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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Fermilab
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Image: Millennium simulation

Galaxy clusters are the largest gravitationally bound structures.

125 Mpc/h

Bound, gravitationally-bound.

Image: Millennium simulation

Galaxy clusters are the largest gravitationally bound structures.
Easy (Relatively) to identify and sensitive to cosmology.

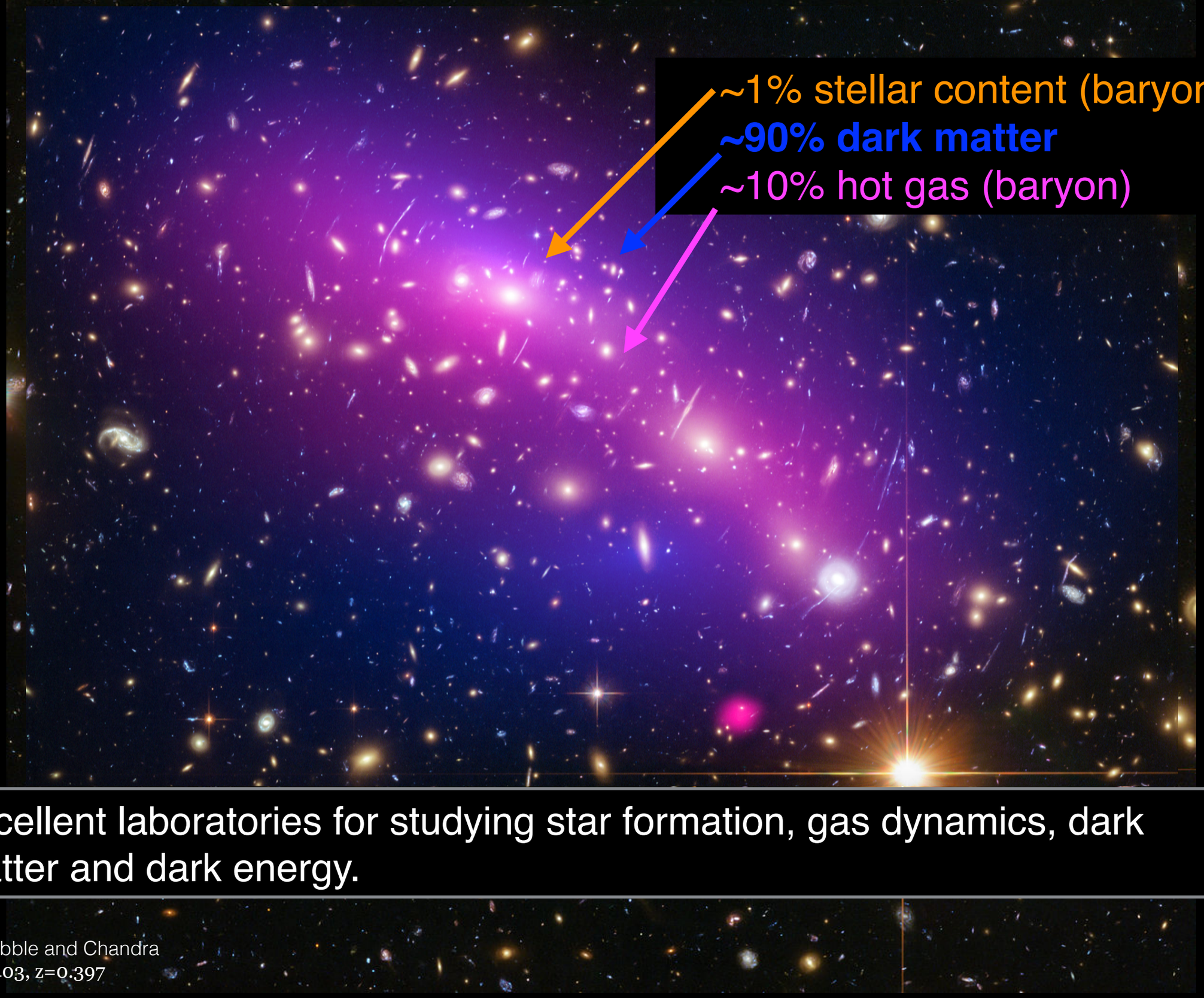
125 Mpc/h

X-ray (hot gas)

Optical (stars)

Image: Millennium simulation

Enormous content and rich processes toward making a cluster.



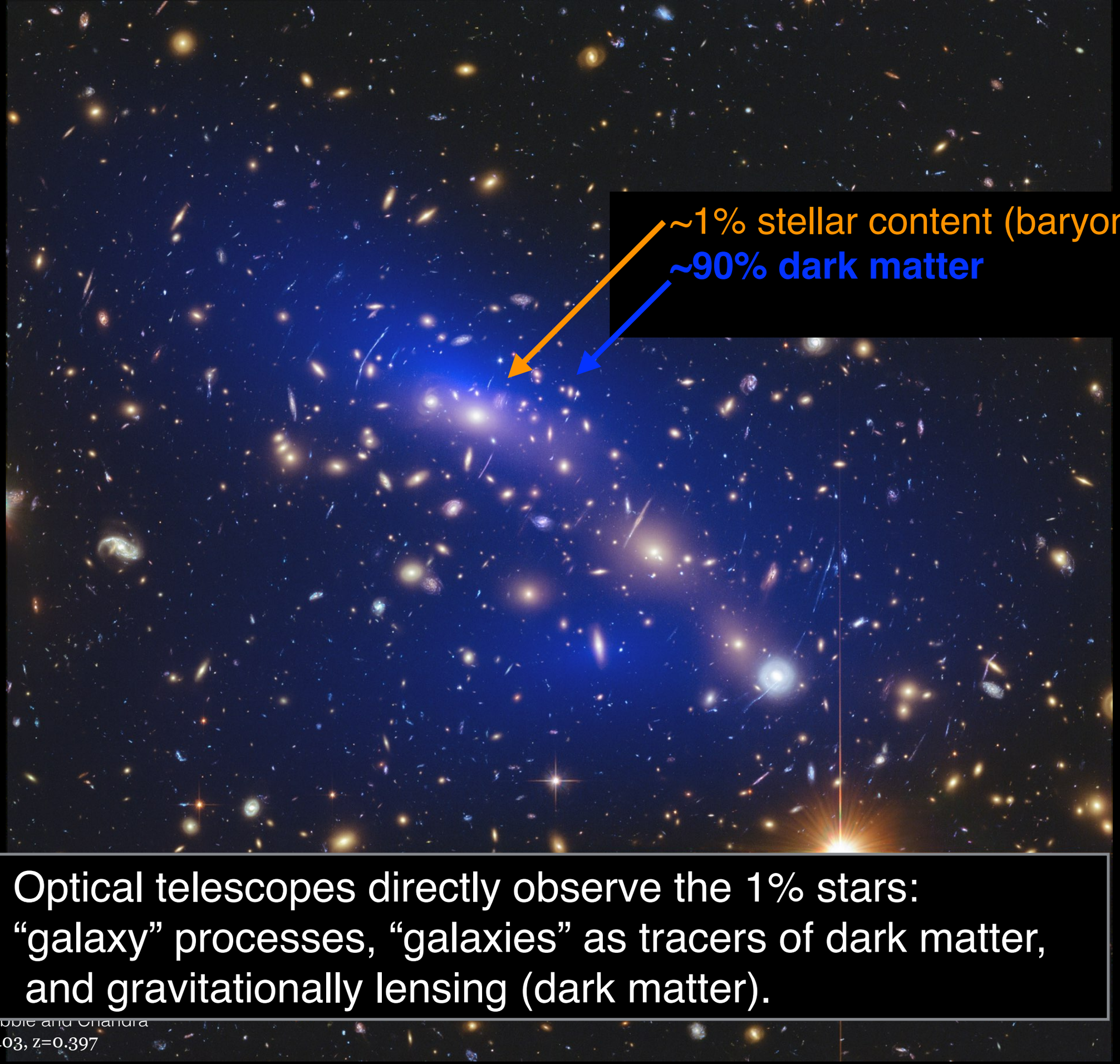
Excellent laboratories for studying star formation, gas dynamics, dark matter and dark energy.

