WEAK LENSING WITH COSMOS: MAPPING THE DARK MATTER CONTENT OF THE UNIVERSE

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1 Introduction

Weak lensing has emerged as a powerful technique to understand the distribution and properties of dark matter. My work to date has been to explore the practicalities of such studies with the Cosmos project. This report describes the Comos survey, it's overall goals, the challenges of weak lensing, and progress to date.

2 COSMOS 2-degree Survey

The COSMOS project [7] is a two degree survey including I($\lambda = 837.5nm$ F814W) band imaging with the HST/ACS and multiwavelength follow up from the ground. With an expected sample of over 2 million galaxies, the COSMOS survey is designed to probe key cosmological issues such as:

- The assembly of galaxies, clusters and dark matter on scales up to $\sim 2 \times 10^{14} M\odot$.
- The evolution of galaxy morphology, galactic merging and star formation as a function of LSS (Large Scale Structure) environment and epoch.
- The evolution of the dark matter halos and their distribution.

The two degree field makes COSMOS unique because it is the first survey to truly encompass the expected scales of LSS from high redshifts ($z \simeq 3$) to the local universe ($z \simeq 0.2$). Covering a comoving area[1] of 50×50 Mpc at $z = 0.5$ and 170×170 Mpc at $z = 3$, the survey will sample a full range of environments including voids, groups and clusters.This dynamic range is crucial to obtaining a full picture of galaxy and LSS evolution.

To adress the above questions, we need to study both the luminous components and the dark matter content of the field. Determining the characteristics of galaxies and mapping the baryons is a well studied procedure whereas the dark matter distribution is less well known. Only recently has weak lensing emerged as a means of mapping dark matter. My aim is to determine the feasibility of measuring the dark matter in the ACS survey with weak lensing techniques. The scientific goals of producing such maps include:

- Identification of clusters and determination of cluster masses. These measurements will calibrate other mass determination techniques such as x-ray emission or velocity dispersion methods. The number density of clusters as a function of mass is a highly sensitive probe of cosmological parameters such as Ω_M, σ_8.
- The comparison of the dark matter distribution with that of the baryons that will tell us the role that dark matter plays in galaxy morphological assembly.
- Given redshifts, the background galaxies can be 'sliced' in redshift to perform shear power tomograpy. This 3-D mapping constrains cosmological parameters and tests the paradigm of growth of structure by gravitational instability.

3 Weak lensing

The difficulty of this technique is that the distortion to be measured is very small ($\sim 2\%$). Weak lensing is therefore extremely reliant upon the precision of galaxy shape measurement methods and requires high quality imaging data. Two main factors are crucial in a weak lensing analysis. Firstly, because of the dispersion in galaxies intrinsic shapes, the lensing signal must be estimated by averaging the ellipticity over many sources. The resolution of the map will therefore increase with the number density of sources. Typically, the ACS permits an extraction of $60 - 80$ resolved galaxies per $arcmin^{-2}$ compared

[1] $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 65$

to 30 $arcmin^{-2}$ for ground-based data. Secondly, the size, anisotropy, and stability of the PSF (Point Spread Function) determines the sizes of the smallest galaxies that can provide accurate shape measurements. Galaxy shapes must be corrected for smearing by the PSF, especially its anisotropic component.

Deep HST observations are thus likely to be ideal for weak lensing studies in both respects. The combination of high surface density of background sources and improved PSF stability increases both the angular resolution and the sensitivity of the maps as compared to ground-based surveys. We must verify however, that all systematic effects, including the PSF, can be tightly controlled.

4 Method

I analysed the various systematic effects and created a pipeline shown in Figure 1 to correct the data and extract the lensing signal.

The first step in the data analysis was to locate objects within the images. I used SExtractor [2] on all 260 ACS images and produced catalogs containing various parameters including position, magnitude and a first estimate of the shapes.

The second step uses a method devised by Rhodes, Refregier and Groth (RRG) [6]. The purpose of this method is to provide a improved measure of the shapes of galaxies and to derive an estimate for the weak lensing shear. Firstly, the PSF moments are derived from stellar images. Galaxy moments are then measured and corrected for the PSF. The result is a catalog containing lensing parameters such as ellipticitys and shear estimates for all galaxies within the field.

The third step is to clean the catalog to the level necessary for weak lensing purposes. Figure 2 shows how stars are discarded based on their magnitude and peak surface brightness properties. Because the weak lensing signal is very weak, other sources of contamination must also be removed including residual cosmic rays, diffraction spikes and the edges of each image where S/N (Signal to Noise) is low due to dithering.

Finally the cleaned shear catalogcan be used to derive mass maps. The mass distribution is reconstructed from the weak lensing signal with a method developed by Kaiser and Squires [5].

5 Dark matter maps

Figures 2 and 3 present the dark matter maps and light maps of the first square degree of COSMOS ACS data produced by this pipeline. This is an exciting but preliminary result. Lensing B-modes show that there are still systematics to account for. I am convinced that data contamination is correctly removed. The PSF correction however needs deeper examination. In future attemps I will also consider implementing Shapelets [5] to improve the shear estimation.

When achieved, these maps, will be unique. This will be the largest contiguous field observed by HST and its highest resolution mass map, probing a volume from $z \sim 0.2$ and $z \sim 1$.

6 Conclusion and perspectives

Currently, half of the COSMOS field has been imaged with HST. A data pipeline has been set up to analyse these data and produce a mass map using weak lensing techniques. The methods employed in this pipeline were studied in order to produce an optimized dataset for weak lensing purposes. The pipeline was also designed to facilitate the integration of new data when they becomes avaliable in 2005. I have demonstrated that many systematics can be corrected but the PSF needs further understanding.

