Weak lensing masses of galaxy clusters for cluster cosmology

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Abstract

Galaxy clusters are amongst the largest gravitationally bound objects in the observable universe. At their largest their masses can be a million billion times the mass of the sun ($10^{15} M_\odot$. As their formation and spatial distribution is sensitively linked to the expansion history of the universe and it's composition the study of galaxy clusters is rich in cosmological information.

In this poster I introduce the topic of weak gravitational lensing for mass estimation of galaxy clusters, it's application to data from the Kilo-Degree Survey and future developments in weak gravitational lensing for galaxy clusters with the Euclid satellite.

Figure 1:Galaxy cluster Abell 1689 imaged by the Hubble space telescope.

Weak gravitational lensing

Galaxy clusters are primarily composed of dark matter, this makes the measurement of the mass of galaxy clusters difficult. 1% of the mass of galaxy clusters resides in galaxies, 9% in hot intracluster gas and 90% in dark matter.

As light travels through the universe its path is perturbed by matter. Occasionally these effects can produce dramatic distortions of galaxies behind massive objects as shown in Figure 1 and Figure 2. However these events are rare. More often than not the perturbation of the light path causes only very small distortions in the images of galaxies. The advantage of weak lensing is that it effects all galaxies. Therefore measuring the shapes of many galaxies and considering their correlations we can reconstruct the mass distribution in the universe.

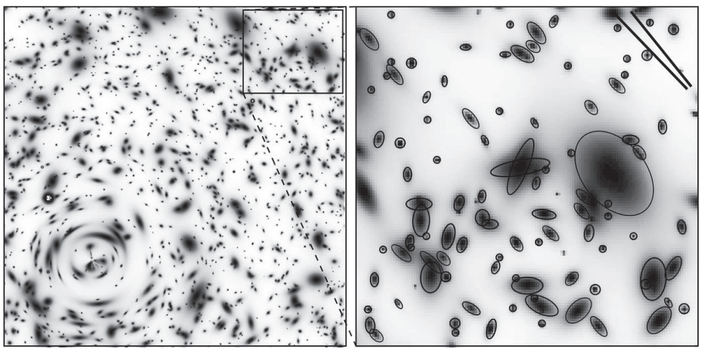

Figure 2:This image shows the lensing of galaxies behind a simulated galaxy cluster. [1]

Figure 2 shows the regimes of lensing. We see near the centre of the lens the dramatic effects of gravitational lensing. Further from the cluster centre lensing effects are no longer clearly visible. However a statistical average over these shapes would reveal systematic correlation in their shapes. This correlation is caused by the gravitational lens distortion. The effect of weak lensing on a circular source is show in Figure 3.

Mass estimation

Considering galaxies behind a galaxy cluster we expect their shapes to be deformed by the mass of the cluster. The galaxy cluster acts as a gravitational lens. Considering a purely spherical lens this deformation is tangential to the cluster centre. We can simply write that the observed tangential component of the galaxy ellipticity ϵ_{obs} is the sum of the weak lensing shear, γ, and the intrinsic ellipticity, ϵ_{int} of the galaxy.

$$\epsilon_{obs} = \gamma(\theta) + \epsilon_{int}$$

Assuming that galaxies are randomly orientated we can measure the shear by averaging over many galaxies.

$$< \epsilon_{obs} > (\theta) = \gamma(\theta)$$

Since the magnitude of the shear depends on the mass of the cluster we can constrain the masses of galaxy clusters with weak gravitational lensing.

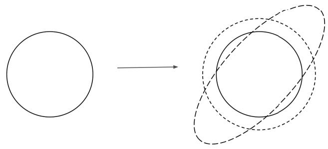

Figure 3:The effect of weak gravitational lensing on a circular source.

Using data from the Kilo-degree survey we can measure tangential and cross shear in radial bins from the centre of galaxy clusters. On individual cluster we can estimate the masses of galaxy clusters with these profiles. This allows us to relate the number of galaxies in a cluster, referred to as its richness, to a mass. This is shown in Figure 4. Here the galaxy clusters are from the Dark Energy Survey redmapper sample.

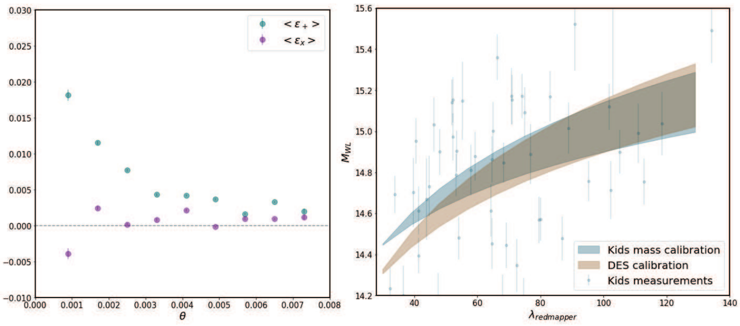

Figure 4:Left, average ellipticity around a stack of 69 galaxy clusters. Right richness-mass calibration using redmapper clusters and weak lensing data from Kids.

Euclid satellite

In order to constrain the masses of galaxy clusters we need many galaxy shape measurements. Euclid a European Space Agency satellite will observe 15,000 deg^2 and measure galaxy shapes for around 10 billion sources. This will allow mass measurements of around 100,000 galaxy clusters and will revolutionise the field.

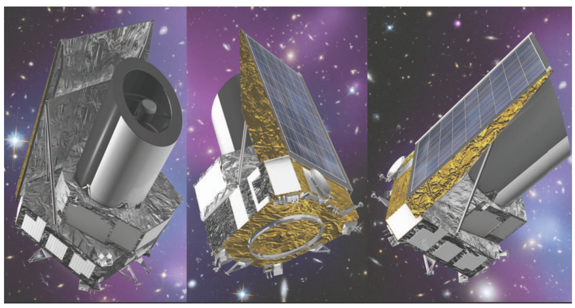

Figure 5:Illustration of the Euclid satellite [2].

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References

1 Mellier, Y , Probing the universe with weak lensing, 1999
2 Euclid consortium, Euclid and the origin of the accelerating universe, 2017 , https://www.euclid-ec.org/