Measuring the scatter in the mass richness relation for galaxy cluster using the correlation function

Julia Campa[1], Juan Estrada[2]

[1].CIEMAT, Madrid, Spain

[2] .Fermilab, Batavia, USA

Abstract

Cluster of galaxies are becoming a powerful tool for constraining the cosmological parameters. This has motivated the design of a new wide-area cluster surveys at mm, optical/near infrared, and X-ray wavelengths. These surveys will have the potential to find hundreds of thousands of clusters.

The ability to constrain the cosmological parameters from the evolution of galaxy clusters counts is limited by the knowledge of the cluster mass. Accurate constraints require a precise model relating observable,such a richness, to total mass. We present a method to constrain the scatter in the mass richness relation by making use of the bias measured in the cluster correlation function.

First we will study the bias in halos on a past lightcone using N-body simulations to study the errors that come from the Halo Model prediction. Finally we assign richness to dark matter halos with scatter and we compare richness bias measured with the model. By performing a likelihood analysis when the true value is 0.4, we find that $\sigma_{lnM} = 0.44 \pm 0.12 (95\%CL)$. **Rozo el al. (2009) obtains similar** accuracy although using optical and X-ray observations. **We conclude that we can constrain the scatter although our method is highly dependent on the mass function and bias model. However, the advantage of this method is that it only needs one kind of observations.**

The Method

The cluster bias can be measured in a cluster catalog by measuring the spatial correlation function $\xi_{cl}(r)$ and comparing it to the correlation function of dark matter halos using the relation :

$$\xi_{cl}(r) = b^2 \xi_{dm}(r)$$

We compare the measured bias with the predicted linear bias using the Halo Model and the Mass Richness relation. The average bias expected for a richness value N_200 is

$$b(N_{200}, z) = \frac{\int dlnM \frac{dn}{dlnM} P(ln(M)|N_{200}) b(M,z)}{\int dlnM \frac{dn}{dlnM} P(ln(M)|N_{200})} \quad (1)$$

- For a given z and N_{200} bin (N_1,N_2) the bias is $$b(N_1, N_2) = \frac{\sum_{N_1}^{N_2} b(N_{200}, z) n_{meas}(N_{200}, z)}{\sum_{N_1}^{N_2} n_{meas}(N_{200}, z)} \quad (2)$$
- The linear bias predictions is calculated with the Sheth Thormen 1999 mass function (p & q parameters fitted to simulations)

The Method

- Assuming a lognormal scatter around the mean scaling relation (Gaussian scatter in lnM) distribution, the probability P(ln(M)|N) of having the true mass M given the observed richness N_{200} is :

$$P(ln(M)|N) = \frac{1}{\sigma_{lnM}(2\pi)^{1/2}} exp \frac{-(ln(M) - \mu)^2}{2\sigma_{lnM}^2}$$

The mean cluster mass for a given N_{200} using weak lensing and X-ray data (*See* **Rozo et al. 2009**,*:arxi0809.2794*)

$$< \mu > = < M|N_{200} > = 10^{14} M_{sun} exp(B) (\frac{N_{200}}{40})^{\alpha}$$

- A likelihood comparing the measurements with the predictions can constrain cosmological parameters and σ_{lnM} :

$$P(\sigma_{lnM}, B, \alpha, , \Lambda) \propto exp \sum_i \frac{1}{2} \left[\frac{b_i(\sigma_{lnM}, B, \alpha, \Lambda) - b^i_{meas}}{\sigma_{b_{meas}}} \right]^2$$

where Λ represents the dependence in cosmological parameters.

Testing the Halo Model at z=0 and in the lightcone

We study the errors that come from the halo model predictions with the Sheth and Thormen prescription to describe the bias in halos.

The halos above a mass threshold is given in terms of the mass function and the halo bias

$$b(M \geq M_{th}, z) = \frac{1}{n_c} \int_{M_{th}}^{\infty} dM \frac{dn}{dM}(M,z) b(M,z)$$

$$n_c = \int_{M_{th}}^{\infty} dM n(M,z)$$

Figure 1 (top right) and **Figure 2** (bottom right) show the halo mass function and the bias measured respectively in the Hubble Volume Simulation HVS at z=0 compared with the theoretical predictions.

Figure 3 (top left) and **Figure 4** (bottom left) show the mass function and the bias measured respectively in the lightcone at 6 redshift bins. The model with the best p and q parameters and fiducial values at the mean redshift value is also plotted.

These results show that for the first redshift bins, we can predict the evolution of bias with a good accuracy but for higher values, the deviations are more significants.

