The Dark Energy Survey Data Management System: The Coaddition Pipeline and PSF Homogenization

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Abstract. We introduce an experimental method of reducing PSF variation effects within coadded images by bringing all images to a common PSF both within an image and from image to image within a coadd tile. This is accomplished by applying position-dependent smoothing kernels determined using power spectrum weighting functions that adjust the relative contributions of large scale and small-scale power within an image in such a way as to bring the PSFs into agreement. This approach has been applied successfully in image differencing algorithms, and we plan to apply it within our coaddition framework. We also present a summary of our coaddition pipeline.

1. Introduction

The Dark Energy Survey (DES) is an optical survey of 5000 deg\(^2\) of the South Galactic Cap to \(\sim\)24th magnitude in multiple filter bands using a new wide field CCD camera, DECam, mounted on the Blanco 4 m telescope at Cerro Tololo Inter-American Observatory. Survey data will be processed into science-ready data products using the DES data management system, which is being developed at the University of Illinois (Mohr et al. 2008).

The DECam is a large focal plane array with a short readout time which will collect approximately 300 GB of science images per night. These images are collected from an array of 62 CCDs that will be combined, after processing, to build sets of 1 degree\(^2\) tiles to cover the entire survey region. The resulting 5000 coadd images, one for each square degree of sky, are arranged on a predefined grid and periodically reprocessed throughout the life of the project.

Each object in the sky is observed \(\sim\)10 to 20 times in each band over the lifetime of the survey. Because of the changing observing conditions from
exposure to exposure and of the large dithering pattern, combining frames of
different quality leads to a PSF that varies discontinuously over the coadd image.
In addition to PSF variation, there is an inhomogeneous noise field that results
from the coaddition of many independent, partially overlapping exposures of a
given portion of the sky. Both these affect star-galaxy separation and contribute
to variation in the completeness at a given photometric depth as a function of
position in the image.

2. DESDM Coaddition Pipeline

To automate the process of PSF homogenization within our coaddition pipeline
(see Figure 1), we have developed an experimental framework incorporating
software and scripts that gather all remapped images available within a DES tile
and automatically imposes a perfectly isotropic target PSF with characteristics
selected from among the images. Once the target PSF has been chosen, all
images are convolved with a space-varying convolution kernel that delivers the
target PSF everywhere in all images. With a well-defined PSF we can then
catalog the coadd using model fitting photometry.

2.1. Choosing a Target PSF

We are currently experimenting with various techniques for selecting an optimum
PSF Full Width at Half-Maximum (FWHM) among single epoch images within a
coadd. Our goal is to select a PSF FWHM which provides accurate photometry,
good completeness and low contamination down to the $10\sigma$ detection limit. We are currently selecting the median FWHM, which has the advantage of minimizing the level of noise correlation in the output image, but we will run tests using both higher and lower FWHMs.

2.2. Image Masking

Removing image defects is extremely important when convolving with a model PSF; otherwise the smallest cosmic ray becomes a PSF-sized defect on the image. We also mask all USNOB stars brighter than 13th magnitude.

Cosmic ray masking was done using the AstrOMatic software EyE and SExtractor. EyE is a program which generates non-linear image filters using a neural network based algorithm (Bertin 2001). We provided a training dataset containing cosmic rays taken in dark exposures with a real DECam CCD to EyE which creates a filter used by SExtractor to mark cosmic ray pixels.

2.3. Measuring the PSF

To model the PSF across images, we are employing new features written into the AstrOMatic software PSFex (Bertin et al. 2009). This code computes a space-varying kernel that will transform the PSF of an image into a reasonably arbitrary PSF. This is a “slowly varying kernel” of the form:

$$P(x, y) = PO + P1x + P2y + P3x^2 + P4y^2 + \ldots$$

Briefly, homogenization kernels are computed as a linear combination of Gauss-Laguerre polynomials in a way similar to Alard & Lupton (1998), except that the input is a variable PSF model derived from the data, and the output, an arbitrary Moffat model.

2.4. Applying Correction Kernel

Application of the kernel is done by convolving the image with each term in the PSF model and adding the results. A testbed application, psfnormalize, has been written to read in the kernel model and apply the terms to the image.

3. Noise

One drawback to PSF homogenization is that this method correlates the noise on scales up to a few PSF FWHMs, which, for the kernel used in our tests, are about 1 arcsecond. We’ve essentially transferred the complexities of a discontinuous PSF to additional complexity in the noise. Hopefully we can track the noise in the coadd images at the pixel level already, so this seems like a wise tradeoff.

4. Results

While our efforts are still in the experimental stage, results are promising. Figure 2 illustrates the effect of our early experiments on one coadd tile.
Figure 2.: Distribution of the half-light radius in pixels for bright stars ($g < 20$) in the coadd. Left: inhomogenized coadd. Right: homogenized version.

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