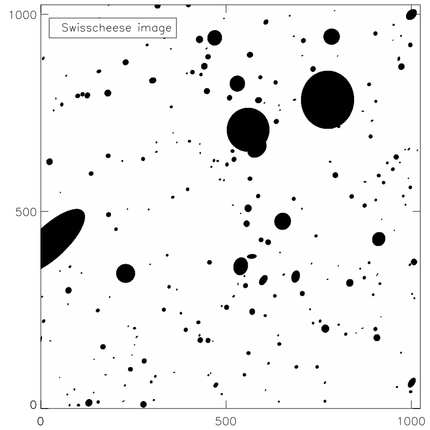


Fig. 3: The "swisscheese" masking map of Fig. 2, generated using the masked regions of the non interesting objects in Fig 1.

erage flux, $A_{iso}$ is the isophotal area above the analysis threshold and $f_{iso}$ is the isophotal flux. Each of these parameters are given by SE in its output catalogue.

In this plane, the object distribution depends on dimensions and flux shape *observed above the SE analysis threshold*. We can distinguish objects with large $W_{dens}$ at the top of the plot as saturated stars ($W_{dens} \approx 10^5$) or bright and widespread objects; objects with small $W_{dens}$ and small $A_{iso}$ as faint and compact objects, usually background galaxies, small stars or spurious detections. Stars describe a locus which is approximately a straight line on the log-log plane ( the range between $W_{dens} \sim 10^2$ and $W_{dens} \sim 10^5$ in Fig.1). Galaxies, saturated sources and other diffuse objects are located to the right of the stellar locus. We define a region where possible LSBG candidates can be found: $W_{dens} < 10^2$ (this value corresponding to $\mu_0 \sim 2.5$ mags brighter than $\sigma_{sky}$, that is $\approx 22.5\ mag\ arcsec^{-2}$ for g band in SDSS), and beyond $3\sigma$ from the stellar locus to the right (the two thick dashed lines in Fig.1 ).

All the objects that are outside this region are not considered as possible LSBG candidates and are therefore masked on the original image by replacing the area with a noise patch. We keep track of masked regions by generating a "swisscheese" masking map, where pixels belonging to them are set to zero and all the other pixels to unity. This map (see Fig. 3) is then used at a later stage for completeness purposes. The whole procedure is automatically iterated on a footprint-by-footprint basis and is thus homogeneous with respect to different footprints, which have slightly different stellar locii depending on image quality and seeing.

### 2.3. Kernels, candidate significance and parameter estimates

Convolution by a fixed size kernel yields a map in which coherent positive deviations, even if of low amplitude, are enhanced with respect to the noise in the convolved image: essentially if the flux of the object, $F$, is spread over $N_{obj}$ independent pixels, then the relative statistical significance in terms of standard deviations with respect to pixel noise gains a factor of $\sqrt{N_{obj}}$. If we *ideally* consider Poisson statistics and examine an object covering an area of $N_{obj}$ pixels over an image with *uncorrelated noise* per pixel $\sigma_{sky}$, then the signal to noise in the case of background subtracted faint signals which are much below the sky average level is: $S/N = \sum_i S_i / \sqrt{\sum_i S_i + N_{obj}\sigma^2_{sky}} \simeq$