Hubble Volume Simulation ΛCDM Snapshot $z = 0$

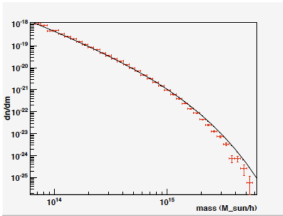


Figure1. Halo mass function derived from simulations (red points) and mass function predictions (solid black line)

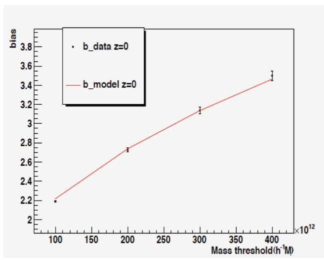


Figure 2. Halo Bias model (red line) and measurements (black line) at z=0

Dark Energy Survey (DESv1.02) ΛCDM Past Lightcone 5000 sq.deg based on PO HVS

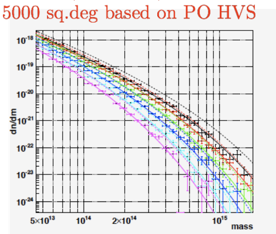


Figure 3. Mass function for halos in DESv1.02 simulation at redshift bins 0.2-0.4 (black), 0.4-0.6 (red), 0.6-0.8 (green), 0.8-1(blue), 1-1.2(sky.blue) and 1.2-1.4 (pink). Solid lines are the mass functions with the best p and q. Dashed lines are the mass function with the p and q fiducial values.

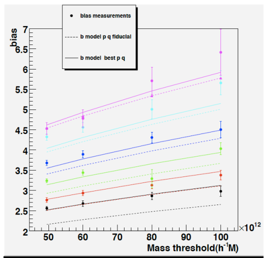


Figure 4. Bias measurements for halos at the same redshift bins than figure 3. Solid lines are the bias model with fhe best p and q at the mean value of the redshift bin. Dashed lines are the bias model with the p and q fiducial values

Richness bias model (1) +(2)

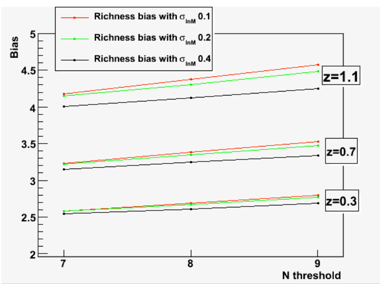


Figure 5. Richness bias decrease with the scatter due to the shape of the mass function (steeply decreasing with mass). This decrement increase with the redshift and richness threshold.

As N threshold reaches the exponential tail of the mass function, the excess of upscatter vs downscatter can become a significant fraction, and the bias decrease. The steepness of the mass function around the threshold and higher values determine the excess due to the uppscatter.

Constraining the scatter

Data:

3 richness catalogs created with 3 scatter values $\sigma_{lnM} = 0.1, 0.2, 0.4$

1D likelihood performed:

Cosmology and mass richness relation parameters fixed

σ_{lnM} free

Two first redshift bins used

Main systematics:

Uncertainty in the mass function and bias model

Mass resolution:M200 minimum limit

Figure 6 shows the most likely value of the scatter with its error versus the true value. The measurements are obtained from the mean and standard deviation of the gaussian distribution. When we take into account the minimum mass limit to model the richness bias, the error bars are increased (red points).

Figures 7 to 10 show the likelihood distributions calculated to constrain the scatter.

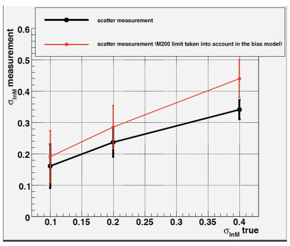
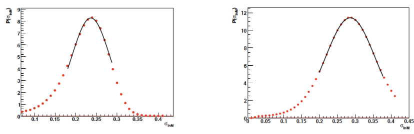
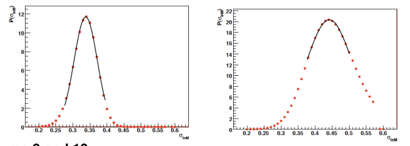


Figure 6. σ_{lnM} recovered within 1σ errors vs true σ_{lnM}



Figures 7 and 8.

1D likelihood.σ_{lnM} true =0.2.Left: Richness bias model integrated in $M_{200} = [10^{12} - 10^{16}] M_{sun}/h$. Right: Richness bias model integrated in $M_{200} = [M_{minimum} - 1^{16}] M_{sun}/h$



Figures 9 and 10.

1D likelihood. $\sigma_{lnM} true = 0.4$. Left:Richness bias model integrated in $M_{200} = [10^{12} - 10^{16}] M_{sun}/h$. Right:Richness bias model integrated in $M_{200} = [M_{minimum} - 10^{16}] M_{sun}/h$

Conclusions

The results show that we can constrain the scatter using the correlation function although we still have to study the effects of the photometric errors and the error covariance for the correlation function. The next steps are combine the likelihood for the bias with the likelihood for the number of clusters as a function of richness and redshift also predicted with the Halo Model. Therefore we could constrain the cosmological parameters and at the same time we calibrate the mass observable relation with the combined likelihood. Finally we want to apply this method to a real galaxy cluster catalog such as the MaxBCG.

References:

Campa et al(In preparation)

Cluster bias: Manera & Gaztañaga, Arxiv:0912.0446

Halo Model of large scale structure: A. Cooray & R. Sheth, astro-ph: 0206508

Self Calibration of dark energy studies: Lima & Hu 2005, 2007

Correlation function of galaxy cluster with MaxBCG:Estrada et al. 2009.