Image Credit: Hubble and Chandra
MACS J0416.1-2403, z=0.397

~1% stellar content (baryon)

Optical telescopes directly observe the 1% stars:
“galaxy” processes, “galaxies” as tracers of dark matter,

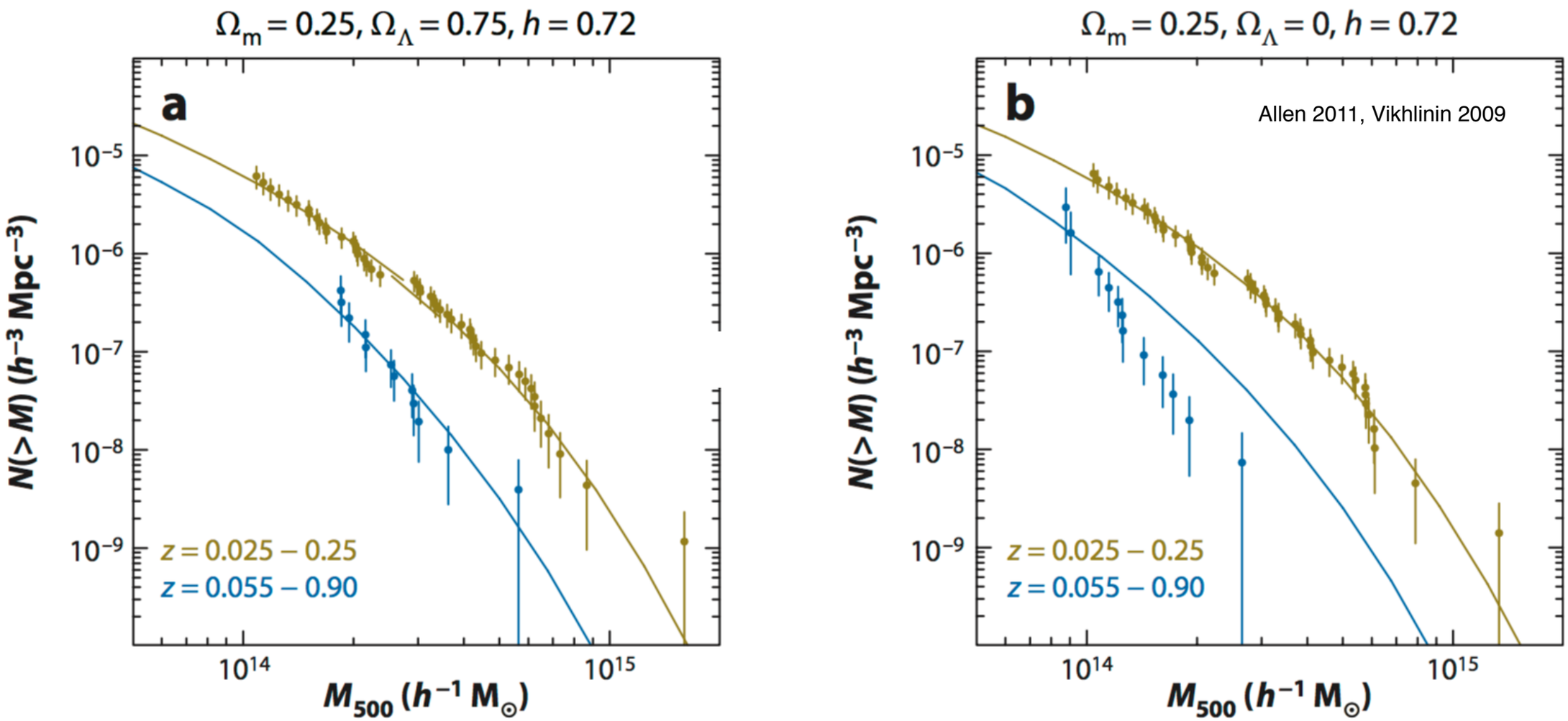
Image Credit: Hubble and Chandra
MACS J0416.1-2403, z=0.397



Optical telescopes directly observe the 1% stars:
“galaxy” processes, “galaxies” as tracers of dark matter,
and gravitationally lensing (dark matter).

