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CALIBRATING THE PLANCK CLUSTER MASS SCALE WITH CLUSTER VELOCITY DISPERSIONS

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Abstract. The potential of galaxy clusters as cosmological probes critically depends on the capability to obtain accurate estimates of their mass. This will be a key measurement for the next generation of cosmological surveys, such as Euclid. The discrepancy between the cosmological parameters determined from anisotropies in the cosmic microwave background and those derived from cluster abundance measurements from the *Planck* satellite calls for careful evaluation of systematic biases in cluster mass estimates. For this purpose, it is crucial to use independent techniques, like analysis of the thermal emission of the intracluster medium (ICM), observed either in the X-rays or through the Sunyaev-Zeldovich (SZ) effect, dynamics of member galaxies or gravitational lensing. We discuss possible bias in the *Planck* SZ mass proxy, which is based on X-ray observations. Using optical spectroscopy from the Gemini Multi-Object Spectrograph of 17 *Planck*-selected clusters, we present new estimates of the cluster mass based on the velocity dispersion of the member galaxies and independently of the ICM properties. We show how the difference between the velocity dispersion of galaxy and dark matter particles in simulations is the primary factor limiting interpretation of dynamical cluster mass measurements at this time, and we give the first observational constraints on the velocity bias.

Keywords: Cosmology: cosmic background radiation, Cosmology: observations, Galaxies: clusters: general, Galaxies: distances and redshifts

1 Introduction

Within the standard cosmological model, the formation of structures takes place from the gravitational collapse of small perturbations in a quasi-homogeneus Universe dominated by cold dark matter. In this frame, galaxy clusters are the largest nearly virialised collapsed objects in the observable Universe, and they are also the last to form. Therefore, they are fundamental tools to test the cosmological scenario and for understanding the formation and evolution of cosmic structures. The potential of galaxy clusters as cosmological probes depends on the capability to obtain accurate estimates of their mass (Allen et al. 2011). However, mass is not directly observable, it can be estimated through many methods based on different physical properties. Clusters are composed by about the 85% of dark matter, 10% of gas and 5% of galaxies. All these components can be investigated with multi-wavelenght observations. Methods to estimate the mass are based on the analysis of the thermal emission of the intracluster medium (ICM), observed either in the X-rays or through the Sunyaev-Zeldovich (SZ) effect, or from optical observations through the dynamics of member galaxies or gravitational lensing. Each method is affected by systematic effects, so a comparison of the estimates obtained with different techniques is a critical check on the reliability of each method under different conditions, and also a test of the cosmological scenario.
We present here the relation between velocity dispersion and mass for a sample of clusters detected by *Planck* and followed-up with spectroscopic observations at the Gemini telescopes, with the aim to calibrate the mass-observable scaling relation.

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2 The Planck mass bias

We have selected a subsample of 17 *Planck* clusters in the last PSZ2 catalog (Planck Collaboration et al. 2016), in a broad range of mass measured by *Planck*, $2 \times 10^{14} M_\odot \lesssim M \lesssim 10^{15} M_\odot$, in the redshift range $0.16 < z < 0.44$. These targets were followed-up for spectroscopic observations with Gemini (GMOS-N and GMOS-S), from which we could typically confirm ~ 20 (10-40) galaxies in each cluster, and get average cluster redshifts and velocity dispersions (see Amodeo et al. 2017, for a detailed description of the sample selection and the spectroscopic analysis).

