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COSMOLOGY WITH THE GTC: A COMBINED MM–OPTICAL GALAXY CLUSTER SURVEY

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RESUMEN

El satélite para el estudio del CMB, *Planck* (ESA), originar'ň catálogo con ∼30 000 cúmulos de galaxias (efecto Sunyaev–Zel'dovich) entre redshifts 0 y ≈2–3 (dependiendo del modelo cosmológico). Tal extenso catálogo de cúmulos permitirá llevar a cabo estudios muy detallados de la evolución de la población de cúmulos con el desplazamiento al rojo, lo cual permitirá a su vez afinar en la estimación del modelo cosmológico. No obstante, la identificación de los cúmulos más distantes tendrá que ser llevada a cabo con telescopios ópticos de gran diámetro (como el GTC) ya que *Planck* no será capaz de dar una estimación del desplazamiento al rojo de los cúmulos. En este trabajo mostramos como sólo hace falta identificar una pequeña porción de ≈300 cúmulos (que hayan sido seleccionados aleatoriamente del catálogo de *Planck*) para distinguir modelos que tienen o no tienen constante cosmológica.

ABSTRACT

The CMB *Planck* satellite (ESA) will provide a catalogue of ∼30 000 galaxy clusters (the Sunyaev–Zel'dovich effect) between redshift 0 and ≈2–3 (depending on the cosmological model). This huge catalogue of clusters will permit detailed studies of the evolution of the cluster population with redshifts that will constrain the cosmological model. The identification of the high redshift clusters should be done with a large telescope (such as GTC) since *Planck* data alone will not provide any clue about the redshift of the clusters. In this article, we show that an optical follow-up of only ≈300 clusters (randomly selected from the *Planck* catalogue) is needed in order to distingish models with or without a cosmological constant.

Key Words: **COSMOLOGY — LARGE-SCALE STRUCTURE OF UNIVERSE — GALAXIES: CLUSTERS: GENERAL**

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1. INTRODUCTION

Clusters of galaxies have been widely used as cosmological probes. Their modeling can be easily understood as they are the final stage of the linearly evolved primordial density fluctuations. As a consequence, it is possible to describe, as a function of the cosmological model, the distribution of clusters and their evolution, the *mass function*, which is usually used as a cosmological test. Therefore, a detailed study of the cluster mass function will provide very useful information about the underlying cosmology.

Unfortunately, cluster masses cannot very well determined for intermediate–high redshift clusters and even for low redshift ones the error bars are still significant. However, instead of the mass function, it is possible to study the cluster population through other functions such as the X-ray flux or luminosity functions, the temperature function or the Sunyaev–Zel'dovich effect (hereafter SZE) function. The advantage of these functions compared with the mass function is that, in these cases, the estimation of the X-ray fluxes, luminosities, temperatures, or SZE decrements of the clusters is less affected by systematics than the mass estimation. The largest catalogue of clusters in the next years will be provided by the CMB satellite *Planck*. It is expected that *Planck* data will contain about 30 000 detectable clusters (see Diego et al. 2002).

The decrement in the CMB temperature due to the SZE is independent of redshift. Therefore, the most distant clusters could be detected through the SZE. Hence, the SZE is the perfect way to look at those high redshift clusters. It is in the high redshift interval where the differences among the cosmological models are most evident when one looks at the cluster population.

Unfortunately, through the SZE it is not possible to measure the redshift of the clusters, and an independent observation (in the optical waveband for instance) of the clusters is needed in order to estimate their redshifts.

Since many clusters will be at high redshift, a telescope with a large diameter (such as the GTC)

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will be needed in order to identify those high z clusters. However, because of the large size of the *Planck* catalogue, any proposal which attempts to make use of a 10 m class telescope to identify 30 000 clusters would be rejected (even if the proposal planned to observe only the high z clusters there would be thousands of them!). In the following sections we will show how an SZE-selected optical survey made with GTC of only a small portion of the clusters in the *Planck* catalogue could be enough to obtain important cosmological constraints.

2. A COMBINED MM–OPTICAL SURVEY

At the end of this decade, the *Planck* satellite will carry out a whole-sky survey in order to measure the CMB with high sensitivity. However, other emissions (not only due to the CMB) will also be present in the data. Most of this non-CMB emission will come from our own Galaxy (dust, free–free, synchrotron) but there will be also some extragalactic emission (point sources and the SZE). The wide frequency range, angular resolution, and high sensitivity of *Planck* will allow the detection of ∼30 000 clusters.

