Mass Estimates of Shear Selected Galaxy Clusters

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Abstract

The detection of galaxy clusters has traditionally been done through optical selection methods by detecting overdensities in galaxies throughout an image. However, UC Davis has been pioneering a method of detecting galaxy clusters by their weak lensing signal alone. The aim of this project is to obtain mass estimates of these clusters so that they may be compared with existing optical data to look for biases. Such biases can yield tighter contraints on the characteristics of dark matter. While there is much work to be done, here I outline the steps taken from the raw data to obtaining mass estimates and outline future areas to examine.

1 Introduction

Characteristics of galaxy clusters such as their population and masses are dependent on cosmological parameters such as dark matter/energy. There are many robust ways of detecting clusters, mostly relying on methods of detecting over population of galaxies within similar redshift throughout the sky. However, as with any method of detection one may be enforcing a bias. Dr. David Wittman of UC Davis has been able to detect clusters of galaxies only by how they exhibit weak gravitational lensing. By examining clusters detected these two ways, differences in their ratio of stellar mass to total mass and in their star formation history and can be observed. If the mass ratios are the same, then any tendency in optically selected clusters, those detected through overdensities, for overluminosity would be due to more young low mass stars. Also, if weak lensing detected clusters had a higher ratio, this would imply that they converted larger portions of their mass into stars early on [1]. Mass, star formation history and other characteristics can be derived by fitting Spectral Energy Distribution (SED) models to observations based on these characteristics. However, there are many steps going from raw telescope data to modelling galaxy SEDs and finally deriving mass estimates which will be outlined below.

2 Data

2.1 Data History

The data consists of over a dozen targets spread out across fields in the sky. The detected clusters were found within the Deep Lens Survey[1] which consists of 5 2x2 degree field surveys. The surveys are in the B,V,R, and z optical bands and were done using the Blanco and Mayall telescopes over five years. All of the data has already been reduced by the DLS team at Davis and was ready to be used. A large part of my project was to do the same with data Dr. David Wittman took in 2006 from the Infrared Array Camera (IRAC). IRAC is part of the Spitzer Space telescope launched in August of 2001 consisting of two 256x256 camera arrays of CCDs, similar in principle to those used in a digital camera. The IRAC data consists of several pointings within fields 2-5[2] in the 3.6, 4.5, 5.8, and 8.0 micron bands. The data was downloaded through the Spitzer Leopard[3] v9.0 software using pipeline version S18.5.0. Spitzer provides the raw data straight from the telescope along with calibration files, basic calibrated data which does the calibration from basic effects of the CCD instrument, corrected versions of these calibrated files, and post data products such as mosaics. The mosaics they provide are very poor, and cannot give results better than twenty percent. Initially, the basic calibrated data was going to be used with corrections applied manually, but the latest version of the pipeline does a good job of applying these corrections for us through the corrected calibrated files. These corrections include masking dead pixels on the camera array, accounting for

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[1]For more information about the Deep Lens Survey see http://dls.physics.ucdavis.edu/
[2]Locations of referenced fields availabe at http://dls.physics.ucdavis.edu/coord.html
[3]http://ssc.spitzer.caltech.edu/propkit/spot/

muxbleed, ghosting and other artifacts created by bright saturated regions on the camera array, column pulldown and other effects[4]. However, since this is an infrared camera it is difficult to do science on a single image because there is a considerable background noise from the telescope emitting radiation. To work around this, a camera will take many frames of a target and combine them in a process called mosaicking.

2.2 Mosaicking

While many sources can be seen from a single image taken by any telescope, artifacts such as cosmic rays are present in the image and the image itself is not very deep. To get around this, astronomers do a process called mosaicking which consists of taking multiple exposures of a target while shifting the center of the image slightly. By overlaying many of these images on top of each other many corrections can be applied. Effects such as cosmic rays which saturate pixels can be masked out by disregarding abnormally high pixel values at a location which give better images. Also, if the camera shifts an amount not evenly divisible by the pixel size an image with a smaller pixel scale can be created. More importantly though it allows astronomers to observe deeper objects. The IRAC

