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Approaching high shear measurement precision on the noisy images

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ABSTRACT

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1. INTRODUCTION

2. THE FOURIER_QUAD METHOD

Fourier_Quad method measures the shear estimators on the $2D$ power spectrum of the galaxy image in Fourier space. The shear estimators are defined as:

$$G_1 = -\frac{1}{2}\int d^2\vec{k}(k_x^2 - k_y^2)T(\vec{k})M(\vec{k}) \tag{1}$$
$$G_2 = -\int d^2\vec{k}k_x k_y T(\vec{k})M(\vec{k})$$
$$N = \int d^2\vec{k}\left[k^2 - \frac{\beta^2}{2}k^4\right]T(\vec{k})M(\vec{k})$$

where $\vec{k}$ is the wave vector.

$$M(\vec{k}) = \left|\widetilde{f}^S(\vec{k})\right|^2 - F^S - \left|\widetilde{f}_N^B(\vec{k})\right|^2 + F^B \tag{2}$$
$$F^S = \frac{\int_{|\vec{k}|>k_c} d^2\vec{k}\left|\widetilde{f}^S(\vec{k})\right|^2}{\int_{|\vec{k}|>k_c} d^2\vec{k}}, \quad F^B = \frac{\int_{|\vec{k}|>k_c} d^2\vec{k}\left|\widetilde{f}_N^B(\vec{k})\right|^2}{\int_{|\vec{k}|>k_c} d^2\vec{k}},$$

average & PDF_SYM approach

3. THE PDF_SYM APPROACH IN FOURIER_QUAD METHOD

3.1. *Noise bias from the faint galaxy*

3.1.1. *Galaxy simulation*

We use two types of galactic profiles in our image simulation to represent the regular galaxies and the irregular ones. We use Galsim (Rowe et al. 2015), an open source image simulation toolkit, to simulate the regular galaxies. The irregular galaxies are generated by the random walk method (Zhang 2008). We use 40 shear points range from -0.04 to 0.04, and generate 8×10^6 galaixes for each shear point. For both type of galaxies, the stamp size is 44×44 pixels.

3.1.2. *Point-source galaxies*

3.1.3. *Galsim galaxies*

We adopt a pure deVaucouleures profile for the Galsim galaxies.

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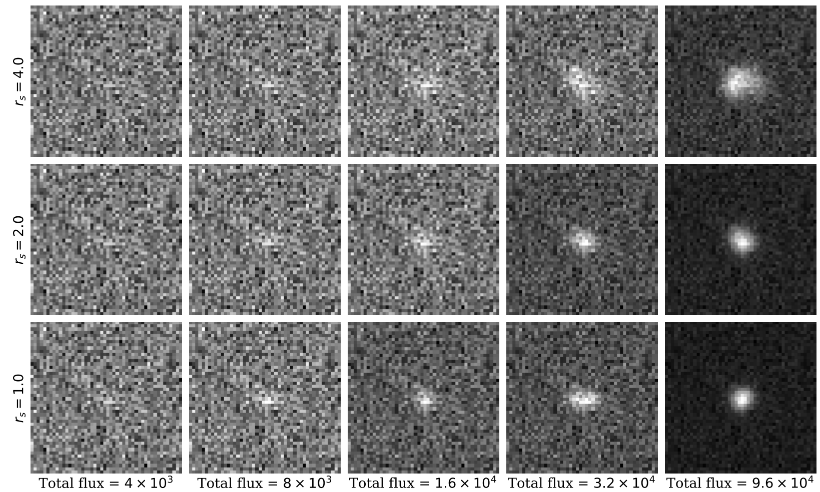

Figure 1. Sample of point-source galaxies. We fix the standard deviation of the backgroud noise at 60.

3.1.4. *Multiplicative bias & Additive bias*

We generate 15 datasets, including 5 SNRs and 3 galactic radii, for each type of galaxy to investigate the bias of shear measurement at different SNR and galactic size. We change the total flux of galaxy to achieve different SNRs. To test the additive bias, we generate the galaxy sample using isotropic and anisotropic PSF ($e_1 = 0.1$, $e_2 = 0$) respectively.