As a thesis project I intend to investigate two of the goals cited above: the growth of LSS and implications for the formation of baryonic structures. By combining redshifts and weak lensing from the COMBO-17 survey, Bacon et al. [1] have detected of the evolution of the matter power spectrum for $0 < z < 1$. The enlarged Cosmos field and the increased depth should allow to extend these results significantly.

References

[1] Bacon et al, 2004, *Mon. Not. R. Astron. Soc*, **000**. 1-11

[2] Bertins E, Arnouts S, 1996, *A&AS*, **117**, 393

[3] Frenk *et al*, 2002

[4] Kaiser N, Squires G, 1993, “Mapping the dark matter with weak gravitational lensing”, *Ap. J*, **404**, 441

[5] Massey R J, 2004, Weighing the universe with weak gravitational lensing

[6] Rhodes J, Refregier A, Groth J, 2000, *Ap. J.* **536**:79-100

[7] Scoville *et al*, 2003, The cosmos 2-Degree ACS Survey

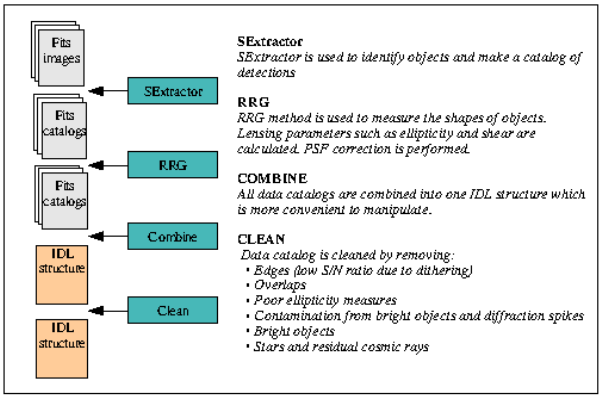

Figure 1: Weak lensing data analysis pipeline. The shapes of objects are measured and corrected for the PSF. The catalogs must also be cleaned before applying lensing techniques.

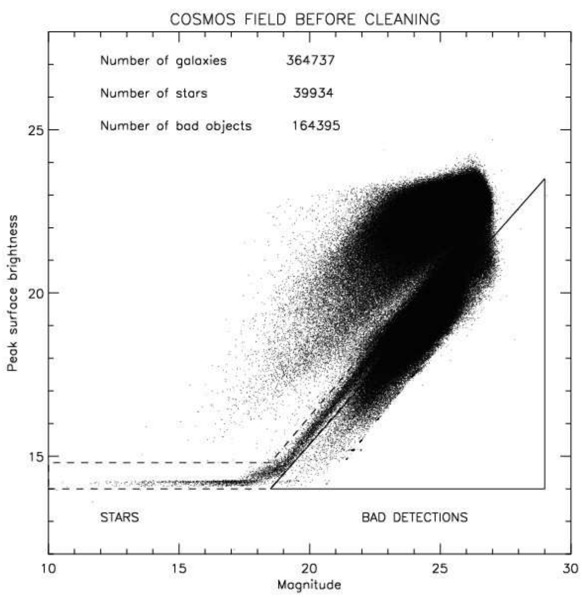

Figure 2: Stars, galaxies and cosmic rays are identified by their distribution within a Magnitude - Peak surface brightness plane.

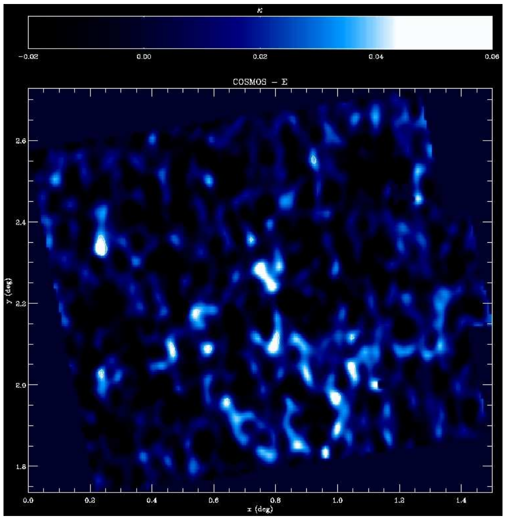

Figure 3: One square degree dark matter map derived by weak lensing

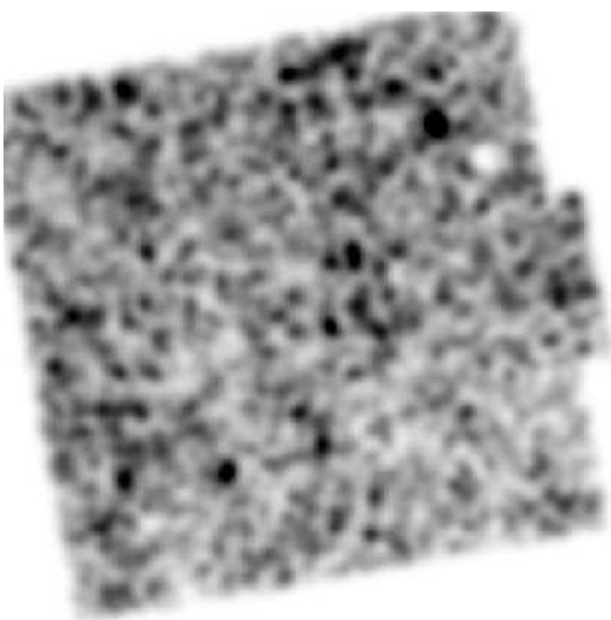

Figure 4: Light map of the same field for objects with apparent magnitude between 20.5 and 22.5.