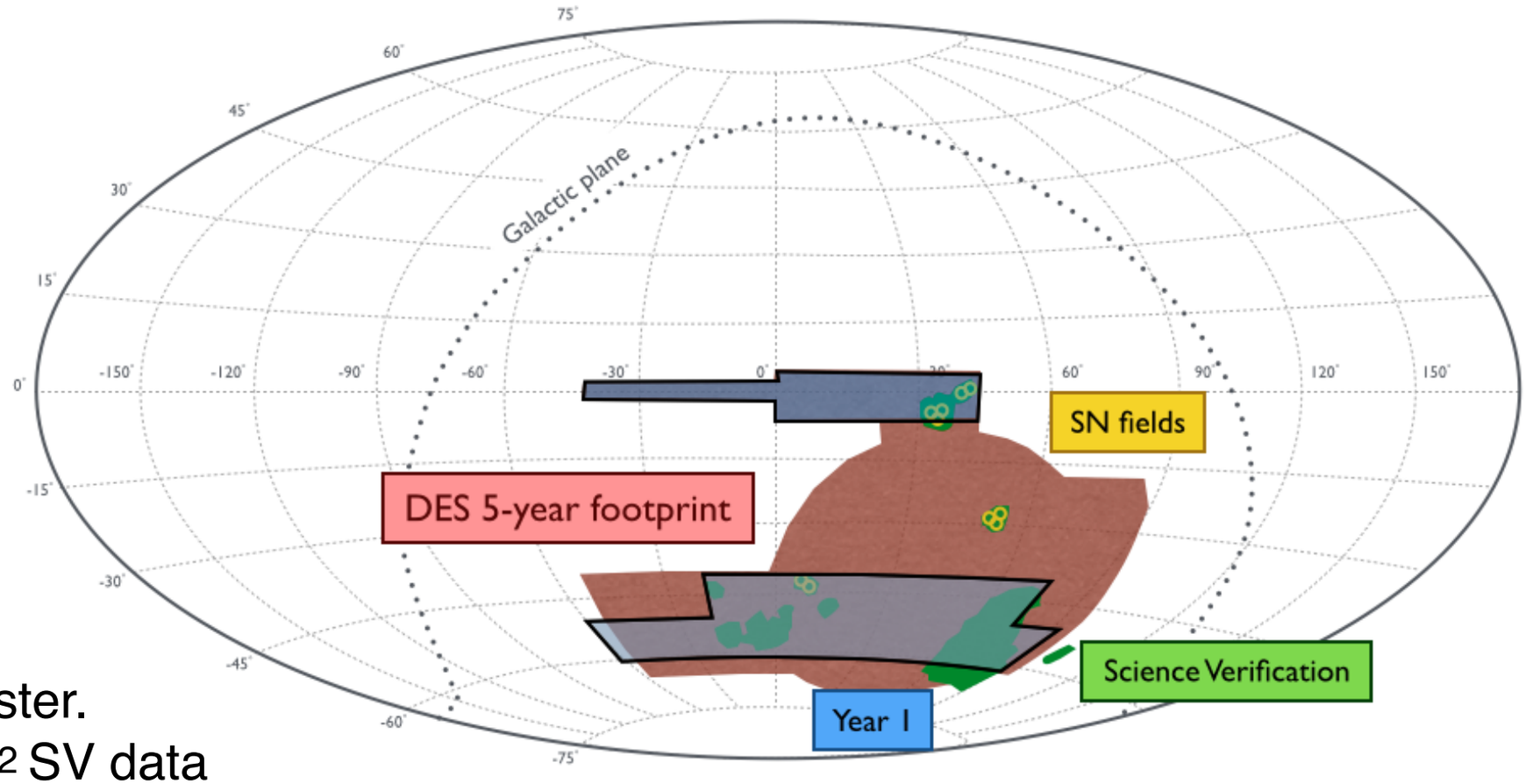
Image Credit: Hubble and Chandra
MACS J0416.1-2403, z=0.397

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 deg^2 per cluster.

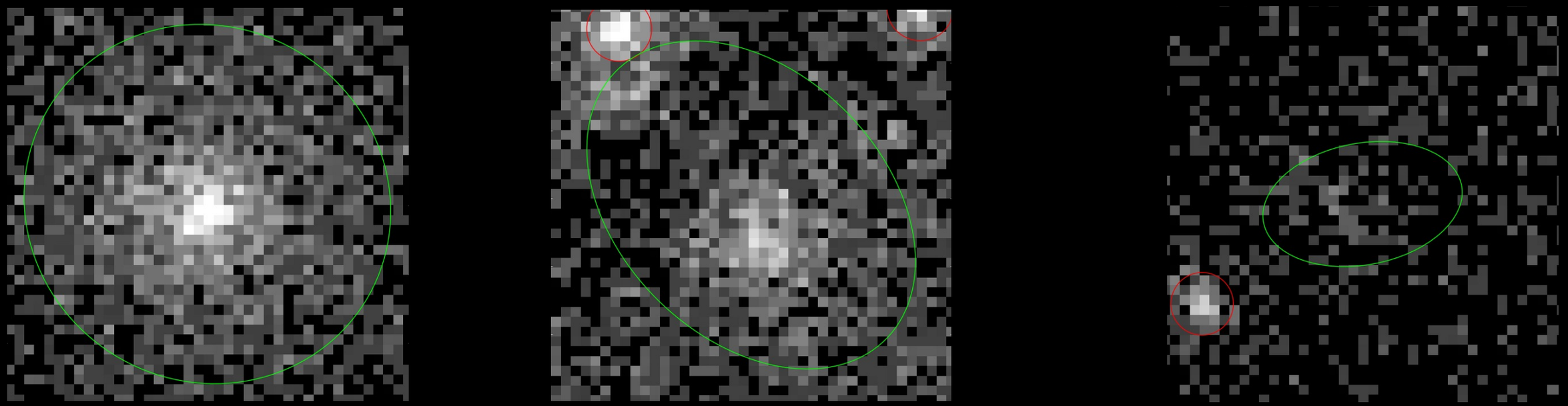
800 to z=0.9 in 150 deg^2 SV data

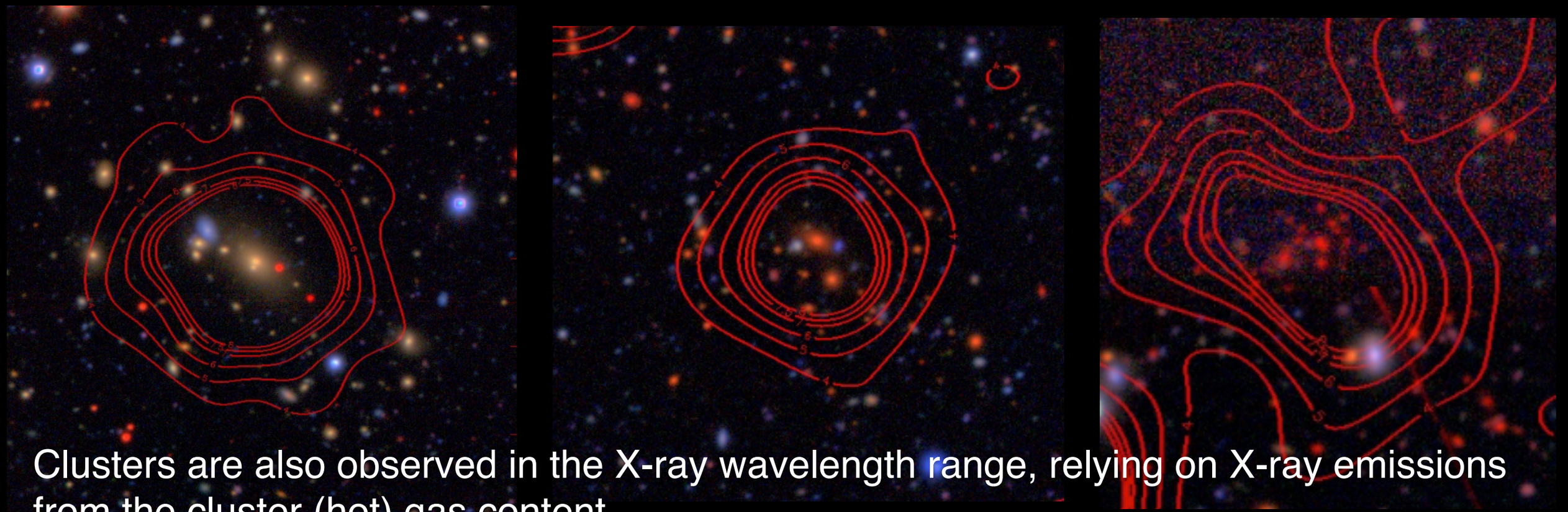
8,000 to z=0.75 in 1,500 deg^2 Y1 data.

