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The ACT Data Release 6 Sunyaev-Zel'dovich Selected Cluster Catalog

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Abstract. The Atacama Cosmology Telescope (ACT) conducted an arcmin resolution survey of the southern sky at millimeter wavelengths from 2008-2022. I present an update on the ACT search for galaxy clusters using the redshift independent Sunyaev-Zel'dovich (SZ) effect, using data from the full ACT survey, covering 15,000 square degrees. The final ACT Data Release 6 (DR6) cluster catalog is expected to contain ~ 10000 galaxy clusters with redshift and mass estimates. I describe the construction of the catalog (in particular the differences with respect to ACT DR5), products and tools associated with the data release, and discuss some science applications of the catalog.

1 Introduction

The Atacama Cosmology Telescope (ACT) conducted science observations of the millimeter sky at arcminute resolution between 2008–2022 from a high altitude site in northern Chile. The cosmological results extracted from the primary cosmic microwave background (CMB) fluctuations associated with Data Release 6 (DR6) of the project [1, 2] are presented and discussed elsewhere in these proceedings. In this article I present an update on the search for galaxy clusters in these data, on behalf of ACT Collaboration. Subsequent to the *mm Universe 2025* conference, a full, detailed description of the ACT DR6 cluster search was submitted for publication in the Open Journal of Astrophysics [3].

Galaxy clusters can be detected in millimeter wavelength maps of the sky via the Sunyaev-Zel'dovich (SZ) effect [4]. This is the inverse Compton scattering of CMB photons by the hot gas atmospheres of galaxy clusters. It provides a measure of the integrated thermal pressure along the line of sight, and so the size of the resulting SZ signal scales with cluster mass. Furthermore, the SZ effect does not depend upon redshift. This makes it an ideal tool for studying the growth of cosmic structure, traced by the evolving number density of massive clusters with redshift. The tightest cosmological constraints to date from SZ surveys come from the South Pole Telescope (SPT) [5].

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2 Cluster Detection in ACT DR6

All large area SZ surveys have used a variation of the multi-frequency matched filter approach [6] to search for clusters. In the ACT project, this is implemented in the Nemo[1] software package, which was also used for the ACT DR5 cluster search [7].

The ACT DR6 maps cover area $\sim$ 19,000 square degrees [8]. These are broken down into smaller tiles for processing by Nemo. Below we briefly describe the differences between the DR6 [3] and DR5 [7] cluster searches:

- For DR6, we use maps at three frequencies (ACT channels f090, f150, f220 [8]) using as much data as possible from 2008–2022 (only the f090 and f150 channels were used for DR5).
- A new multi-pass filtering and source detection algorithm was implemented for DR6 (full details are given in ref. [3]).
- The flagging infrastructure was updated to implement the following types of flags:
  - Finder flags (for identifying regions affected by the subtraction of point sources)
  - Dusty regions (identified using a thresholded *Planck* 353 GHz map)
  - Extended objects (for regions containing nearby galaxies, nebulae, etc., which can produce spurious SZ cluster candidates if not treated)
  - Regions near bright stars (where it is harder to obtain optical confirmation and/or photometric redshifts)
- Additional sources for redshift estimates were added:
  - Updated Dark Energy Survey (DES) and Hyper Suprime-Cam (HSC) cluster catalogs based on the latest data from these surveys [9–11]
  - Cluster catalogs based on Legacy Survey [12] DR9/10 catalogs [13, 14] and eROSITA X-ray data [15]
  - Photometric and spectroscopic redshifts extracted from public survey data by the ACT team, in a similar manner to that described for the DR5 release [7]
- Cluster mass estimates are reported in DR6 using a calibration that is consistent with recent weak-lensing measurements [16, 17]. However, we still report masses based on the previously used mass calibration [18] for comparison with previous work.

Figure 1 shows the sky region searched for clusters, and the locations for the ~10,000 optically confirmed clusters with redshifts. Figure 2 shows the mass and redshift distribution for the sample. We detect > 1000 clusters at $z > 1$, and > 100 clusters at $z > 1.5$. At the time of writing, this is the largest SZ-selected cluster catalog to date.

3 Extreme Clusters

Despite the large volume searched by ACT, we see no cluster that is sufficiently massive at its redshift to falsify the ΛCDM model with Gaussian initial conditions. This is illustrated in Figure 3 where we show the sample in comparison to ΛCDM exclusion curves [19]. The most extreme clusters are El Gordo [20, 21] and J0329.2–2330 [22]; we note that these are both major merging systems that host diffuse, giant radio haloes [23], and so it may be the case that their SZ signal strength has been boosted by the ongoing mergers.

