Ellipticity Correlation of the LSST PSF and the Optimal Interpolation Scheme

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The weak lensing science goals of the Large Synoptic Survey Telescope (LSST) require that we carefully model and separate the instrumental artifacts from the intrinsic shear signal caused by gravitational lensing. The dominant source of the systematics for the LSST (and also for other ground based facilities) is the spatial correlation of the point spread function (PSF) modulated both by the atmospheric turbulence and by the optical aberration. In this work, we present our simulation of the Cerro Pachón’s atmosphere with a six layer phase-screen model and its impact on the LSST’s spatial PSF correlation. We also demonstrate how efficiently these systematics can be controlled with our optimal PSF interpolation scheme.

INTRODUCTION

It is paramount to understand the behavior of the point spread function (PSF) of the Large Synoptic Survey Telescope (LSST) and to correct the systematics thereof. We investigate the issue here by simulating the PSF of the telescope under the influence of both the atmospheric and the optical aberrations, and by modeling the spatial variation of the PSF across the full (3.5 degree x 3.5 degree) field-of-view with the principal component analysis (PCA) technique.

SIMULATION OF ATMOSPHERE

To simulate the effects of atmospheric turbulence, we generated 6 layer Kolmogorov phase screens with an outer scale of 20 m (Figure 1). Because the field-of-view of the LSST is large, the highest altitude layer needs to have a physical size greater than ~1 km x 1 km. In addition to this, there should be ample margins at the boundaries to allow for wind-shifts during the proposed integration of 15 sec. With the 0.65pixel scale set to 1, we choose the dimension of the phase screen to be 8192x8192, which corresponds to the physical size of 1.5 km x 1.5 km. The altitude and the weight for each layer are adopted from Ellerbroek (2002). Table 1 summarizes these values and also randomized wind velocities. Considering the highest wind velocity (~20 m/s), we chose the time step of the simulation to be 0.005 s, which corresponds to ~0.5 pixel shift for this layer (i.e., Nyquist sampling rate).

**Table 1. Atmospheric Turbulence Profile**

<table>
<thead>
<tr>
<th>Layer Altitude (km)</th>
<th>Mean rms wind (m/s)</th>
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<tbody>
<tr>
<td>1</td>
<td>0.05</td>
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<tr>
<td>2</td>
<td>0.12</td>
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<tr>
<td>3</td>
<td>0.17</td>
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<tr>
<td>7</td>
<td>0.54</td>
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<tr>
<td>8</td>
<td>0.65</td>
</tr>
</tbody>
</table>

**SIMULATION OF OPTICAL ABBERRATIONS**

We randomized the Zemike coefficients for the focus (Zf), the 0° astigmatism (Z1), and the 45° astigmatism (Z2) to simulate the effects of the optical aberrations. Figure 2 shows the position-dependent variation of these coefficients across the field of view. We display the ellipticity (defined as (a-b)/(a+b)) of the PSFs induced by these aberrations in Figure 3.

**Figure 2.** Simulated optical aberrations in terms of Zemike coefficients. Combined with the focus offset Zf, Zf is responsible for the elongation along x or y, whereas Z1 determines the elongation along the diagonal direction. We display the resulting variation of the PSF ellipticity in Figure 3.

**ELLIPITICITY AND SIZE VERSUS EXPOSURE TIME**

In general, the ellipticity of PSF decreases as a function of exposure time. This is because, as exposure time increases, the telescope’s pupil sees more uncorrelated phase screens. Here, without tuning on the above optical aberrations, we purely investigated the mean PSF ellipticity and size as a function of exposure time. The decrease of mean PSF ellipticity as a function of exposure time was also observed in de Vries et al. (2007).

**Figure 3.** “Whisker” plot showing the ellipticity of the LSST PSF due to the input aberrations illustrated in Figure 2. The sticks are aligned in the direction of the PSF elongation, and the length of the stick is proportional to the magnitude of ellipticity.

INTERPOLATION THROUGH PRINCIPAL COMPONENT ANALYSIS

In order to model the variation of PSFs, we first decompose the PSFs with some basis functions using Principal Component Analysis (PCA). Jee, 2007. By construction, PCA provides the most compact basis functions for a given data set.

**Figure 4.** PSF ellipticity as a function of exposure time.

**Figure 5.** PSF FWHM as a function of exposure time.

**Figure 6.** The first 30 eigen-PSFs (i.e., principal components) used in the decomposition of the simulated LSST PSFs.

**Figure 7.** Ellipticity distribution of the simulated LSST PSFs (left). The middle panel shows the ellipticity distribution of the PCA interpolated PSFs. Comparison of these two plots along with the residual plot (right) illustrates that our PCA interpolation closely approximates the PSF variation in the LSST field.

**CONCLUSIONS**

- Longer exposure time tends to give larger and rounder PSFs. For the normal exposure time of 15 seconds for the LSST, the typical ellipticity and the FWHM of the PSFs becomes ~0.01 and ~6.4°, respectively, when only the atmospheric turbulence is included. The final seeing becomes ~0.6° because of the additional ~0.4° contribution from the detector, dome, and camera.
- When both the optical and the atmospheric aberrations are turned on, the resulting PSF anisotropy pattern resembles the feature that is already observed for the optical aberration simulation. Of course, the magnitude of the ellipticity is significantly (approximately a factor of 4) reduced because of the atmospheric convolution.
- Our PSF interpolation through PCA precisely describes the observed PSF pattern. The residual ellipticity correlation is of an order of 10¹, far smaller than expected cosmic shear signals. In addition, because this PCA interpolation gives the full-drawn PSF shape (not just ellipticity or FWHM), we can apply the model to objects with different sizes and radial profiles in a consistent manner.

**FUTURE PLANS**

- More realistic optics model of the LSST is to be added including periodic detector-focal plane errors (i.e., tilting error), field-dependent pupil obscuration, detector charge diffusion, etc. However, the inclusion is not expected to affect results.
- For now, the simulation is limited to monochromatic light at 5000Å. We plan to sample the PSFs at other wavelength as well in order to generate more realistic PSFs for a given throughput curve.
- We have not observed any significant correlation between the directions of wind and PSF anisotropy such as the findings of Asta et al. 2007. However, this issue still needs to be explored further with different wind velocities.

**REFERENCES**