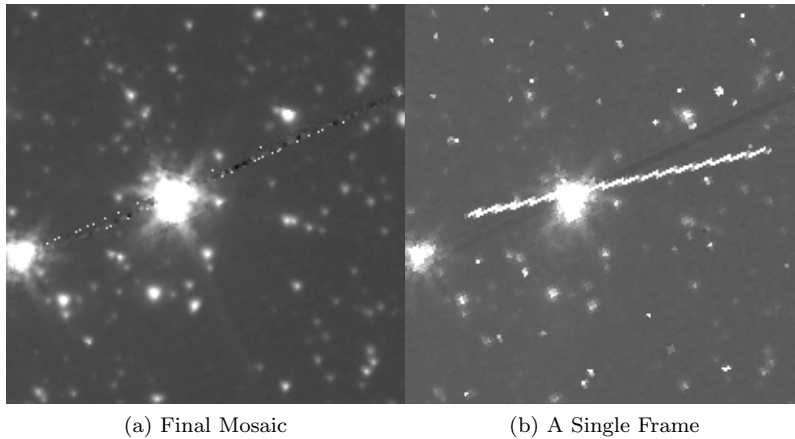(a) Final Mosaic   (b) A Single Frame

Figure 1: The long streak on top of the star in the single frame is a cosmic ray striking parallel to the CCD. The small white dots are cosmic rays striking perpindicular to the CCD. By taking multiple exposures of a target these can be masked out as on the mosaic on the left of the same target. In addition the mosaic is clearer and contains more objects. These objects are present in the single frame, but very hard to make out. By stacking multiple frames these deeper objects become more visible.

data was mosaicked using the Spitzer provided MOPEX (MOsaicker and Point source Extractor) software[5]. For the most part, mosaicking was done according to the COSMOS cookbook[6] with a few exceptions to match the geometry of the images with the optical data. In mosaicking, first a Fiducial Image Frame is created which is the large image that all of the frames will be projected onto with the specified coordinate system. Each frame then has a constant value added to each one so the backgrounds are the same across all frames. The images are then interpolated onto the FIF. Outlier rejection is then performed, which creates a mask of pixels to not include in mosaicking such as pixels on the CCD that no longer function. Cosmic rays and other abnormally high pixels in frames are also masked out. The images are then stacked onto the FIF. This can be done by taking an average of pixels across over laping frames, or by a weighting scheme. The images are then background subtracted and a mosaic is produced. This is a high quality image, which shows deeper objects with significant less uncertainty.

2.3 Colorpro of Data

Now comes to task of obtaining measurements of flux for each object, a process commonly referred to as photometry. A common approach is aperture photometry, where a circle is placed over each ring and the measured flux is the light inside the circle. A ring is then drawn farther outside the circle to determine the background level, and the object flux is the flux within the circle subtracted by the flux in the ring. This works very well for point sources

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and with MOPEX is fairly straightforward as it contains a package ready to be used. However, these galaxies are not point sources so performing aperture photometry is more difficult. Also, because the quality of the data varies in the 8 bands, the R optical band being the best, if aperture photometry was to be used everything would have to be degraded to the lowest quality band. This is because aperture photometry is dependent on how a point source is spread across an image. So, instead of simple aperture photometry a package called Colorpro[7] written by Dan Coe was used instead. This is a series of python scripts which wrap around another photometry package called SExtractor[8] which performs photometry through several different types of apertures. Colorpro uses isophotal apertures which are basically traced outlines around each object. An image of these apertures are provided from previous runs that have been performed already, and it is used on all eight bands. To avoid degrading all the images to the lowest quality image, Colorpro will convolve the best seeing image with the current band's point source function which essentially blurs it. The measured flux is the flux measured in the best band through an elliptical aperture and the difference between the current band isophotal and the degraded best band isophotal. These are combined and will account for the lost flux in blurring the image. The main point to be made is that Colorpro is our work around of aperture photometry and has the advantage of working with images of varied quality. Colorpro was performed on each target using cropped images of the DLS optical data and of the IRAC data. Point Spread Functions were created using IDL scripts written by Russell Ryan of UC Davis, and calibration factors such as zero points were provided for the optical data and derived for the IRAC data as according to the Spitzer's website[9]. One of the current issues with the photometry is that there have been shifts for the differences between optical bands. Since there are four bands, four shifts are needed but for reasons that are still being worked on currently for the majority of the data only three are possible to be obtained. This does have a large effect on the results and is non trivial, the issue is currently being worked on by David Wittman's team.

