A Comparison of Three Methods for Weak Lensing Measurement

Overview

Gravity stands alongside neutrino and electromagnetic radiation as an independent probe of the cosmos. Gravitational lensing, because it arises solely from spacetime curvature, allows physicists to map baryonic and dark matter in the sky. Theorists have shown that gravitational lensing's weakest regime probes structure on scales from galaxy halos to galaxy superclusters. Weak gravitational lensing allows us to directly measure, for example, the power spectrum of mass density perturbation on the scale of eight megaparsecs.

The power spectrum tells us how matter clumps together in the domain of large-scale structure (LSS). From it we can infer the interplay between matter condensation and cosmological expansion, and thus the early evolution of the universe as well as its fate. Measuring the power spectrum via weak gravitational lensing therefore yields a better understanding of our universe.

Three Principal Problems

A weak lensing signal manifests as about a two to ten percent shear and convergence[1] in an image. Our earthbound perspective prevents us from knowing directly how the image would appear without the shear. One principal problem is to extract this signal without reference to the unbiased image.

A second principal problem involves systematic error. We want to analyze small background galaxies because it is their images that foregrounding LSS biases with weak lensing. An anisotropic point-spread function (PSF), which also manifests as a small shear, can distort weak lensing signals. Pixelization also distorts smooth galaxy shapes. Identification and deconvolution of systematic error from PSF and pixelization effects are essential for measuring the weak lensing shear. We must keep systematic error below the threshold of the weak lensing shear, which requires of our images high resolution, low noise, and correctible PSF. This pushes the limits of current technology.

A third principal problem is that we need not only deep images with a high density of small galaxies, but wide images as well, for weak lensing analysis is statistical by nature. We postulate that (1) distant galaxies appear elliptical in our images, and (2) in the absence of shear, a local ensemble has null average ellipticity. Shear manifests as a locally non-zero average. To generate a meaningful shear map, though, we need to average over multiple locales. Our images must therefore resolve many distant galaxies over a wide region of the sky.

Modern Data and Methods

These three principal problems dictate that we need wide and deep images with low systematic error to map matter with weak lensing. Fortunately, the Hubble Space Telescope (HST) fulfills these requirements. The Great Observatories Origins Deep Survey, or GOODS, which, in part, uses HST, has resolutions from 0.05 down to 0.03 arcseconds per pixel with varying but low noise. And whereas GOODS covers roughly 320 square arcminutes in two disjointed fields, another HST project currently underway, the Cosmic Evolution Survey, or COSMOS, covers solidly two square degrees at comparable resolution.

To tackle the three principal problems given modern HST data, three methods have become prominent. Kaiser, Squires, and Broadhurst (KSB, 1995) propose an elegant and simple method to measure galaxy shape

[1] From this point I will call shear and convergence simply shear.

and determine PSF using nearby stars. Rhodes, Refregier, and Groth (RRG, 2000) revisit the KSB algorithm, seeking to improve on it. Then, in 2003, Refregier and Bacon introduce their innovative Shapelets method, which involves mapping galaxy shapes onto the two-dimensional quantum harmonic oscillator space. Here image deconvolution reduces to simple matrix operations.

Objectives

Using actual and simulated HST data, what are the relative merits and shortcomings of the KSB, RRG, and Shapelets methods? How does each method perform when analyzing galaxies of varying flux, area, shape, and ensemble distribution? Can they accurately calculate PSF and recover the weak lensing shear? With existing software, can we measure weak lensing and map matter in GOODS and COSMOS? My SURF project with Professor Richard Ellis and Postdoctoral Fellow Jason Rhodes at Caltech will answer these questions. These objectives are consistent with those of my Honors Senior Thesis, entitled "Weak Gravitational Lensing in GOODS,"[2] which I conduct at the Lawrence Berkeley National Laboratory with Professor George F. Smoot. For my thesis I measure the LSS power spectrum and its normalization factor, σ_8, using GOODS.

Approach

Having already begun weak lensing research for my undergraduate Honors Senior Thesis has prepared me for this SURF project. To further prepare for SURF I plan to consolidate my knowledge of lensing theory and the three methods before arriving at Caltech. Studying the papers will accomplish this. Also, I have discovered that HST image analysis is computer intensive, so during that time I will ensure I have a working knowledge of the necessary programming languages and software such as C++, Matlab, IDL, and Perl.

Together, my group and Dr. Ellis's have implemented the software for most aspects of these methods already, and we are able to generate simulated HST images. I will fill in the gaps by writing the KSB PSF correction code and the Shapelets PSF correction code.

I plan to analyze the simulated HST images with our software, varying input galaxy parameters and PSF. The software will attempt to recover the galaxy parameters and PSF, and I will compare these results to the known input to determine the error. To search for a real signal, I will also process GOODS and COSMOS data, after which our HST simulations are modeled. In the last part of the SURF period I will analyze the resultant data, as is appropriate for the above Objectives, my Honors Senior Thesis, and possibly journal publication.

Acknowledgements

I thank Dr. Ellis for offering me his research group's auspices through SURF, and informing me of the COSMOS project, and Dr. Jason Rhodes of Caltech for suggesting this proposed project as stated. I owe Dr. Smoot credit for introducing me to the weak lensing problem and to GOODS, and providing the means for my current thesis research. Dr. Jodi Lamoureux of LBNL, who advises me on my Honors Senior Thesis, provides me continual instruction.

References

COSMOS website: <http://www.astro.caltech.edu/cosmos/>

GOODS website: <http://www.stsci.edu/ftp/science/goods/>

Kaiser, N., Squires, G., & Broadhurst, T., 1995, ApJ, 449, 460.

Refregier, A., & Bacon, D., 2003, MNRAS, 338, 48R.

Rhodes, J., Refregier, A., & Groth, E., 2000, ApJ, 536, 79.

[2] http://aduro.lbl.gov/fwh/