Density profiles of galaxy clusters in the CFHT Stripe 82 survey from weak gravitational lensing

Maria Elidaiana da Silva Pereira[1], Leandro Beraldo[2], Martín Makler[1] & CS82 collaboration

[1]Brazilian Center for Physics Research (CBPF, Ministry of Science, Technology and Innovation - MCTI), [2]University of São Paulo (IAG/USP)

mariaeli@cbpf.br #VoltaMCTI #SaveBrazilianDemocracy

Abstract

Galaxy clusters are important tools to study the matter distribution in the Universe. A range of techniques has been used to obtain the clusters mass such as X-rays, Sunyaev–Zel'dovich effect and Weak Lensing (WL). The only direct mass estimator that can be constructed from photometric data alone is WL, which also has the advantage of being insensitive to the dynamical state of the cluster and is a direct probe of the total mass. To perform WL measurements a high quality imaging survey is mandatory, which is the case of CFHT Stripe 82 (CS82) survey. The CS82 survey covered an area of ~ 170 square degrees on the SDSS Stripe 82 region in the i-band to a depth of mag AB 23.5 and mean seeing of ~ 0.6″. In this work we focus on the WL measurements - stacking the tangential shear profiles - around galaxy clusters, which allows one to obtain high signal-to-noise profiles even for low mass clusters. In our analysis, the shear measurements of galaxies were computed with the Lensfit code and the cluster detection was made using the redMaPPer algorithm. We fit the derived mean radial profiles by models such as the Navarro-Frenk-White and Einasto ones.

Introduction

The Cold Dark Matter (CDM) model of the structure formation has a number of predictions for galaxy clusters which can be tested observationally, e.g. the dark matter distribution, the halo mass function, cluster clustering, etc. However, to perform these tests we need precise measurements of the galaxy cluster masses. Actually, most of the techniques rely on physical assumptions, such as virial equilibrium, to perform a mass measurement. The WL effect has been shown a great tool to probe the dark matter in clusters, since it is sensitive to all mass associated with the cluster. In practice, the clusters have different properties (e.g. mass, shape, redshift) so that, we can use the technique of the stacking WL to have an average estimate of the mass with a higher significance than we would have by the mass measurements of individual clusters. In this work we performed a stacking WL analysis of the CS82 galaxy clusters in order to obtain a mass-observable relation for these clusters.

Aims

1. To measure the stacked tangential shear profile for the CS82 clusters.
2. To perform the profile-fitting using realistic models: Navarro-Frenk-White (NFW), Baltz-Marshall-Oguri (BMO) and Einasto.

Methodology

In this work, to obtain a good estimate of the cluster masses we used the data from the CFHT Stripe 82 survey (CS82). First, we detected the objects, then we applied the Lensfit [1] code to measure the shear components of the sources. The clusters were detected with the redMaPPer [2] code and we computed the average tangential profile in rings around the center of these lenses. Finally, we performed a profile-fitting to the average tangential profile to determine the mass and concentration to them.

The CFHT Stripe 82 survey

CS82 is an i-band survey in $170\,deg^2$ of the Sloan Digital Sky Survey (SDSS) Stripe 82 that was specially designed for weak lensing measurements. It has an excellent image quality with mean seeing $\sim 0.6''$ and completeness magnitude of ~ 23.5 in the i-band. The survey detected around 17 million objects.

Sources: shear components with Lensfit

From the detection catalog we obtained the source catalog through Lensfit [1]. The code relies on a Bayesian method to measure the shape of galaxies through a model-fitting approach. In practice, Lensfit starts by measuring the PSF, then generates a model, convolves with the PSF and corrects the distortion and finally determines the likelihood of the fit. Lensfit computes the posteriori likelihood to the ellipticities by

$$p(e|\boldsymbol{y}_i) = \frac{\mathcal{P}(e)\mathcal{L}(\boldsymbol{y}_i|e)}{\int \mathcal{P}(e)\mathcal{L}(\boldsymbol{y}_i|e)de}. \quad (1)$$

Using the prior and the likelihood Lensfit compute the mean ellipticity

$$\langle e \rangle = \frac{1}{N}\sum_i \int e p_i(e|\boldsymbol{y}_i)de. \quad (2)$$

The unbiased shear is given by

$$\hat{g} = \frac{\sum_i^N \langle e \rangle_i}{\sum_i^N |\frac{\partial \langle e \rangle_i}{\partial g}|}. \quad (3)$$

Lenses: cluster detection with redMaPPer

The clusters in CS82 were identified by a code based on the presence of the red-sequence — the red-sequence Matched-filter Probabilistic Percolation (redMaPPer) method [2] — using magnitudes from SDSS in Stripe 82. For the CS82 sample we found 1502 clusters.