3   Modelling

To obtain mass estimates, modelled galaxy spectra based on several free parameters such as mass are fit to each detection. To do this, the latest version of Galaxev by Bruzual and Charlot[10], the stellar population synthesis code, was used. This code generates stellar population spectra based on specified metallicity, initial mass function, star formation rate, and age. Metallicity represents a measurement of the ratio of Fe III to Hydrogen and is assumed to be the same as our own sun. The initial mass function describes the initial distribution of the masses of the stars at the time of galaxy formation. The most common and typical form is the Salpeter function which states that the number of stars with a given mass is proportional to that mass raised to -2.35 with cutoffs at 0.01 and 100 solar masses. Also common is an exponential form for the star formation rate which describes the rate at which stars form since the start of formation for the galaxy, $SFR = \psi_0 e^{t/-\tau}$. Galaxev uses stellar libraries to build it's output spectra and these libraries are based off of factors such as the metallicity and initial mass function preventing them from acting as free parameters. Also, Galaxev holds the functional form of the stellar formation rate the same, but tau is allowed to vary. Galaxev then outputs spectra as specific luminosity in units of solar luminosity per angstrom per solar mass, l_λ. However, this does not represent the galaxy spectra and must be converted to a band-pass average flux to compare to the measurements in each band including factors such as mass, redshift, and dust. The following equations are the steps performed to compare to measurements and are shown for understanding of how these factors affect the spectra. These steps are described more thoroughly by Papovich et. all [2].

$$L_\nu(\lambda, t, \tau, A_{\lambda_0}, M) = \frac{\lambda_0^2 M}{c m^*(t)} l_\lambda(\lambda_0, t, \tau) 10^{-0.4 A_{\lambda_0}} \tag{1}$$

The Galaxev output was normalized to one stellar mass, so it is multiplied by the galaxy mass divided by the stellar mass fraction. The $\frac{\lambda^2}{c}$ being the conversion from lambda space to frequency space and the last power term accounting for dust extinction. The dust in a galaxy will scatter blue light and emit infrared light, this effect is modelled according to the equations developed by Calzetti et. al [3]. Luminosity, the rate at which a body radiates energy, is then converted to a flux density,

$$F_\nu(z, \lambda, t, \tau, A_{\lambda_0}, M) = (1 + z) \frac{L_\nu(\lambda_0, t, \tau, A_{\lambda_0}, M)}{4 \pi D_L^2(z)} \tag{2}$$

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[7]http://acs.pha.jhu.edu/ coe/ColorPro/
[8]http://astromatic.iap.fr/software/sextractor
[9]http://ssc.spitzer.caltech.edu/archanaly/quickphot.html
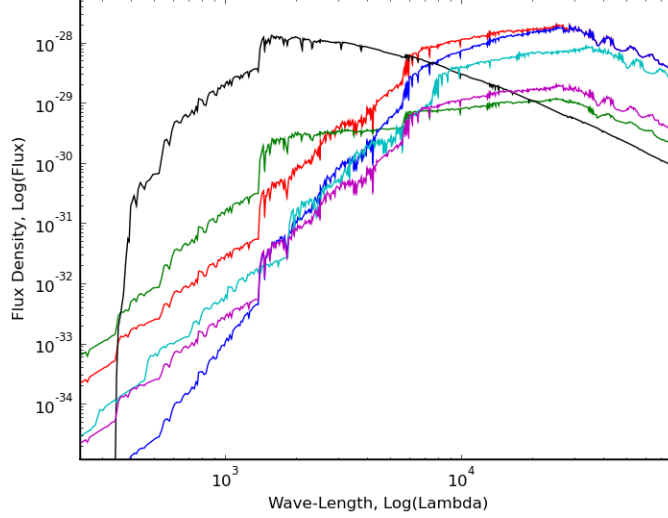[10]http://www2.iap.fr/users/charlot/bc2003/

Figure 2: Comparison of the output spectra by changing different parameters.

