Galaxy populations study on Clusters of Galaxies detected by the South Pole Telescope

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OUTLINE

- The south Pole Telescope and the SZE
- Photometric redshifts
- Galaxy populations
- Conclusions
- 10m telescope located in the geographical South Pole at 2700 m altitude
- 1 deg FOV
- 1.1' FWHM beam at 150GHz
- 2" pointing accuracy
- Feb. 16, 2007 first light
- Nov. 2011 2500 survey complete
Sunyaev-Zel’dovich Effect

Promise: clean, low scatter, redshift independent cluster selection technique!
Also \( y \) is a mass proxy.

\[
\frac{\Delta T_{\text{SZ}}}{T_{\text{CMB}}} = f(x) y = f(x) \int n_e \frac{k_B T_e}{m_e c^2} \sigma_T \, d\ell
\]

e.g., Motl et al (2005), Nagai (2006)
The South Pole Telescope

Example of a cluster in an SPT map
**Blanco Cosmology Survey: First four Blindly selected SPT Clusters**

**BCS gri pseudo color images of the SPT detection fields**

Green circles mark 1’ diameter centered on SPT location

Cluster Photo-z and Red Galaxy pop

Red sequence redshifts

High et al. (2010), Song et al. (2011), Bleem et al. (2015)
2500 deg$^2$ surveyed
677 (409) cluster candidates above SN of 4.5 (5): 28% observed with Blanco (Bleem+15).
76 (95)% of SN > 4.5 (5) candidates confirmed but Space- and ground-based OIR imaging
415 clusters discovered for the first time
Median mass $M_{500c} \sim 3.5 \times 10^{14} M_\odot$
Median redshift of 0.55 with highest-z at $\sim 1.4$
The South Pole Telescope: SZ Survey

- 26 most massive systems (Williamson et al. 2011)
- Mass $M_{500c} > 6.0 \times 10^{14} M_{\odot}$
- Wide redshift range from 0.1 to 1.13

Figure 6.

Figure 7.
Details:

BCG position == cluster center
BCG luminosity set as the bright end limit
R200 via SZ mass*
Local statistical background subtraction
Red-sequence width of \pm 0.22 (3 sigma)**
LF fitting done fixing m* to a Single Stellar Population model*** on the band redwards of the 4000A break.
RP stacks done simultaneously fitting cg and N(M200) and marginalizing over the background.
Typical depth of m*+2 at 10 sigma

* Bocquet et al. (2015)
** Lopez-Cruz (2004)
**GALAXY POPULATIONS: Radial Profile**

NFW integrated along the line-of-sight

\[ N_{cyl}(r) = 4\pi \rho_s r_s^3 f(x) \]

\[ f(x) = \begin{cases} 
\ln \frac{x}{2} + \frac{2}{\sqrt{x^2-1}} \arctan \sqrt{\frac{x-1}{x+1}} & \text{if } x > 1, \\
\ln \frac{x}{2} + \frac{2}{\sqrt{1-x^2}} \arctanh \sqrt{\frac{1-x}{x+1}} & \text{if } x < 1 \\
\ln \frac{x}{2} + 1 & \text{if } x = 1
\end{cases} \]

\[
c_{g,\text{red}} = 3.55^{+0.66}_{-0.81} \times (1+z)^{-0.57\pm 0.57}
\]

\[
c_{g,\text{all}} = 2.14^{+0.35}_{-0.42} \times (1+z)^{-0.3\pm 0.49}
\]

*Zenteno in prep*
GALAXY POPULATIONS: LUM. FUNCTION

M* IF WE FIT ALL THREE PARAMETERS OF THE SCHECHTER FUNCTION
GALAXY POPULATIONS: LUM. FUNCTION

\[ \phi(m) = 0.4 \ln(10) \phi^* 10^{0.4(m^* - m)(\alpha+1)} \exp(-10^{0.4(m^* - m)}) \]

Stacked LF of the 26 clusters consistent with literature

\[ \alpha_{\text{all}} = -1.04^{+0.04}_{-0.03}, \quad \alpha_{\text{rs}} = -0.76^{+0.05}_{-0.03} \]

Paolillo+01
Lin+04
Popesso+05
Rudnick+09
etc.

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GALAXY POPULATIONS: LUM. FUNCTION

M* EVOLUTION WITH THE FAINT END SLOPE FIXED TO THE STACK VALUE

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Fixing $m^*$ to an SSP model to explore alpha and phi evolution

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Halo Occupation Number

$N = 1 + N^s$, with $N^s = V \phi^* \int_{y_{low}}^{\infty} y^\alpha e^{-y} dy$

GALAXY POPULATIONS

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Fig. 5.— LF parameter evolution with redshift. As noted before, the LFs are extracted using the band redward of the 4000 Å Break. We fit a line in each case, marking the allowed 1σ region.

Panel (a): There is no significant evolution in $\Delta \text{mag} = (m^\star_{\text{model}} - m^\star_{\text{model}})$, indicating the SSP model provides a good description of cluster galaxies over this redshift range.

Panel (b): Evolution of $\alpha$ is suggested by the data with best fit line having intercept $0.07 + 0.07$ and slope $0.06 + 0.16$.

Panel (c): $\alpha/E^2(z)$ extracted using fixed $m^\star$ is consistent with no evolution at 1σ level.

Panel (d): Ratio of HON from this work and the redshift independent L04 prediction. Slope and intercept are found to be $0.68 + 0.50$ and $0.50 + 0.5$, respectively, which indicate a mild evolution where clusters have typically 30% fewer galaxies than their low redshift counterparts of the same mass.

Fig. 6.— Same as Fig. 5 for red sequence galaxies.

Panel (a): There is no significant evolution in $\Delta \text{mag} = (m^\star_{\text{model}} - m^\star_{\text{model}})$, indicating the SSP model provides a good description of cluster galaxies over this redshift range.

Panel (b): Evolution of $\alpha$ is suggested by the data with best fit line having intercept $0.93 + 0.06$ and slope $0.2 + 0.15$.

Panel (c): $\alpha/E^2(z)$ extracted using fixed $m^\star$ is consistent with no evolution at 1σ level.

At high redshift. Thus, to explore for density evolution beyond this we examine measurements of $\alpha/E^2(z)$ in the case where $\alpha$ is free to float and $m^\star$ comes from the SSP model. Results appear in panel (c) of Fig. 5 for all galaxies, and Fig. 6 for the red sequence sub-sample. By fitting a linear relation for both sets of measurements, using $m^\star$ fixed to the model we find best fit parameters for the slope to be $0.67 + 0.43$ consistent with no evolution. On the red sequence population we find the slope $0.64 + 0.36$ confirming a similar picture shown by the total population in case of $m^\star$ fixed to the SSP model.

As it has been already mentioned in §4.2.1 our LF normalization is consistent with values in the low redshift regime when accounting the high masses of our clusters. At high redshift this is among the first study of its kind. Our approach to studying the characteristic galaxy density.
CONCLUSIONS:

- The spatial distribution of galaxies shows no evidence of evolution.
- The most massive clusters in the universe tend to have lower concentrations.
- LF for red and total population have not change their shape from redshift 1.
- Larger samples are needed, specially in the high redshift end: DES, see Yuan-Yuan Zhang.
  Talk for a sneak peek!