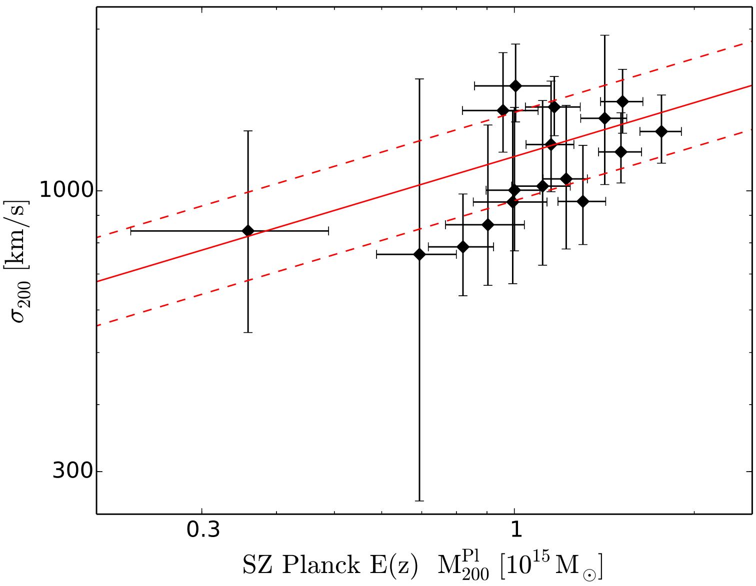

Fig. 1. Relation between the *Planck* SZ mass proxy and velocity dispersion for our sample of 17 galaxy clusters observed with Gemini (diamonds). The solid red line shows the best fit to the functional form of Eq. (2.1) in log-space, where the slope is set to 1/3, with the dashed lines delineating the dispersion of the data about the best-fit line.

Figure 1 plots the velocity dispersions that we obtained versus the mass estimated by *Planck*. The red curve is the fit to the data of the following power-law relation predicted for complete virialization*:

$$\sigma_{200} = A \left[\frac{h(z)\, M_{200}}{10^{15} M_\odot} \right]^{1/3} . \tag{2.1}$$

The normalization A is the only free parameter in the fit, while the slope is fixed to 1/3, which is the value predicted for a virial relation and confirmed by simulations.
Planck mass estimates are based on a combination of *Planck* data and an X-ray scaling relation established with XMM-Newton (Planck Collaboration et al. 2014). Any possible systematic due to this assumption or to the X-ray analysis, and more generally, any difference between mass determined by *Planck* and the true halo mass is expressed in terms of the bias factor $(1 - b) = M_{200}^{\rm Pl}/M_{200}$. In order to estimate this bias, we compare the fit of our observed relation to Eq. (2.1) with the relation predicted by Evrard et al. (2008) from DM simulations, accounting for effects due to GMOS finite aperture, Eddington bias and correlated scatter between velocity dispersion and the *Planck* mass proxy. The details of this analysis are discussed in Amodeo et al. (2017). The main problem in calibrating the $\sigma - M$ relation with simulations is that galaxies may have a different velocity dispersion than their dark matter host because they inhabit special locations within the cluster (e.g., subhalos). While the scaling relation is very well constrained for simulations of dark matter particles, it is not as well understood for galaxies, as discordant results in the literature demonstrate (e.g. Munari et al. 2013; Caldwell et al. 2016). We find that the unknown velocity bias of the member galaxy population, quantified by the ratio between the galaxy and the DM velocity dispersions, is the largest source of uncertainty in our result on the mass bias parameter:

*Estimates of mass and velocity dispersion are quoted at a radius R_{200}, within which the cluster density is 200 times the critical density of the universe at the cluster's redshift.

$(1-b) = (0.51 \pm 0.09) b_{\mathrm{v}}^3$. Using a baseline value of $b_{\mathrm{v}} = 1.08$ from Munari et al. (2013), we find $(1-b) = (0.64 \pm 0.11)$, consistent within weak lensing results and within 1σ of the value $(1-b) = (0.58 \pm 0.04)$ needed to reconcile the *Planck* cluster counts with the primary CMB.
Turning the analysis around, we propose to obtain observational constraints on the velocity bias by combining accurate mass estimates from weak lensing measurements with velocity dispersion measurements. Assuming a prior on the mass bias from Penna-Lima et al. (2017), we derive $b_{\mathrm{v}} = 1.12 \pm 0.07$, i.e., $b_{\mathrm{v}} \gtrsim 0.9$ at 3σ.

3 Conclusions

We have measured the *Planck* cluster mass bias using velocity dispersions of a subsample of 17 *Planck*-detected clusters. We have achieved a precision of 17% on the mass bias measurement with our limited sample. On the other hand, we have provided the first observational constraints on the velocity bias combining accurate mass estimates from weak lensing with velocity dispersion measurements. Assuming that simulations and observations will eventually settle on a value for the velocity bias, this motivates continued effort to increase our sample size to produce a 10% or better determination, comparable to recent weak lensing measurements.

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