In figure 4, we present the multiplicative and additive bias from both average and PDF_SYM approach. We find that the average approach, as the Eq() shows, gives an unbiased shear estimate. The multiplicative and additive bias are well consistent with zero even in the faintest sample of which the galaxies are hardly identified. However, we find the bias from PDF_SYM approach varies with SNR and galactic morphology. The bias will be enlarged by the lower SNR or small galaxy size. Both multiplicative and additive bias vanish in the brightest sample. It should be noted that both approaches give unbiased shear estimate for the noise free image.

To find the origin of the bias in PDF_SYM approach, we divide the noisy galaxy image into two components, *i.e.* , the noise free galaxy image (GI, hereafter) and the backgroud noise image (NI, hereafter). Therefore, the power spectrum of the galaxy image can be written as

$$\left|\widetilde{f}^S(\vec{k})\right|^2 = \left|\widetilde{f}^S_G(\vec{k})\right|^2 + \left|\widetilde{f}^S_N(\vec{k})\right|^2 + \widetilde{f}^S_G(\vec{k})\widetilde{f}^S_N(\vec{k})^* + \widetilde{f}^S_G(\vec{k})^*\widetilde{f}^S_N(\vec{k}), \tag{3}$$

where the $\widetilde{f}^S_G(\vec{k})$ is the Fourier transform of GI, and the $\widetilde{f}^S_N(\vec{k})$ is the Fourier transform of NI. Then, we re-write the modified galaxy image power as the summation of three parts, the power spectrum of the GI ($\left|\widetilde{f}^S_G(\vec{k})\right|^2$, FGI), the difference between the power spectrum of NI and that of the neighboring background noise image ($\left|\widetilde{f}^S_N(\vec{k})\right|^2 - \left|\widetilde{f}^B_N(\vec{k})\right|^2$, DNI), and the mixture term ($\widetilde{f}^S_G(\vec{k})\widetilde{f}^S_N(\vec{k})^* + \widetilde{f}^S_G(\vec{k})^*\widetilde{f}^S_N(\vec{k})$, FMI) due to the Fourier transform.

$$M(\vec{k}) = \left|\widetilde{f}^S_G(\vec{k})\right|^2 + \Delta\left|\widetilde{f}_N(\vec{k})\right|^2 + \widetilde{f}^S_G(\vec{k})\widetilde{f}^S_N(\vec{k})^* + \widetilde{f}^S_G(\vec{k})^*\widetilde{f}^S_N(\vec{k}), \tag{4}$$

where $\Delta\left|\widetilde{f}_N(\vec{k})\right|^2$ is DNI term. We have dropped the terms estimates the Possion noise power spectrum of the source and noise image (F_S and F_B), because we find the Possion noise here would not change the result. Then, we run measurement on FGI, FGI+DNI, and FGI+FMI respectively. The FMI term is found to bias the measurement in the noisy samples significantly. Figure 3 shows the results from the PDF_SYM approach.

The FMI term, $\widetilde{f}^S_G(\vec{k})\widetilde{f}^S_N(\vec{k})^* + \widetilde{f}^S_G(\vec{k})^*\widetilde{f}^S_N(\vec{k})$, contains the Fourier transform of galaxy image, $\widetilde{f}^S_G(\vec{k})$, rather than the power spectrum, $\left|\widetilde{f}^S_G(\vec{k})\right|^2$. Therefore, the shear estimators measured from FMI compared with that from FGI would become negligible in the shear estimation when the galaxy has very high SNR. However, when the brightness of the galaxy decreases to a certain level, the bias due to FMI would become significant. In the deconvolution process, the image power spectrum is divided by the power spectrum of PSF, $\left|\widetilde{W}_{PSF}(\vec{k})\right|^2$. For the FMI term, the deconvolution operation would leave the imprint of the anisotropy of PSF on the image power spectrum. Therefore, the asisotropic PSF would give rise to the additive bias in the faint sample.

