SPT-CL J0546-5345: A MASSIVE $z > 1$ GALAXY CLUSTER SELECTED VIA THE SUNYAEV–ZEL’DOVICH EFFECT WITH THE SOUTH POLE TELESCOPE

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ABSTRACT

We report the spectroscopic confirmation of SPT-CL J0546-5345 at $z = 1.067$. To date this is the most distant cluster to be spectroscopically confirmed from the 2008 South Pole Telescope (SPT) catalog, and indeed the first $z > 1$ cluster discovered by the Sunyaev–Zel’dovich Effect (SZE). We identify 21 secure spectroscopic members within 0.9 Mpc of the SPT cluster position, 18 of which are quiescent, early-type galaxies. From these quiescent galaxies we obtain a velocity dispersion of $1179^{+232}_{-167}$ km s$^{-1}$, ranking SPT-CL J0546-5345 as the most dynamically massive cluster yet discovered at $z > 1$. Assuming that SPT-CL J0546-5345 is virialized, this implies a dynamical mass of $M_{200} = 1.0_{-0.4}^{+0.6} \times 10^{15} M_\odot$, in agreement with the X-ray and SZE mass measurements. Combining masses from several independent measures leads to a best-estimate mass of $M_{200} = (7.95 \pm 0.92) \times 10^{14} M_\odot$. The spectroscopic confirmation of SPT-CL J0546-5345, discovered in the wide-angle, mass-selected SPT cluster survey, marks the onset of the high-redshift SZE-selected galaxy cluster era.

Key words: galaxies: clusters: individual (SPT-CL J0546-5345) – galaxies: distances and redshifts – galaxies: evolution

Online-only material: color figure

1. INTRODUCTION

Formed from the extreme peaks of the primordial density field, galaxy clusters are both a sensitive probe of cosmology and an excellent laboratory for galaxy evolution studies. Although massive galaxy clusters are easy to identify in the local universe, finding such objects at large lookback times has been extremely challenging. A patchwork of optical, infrared, and X-ray techniques has led to a heterogeneous sample of distant galaxy clusters (e.g., Stanford et al. 1997; Rosati et al. 2004; Gladders & Yee 2005; Mullis et al. 2005; Brodwin et al. 2006; Elston et al. 2006; Stanford et al. 2006; Eisenhardt et al. 2008; Muzzin et al. 2009; Papovich et al. 2010). While each technique...
of the optical data.

Along with the $r$ and $i$ BCS photometry, the IRAC 3.6 $\mu$m data were used to select promising cluster member candidates for spectroscopy as described below. A false-color optical ($r$) + IRAC (3.6 $\mu$m) image is shown in Figure 1 (right). The optical-only ($griz$) image (Figure 1, left) indicates how optically (rest-frame UV) faint the cluster members are, and highlights the importance of Spitzer/IRAC imaging for high-redshift cluster detection and study.

2.3. Chandra

SPT-CL J0546-5345 was observed with Chandra/ACIS-I on four separate occasions, for a total exposure time of 55.6 ks (PID 09800046; PI Garmire, PID 11800471; PI Mohr). This yielded 1304 source counts in the 0.5–7.0 keV energy range within $r_{500}$. Background was subtracted using blank sky data normalized to the flux in the 5.9–12 keV energy band. The cluster luminosity is \( L_X (0.5 – 2 \text{ keV}) = 6.4 \pm 0.4 \times 10^{44} \text{ erg s}^{-1} \), and the temperature, estimated in the (0.15–1) $r_{500}$ annulus, is \( T_X = 7.5^{+1.7}_{-1.1} \) keV. The gas mass was estimated to be $M_{\text{gas}, 500} = 7.3^{+0.4}_{-0.3} \times 10^{13} M_{\odot}$ from the X-ray surface brightness in the 0.5–2.0 keV band following the analysis method described in Vikhlinin et al. (2006), where the gas density is assumed to follow a modified $\beta$-model (Cavaliere & Fusco-Femiano 1978) that is allowed to steepen at large radii and to have a power-law cusp at the cluster center. The Chandra X-ray contours are overlaid in Figure 1 (right). The reader is referred to Andersson et al. (2010, hereafter A10) for a full description of the X-ray analysis of SPT-CL J0546-5345, as well as a study of the X-ray properties of 15 of the SZE-selected clusters from the V10 sample.

