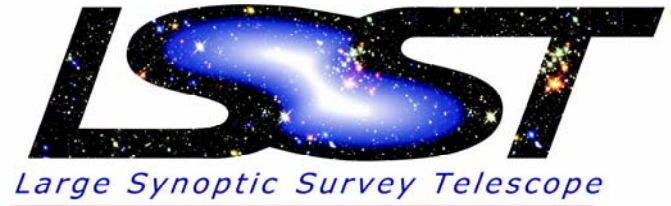


The LSST Deep Detection and Analysis Pipeline: Optimal Reconstruction of Galaxy Shapes



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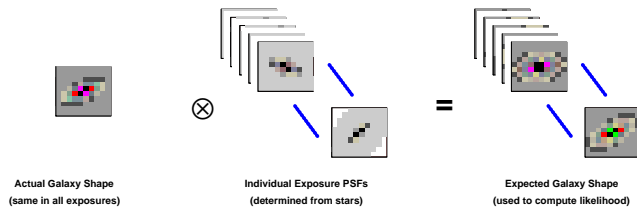
The LSST deep catalog will be derived from hundreds of observations of each field in each filter. The first step is the creation of a single deep stacked image for each field in each filter. This stack is a highly compressed version of the LSST dataset and will be valuable for many applications which require speed and ease of handling rather than utmost accuracy. For example, these stacks will be used by the general public and by astronomers to conduct preliminary analysis, plan observations, match with other surveys, etc. However, some applications will require analysis of the full dataset using the stack and its associated catalog only as a starting point. One of these is weak lensing, for which full advantage must be taken of the best-seeing images. Although lensing is the driver for this work, the following approach should in principle also improve the accuracy of photometry, bulge/disk fits, star/galaxy separation, etc

Galaxy shape parameter measurement for weak lensing studies will be done by simultaneously fitting individual exposures to a common profile model convolved with each exposure's point spread function (PSF) at that position in the image. This technique allows more accurate reconstruction of smaller galaxies than previous techniques that used co-addition of images because information is not degraded during the process of co-addition. Technically, the benefits of fitting individual exposures are: the direct incorporation of PSF estimation errors in the formal error calculation, and more reliable PSF interpolation since no dithering has occurred. In addition, this technique is robust at measuring shapes of small galaxies that are inaccessible to previous methods. Using these smaller galaxies leads to an increase in the effective number of galaxies in a weak lensing survey of 35% at high redshifts.

Introduction

We present details of a method for fitting the shapes of galaxies that have been imaged in multiple exposures. Instead of the traditional approach of co-adding several exposures to produce a single image for measurements, this method simultaneously analyzes all individual exposures to determine the galaxy shape and size that best fits all images of a single galaxy. This process effectively uses knowledge about the point spread function (PSF) of individual exposures, taking advantage of the detailed information present in highly resolved images, while still extracting the limited information available in images with poorer resolution. The simultaneous fit is performed using a maximum likelihood technique that combines the likelihoods calculated from each individual exposure.

The figure below sketches the main idea of the technique. First, a parameterized model for a galaxy radial light profile is chosen. The model is convolved with each of the PSF models measured from the individual exposures (the PSFs shown are exaggerated to demonstrate the effect). The final, convolved light distributions are compared to the data pixels surrounding the galaxy images on each individual exposure to determine a likelihood. The fitting procedure adjusts the parameters of the input model until the likelihood is maximized, resulting in a best-fit model of actual galaxy shape prior to the effects of PSF smearing.



Schematic view of the convolution process. An individual galaxy's shape on the sky (left) becomes convolved with the PSF of the system (middle, exaggerated) producing the measured shape (right). The likelihood fitting process determines the actual galaxy shape which produces the best fit to the data.

Advantages

There are several advantages to using a procedure that fits multiple exposures. First, errors that are made in PSF estimation in each exposure are treated as random errors, and these errors are propagated into the statistical error calculated during the fitting process. Thus, these errors are determined directly for each individual galaxy basis, rather than being an unknown systematic error. Compared to interpolating PSF estimation on a co-added image, this also reduces any spatial correlation introduced by PSF mis-estimation in any given region of sky.

A second advantage of this method is that the PSF interpolation is done on each individual exposure, where the PSF is expected to vary smoothly. Other methods interpolate on a co-added image, which has been made using many exposures that have been dithered relative to each other. The spatial variation of the PSF on a co-added image is not smooth near the boundaries of the underlying chips, making accurate interpolation more difficult.

Another advantage, specific to any technique that uses fitting, is that prior information can be directly incorporated into the fit. The choice of an underlying galaxy shape profile is one such piece of information. Parameters of the galaxy-model or the PSF-model can be constrained with additional terms in likelihood calculation. For example, if the PSF determination is uncertain, those uncertainties can be used in the fit and directly propagated into the final measurement error.