Effectively, the luminosity is shifted for redshift then divided by the area of a sphere to represent the amount of light we observe. D_L is the luminosity distance, the length a photon travels along in curved space [4]. Lastly, the flux density must then be averaged with each of the four optical and infrared bandpass curves to compare with the measurements obtained through these filters,

$$\langle F_\nu(z, t, \tau, A_\lambda, M) \rangle = \frac{\int T_\nu F_\nu(z, \lambda, t, \tau, A_{\lambda_0}, M) d\nu/\nu}{\int T_\nu d\nu/\nu}, \tag{3}$$

yielding the bandpass average fluxes. In fitting the models to data mass, t, τ, and A_λ are allowed to vary. Redshift is also allowed to vary, for the purpose of sorting out detections not in the cluster. Over 10^6 models were generated letting A_λ vary from 0.0-2.0 mag, t from 0.001-20 Gyr, and τ from 0.01-1 Gyr also with 1000 Gyr. A best-fit is then obtained by searching for the model with a minimal χ^2 value,

$$\chi^2 = \sum_i \frac{\left[f_\nu^i - \langle F_\nu(z, t, \tau, A_\lambda, M) \rangle\right]^2}{\sigma^2(f_\nu^i) + \sigma^2_{sys}}. \qquad Mass_{\chi^2_{min}} = \frac{\sum_i \frac{f_\nu^i F_\nu^i}{\sigma_i^2}}{\sum_i \frac{F_\nu^{i\,2}}{\sigma_i^2}} \tag{4}$$

The uncertainty derived from the data is represented as $\sigma(f_\nu^i)$ and the added systematic uncertainty also included and is assumed to be seven percent of the measurement. Since mass is only a multiplicative factor for F_ν it can easily be shown that the mass for the minimized χ^2 is the above. All of this is performed using scripts written by myself in Python using SciPy libraries from the output catalog created by Colorpro. To further illustrate the effects of these parameters Figure 2 shows a typical observed galaxy spectra (red curve). An important feature of this galaxy spectra is that it peaks in the near infrared, which is why it is essential to get the infrared and the optical data so that both sides of the peak can be constrained. The fact that the 3.6 micron band is so close to the peak is essential as the mass represents a vertical shift in the SED. The magenta curve shows the same SED, but with a fraction of the original mass. Having a data point on the peak can distinguish which of these curves fit the best. The other curves are changing of different parameters. The blue curve has one more magnitude of extinction applied, showing that more of the bluer light is scattered. The green curve is with a large τ value, essentially representing a constant stellar formation rate. It has a very different shape than the original red curve as more stars are younger and emit higher energy light. The black curve is of a very young galaxy, and likewise all the stars are young so the entire spectrum peak is towards the bluer end of the spectrum. Lastly the magenta curve is of a galaxy at twice the original redshift. It is both shifted from the normal effects of redshift and lower because the galaxy is at a farther distance away.

4 Results and Future Work

Currently, the modelling code correctly fits data and obtains mass estimates of detected objects along with a χ^2 value indicating goodness of fit. By sorting out the objects by imposing limits on how poorly the data can fit and the estimated redshift that cluster members should be located in the cluster members should be able to be separated from the rest of the data. In the first image, one can see that there is a clump near the center off to the