Up to 40,000 to z=1.0 in future DES data.

5000 deg^2, wide coverage, large number of clusters
24 mag depth in g, r, i, z, detecting clusters to z~1.0.

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

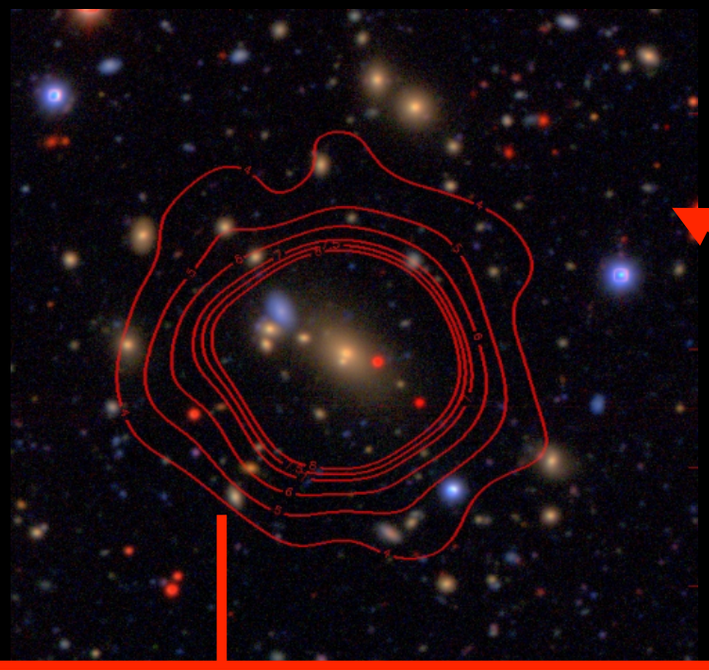




Clusters are also observed in the X-ray wavelength range, relying on X-ray emissions from the cluster (hot) gas content.

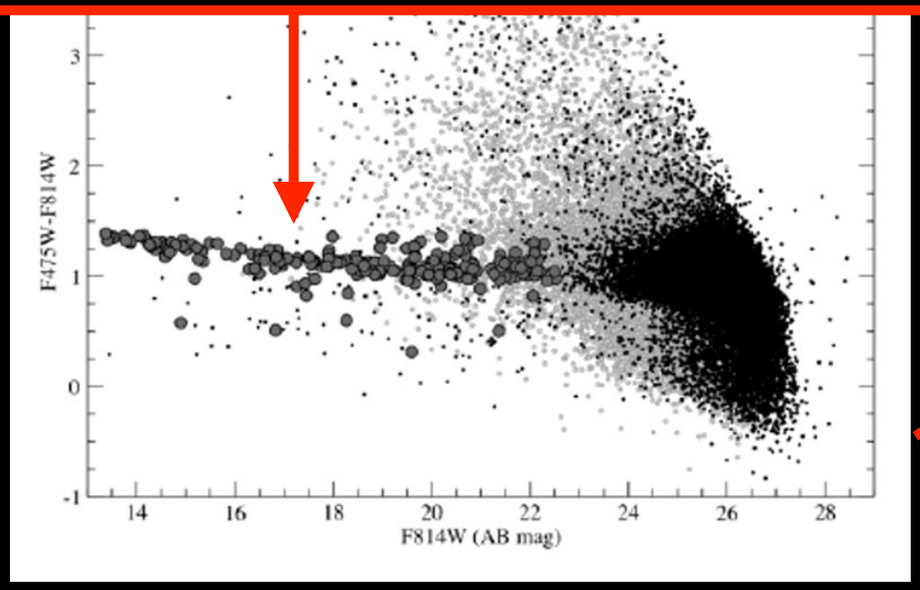
Credit: The XMM cluster survey, Miller, Rooney et al. in prep.

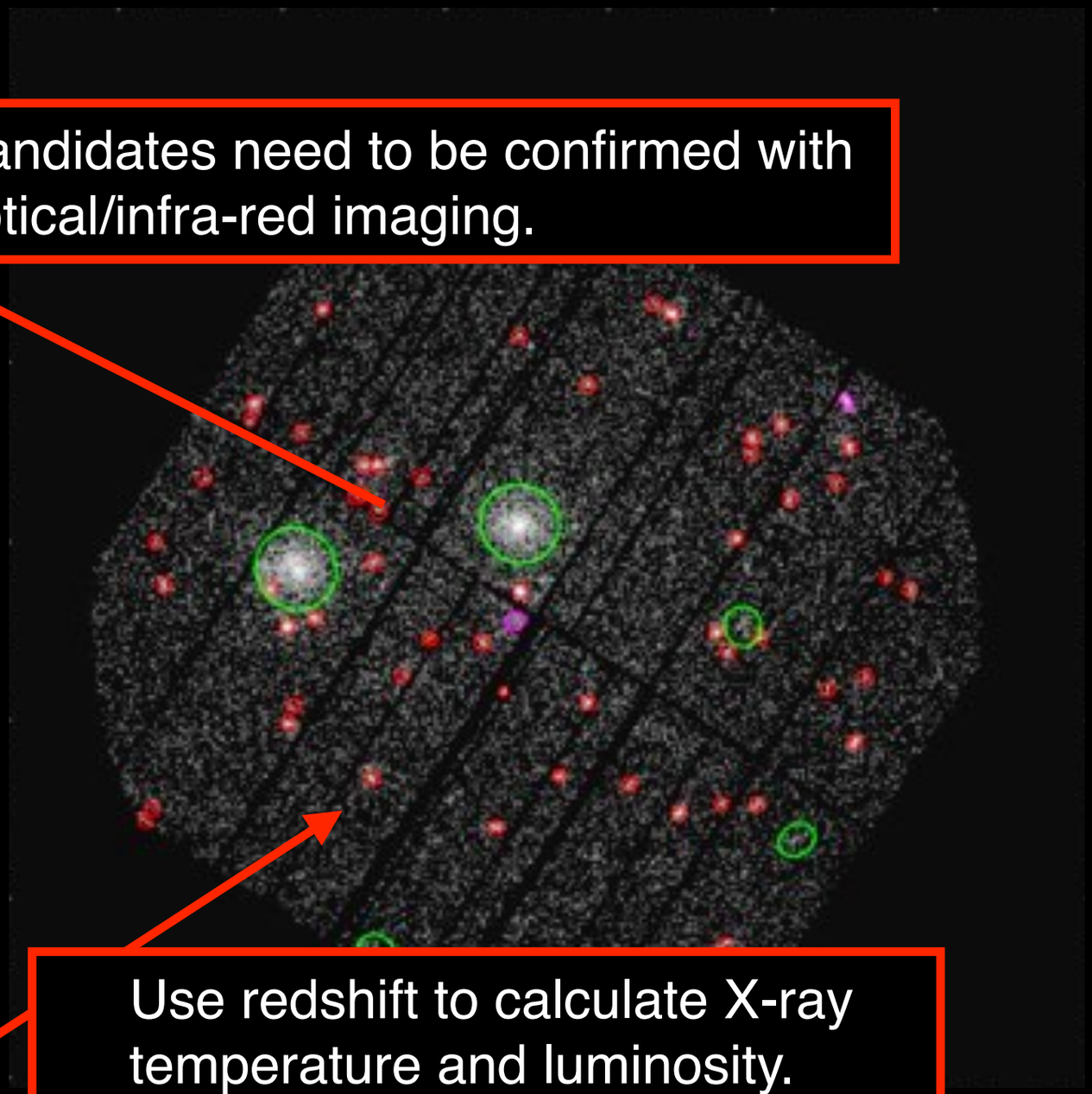
The XMM Cluster Survey selects clusters with X-ray data but relies on optical data for confirmation and redshift measurement.