Observing galaxy clusters in the mm sub-mm band through the SZE has a unique advantage. The amplitude of the decrement in the center of the cluster is independent of its redshift. Because of this fact, the catalogue of clusters obtained by *Planck* will have a privileged selection function and the proportion of high to low redshift clusters will be maximum if we compare the catalogue with others obtained in optical or X-ray surveys.

Galaxy clusters are the best tracers of the large scale structure and by studying the evolution of their abundance with redshift it is possible to impose very strong constraints on the cosmological model. For instance, using the local abundance of clusters it has been possible to find a strong correlation between the amplitude of the power spectrum (σ_8) and the matter density (Ω). However, all the models in that correlation having different values of σ_8 and Ω predict the same observed local abundance of clusters (within the error bars). Therefore, by using just the local abundance of clusters it is not possible, for instance, to rule out models with high or low values of Ω. However, this can be done if we go back in time and study the evolution of the cluster abundance with redshift. In this case, the further we go in redshift, the better are the constraints in the cosmological parameters.

As we have mentioned, the selection function of *Planck* will be privileged in the sense that the final

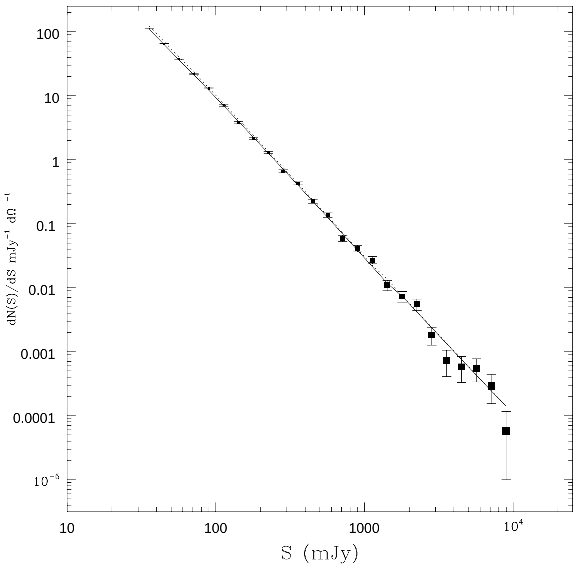

Fig. 1. Cluster number counts for *Planck*. Two models are plotted for comparison. The OCDM model is the solid line (Ω = 0.3, Λ = 0.0) and the ΛCDM model is represented by the dotted line (Ω = 0.3, Λ = 0.7). The data are consistent with both models. Only the number counts as a function of redshift can distinguish both models.

catalogue will have a large proportion of high redshift clusters. It is interesting to exploit this fact and study the cosmological implications of such a large and redshift-independent catalogue. Unfortunately, since the SZE is independent of redshift, it will not be possible to determine the redshift of the clusters by just looking at their SZE emission. This consideration will limit the kind of cosmological studies that can be done with the *Planck* catalogue since the only observable will be the flux of the cluster. In Figure 1 we show the expected number counts for the *Planck* catalogue as a function of the observed flux.

Despite the large number of clusters in the catalogue, this number will not be sufficient to discriminate between a model with and a model without a cosmological constant.

However, both models can be distinguished if one uses the evolution of the number counts with redshift. To build these data one needs, obviously, to estimate first the redshift of the clusters, and since this can not be done through the SZE one should make an independent optical observation for each one of the clusters. This can be a huge task if one attempts to measure the redshift for each of the expected 30 000 clusters. Some of them will be nearby clusters and they can be easily identified in previous surveys like the Sloan. Others at intermediate red-

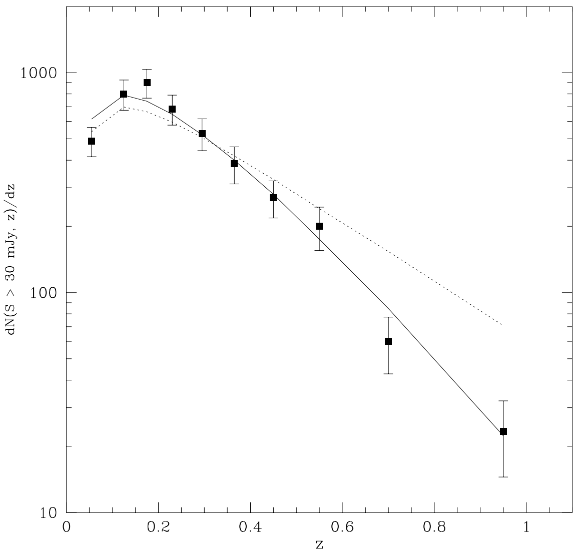

Fig. 2. Evolution of the number counts for the subsample of 300 clusters The data points were obtained from a Monte Carlo simulation of the ΛCDM model. The solid line represents the mean expected number counts for the same model (ΛCDM) and the dotted line shows the corresponding expected number counts for the OCDM model. The OCDM model is excluded at 3σ level.