Stacking the shear measurements

The shear components obtained from Lensfit are used to compute the tangential and the cross components in the clustercentric frame. They are given by

$$\gamma_t = -\gamma_1 \cos(2\phi) - \gamma_2 \sin(2\phi) \;\; \text{e} \;\; \gamma_\times = \gamma_1 \sin(2\phi) - \gamma_2 \cos(2\phi). \quad (4)$$

The weak lensing signal is given by the average tangential shear in thin rings of radius R

$$\gamma_t(R) = \frac{\Delta\Sigma}{\Sigma_{crit}} \equiv \frac{\overline{\Sigma}(< R) - \langle \Sigma(R) \rangle}{\Sigma_{crit}}, \quad (5)$$

where $\Sigma_{crit} = \frac{c^2}{4\pi G}\frac{D_s}{D_l D_{ls}}$. For CS82 we divide the clusters in two bins of redshift and compute the $\Delta\Sigma$ in 8 radial bins from $0.1h^{-1}$ to $10h^{-1}Mpc$.

Profile-fitting of the average tangential shear

We performed a profile-fitting for the average tangential shear by using the NFW, BMO and Einasto models. We also provide correction terms for the central mass, miscentering and the 2-halo term. We then determined the property of the clusters such as mass and concentration to be used in the mass-observable relations.

Preliminary Results

Here we show the preliminary results we obtained for the two bins of redshift, low-z (0.2 to 0.4) and high-z (0.4 to 0.6) for the redMaPPer clusters and Lensfit sources in 8 radial bins.

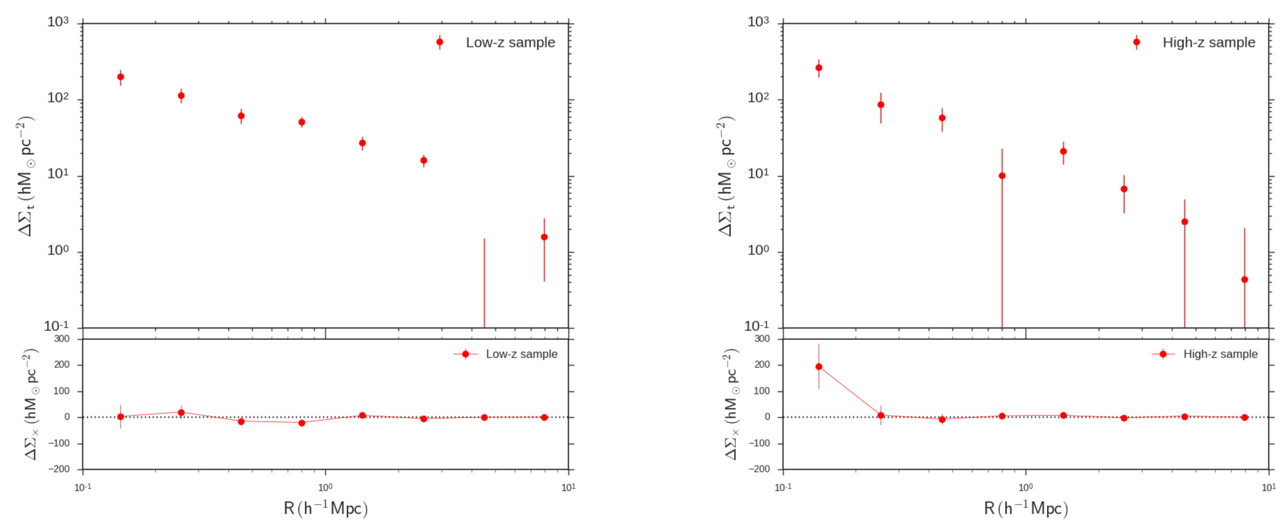

Figure 1: Average tangential and cross shear profile to low-z and high-z sample, respectively.