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.

Credit: The XMM cluster survey, Miller, Rooney et al. in prep.

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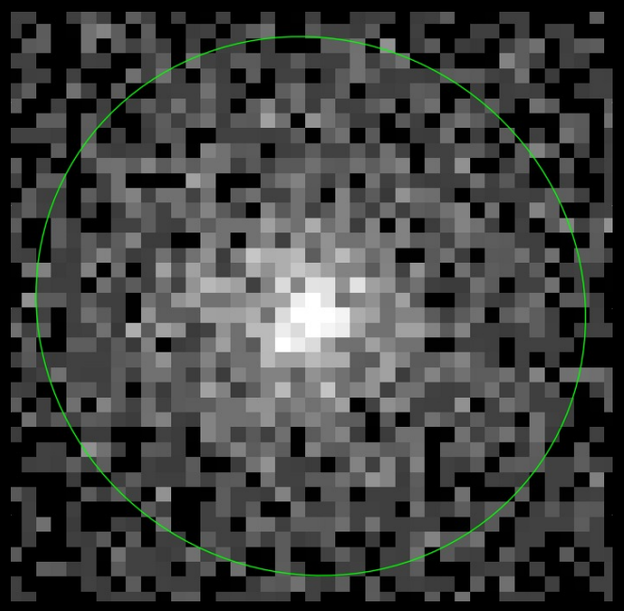