show the bias & origin of the bias

average method & PDF_SYM method

Galsim & point source galaxy

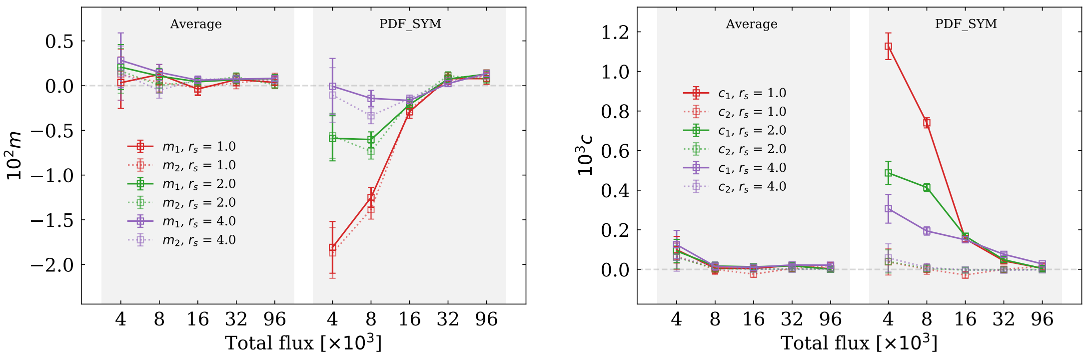

Figure 2. The shaded areas show the multiplicative and additive bias measured by average and PDF_SYM approach repectively. We use a slightly sheared PSF ($e_1 = 0.1$, $e_2 = 0$) to show the effect of the PSF anisotropy. The measurement of the PDF_SYM approach would be biased by the small and faint galaxies.

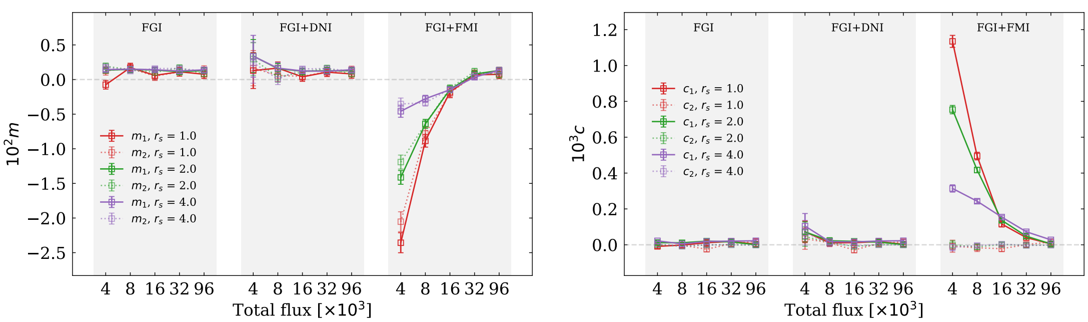

Figure 3. Multiplicative and additive bias measured from different components of the galaxy power spectrum by the PDF_SYN approach. The measurement is biased by FMI which is the mixture of the power spectrum of galaxy image and that of the background noise.

power of the galaxy, the noise residual and the galaxy-noise crossing term.