2.4. Optical Spectroscopy

Mid-infrared Spitzer/Infrared Array Camera (IRAC) imaging was obtained in 2009 September as part of a larger program to follow up clusters identified in the SPT survey (PID 60099; PI Brodwin). The on-target observations consisted of 8 $\times$ 100 s and 6 $\times$ 30 s dithered exposures at 3.6 and 4.5 $\mu$m, respectively. The deep 3.6 $\mu$m observations are sensitive to passively evolving cluster galaxies down to 0.1 $L^* \approx 1.5$. The data were reduced following the method of Ashby et al. (2009). Briefly, we correct for column pulldown, mosaic the individual exposures, resample to 0\'0.86 pixels (half the solid angle of the native IRAC pixels), and reject cosmic rays.

Optical data were provided by the Blanco Cosmology Survey (BCS), an NOAO survey program with deep $griz$ imaging over 100 deg$^2$ in a subset of the SPT 05 hr and 23 hr fields (Ngew et al. 2009). The Stellar Locus Regression method of High et al. (2009) was used for photometric calibration, extinction correction, and Galactic de-reddening. The independent calibration from the DES data management system (Mohr et al. 2008) gave consistent results. The BCS data typically reach 5$\sigma$ AB depths of 24.75, 24.65, 24.35, and 23.5 in $griz$. See S09 and H10 for a more detailed description of the optical data.

In designing the mid-infrared mask, galaxies were assigned a weight proportional to their $i$-band brightness and their proximity to the cluster center, and inversely proportional to their distance in color space, in both $r - i$ and $i - [3.6]$, from the predicted color from a Bruzual & Charlot (2003), hereafter
BC03) passively evolving 100 Myr burst model with formation redshift $z_f = 3$.

The COSMOS reduction package\(^{29}\) was used for standard CCD processing, resulting in wavelength-calibrated two-dimensional spectra. The one-dimensional spectra were then extracted from the sum of the reduced data. We flux calibrated the data and removed telluric absorption using the continuum of a spectrophotometric standard (Foley et al. 2003).

3. RESULTS

3.1. Redshifts

Redshifts for galaxy spectra exhibiting significant absorption features were found through cross-correlation using the RVSAO package in IRAF\(^ {30}\) (Kurtz & Mink 1998). The validity of the cross-correlation redshift was checked by visual inspection and judged by the presence of visible absorption lines; most of these displayed clear Ca HK lines. For three members the redshift was determined from a strong, unresolved $\text{[O II]}$ emission line. Redshift uncertainties were estimated as twice those given by RVSAO (Quintana et al. 2000). An independent extraction and visual redshift determination yielded identical redshifts for all cluster members within the errors.

From these Magellan observations we obtained 28 secure redshifts, of which 21 are spectroscopic cluster members within $r < 0.9$ Mpc of the SPT cluster position. This high success rate validates our spectroscopic selection algorithm. Representative spectra are shown in Figure 2. The majority of the members (18) are quiescent, with redshifts determined from Ca HK absorption, as expected given their red-sequence selection, central location, and the extreme mass of the cluster.

3.2. Velocity Dispersion

An iterative $3\sigma$ clipping algorithm was used to identify cluster members. We list the 21 secure cluster members in Table 1, and plot the redshift histogram in Figure 3 (left). In this figure the 18 passive members, for which the redshift was obtained from Ca HK absorption lines, are shaded red. Redshifts of the remaining three members, shaded blue, were secured from strong $\text{[O II]}$ emission. Spectroscopic non-members are unshaded. From the spectroscopic redshift histogram, SPT-CL J0546-5345 appears to be a single massive halo, with no evidence of substructure or merger activity. We note, however, that the X-ray image (Figure 1) shows a substructure extending to the SW indicating that a minor merger may be taking place (A10).

We use the robust biweight estimator of Beers et al. (1990) to estimate the mean velocity and velocity dispersion, applying the relativistic correction and the usual correction for velocity

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\(^{29}\) http://obs.carnegiescience.edu/Code/cosmos/

\(^{30}\) IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
errors (Danese et al. 1980). For the full membership, we find a mean redshift and velocity dispersion of \( z = 1.0665 \pm 0.0019 \) and \( \sigma = 1181^{+215}_{-183} \) km s\(^{-1}\), respectively. The errors in both quantities, obtained from bootstrap resampling, represent the 68% confidence interval.