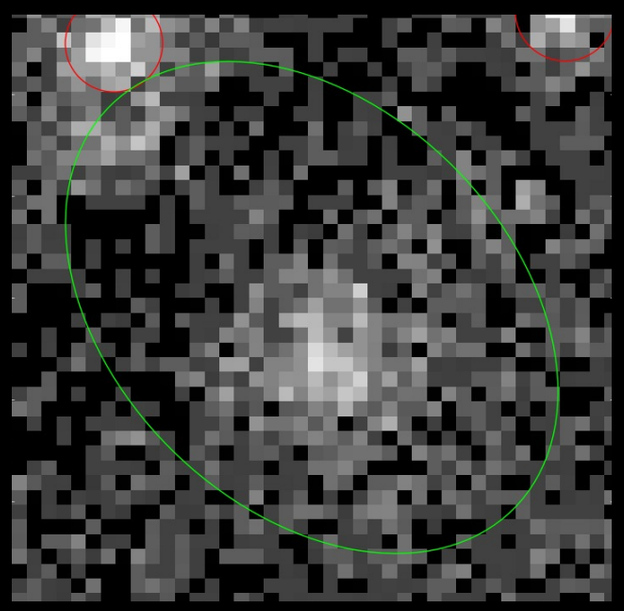

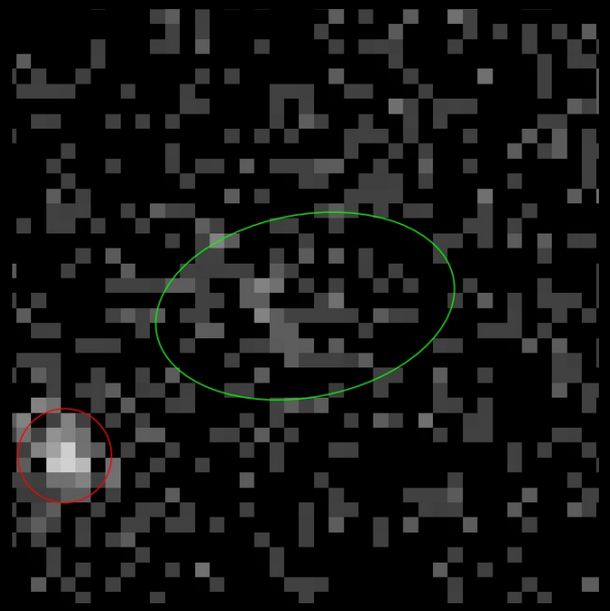

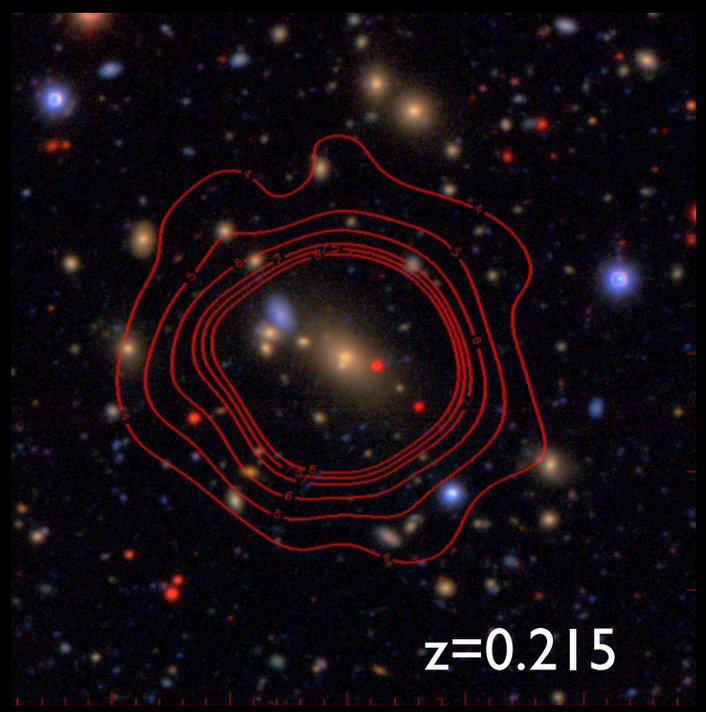

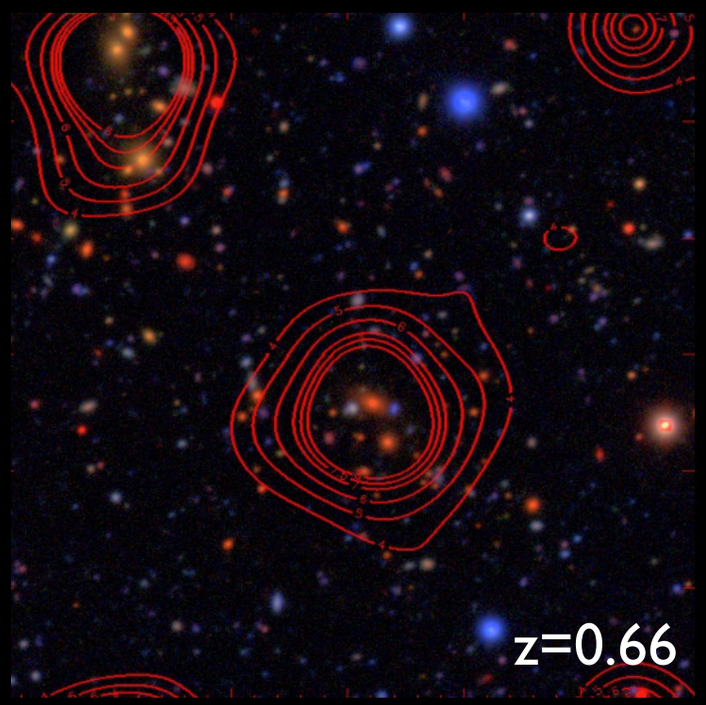

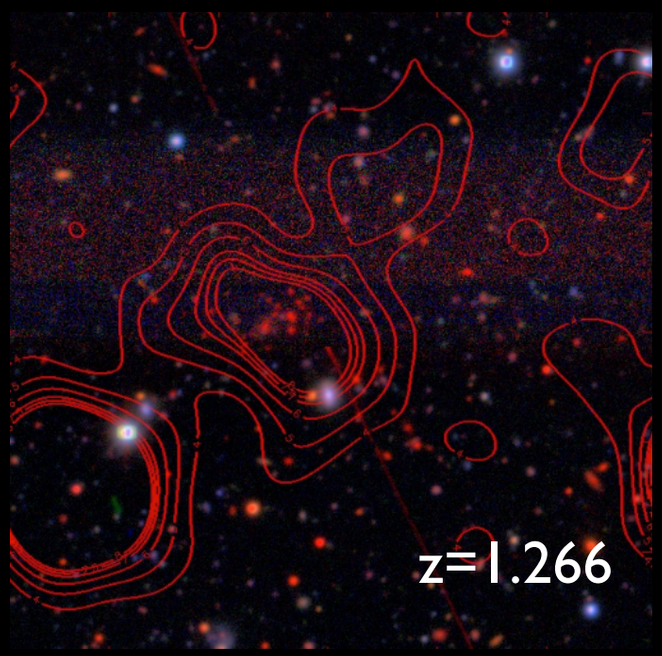

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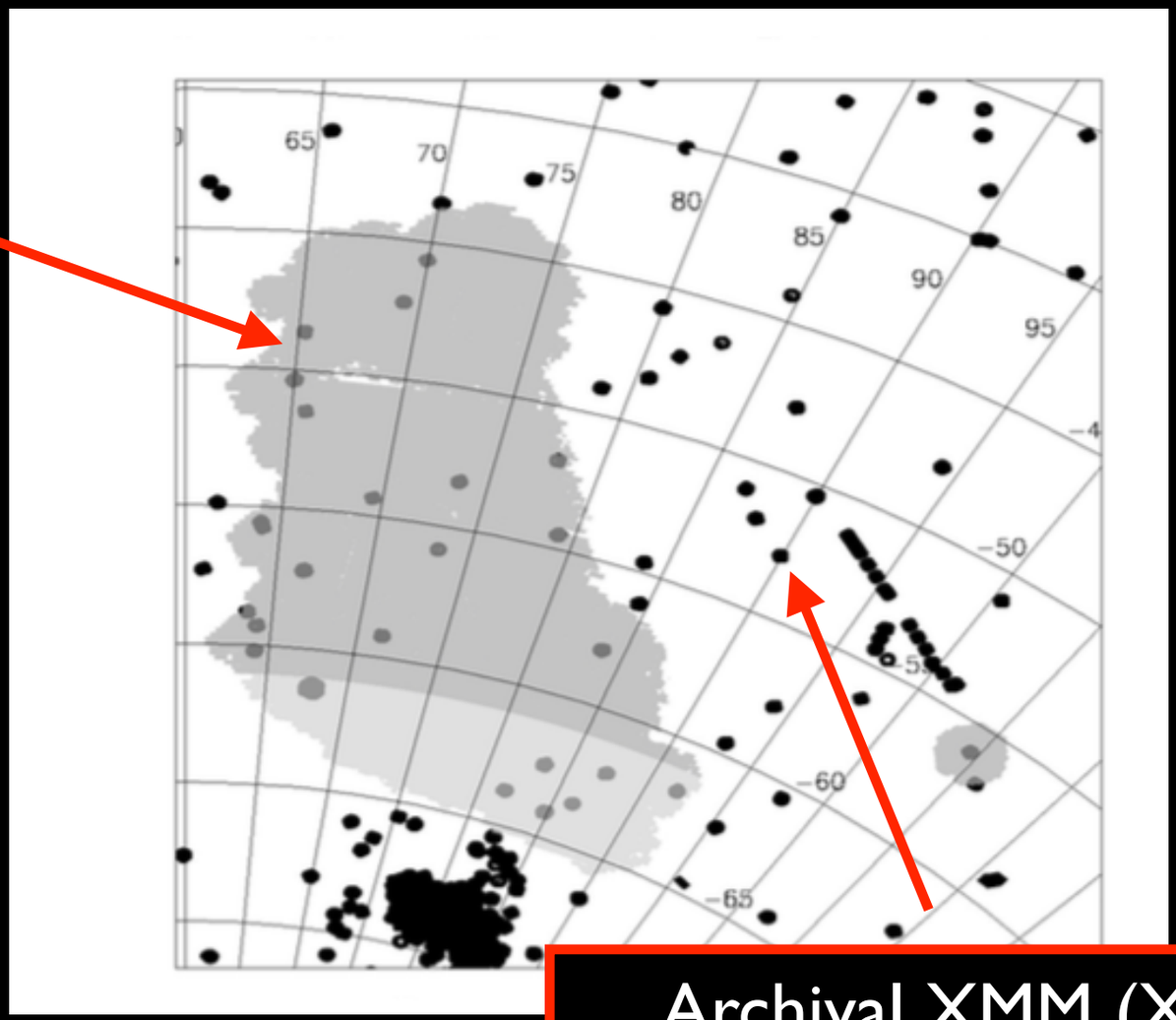
Optical data from DES