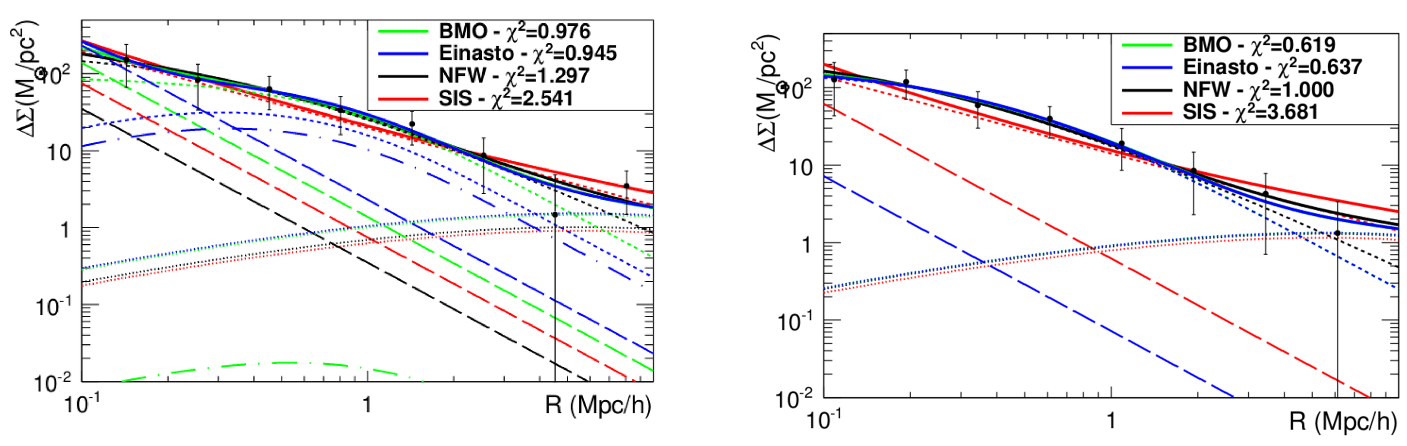

Figure 2: Profile-fitting for the low-z and high-z sample, respectively. The different colors represent the different profiles used in the fit. The dotted lines show the contribution of the additional terms, e.g., central point mass, 2-halo, etc.

r_s $\frac{Mpc}{h}$	ρ_s $\frac{hM_\odot}{Mpc^3}$	M_p $10^{12}\frac{M_\odot}{h}$	σ_{off} $\frac{Mpc}{h}$	p_{cen}	shape p.	χ^2	χ^2_{red}	Conc.	M_{vir} $\frac{M_\odot}{h}$	Bias
0.184	1176.95	–	–	–	–	1.309	0.218	3.976	1.098e+14	1.886
0.224	845.10	–	–	–	12.833	1.226	0.245	3.367	1.197e+14	1.937
0.218	215.86	–	–	–	3.936	1.244	0.249	3.430	1.174e+14	1.925
0.201	949.93	0.740	–	–	–	1.296	0.259	3.609	1.069e+14	1.871
0.313	421.34	1.723	–	–	7.423	1.117	0.279	2.382	1.163e+14	1.920
0.224	202.18	0.740	–	–	3.686	1.214	0.304	3.321	1.150e+14	1.913
0.201	949.98	0.740	0.139	0.999	–	1.296	0.432	3.609	1.069e+14	1.871
0.486	424.74	2.912	7.626	0.447	3.036	0.976	0.488	2.142	3.161e+14	2.714
0.359	203.19	4.887	0.048	0.242	1.486	0.945	0.472	3.014	3.540e+14	2.836

r_s $\frac{Mpc}{h}$	ρ_s $\frac{hM_\odot}{Mpc^3}$	M_p $10^{12}\frac{M_\odot}{h}$	σ_{off} $\frac{Mpc}{h}$	p_{cen}	shape p.	χ^2	χ^2_{red}	Conc.	M_{vir} $\frac{M_\odot}{h}$	Bias
0.116	2324.88	–	–	–	–	1.000	0.167	4.183	5.651e+13	1.513
0.167	1246.52	–	–	–	8.130	0.628	0.126	3.014	6.323e+13	1.555
0.164	322.06	–	–	–	2.969	0.658	0.132	3.099	6.454e+13	1.563
0.116	2324.88	3.650e-07	–	–	–	1.000	0.200	4.183	5.651e+13	1.513
0.167	1229.62	2.087e-07	–	–	8.931	0.619	0.155	3.014	6.354e+13	1.557
0.158	348.21	0.151	–	–	2.838	0.637	0.159	3.201	6.381e+13	1.559
0.116	2324.9	5.704e-08	0.087	1	–	1.000	0.333	4.183	5.651e+13	1.513
0.167	1229.68	2.063e-07	0.014	0.999	8.932	0.619	0.310	3.014	6.353e+13	1.557
0.158	348.21	0.152	0.875	1	2.839	0.637	0.319	3.201	6.381e+13	1.559

Figure 3: Parameters from the profile-fitting for low-z and high-z sample, respectively. The different colors represent the different fitted profiles as shown in the previous figure.

Conclusions

- We measured the average tangential shear for CS82 clusters in two redshift bins.
- We performed a profile-fitting for the average tangential shear using the NFW, BMO and Einasto models and correction terms for the central mass, miscentering and 2-halo term.
- The fit results are inconclusive: it was not possible to distinguish from the models which one is the best. On one hand there are significant degeneracies due to the large number of parameters. On the other hand, we are comparing models with different degrees of freedom.

Next Steps

Check if the data allows one to distinguish between models with the same degrees of freedom, i.e. Einasto and BMO with only 1 and 2-halo terms, or NFW adding miscentering and/or point mass. Also we want to build mass-observable relations for the CS82 redMaPPer clusters.

References

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