bias depends on SNR and morphology

3.2. *Improving the statistics towards sub-percent precision*

gN & gU

4. CONCLUSION

We

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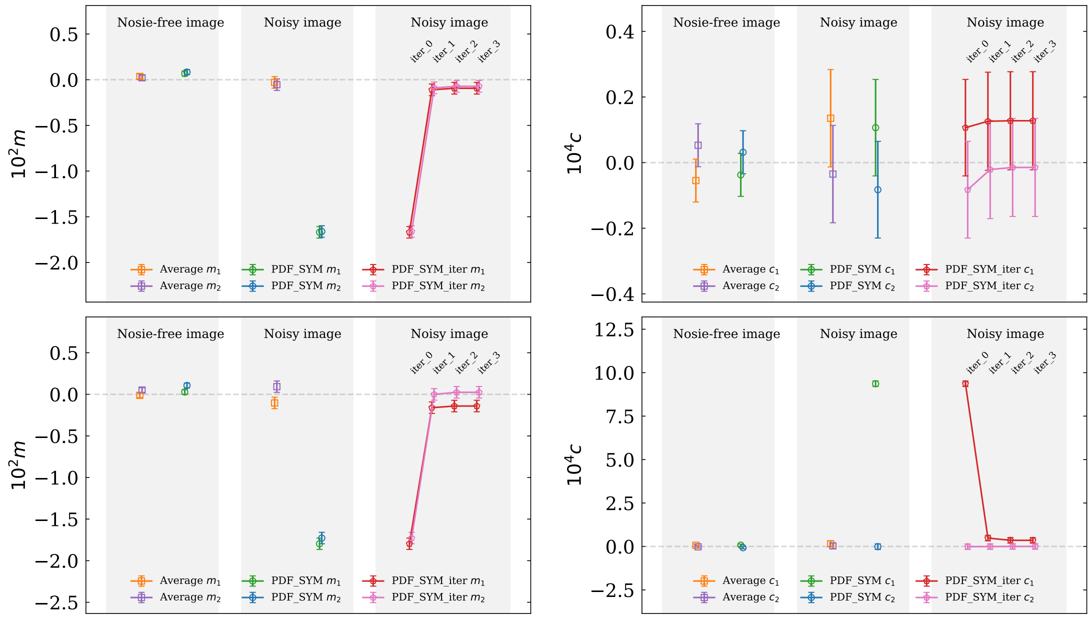

Figure 4. 8×10^6 Random walk galaxies. Aisotropic PSF ($e_1 = 0.1$, $e_2 = 0$)

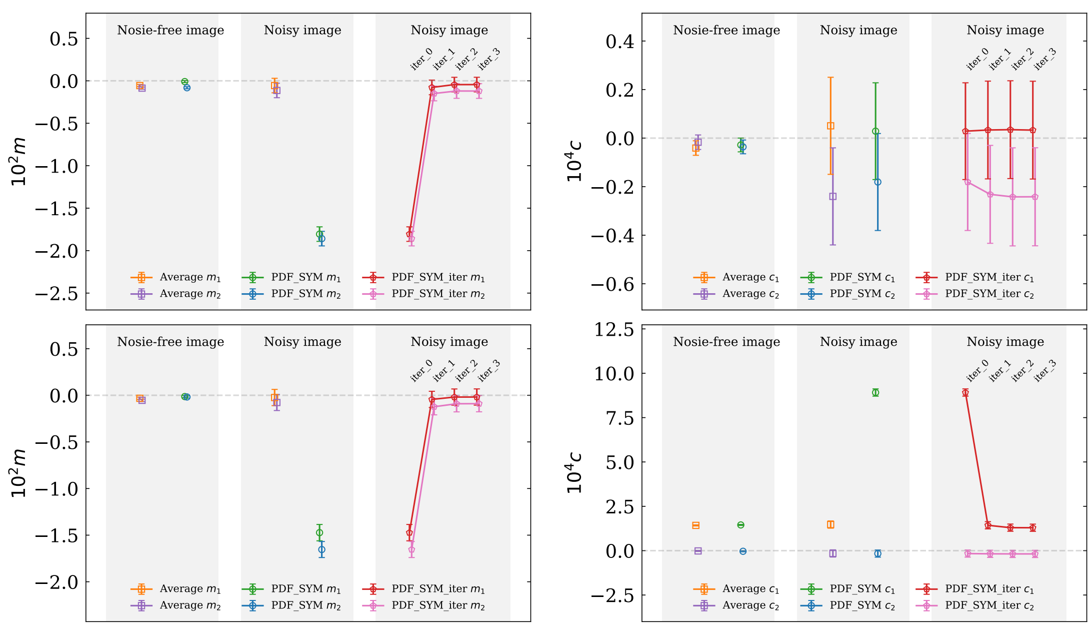

Figure 5. 4×10^7 galsim galaxies.