A More Precise Method of Sky Subtraction in SDSS Astronomical Image Processing

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***Abstract*—We review a more precise method of sky subtraction for the astronomical images of the Sloan Digital Sky Survey (SDSS), which was presented by our group before. The SDSS images are originally processed by the photometric pipeline (PHOTO), which often over-estimates the sky background in processing images of galaxies with large size and/or in crowded fields. We use the second-order Legendre polynomials to fit both rows and columns of a image respectively to consctruct a more correct sky background model. Our method makes the subtracted-backgournd counts follow a Gaussian distribution with a mean close to zero, which shows our sky background model is successful.**

***Index Terms*—SDSS, image processing, CCD, sky background, point spread function**

I. Introduction

It is quite clear what astronomers mean by $'$sky$'$: the mean value of all pixels in an image which are not explicitly identified as part of any detected object. It is this quantity which, when multiplied by the effective number of pixels in an object, tells us how much of the measured flux is not in fact associated with the object of interest. Unfortunately, means are not very robust, and the identification of pixels not explicitly identified as part of any detected object is fraught with difficulties.

The Sloan Digital Sky Survey (SDSS) is one of the most ambitious and influential surveys in the history of astronomy. The SDSS used a dedicated 2.5-meter telescope at Apache Point Observatory, New Mexico, equipped with two powerful special-purpose instruments. The SDSS imaging camera contains two sets of CCD arrays: the imaging array and the astrometric arrays[1].

The imaging array consists of 30 2048 $\times$ 2048 Tektronix CCDs, placed in an array of six columns and five rows. The telescope scanning is aligned with the columns. Each row observes the sky through a different filter, in temporal sequence r', i', u', z', and g'. The pixel size is $24\mu m$. The imaging survey is taken in the drift-scan mode. The effective integration time per filter is 54.1 seconds, and the time for passage over the entire photometric array is about 5.7 minutes (Gunn et al. 1998). The five filters in the imaging array of the camera, [u', g', r', i' and z'] have effective wavelengths of [3590 Å, 4810 Å, 6230 Å, 7640 Å and 9060 Å] [1, 2]. An a priori model estimate of the telescope and camera throughputs and of the sky brightness predicted that we would reach the 5σ detection limit for point sources in $1''$ seeing at [22.3, 23.3, 23.1, 22.3, 20.8] in the (u', g', r', i', z') filters, respectively.

The images obtained by SDSS are processed by the photometric pipeline (PHOTO). Some researchers[3] pointed out that the SDSS photometric reduction systematically under-estimates the luminosities and half-light radius of the Brightest Cluster Galaxies (BCGs). This arises because the PHOTO pipeline often over-estimates the sky background for galaxies with large size and/or in crowded fields. As a result, some authors[4] performed their own photometric reductions for their studies. On the other hand, von der Linden et al.[5] address this problem by adding up to 70% of the difference between the local (256 $\times$ 256 pixels) and the global (2048 $\times$ 2048 pixels) sky background (both are available from PHOTO). However, the sky background in the SDSS frames often shows spatial gradients and asymmetry. Therefore, adding a constant background value to the photometric targets may not yield the most accurate results, at least on one-to-one basis. It is necessary to construct correct sky background model.

In this paper, we report a more precise method of sky subtraction for the SDSS images, which was presented by our group before[6]. The outline of the paper is as follows. In §2 and §3 we describe the method of sky subtraction by the SDSS and ourselves, respectively. A conclusion is drawn in §4.

II. Sky estimates in SDSS

The corrected frames in SDSS have already been processed by the SDSS photometric pipeline (PHOTO), including bias-subtraction, flat-fielding, cosmic ray removal and corrections for pixel defects. PHOTO then performs two levels of sky subtraction; when first processing each frame image it estimates a global sky level, and then, while searching for and measuring faint objects, it re-estimates the sky level locally.

The initial sky estimate is taken from the median value of every pixel in the image (more precisely, every fourth pixel in the image), clipped at 2.3 sigma. This estimate of sky is corrected for the bias introduced by using a median, and a clipped one at that. The statistical error in this value is then estimated from the values of sky determined separately from the four quadrants of the image.

Using this initial sky estimation, PHOTO proceeds to find all the bright objects (typically those with more than 60 sigma detections). Among these are any saturated stars present on the frame, and PHOTO is designed to remove the scattering wings from at least the brighter of these — this should include the scattering due to the atmosphere, and also that due to scattering within the CCD membrane. In fact, the wings of stars are not aggressively subtracted, partly because of the difficulty of handling the wings of stars that do not fall on the frame, and partly due to our lack of a robust understanding of the outer parts of the Point Spread Function (PSF). With the parameters employed, only the very cores of the stars (out to 20 pixels) are ever subtracted, and this has a negligible influence on the data.

PHOTO then proceeds with a more local sky estimate. This is carried out by finding the same clipped median, but now in 256x256 pixel boxes, centered every 128 pixels. These values are again debiased.

This estimate of the sky is then subtracted from the data, using linear interpolation between these values spaced 128 pixels apart; the interpolation is done using a variant of the well-known Bresenham algorithm usually employed to draw lines on pixellated displays.

It is understandable if a large fraction of the pixels in a 256x256 pixels is part of an object rather than blank sky, this procedure casues the local sky to be an overestimate of the true sky background. This may happen for galaxies with large size and/or in crowded fields, since the wings of the PSF result in a considerable stellar halo.

III. Our method

Although the images from the SDSS archive were processed with photometric corrections, as Wu et al.[7] pointed out, some spurious features still exist in some images. The spatial variation of these features was about 1-2 ADU. Without corrections, target galaxies that happen to be located within such features will have inaccurate background subtraction. We thus first correct for these structures following Wu et al.[7] before constructing our sky background model below.

