Galaxy Cluster ICM and Stellar Mass Fraction Trends with Mass and Redshift within the SPT Sample

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+SPT, +DES

KICC Workshop on Galaxy Clusters

Cluster Baryon Scaling Relations

- Existence of scaling relations constrains cluster formation
- Trends in ICM and stellar mass fraction with redshift and mass constrain the physical processes important in cluster evolution
- Measurements of $f_*(M,z)$ and $f_{icm}(M,z)$ can be compared directly to simulated clusters

Steep than Self-Similar Scaling Relations

Require: Simple selection, broad redshift and mass range, accurate masses

Mohr & Evrard, 1997

$L=1.5\times10^{-14}$ cgs

$P_{[h^{-2}\text{Mpc}^3]}$

$T_X [\text{keV}]$
Overview

- SPT Cluster Sample
- Virial Mass Estimates
- Stellar and ICM Masses and Fractions
- RS Width and Concentration
- Future SZE and X-ray Surveys

Sunyaev-Zel’dovich Effect Galaxy Cluster Selection

Cluster SZE Signature

- Measures total thermal energy in ICM
- Strongly correlated with mass (low scatter)
- Signature at fixed mass is ~independent of redshift!

\[ \frac{\Delta T(R)}{T_{\text{e}}(R)} = -2 \frac{\mu}{\omega} \int dR n_e(l, R) k_B T_e(l, R) \]

Adapted from L. Van Speybroeck
SPT-SZ 2500 deg² Survey
Carlstrom+10

- Matched filter selection
- Painstaking optical followup

First SZE selected clusters pulled from first year SPT data (Staniszewiski+09)

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SPT-SZ Sample
Song+12, Bleem+15

- 2500 deg² sample
  - 516 at \( \xi > 4.5 \)
  - 387 at \( \xi > 5.0 \)
  - Bleem+15

- High z subsample
  - 36 at \( z > 1 \)
  - Max \( z_{\text{spec}} = 1.47 \)
  - Bayliss+13
  - Highest phot-z
  - Strazzullo+

- Clean sample with \( M_{500} > 3 \times 10^{14} M_\odot \) to \( z \sim 1.7 \)

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Highest Redshift: SPT-CLJ 0459
Strazzullo+ in prep

Cosmology with SPT Sample?
Bocquet+16; de Haan+16

- Sure:
  (see Haiman, Mohr & Holder 2001)
  - Observable distribution $d^2N/dzdz$ must be mapped to cosmology dependent hydro mass function $d^2N/dzdM$
  - Need observable-mass relation

The resulting masses also support studies of the stellar and ICM mass fractions
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Observable-Mass Relation

Bocquet+15

- Statistical relationship between observable and underlying halo mass
  - Clusters are young, merging objects
  - Crucial for selection observable (S/N, Y, L_y)
  - Include lower scatter mass proxies (Y, M_{ICM})

Characteristic SZE based mass scatter ~15-20%

- SZE Observable-Mass relation
  - Minimum of four free parameters: power law plus (log-normal) intrinsic scatter
    \[ \xi = A_{sz} \left( \frac{M_{500}}{3 \times 10^{14} h^{-2} M_\odot} \right)^{B_{sz}} \left( \frac{E(z)}{E(0.6)} \right)^{C_{sz}} \]
    4 params: A_{sz}, B_{sz}, C_{sz} and D_{sz}

  - Parametrization allows systematic uncertainties to be included
  - Mass information added through weak lensing, galaxy kinematics, external priors

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**SPT Cluster Masses**

**Bocquet+15**

- External cosm priors (Planck, WMAP) tend to prefer higher cluster masses
- Direct constraints (WL, Dyn, Hydro) prefer lower values
- Constraints are still weak—everything statistically consistent

\[ \xi = A_{SZ} \left( \frac{M_{500}}{3 \times 10^{14} h^{-1} M_\odot} \right) ^{\frac{\eta_{SZ}}{E(z)}} \]

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**Planck Cluster Mass Priors**

**Planck Collaboration XXIV (2015)**

- External cosmology priors prefer higher masses than direct measurements
- CMB lensing and LoCUSS WL imply no hydrostatic mass bias (in conflict with simulations)
- Some tension among mass priors
  - WtG: \(1-b=0.69 +/- 0.07\)
  - CCCP: \(1-b=0.78 +/- 0.09\)
  - CMBLens: \(1-b=0.99 +/- 0.19\)
  - LoCUSS: \(1-b=0.95 +/- 0.04\)

Planck adopts hydrostatic masses as baseline
\[ M_{\text{hydro}} = b M_{\text{true}} \]
SPT Mass Calibration Continues

- Direct mass calibration of clusters
  - Dynamical masses:
    - Bocquet+15 (with dispersions)
    - Capasso+ (Jeans analysis)
  - Magnification masses:
    - Chiu+16
  - Shear masses:
    - Dietrich+ (Magellan imaging)
    - Schrabback+ (HST+VLT imaging)
    - Stern+ (DES imaging)

Still wiggle room in mass scale of SPT clusters

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Trends in Stellar Mass
Chiu+15

- Massive clusters grow through accretion of low mass clusters and groups

- But on average groups have many times higher stellar mass fraction than clusters.