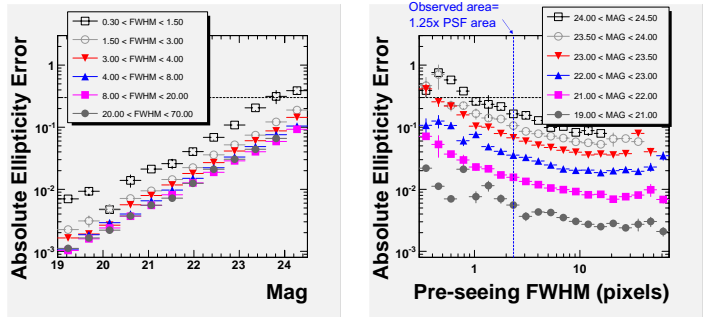
References

- Erben, et. al. *Astronomy and Astrophysics*, v.366, p.717-735 (2001)
- Ferguson, et. al. *The Astrophysical Journal*, v. 600, p.107-110 (2004)
- Heymans, et. al. Submitted MNRAS, astro-ph/0506112.

STEP Results

The Shear TEsting Program (astro-ph/0506112) is a collaborative effort that provided weak-lensing analysts with a standard, uniform set of simulations on which to test their methods. The ongoing program has several stages; here we report on results from the first phase. STEP I was based on 1,920 simulated images created using SkyMaker (Erben et al, 2001), containing bulge+disk type galaxies. While STEP is primarily designed to test shear measurement techniques, these simulations also provide a testbed for studying shape measurement techniques. The following plots illustrate how well the ellipticity of galaxies of different magnitudes and sizes can be measured. Below a pre-seeing size of 0.5 pixels, fitting becomes unstable due to the small size. Above a FWHM of 10 pixels, a minimum error is reached for a fixed magnitude. A joint fit to the size and magnitude dependence of the error, between 0.5 and 10 pixels, gives the expected statistical dependence based on signal-to-noise, thus demonstrating the extreme robustness of this technique.

$$\sigma_{\epsilon, meas} \propto (size)^{-0.48 \pm 0.02} \cdot 10^{0.39 \pm 0.02 \cdot mag}$$

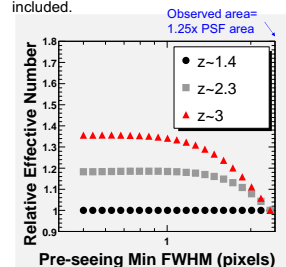


Dependence of galaxy shape measurement error on magnitude (left) and galaxy size (right) in a STEP I simulated exposure. The dotted horizontal line indicates the level of shape noise – the intrinsic distribution of galaxy shapes. The magnitude variation is due to the higher signal-to-noise measurement possible with brighter objects. The variation of error with size shows that larger objects are measured better up to a magnitude-dependent noise floor. The vertical line is the level below which many current methods become unstable – when the observed area is 1.25x the PSF area.

Predictions

The statistical figure of merit for a weak-lensing survey is the effective number of galaxies for which shapes have been measured. In this context, "effective" means the number of perfectly measured galaxies which would give the same statistical precision as the survey's results. By measuring ever smaller and fainter galaxies, a survey can dramatically increase galaxy sample size, but at the cost of using noisier measurements. Many current methods for shape measurement become unusable when observed objects have sizes close to the PSF size. Often, galaxies observed to be less than ~1.25 times the area of the PSF are discarded. With fitting techniques, this limit can be reduced and galaxies can be measured almost down to the size of the PSF.

Based on the error analysis of the STEP I simulations, the variance of a shape measurement decreases as the square-root of the pre-seeing area for small galaxies. Since the number of galaxies increases with the decreasing angular size, the rapid increase in sample size can compensate for increased noise. Consequently, the effective number of galaxies of a survey can be substantially increased by recovering barely resolved galaxies. The following figure depicts the relative increase in a survey's effective sample size as galaxies less than 1.25x the PSF area are included.



Effective sample size relative to a sample in which the cutoff is made when the observed galaxy size is 1.25x the PSF size (2.35 on the x-axis, in these units). The effective number is given by

$$N_{eff} = \frac{\int_{d_{min}}^{d_{max}} \frac{1}{\sigma_{meas}^2 + \sigma_{shape}^2} N_{HST}(size) 10^{0.4 \cdot mag} dsiz e dmag}{\int_{d_{min}}^{d_{max}} \frac{1}{\sigma_{meas}^2 + \sigma_{shape}^2} dsiz e dmag}$$

where N_{HST} is a log-normal fit to the observed galaxy size distribution (Ferguson 2004) at each of the redshifts shown. At low redshift, there are few galaxies present to add to the sample, while at higher redshift, there is some gain in measuring galaxies down to a cutoff of ~ 1 .