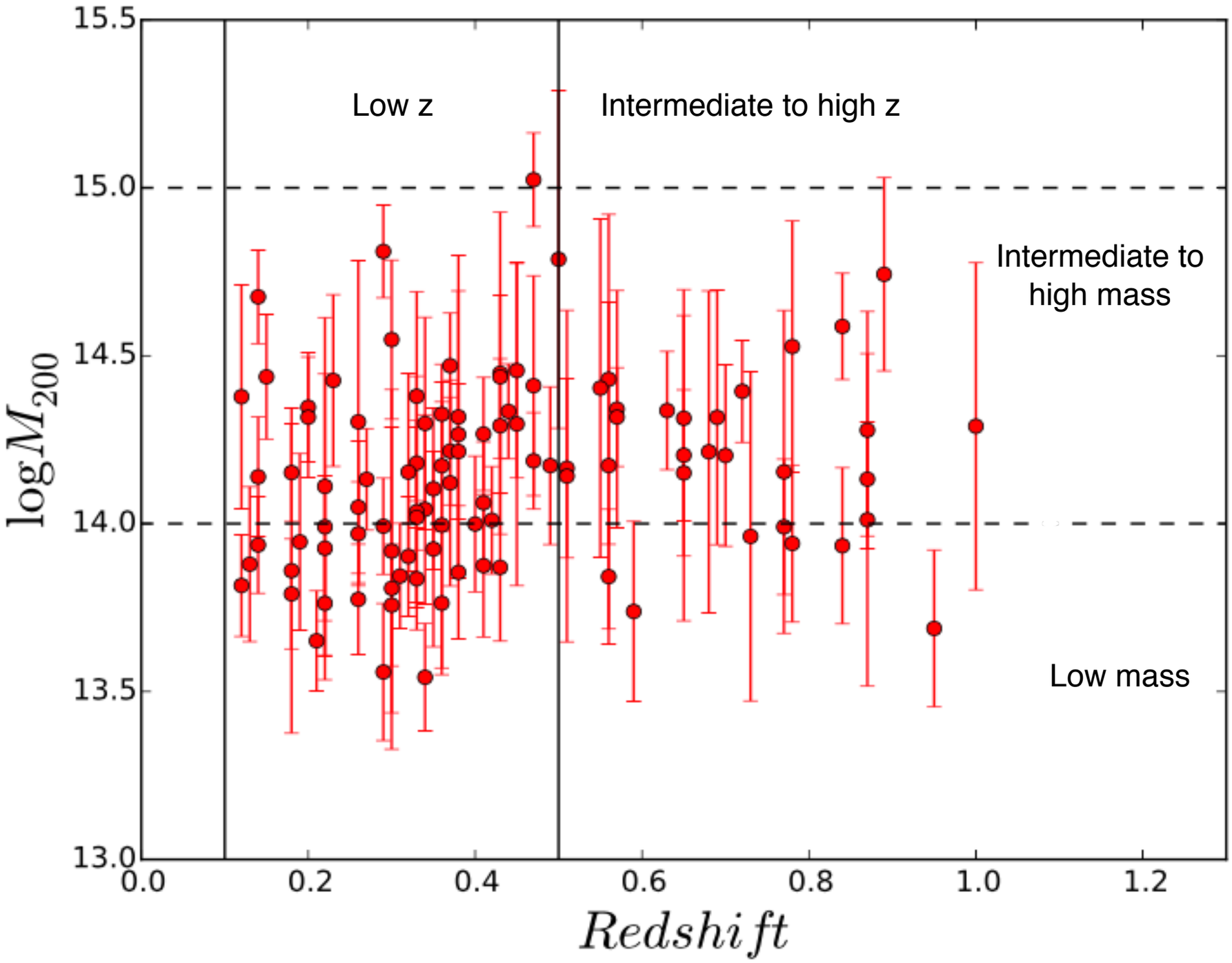


Archival XMM (X-ray) data

DES data helps making use of archival X-ray data.

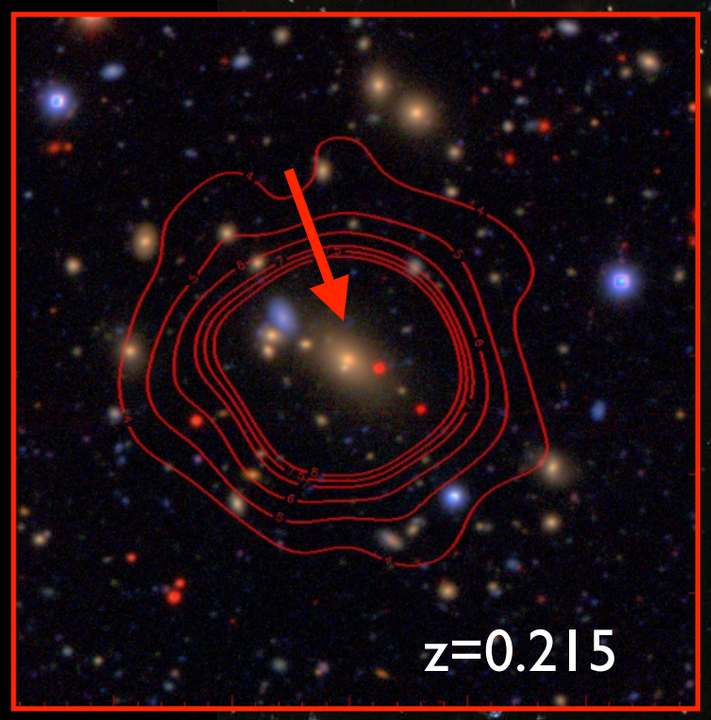
Miller, Rooney et al. in prep.

The XMM Cluster Survey has found hundreds of clusters with DES-SV data.