[1] https://nemo-sz.readthedocs.io

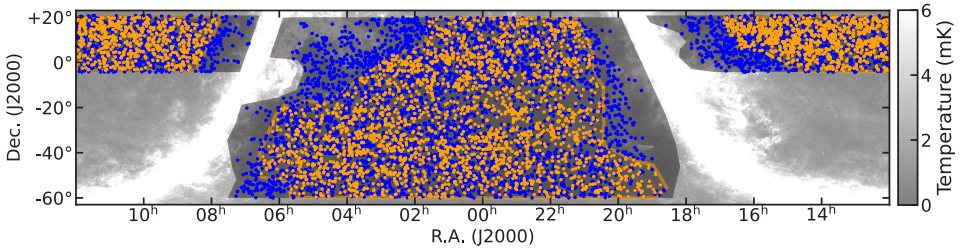

Figure 1. The ACT DR6 cluster sample on the sky. Blue points mark the locations of ∼10,000 optically confirmed SZ-detected clusters, while orange points mark a sample ∼ 3700 clusters with S/N > 5.5 that may be used for cosmological analyses in the future. The full ACT search area is shown by the dark gray shaded region. The *Planck* 353 GHz map is shown in the background, to highlight regions of sky that have more thermal emission from dust.

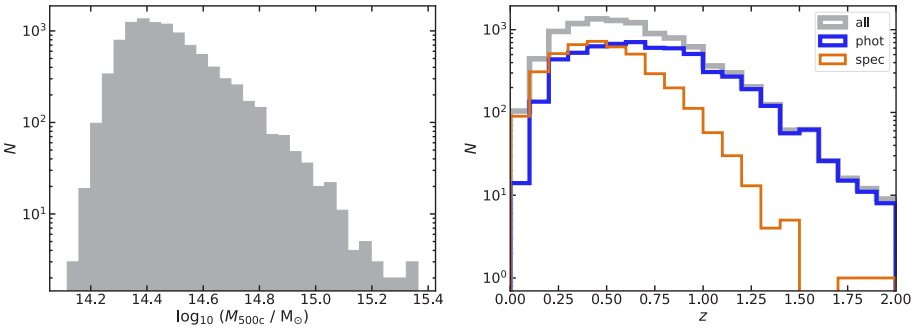

Figure 2. Mass and redshift distributions for the ACT DR6 cluster sample. In the right panel, objects with photometric redshifts are shown in blue, while those with spectroscopic redshifts are shown in orange. The gray histogram shows the full sample.

4 Summary

The SZ effect provides approximately mass limited galaxy clusters samples with no redshift limit – ideal for measuring the growth of massive structures over cosmic time. With ACT, we have gone from samples of ∼ 10 SZ-detected clusters to ∼ 10,000 over the lifetime of the project (2008–2022). We do not see any cluster at high redshift that is sufficiently massive to falsify ΛCDM, despite the large volume searched. A full cosmological analysis of the cluster sample is planned.

ACT DR6 data products are publicly available on LAMBDA[2]. The cluster search products will follow later, but at the time of writing can be accessed at https://extragalactic.phys.wits.ac.za/act-dr6-clusters/v0.11/. The documentation for Nemo provides instructions for how to reproduce the ACT DR6 cluster search products using the public maps and code[3].

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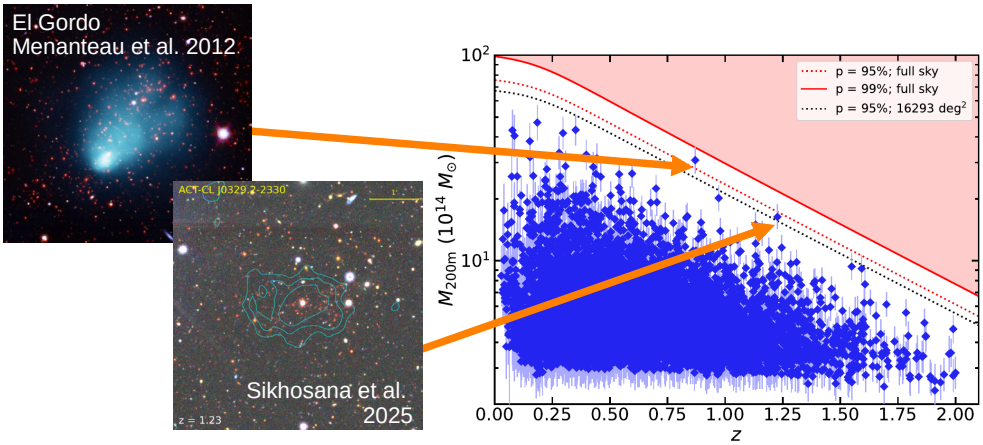

Figure 3. Mass versus redshift plot for the ACT DR6 sample. The pink shaded region indicates the mass and redshift required for a single detected cluster to falsify the ΛCDM model. The two most extreme clusters, El Gordo and J0329, are highlighted. Both of these are undergoing major merging events. The inset for El Gordo shows the irregular X-ray morpology observed with *Chandra* [20]. The inset for J0329 shows the radio halo detected with *MeerKAT* as the contour overlay on the optical image [22].

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