Since late-type members are often infalling, they tend to yield broader dispersions than early types (e.g., Girardi et al. 1996; Fadda et al. 1996; Mohr et al. 1996; Koranyi & Geller 2000). We therefore explore limiting our analysis to the 18 early-type members, as these are expected to better reflect the cluster potential. This approach yields nearly identical results, with a mean redshift of \( z = 1.0665^{+0.0019}_{-0.0021} \) and a dispersion of \( \sigma = 1179^{+232}_{-167} \) km s\(^{-1}\). Although the biweight estimator is optimal, we also compute dispersions for these 18 members using both the gapper method (Beers et al. 1990) and the simple standard deviation. These yield \( \sigma_{\text{gapp}} = 1170^{+220}_{-126} \) km s\(^{-1}\) and \( \sigma_{\text{SD}} = 1138^{+205}_{-132} \) km s\(^{-1}\), respectively, both in excellent agreement with the biweight dispersion. There is no evidence of merger activity in SPT-CL J0546-5345 from the line-of-sight velocities, in either the appearance of Figure 3 or in the dispersion measures, although our redshift sampling is too sparse to rule it out.

![Figure 3](image-url)

### Table 1

Spectroscopic Members of SPT-CL J0546-5345

| ID            | R.A. (J2000) | Decl. (J2000) | \( z \)   | \( \delta z^a \) | Principal Spectral Feature |
|---------------|--------------|---------------|-----------|-----------------|---------------------------|
| J054637.2-534525 | 05:46:37.23  | −53:45:25.6   | 1.0647    | 0.0002          | Ca HK/D4000               |
| J054636.2-534413 | 05:46:36.22  | −53:44:13.4   | 1.0656    | 0.0004          | Ca HK/D4000               |
| J054642.3-534554 | 05:46:42.36  | −53:45:54.5   | 1.0548    | 0.0003          | Ca HK/D4000               |
| J054636.6-534540 | 05:46:33.67  | −53:45:40.5   | 1.0775    | 0.0005          | Ca HK/D4000               |
| J054635.1-534502 | 05:46:35.14  | −53:45:02.0   | 1.0676    | 0.0003          | Ca HK/D4000               |
| J054638.9-534356 | 05:46:38.90  | −53:43:56.2   | 1.0743    | 0.0003          | Ca HK/D4000               |
| J054634.8-534555 | 05:46:34.81  | −53:45:55.6   | 1.0567    | 0.0002          | Ca HK/D4000               |
| J054635.8-534542 | 05:46:35.82  | −53:45:42.0   | 1.0710    | 0.0003          | Ca HK/D4000               |
| J054638.6-534513 | 05:46:38.68  | −53:45:13.7   | 1.0692    | 0.0003          | Ca HK/D4000               |
| J054645.0-534538 | 05:46:45.04  | −53:45:25.9   | 1.0662    | 0.0003          | Ca HK/D4000               |
| J054641.8-534613 | 05:46:41.84  | −53:46:13.5   | 1.0712    | 0.0004          | Ca HK/D4000               |
| J054630.3-534425 | 05:46:30.37  | −53:44:25.3   | 1.0502    | 0.0005          | Ca HK/D4000               |
| J054638.8-534620 | 05:46:38.80  | −53:46:20.2   | 1.0681    | 0.0004          | Ca HK/D4000               |
| J054633.8-534409 | 05:46:33.86  | −53:44:09.3   | 1.0586    | 0.0005          | Ca HK/D4000               |
| J054646.8-534610 | 05:46:46.89  | −53:46:10.9   | 1.0625    | 0.0005          | Ca HK/D4000               |
| J054634.9-534437 | 05:46:34.92  | −53:44:37.5   | 1.0705    | 0.0005          | Ca HK/D4000               |
| J054636.4-534619 | 05:46:36.43  | −53:46:19.5   | 1.0805    | 0.0007          | Ca HK/D4000               |
| J054644.4-534502 | 05:46:44.42  | −53:45:02.7   | 1.0661    | 0.0025          | [O\(\pi\)]               |
| J054646.8-534557 | 05:46:46.87  | −53:45:57.6   | 1.0686    | 0.0002          | [O\(\pi\)]               |
| J054620.2-534543 | 05:46:42.08  | −53:45:43.9   | 1.0524    | 0.0002          | [O\(\pi\)]               |

Note. 