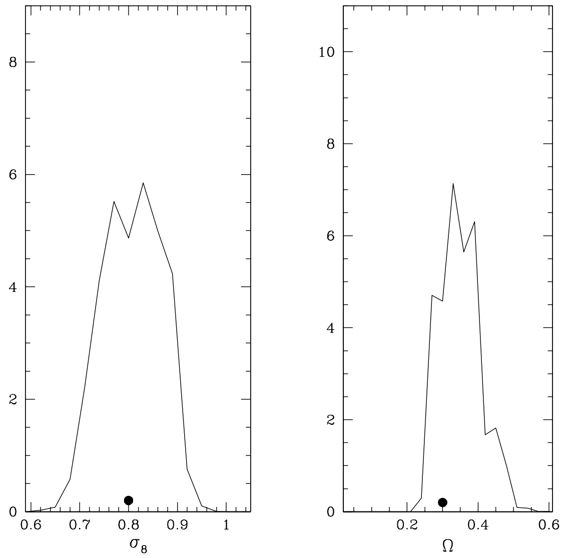

Fig. 3. Cosmological constraints (marginalized probability) obtained after combining the *Planck* number counts (Figure 1) with the evolution of the number counts of the optically observed subsample of 300 clusters (Figure 2). The fiducial model used to simulate the two data sets is indicated by the big black dots.

shift could be observed with medium-size telescopes. There will be, however, a large number of high z clusters. In these cases, a large telescope like GTC will be needed. But even observing only the high z clusters, their expected number is still too large to make a project like this one possible. However, instead of trying to identify all the *Planck* cluster catalogue, one could try to estimate the redshifts for only a small portion of it and build the number counts (as a function of z) from them. The question now is, how small should the subsample of clusters be if we want to extract useful information about the cosmological information form that subsample?

In Diego et al. (2001) we computed such a number and we found that because of the particular selection function of *Planck*, by randomly selecting a subsample of only 300 clusters we could discriminate between ΛCDM and OCDM models. This is an important conclusion since it tells us that we do not need to identify all the clusters in the *Planck* catalogue. The selection function of *Planck* is such that a random subsample of 300 clusters contains enough high z clusters to make possible the distinction between the two models.

As we suggested before, part of those 300 clusters could be identified with existing cluster catalogues. Others could be identified using medium-size telescopes, and only a small portion of them (≈20%) would require a telescope like the GTC. In the same paper we calculated that, in order to estimate the photometric redshifts for the most distant clusters with the GTC, we should observe them with two hours of integration time (eight bands and 900 s per band) per cluster. These numbers show that this is a feasible project, and that the evolution of the number counts of the SZE-selected subsample of 300 clusters could be determined.

In Figure 2 we show the expected number counts as a function of redshift for a Monte Carlo realization of the ΛCDM model. Also plotted are the mean number counts for the ΛCDM (solid line) and for the OCDM model (dotted line). As we mentioned earlier, with just 300 clusters the OCDM model could be excluded by the high z bins.

By combining the two data sets (number counts of *Planck* [Figure 1] and evolution of the number counts of the subsample [Figure 2]) it is possible to constraint the cosmological parameters of the ΛCDM model.

The first data set is very good to constrain the σ_8–Ω correlation. The second data set can be used to break the previous degeneracy between both parameters. The result of combining the *Planck* number counts (30 000 clusters, Figure 1) with the GTC follow-up (300 clusters, Figure 2) can be seen in

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Figure 3.

3. CONCLUSIONS

We have seen how combining two very different instruments (*Planck* and the GTC) it is possible to constraint the cosmological model. *Planck* will provide a unique way of selecting distant clusters. However, a subsequent redshift estimation will be needed. We have seen that a subsample (randomly selected from the *Planck* catalogue) of 300 identified clusters is large enough in order to distinguish between a ΛCDM and a OCDM model. Among these 300 clusters there will be many of them which can be identified using existing galaxy cluster catalogues or medium-size telescopes, but there will be a portion ($\approx$20%) that will require a telescope like the GTC. A survey made with the GTC over the SZE-selected subsample will enable the cosmological model to be constrained in an independent test.

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