As we have stated in the introuduction that the SDSS PHOTO pipeline often over-estimates the sky background for galaxies with large size and/or in crowded fields. The sky background in the SDSS frames often shows spatial gradients and asymmetry (see the third row of Fig. 1 for an example). Therefore, adding a constant background value to the photometric targets may not yield the most accurate results, at least

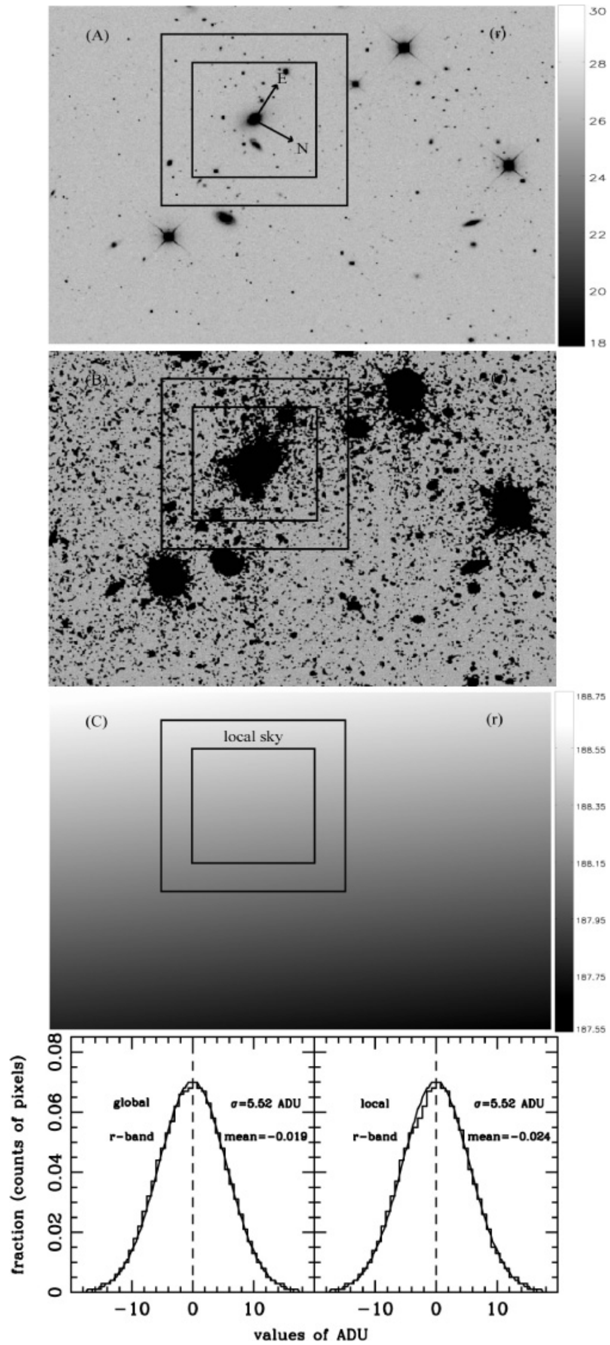

Fig. 1. An example of sky subtraction (for target galaxy C4 3086) best-fit Gaussians to the distributions.

on one-to-one basis. Therefore, it is necessary to construct correct sky background model.

To obtain accurate information of the sky background, we first generate a 2048 $\times$ 1498 pixels background-only image using SExtractor[8] by masking all the detected objects with counts above 1σ noise (of the whole frame) in a frame smoothed by a circular Gaussian with a standard deviation σ = 3 pixels. As most of targets have sizes of a few square arcminutes, there are sufficient regions in the masked image to determine the sky background. A median filter with 51×51

pixels is then convolved with the unmasked pixels, after which second-order Legendre polynomials are used to fit both rows and columns respectively[9, 10]. The fitted Legendre polynomials are then further smoothed using a circular Gaussian filter with σ = 9 pixels to obtain our final sky background model. For most cases, we find that the sky background is tilted with a spatial variation about $1-2$ ADU across the whole frame. We can subtract this model from the frame to obtain the sky-free image.

Our procedure is illustrated in Fig. 1 for a target galaxy (C4 3086). The first, second and third rows of Fig. 1 show the frame, the masked frame and the smoothed sky background in the $r-$band. Notice that the sky background shows a gradient across the frame. The bottom panels show the distributions of counts in the sky-subtracted frame for all unmasked pixels and for the local vicinity around the target. If the sky background model is successful, then we expect the background counts to follow a Gaussian distribution with a mean close to zero. This is indeed the case, as can be seen from the bottom panels of Fig. 1. The distributions in the $r-$band for the whole image and the local region are well-fit by Gaussians with dispersion of 5.52 ADU and a mean value of about -2×10^{-2} ADU.

IV. CONCLUSION

The SDSS photometric pipeline PHOTO estimates the global sky within a frame(2048x1498) from the median vale of the pixels in the frame, clipped at 2.3 sigma. The local sky background is then determined with the same sigma-clipping within a box of 256x256 pixels on a grid every 128 pixels, and interpolated between these positions. This sky estimate is then subtracted from the image. This method often over-estimates the sky background for galaxies with large size and/or in crowded fields. We review a more precise method of sky subtraction for the SDSS images, which was presented by our group before. We use the second-order Legendre polynomials to fit both rows and columns of a image respectively to consctruct a more correct sky background model. Our method makes the subtracted-backgournd counts follow a Gaussian distribution with a mean close to zero, which shows our sky background model is successful. Our developed method is useful to perform precise photometry, which has been used successfuly in several studies[11, 12, 13, 14].

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