^a Redshift errors are twice those given by RVSAO.
3.3. Color–Magnitude Relation

We plot the $i - [3.6]$ color–magnitude diagram for galaxies within a 2.5 (1.22 Mpc) radius of SPT-CL J0546-5345 in Figure 3 (right). The spectroscopically confirmed passive galaxies define a rich red sequence, indicative of a cluster that is already well evolved at $z = 1.067$. The dashed line indicates the $5\sigma$ color–magnitude limit; one confirmed member is not detected robustly enough in the optical for inclusion in this plot. The solid red line indicates the slope of the rest-frame color–magnitude relation (CMR) of Coma (Eisenhardt et al. 2007), normalized to $L^*$ at 3.6 $\mu$m in the passively evolving $z_f = 3$ BC03 model described above.

3.4. Dynamical Mass

There are several approaches in the literature for calculating the dynamical mass. Perhaps the most widely adopted is that of Carlberg et al. (1997), who use the simple definition $M_{200} = 4/3\pi r_{200}^3 \rho_c$, where $r_{200} = \sqrt{3/2} \sigma / 10 H(z)$ and $\rho_c$ is the critical density. Although this approach provides a convenient basis for comparison with other studies, it relies on the simplifying assumption that clusters are singular isothermal spheres. We therefore prefer to use the simulation-based $\sigma - M_{200}$ relation of Evrard et al. (2008),

$$M_{200} = \frac{10^{15}}{h(z)} \left( \frac{\sigma_{\text{DM}}}{\sigma_{\text{DM,15}}} \right)^{1/\alpha},$$

where $\sigma_{\text{DM,15}} = 1082.9$ km s$^{-1}$, $\alpha = 0.3361$, and $\sigma_{\text{DM}}$, the dark matter velocity dispersion, is related to the observed galaxy velocity dispersion by the velocity bias parameter, $b_v \equiv \sigma / \sigma_{\text{DM}}$. Simulations generally suggest that $0.9 < b_v < 1.1$, and the most recent numerical results (Evrard et al. 2008, and references therein) indicate that galaxies are essentially unbiased tracers of the dark matter potential (i.e., $b_v = 1$). Adopting this value, we obtain $M_{200} = 1.04^{+0.61}_{-0.64} \times 10^{15} M_\odot$. Dynamical masses corresponding to the various velocity dispersion measurements reported in Section 3.2 are tabulated in Table 2. The Carlberg et al. (1997) relation yields masses a factor of $\approx 1.5$ larger.

Detailed studies of the velocity dispersion profile (e.g., Girardi et al. 1993; Fadda et al. 1996) indicate that dispersions measured within radii less than $r_{200}$ may be biased high. In A10, $r_{200}$ for SPT-CL J0546-5345 is estimated to be $\approx 1.57$ Mpc, and we are therefore probing an aperture of $\approx 0.57r_{200}$. Numerical (Biviano et al. 2006) and observational (Rines & Diaferio 2006; Katgert et al. 1996, 1998) studies suggest that for our early-type galaxy sample and the clustercentric radius probed, the bias is expected to be small. For example, Biviano et al. (2006) report the expected bias in the dispersion as a function of the fractional virial radius probed; for our dispersion measurement the expected upward bias is $\lesssim 2.5\%$. This implies a corresponding bias in the dynamical mass of $\lesssim 7\%$, which would lower the dynamical mass to $\approx 0.6 \times 10^{15} M_\odot$. While this may well be a more accurate value, the bias correction is both uncertain and small. We therefore defer a more extensive analysis to a future paper, when a larger sample of spectroscopic members out to $r_{200}$ is available.

Finally, we note that no other $z > 1$ cluster with $\geq 10$ spectroscopically confirmed members has $\sigma > 1000$ km s$^{-1}$. With a dispersion of $\sigma = 1179$ km s$^{-1}$, SPT-CL J0546-5345 is unambiguously the most dynamically massive cluster yet identified at $z > 1$.

4. DISCUSSION

4.1. $\sigma - T_X$ Relation

At $T_X = 7.5^{+1.7}_{-1.1}$ keV, SPT-CL J0546-5345 is among the hottest clusters yet observed in the X-ray at $z > 1$ (Rosati et al. 2009). Figure 4 shows the well-known correlation between X-ray temperature and galaxy velocity dispersion (Lubin & Bahcall 1993; Bird et al. 1995; Girardi et al. 1996; Horner et al. 1999; Xue & Wu 2000; Ortiz-Gil et al. 2004). The clusters shown are the subset of the well-studied, low-redshift X-ray cluster sample of Vikhlinin et al. (2009) for which accurate velocity dispersion measurements, from at least 40 galaxies, are available from Girardi et al. (1996). The temperatures are measured in an identical manner to that of SPT-CL J0546-5345, which is plotted as the large red circle. The dashed line is the best-fit relation Girardi et al. (1996) obtained using previous temperatures from the literature, and the solid line is our own fit using the Vikhlinin et al. (2009) temperatures. Both fits exclude SPT-CL J0546-5345, and are consistent with typical measurements (e.g., Lubin & Bahcall 1993; Horner et al. 1999). Although the comparison clusters are all at low redshift ($z < 0.1$), there is no expectation of, nor evidence for, evolution in this relation to $z \sim 1$ (e.g., Wu et al. 1998; Tran et al. 1999). The measured dispersion
and X-ray temperature for SPT-CL J0546-5345 fall right on the \( \sigma - \tau_X \) relation, offering strong corroboration of the very large dynamical mass presented here.

