Understanding Cluster Central Galaxies with the Dark Energy Survey: The Past Eight Billion Years and Beyond

Outline

• The DES power of galaxy cluster science.
• The growth of cluster central galaxies.
• Future prospect at high redshift.

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Image: Millennium simulation
Galaxy clusters are the largest gravitationally bound structures.
Galaxy clusters are the largest gravitationally bound structures. Easy (Relatively) to identify and sensitive to cosmology.
Enormous content and rich processes toward making a cluster.

Excellent laboratories for studying star formation, gas dynamics, dark matter and dark energy.
Optical telescopes directly observe the 1% stars: “galaxy” processes, “galaxies” as tracers of dark matter,
Optical telescopes directly observe the 1% stars: “galaxy” processes, “galaxies” as tracers of dark matter, and gravitationally lensing (dark matter).
Galaxy clusters are rare (and sensitive to cosmology).

Large area and deep depth are good friends to cluster science.
Wide field optical surveys (DES) provide excellent opportunities for optical studies of clusters.

DES cluster density:
- 0.1 - 0.2 deg² per cluster.
- 800 to z=0.9 in 150 deg² SV data
- 8,000 to z=0.75 in 1,500 deg² Y1 data.
- Up to 40,000 to z=1.0 in future DES data.

5000 deg², wide coverage, large number of clusters
24 mag depth in g, r, i, z, detecting clusters to z~1.0.
Clusters are also observed in the X-ray wavelength range, relying on X-ray emissions from the cluster (hot) gas content.

Wide field optical surveys (DES) also helps with studies that rely on the cluster gas content.

Credit: The XMM cluster survey, Miller, Rooney et al. in prep.
The XMM Cluster Survey selects clusters with X-ray data but relies on optical data for confirmation and redshift measurement.

Candidates need to be confirmed with optical/infra-red imaging.

Imaging data confirm the existence of clusters, which also contain redshift information.

Use redshift to calculate X-ray temperature and luminosity.

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Miller, Rooney et al. in prep.
The XMM Cluster Survey has found hundreds of clusters with DES-SV data.
Studying cluster central galaxies is one example of what we can do in terms of DES cluster science.
Merging (hierarchical structure formation) is important in explaining BCG formation.

BCG grows significantly with time.

De Lucia 2007
Merging (hierarchical structure formation) is important in explaining BCG formation.
But merging does not seem to explain all…

Observations do not agree with a simple merging prediction on BCG growth. Observations also do not agree with each other.
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BCG photometry:
optical data processing pipeline struggles with object detection around BCGs.

Before SVA1

SExtractor tweaking
BCG photometry: we wrote a package to help with object detection around BCGs.

The Gradient And Interpolation Based Deblender (GAIN deblender)
BCG photometry: optical data processing pipeline struggles with measuring quantities around BCGs.

The "wrong" measurement limit

Where it should be
BCG photometry: optical data processing pipeline struggles with measuring quantities around BCGs.
Issues with observations:
- BCG photometry
- Sample selection
- Uncertainty estimation

Mass dependence effect:
- mass range is important.

Redshift evolution
mass selection is important.

Issues with observations:
- BCG photometry
- Sample selection
- Uncertainty estimation

The DES-XCS sample covers a large redshift and mass range.
A simple matching Method:
Match simulation BCGs with observations, considering uncertainties.

Result:
The observed BCGs are under-luminous/massive at low redshift.
A modeling method: Model BCG evolution for both simulation and observation — convenient to incorporate all measurement uncertainties.

\[ \log m_\star = \log m_0 + \alpha \log \left( \frac{M_{200}}{M_{\text{piv}}} \right) + \beta \log(1+z). \]
There indeed exists a discrepancy between the merging prediction and the observation.
There indeed exists a discrepancy between the merging prediction and the observation. The \textit{disagreement between previous observations is gone} after considering measurement uncertainties.
There indeed exists a discrepancy between the merging prediction and the observation.

There exists other processes that affect BCG formation.
Star formation makes the simulated BCGs grow even faster.

There exists other processes that affect BCG formation.
ICL can make the simulated BCGs grow slower.

\[ \log \left( \frac{m_{*}(z=1)}{m_{*}(z=1)} \right) \]

- Simulation - 40M_{\odot}/yr (ICL)
- Simulation - 20M_{\odot}/yr (ICL)
- Simulation + 20M_{\odot}/yr (SF)
- Contini 2014, simulation, \( z=1.05 \rightarrow 0 \)

\( \sim 10 \) to 50 \( M_{\odot}/yr \) after \( z = 1.0 \).

\( \sim 10\% \) to 40\% the total of BCG+ICL stellar masses.
What is next?
Current and future DES data releases will significantly improve the sensitivity. Constraints on ICL and BCG star formation can be tested directly.

Future XCS-DES release: 3 times improvement in sensitivity.
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Wide fields surveys makes it possible to stack hundreds of clusters to detect faint diffused light.
DES has the capacity for conducting ICL analysis to $z \sim 0.7$
Can we go beyond redshift 1.0?
Does DES have clusters beyond redshift 1.0?

XCS, $z \sim 1.266$
XCS, $z \sim 1.2$
DES wide field. Depth: $m^*$

Public Infrared data available

WISE

DES Pseudo-color

SSDF
Bleem 2015, z~1.7!

DES Pseudo-color
Can we find high redshift clusters?

Yes. See examples by XCS and SPT.

What resources do we have?

- DES supernovae field, 30 deg squared. Deep to m*+2 mag. Good Spitzer infrared coverage.
- DES wide field, deep to m*. Serendipitous Spitzer infrared coverage. WISE all sky data.
- SPT multi-wavelength data.
- Follow-up opportunities with OzDES.

What is being done now?

Not much.
- XCS and SPT will continue to find high redshift clusters.
  - XCS searches serendipitously. SPT find massive clusters.
- DES wide field: EC proposal with the Spitzer SSDF team.
- DES supernovae: in contact about ECs with a couple Spitzer teams.
What can DES do?

We want to fully develop the potential of DES data!

• DES wide field: making use of \textit{WISE} data?
• DES supernovae: making use of the deep z band data and public \textit{Spitzer} data.

Specifically, combine publicly released infrared data with DES data.

What can we do after finding z$>1.0$ clusters?

• Cosmology?
• Galaxy evolution. Definitely Yes. Especially BCG studies (growth and star formation).