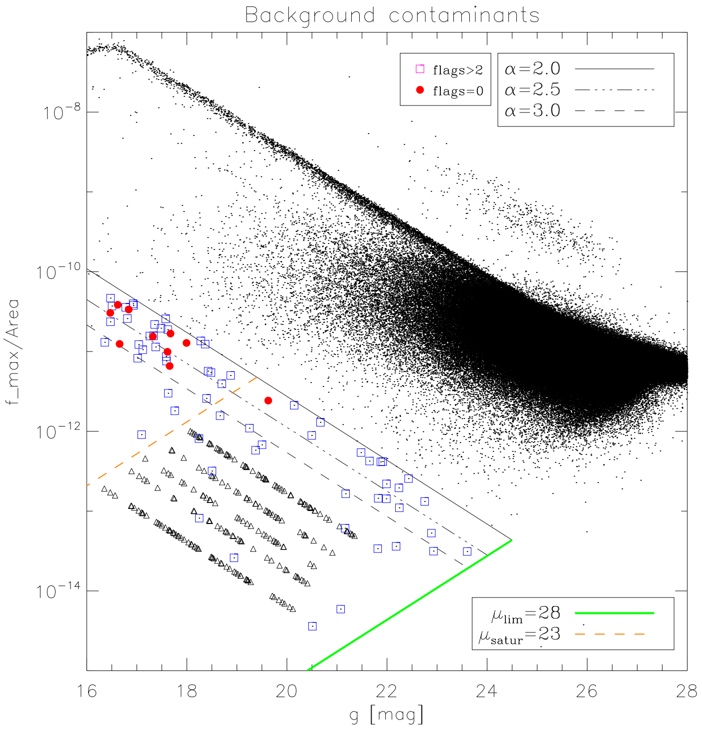


Fig. 4: The interesting regions of parameter space expected to be sampled by the ongoing LBT Deep Virgo Survey are delimited by the tranverse lines. Dots are background objects, Objects of different nature lie in different regions of the plot. A stellar locus (from top left to bottom right) is clearly visible, while LSB galaxies lie in the lower left part of the plot. Top left to bottom right oblique lines show the locus occupied by galaxies with exponential proles of different scale length $\alpha$; bottom left to top right oblique lines give the surface brightness limits of our region of interest for the proposed survey: from saturation at 23 g mag/arcsec$^2$ (dashed line) to the 5 sigma level of 28 g mag/arcsec$^2$ (solid green line). For comparison we also plot galaxies found in the INT survey (Sabatini et al. (2003)) as triangles to show the parameter space covered by that wider but shallower survey.

$\sum_i S_i / \sqrt{N_{obj}\sigma^2_{sky}}$ where $S_i$ is the signal of pixel $i$ (here $i = 1...N_{obj}$). For a kernel of scale R, the convolved flux is given by $F_{conv}(R) = \sum_j w_j S_j$ (with $j = 1...\mathcal{N}$ denotes the pixels covered by the kernel of size $R$), where $w_j$ are the convolving kernel normalized weights ($\sum_j w_j \equiv 1$). The variance of the convolved field is given by $\Sigma^2_F(R) = \sigma^2_{sky} \sum_i (w_i^2) \equiv \mathcal{N}_{eff}\sigma^2_{sky}$. By dividing the value of $F_{conv}(R)$ with the standard deviation $\Sigma_F$ of the convolved image at the scale R, we obtain the significance of a detection $\nu(R)$, i.e. a convolved S/N ratio: $\nu(R) \equiv F_{conv}(R)/\Sigma_F(R)$

For each kernel profile there is a relationship between the scale length, $\alpha$, and the scale at which the significance has a maximum (see Scaramella and Sabatini (2008)) Therefore from the value of $\nu_{Max}$ an estimate of scale length and central surface brightness of the candidate LSBG can be obtained. Results of simulations which show the fravtion of recovered objects for as a function of size and different levels of signal to noise ratio is given in Scaramella and Sabatini (2008).

For each pixel on the original image, the procedure compares the significance of the detection on the stack of kernels and produces a final map where the most significant value (i.e. the one with the greatest value of $\nu(R)$) is kept. In a different array, for each pixel, the kernel scale corresponding to the maximum value of $\nu$ is stored. We use the former (i.e. the final single "significance map") for galaxy detection and the latter for the estimation of galaxy structural parameters.

A previous version of this method was successfully used in the Virgo INT survey (Sabatini et al. (2003)). In the current version we have also implemented direct automatic fits to brightness radial profiles of the significant candidates. This also help in discarding the majority of contaminants, due to positive perturbations which are not due to centrally condensed objects. An example is given in Scaramella and Sabatini (2008).

We plan to apply the new version in areas of the SDSS and on a proposed very deep survey on selected regions of the Virgo cluster to be carried on at the Large Binocular Telescope.

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