### 4.2. X-ray, SZE, and Optical Mass Measures

We now compare the dynamical mass with several other mass measures available for SPT-CL J0546-5345, all reported in terms of \( M_{200}(\rho_c) \). A summary of these mass measures is given in Table 2.

In A10, the cluster mass within \( r_{500} \) is measured using the \( Y_X - M_{500} \) relation (Vikhlinin et al. 2009) to be \( M_{500, Y_X} = (5.33 \pm 0.62) \times 10^{14} \, M_\odot \). The systematic uncertainty of this scaling relation calibration was estimated by Vikhlinin et al. (2009) to be \( \pm 9\% \) by comparing X-ray mass estimates to weak lensing mass measurements for a representative sample of clusters. We include this uncertainty in quadrature when converting to \( M_{200, Y_X} \), and we estimate that \( M_{200, Y_X} = (8.23 \pm 1.21) \times 10^{14} \, M_\odot \). This X-ray mass is consistent with the measured dynamical mass within the errors. Although the X-ray image shows evidence of a possible merger, the \( Y_X \) estimator is expected to be robust to such events (Vikhlinin et al. 2009). Indeed, the majority of high-redshift clusters have asymmetrical X-ray morphologies (e.g., Vikhlinin et al. 2009; A10), so the inferred X-ray mass of SPT-CL J0546-5345 should be of comparable accuracy to other clusters at similar redshifts. We also estimate the mass from the temperature, via the \( T_X - M_{500} \) relation of Vikhlinin et al. (2009), to be \( M_{200, T_X} = (8.11 \pm 1.89) \times 10^{14} \, M_\odot \).

The SZE measurement of the integrated Comptonization, \( Y_{SZ} \), is expected to be the most accurate Sunyaev–Zel’dovich (SZ) mass proxy (Motl et al. 2005; Nagai 2006). In A10, they measure a spherically deprojected Comptonization of \( Y_{SZ} = (3.5 \pm 0.6) \times 10^{14} \, M_\odot \, \text{keV} \), where the uncertainty is estimated from the quadrature sum of statistical errors and the uncertainty in the assumed gas profile. From this measurement, we use the \( Y_{SZ} - M_{500} \) relation reported in A10 to estimate a mass, where we marginalize over the allowed range of normalization and slope parameters from their fit. We include an additional \( \pm 9\% \) uncertainty to account for the systematic uncertainty of the \( Y_X \)-based masses used to calibrate their relation.\(^{31}\) Using this method, we infer a mass of \( M_{200, Y_{SZ}} = (7.19 \pm 1.51) \times 10^{14} \, M_\odot \), in agreement with the X-ray and dynamical mass estimates.

Another SZE mass estimate can be inferred from the SZE significance-mass scaling relation established via WMAP7-constrained simulations in V10. A10 compared this SZE significance-based mass proxy with X-ray-inferred masses for their sample of 15 SZE-selected clusters, finding that the significance-based SZE masses may be biased low, with an average ratio of the SZE to X-ray masses of 0.89 \( \pm 0.06 \). The result for SPT-CL J0546-5345, \( M_{200, SZE} = (5.03 \pm 1.13 \pm 0.77) \times 10^{14} \, M_\odot \), where the uncertainties are statistical followed by systematic, is indeed \( \sim 1.6 \sigma \) below the 68\% confidence interval of the more precise X-ray mass, although it is in agreement with the dynamical mass within the errors. Accounting for the bias quantified in A10 brings the significance-based mass estimate into agreement with the X-ray mass.