(a) All Objects

(b) Those with a χ^2 less than 10

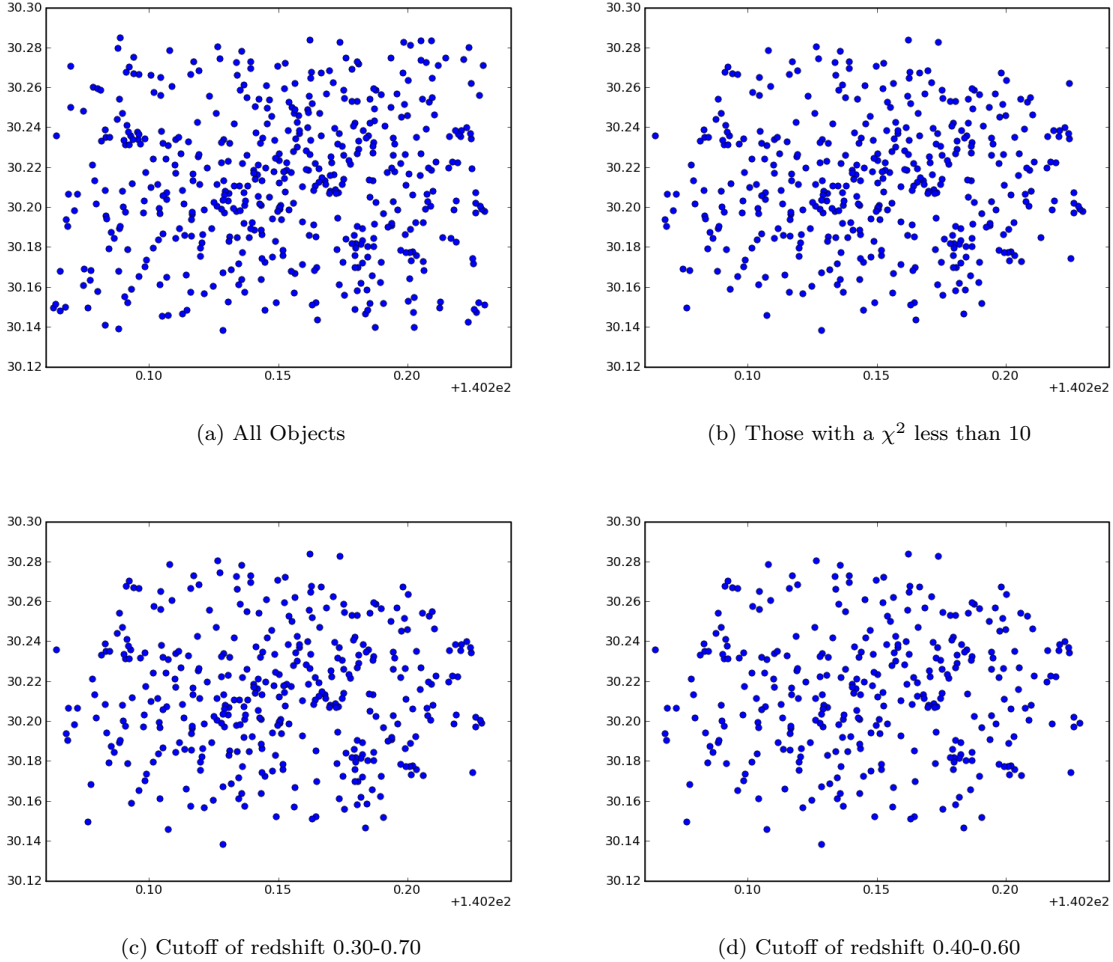(c) Cutoff of redshift 0.30-0.70

(d) Cutoff of redshift 0.40-0.60

Figure 3: Objects plotted as Right Ascension vs Declination for a sample cluster with various cutoffs applied for a cluster in Field 2

right a small amount which is the cluster. The goal is to get only those objects by flitering out certain parameters. In the second image objects are filtered by χ^2 values. Objects near the edges are filtered out which is a good sign as most of those have nonsense data points in the infrared as the image in those bands doesnt extend that far. That said clearly there is an issue as filtering by redshift is not giving the cluster members. In fact several of them are being filtered out. This indicates that there exists a problem with the data itself. The data points themselves look correct, but the error bars are very large. Colorpro has been running smoothly on the optical data, giving correct measurements and appropriate error bars but the IRAC error bars are sometimes within a magnitude of the data point itself. I currently believe this to be the main issue and have been working to determine a solution. There have been several other problems in the same nature of this regarding colorpro and the IRAC data that I have been solving, one involving creating PSF images and ensuring that the zeropoints are correct. In addition, there is another issue that will be a large problem even if all of this works. The optical data is given in square fields with a small amount of overlap. These areas of overlap are not the same, and are derived from different data sets. For the majority of the IRAC data the fields are not all contained within one optical mosaic. This means somehow both images will need to be used which is difficult because the background between the two images are different. This

could be gotten around by taking a cut in the IRAC image and running Colorpro twice but one would have to be careful to not cut through a galaxy creating two objects and several other serious issues. Furthermore for three of the five fields there are three given calibration shifts for four bands, meaning that one must assume zero for an arbitrary band and assume it is correct. This is very problematic as the modelling and fitting are very dependent on the optical data. As of right now there is much more work to be continued on this project. The mosaicking is complete, the modelling and fitting code is working well and there is a large understanding of how colorpro can work with the IRAC data. The problems outlined previously all need to be resolved until a full answer can be given about the mass ratios of these clusters. The hardest parts of this project have been completed, but without fixing these errors no results can be made. I will be continuing this project with the goal of fixing these errors and to derive mass estimates throughout the Fall.

4.1   Acknowledgements

References

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[2] Papovich, C., Dickinson, M., Ferguson, H. C. 2001,ApJ,559,620

[3] Calzetti, D., Armus, L., Bohlin, R. C., Kinney, A. L., Koornneef, J., & Storchi-Bergmann, R. 2000,ApJ,533,682

[4] Hogg, David. *Distance measures in cosmology* (2000), arXiv:astro-ph/9905116v4.