- How can this be?
  - Intracluster light? (Lin et al 2004)
  - $M_{\text{vir}}$ errors? (Bocquet et al 2015)
  - $M_*$ errors?
  - Redshift trends?

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SED Fitting Provides $M^*$ estimates
Chiu+15

- One must use consistent stellar IMF
- In Chiu+15 we use 6 bands (VLT+HST+IRAC) to estimate galaxy stellar masses
- Possible to robustly examine trends in $M_{\text{vir}}$ and $z$ under assumption IMF trends are small
Redshift Trends in Stellar Mass

Chiu+15,16

- None are seen in high mass sample (SPT&ACT + low-z)
  - Chiu+2015

- None are seen in recent study of X-ray sample of groups and low mass clusters extending to $z \sim 1$

- So what is going on?

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Dark Energy Survey

5000 deg$^2$
griz imaging
525 nights
Blanco 4m
3 deg$^2$ Camera
$\sim 0.9''$ FWHM riz
$\sim 2$ mag deeper than SDSS

Goal: Use DES (+Spitzer, WISE) to study stellar mass fractions over full SPT sample
XVP Sample: Trends in Stellar Mass
Chiu thesis

- 61 XVP clusters with available DES data in black
- Evidence for redshift trend still weak
- Infall from field (low $f_\ast$) roughly offset by infalling subclusters (high $f_\ast$)

Preliminary Results

\[ M_\ast \propto M_{500}^{0.75 \pm 0.14} (1 + z)^{0.23 \pm 0.34} \]

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XVP Sample: Trends in ICM Mass
Chiu thesis

- 91 XVP clusters in black
- Evidence for redshift trend is also weak
- Infall from field (high $f_{\text{icm}}$) roughly offset by merging subclusters (low $f_{\text{icm}}$)

Preliminary Results

\[ M_{\text{icm}} \propto M_{500}^{1.24 \pm 0.06} (1 + z)^{0.19 \pm 0.14} \]

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Galaxies in DES-SV Subsample

Hennig+16

- DES imaged a region of ~150 deg$^2$ of SPT-SZ to “full depth” as part of science verification
  - Image quality ~1.1"
  - Mean 50% completeness depths for SPT candidates: griz=24.3,24.0,23.1,22.8
- SPT-SZ subsample
  - 85 candidates/77 confirmed
  - RS z’s: $\delta z/(1+z) \sim 0.016$
  - z<1.2 and $M_{200}>3\times10^{14}M_\odot$
Galaxy Colors, Red Sequence
Hennig+16

- By stacking and projecting in color space, we define red and blue components as f(z)
  - 8 bins with ~10 clusters each
  - 0.06-0.3-0.4-0.425-0.56-0.70-0.8 8-1.0-1.2

- RS present at all redshifts, lower contrast at higher z, blue pop also present

- No clear width evolution to z~1.
  - Simple z=3 burst (τ~0.5Gyr) describes RS color evolution

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Transition from Field to Cluster
Hennig+16

- Cluster galaxies are predominantly ellipticals, while field galaxies are predominantly spiral

- Radial profile insights
  - RS galaxies c=5.37
  - Blue non-RS c=1.38
  - No clear redshift trend
  - Variation from cluster to cluster (38% RS and 55% full)
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Future SZE Surveys
Carlstrom, Delabrouille, Staggs, ++

- SPTpol + SPT-3G + AdvACT underway
- CORE space mission proposed for ESA M5
- CMB-S4 ground based (US coordinated, seeking European participation)
- Large cluster samples: z>1.5: 500, 5000, 20,000 clusters
- Exquisite mass constraints

Melin+16 forecasts for CORE
e-ROSITA All Sky X-ray Survey
Predehl+10, Merloni+12

- Good angular resolution –
  - ~16" HEW on axis, 28" HEW averaged over field (survey mode)
- Characteristic flux limit is ~2x10^{-14} erg/s/cm^2
  (~30X deeper than ROSAT All Sky Survey w/ CCD spectroscopy)

~10^5 X-ray selected galaxy clusters
~3x10^6 X-ray selected AGN

Cosmological Studies
Structure Formation Studies
Launch scheduled end of 2017

Summary

SPT Cluster Sample Spans Broad Range
- Simple selection, extends to z~1.75
- Low scatter mass proxy provides 15-25% virial mass scatter
- Systematic mass uncertainties included with mass-obs relation
  - Calibration w/ Weak Lensing and Galaxy Dynamics ongoing

DES Enables Cluster Galaxy Studies to z~1
- Depth is good match to probe SPT clusters to m^*+2 out to z~1
- Homogeneous, contiguous imaging enables infall region studies

Galaxies, Stellar Masses and ICM Masses
- Width of RS ~constant to z=1; RS fraction falls moderately to z~1
- Strong mass trends in stellar and ICM mass fractions persist to z~1
- At fixed cluster mass, redshift trends in ICM and stellar mass are modest
LMU Cosmology and Structure Formation Group

- **Focus:**
  Observational cosmology and structure formation studies

- **Survey Projects**
  South Pole Telescope
  Dark Energy Survey
  eROSITA
  Euclid and LSST
  D-MeerKAT and CORE

- **Group Members:**
  **Research Scientists**
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DES Gallery of SPT Clusters

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