H10 present a scaling relation between SZE-derived mass and two optical richness measures, \( N_{gal} \) and \( N_{200} \). These richness measures count the number of galaxies on the red sequence at the cluster redshift within clustercentric radii of 1 h\(^{-1} \) Mpc and \( r_{200} \), respectively. The derived masses, \( M_{200}(N_{gal}) = (9.2 \pm 4.9 \pm 2.7) \times 10^{14} \, M_\odot \) and \( M_{200}(N_{200}) = (8.5 \pm 5.7 \pm 2.5) \times 10^{14} \, M_\odot \), are consistent with the independent richness-based mass estimate of Menanteau & Hughes (2009) for this cluster. Although noisy mass proxies, these richness measures offer independent evidence of the high mass of SPT-CL J0546-5345.

### 4.3. Combined Mass for SPT-CL J0546-5345

Table 2 lists total mass measures for SPT-CL J0546-5345 from dynamical, X-ray, SZE, and optical richness mass proxies. For each physical probe, the bold entries indicate the specific proxy expected to yield the most robust mass. For dispersions, this is the biweight measure, which is optimal for the number of spectroscopic members we have (Beers et al. 1990). For the X-ray, the YX estimator is chosen over the \( \tau_X \) estimator because it is expected to be significantly less biased for mergers and to have less intrinsic scatter with mass (Kravtsov et al. 2006; Vikhlinin et al. 2009). For the SZE, the \( Y_{SZ} \) estimator is chosen over the \( S/N \) estimator because its scaling relations have been calibrated directly from external observations rather than simulations and it is expected to have less intrinsic scatter with mass (Kravtsov et al. 2006; V10). Finally, the \( N_{200} \) estimator is the best-tested optical richness measure.

We optimally combine these independent measurements, weighting them by their errors. We symmetrize the errors on the dynamical mass and add the statistical and systematic errors weighting them by their errors. We symmetrize the errors on the dynamical mass and add the statistical and systematic errors weighting them by their errors. The resulting mass is \( M_{200} = (7.95 \pm 0.92) \times 10^{14} \, M_\odot \), which we take as our best estimate of the mass of SPT-CL J0546-5345.

\(^{31}\) The SZ and X-ray mass estimates are not completely independent. We expect that their largest correlation will be from the mass calibration of the \( Y_X - M_{500} \) and \( Y_{SZ} - M_{500} \) relations, which are based on the same X-ray measurements from Vikhlinin et al. (2000). We add the 9\% uncertainty to the \( Y_{SZ} \) mass estimate to account for this, and assume that any other correlated uncertainty is negligible.

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**Figure 4.** Empirical \( \sigma - \tau_X \) correlation for the X-ray clusters from Vikhlinin et al. (2009), with velocity dispersions taken from Girardi et al. (1996). The temperatures are measured exactly as for SPT-CL J0546-5345. The fits, described in the text, are typical of those found by other authors (e.g., Lubin & Bahcall 1993; Homer et al. 1999). SPT-CL J0546-5345 (red circle) falls right on this relation.
4.4. SPT-CL J0546-5345 in a Cosmological Context

Using the Tinker et al. (2008) mass function we calculate that SPT-CL J0546-5345, which at $z = 1.067$ is already almost as massive as the Coma cluster, will increase in mass by a factor of $\sim 4$ over the next 8 Gyr. It should therefore grow into one of the most massive clusters in the universe by the present day.

Historically, the existence of individual massive galaxy clusters at high redshift has been used to constrain cosmological models (e.g., Donahue et al. 1998). While we are entering an era where large samples of SZ clusters will soon be available in addressing such questions, it is interesting to ask whether the existence of SPT-CL J0546-5345 is expected in our survey volume is unsurprising. The inherent in this calculation, we conclude that the existence of SPT-CL J0546-5345 in our survey volume is unsurprising. The complete SPT sample will provide the large sample of SZ clusters that will be robustly tested at high redshift.

5. CONCLUSIONS

We report the spectroscopic confirmation SPT-CL J0546-5345 at $z = 1.067$, the first SZE-selected galaxy cluster at $z > 1$. We measure a robust velocity dispersion from 18 early-type members of $\sigma = 1179^{+232}_{-160}$ km s$^{-1}$, corresponding to a dynamical mass of $M_{200} = 1.6^{+0.6}_{-0.4} \times 10^{15} M_{\odot}$. SPT-CL J0546-5345 is the most dynamically massive cluster yet identified, from any method, at $z > 1$.

We find excellent consistency across several independent mass measures. The measured dispersion and X-ray temperature relations based on complementary mass measures, will permit ACDM predictions for the high end of the cluster mass function to be robustly tested at high redshift.

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