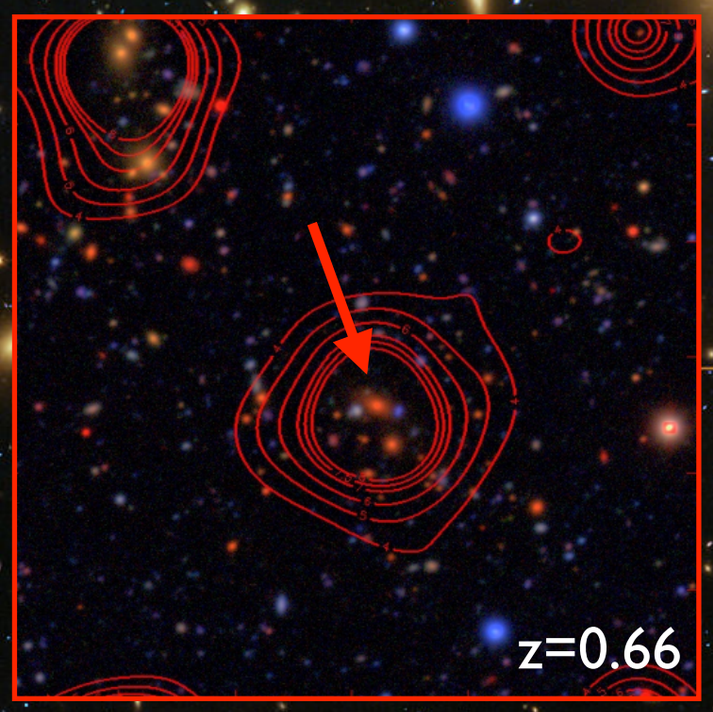


Studying cluster central galaxies is one example of what we can do in terms of DES cluster science.

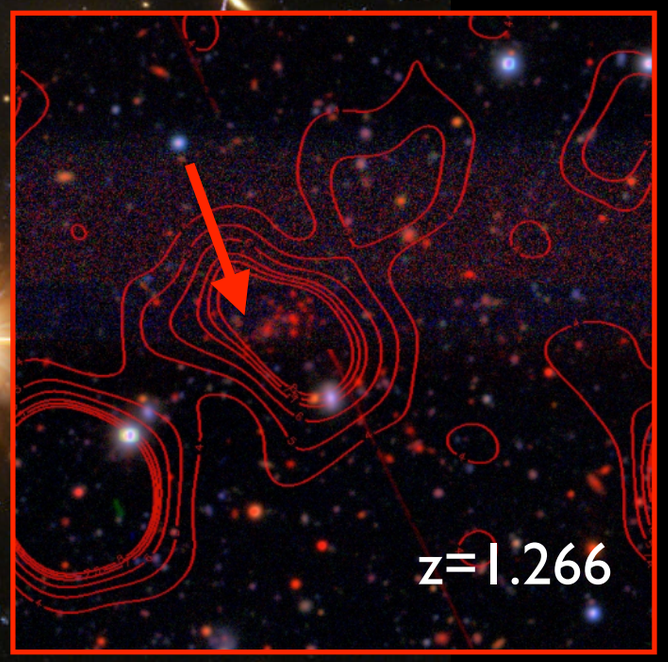
Bright Central Galaxy(BCG)



z=0.215

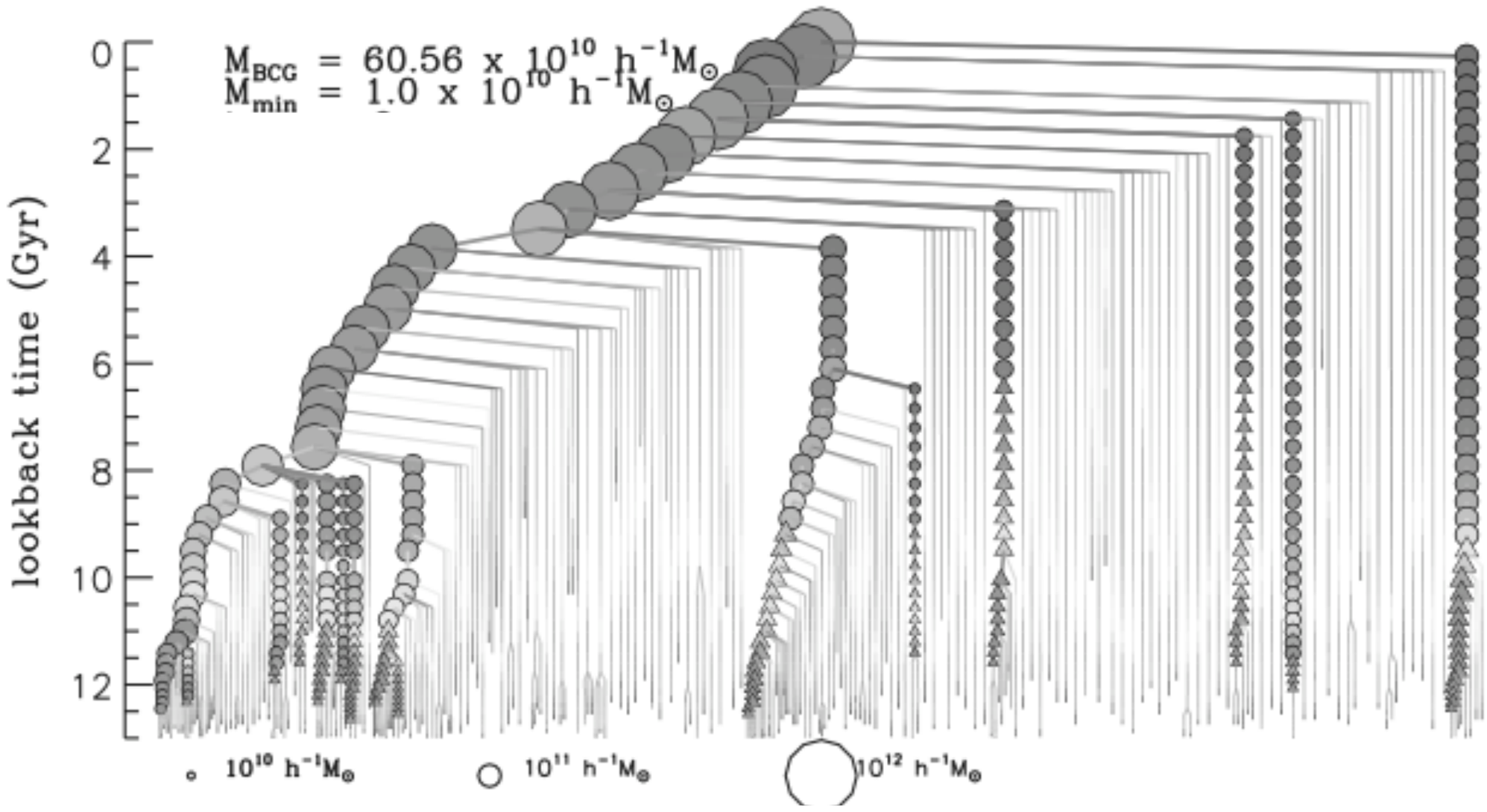


z=0.66



z=1.266

Merging (hierarchical structure formation) is important in explaining BCG formation.



BCG grows significantly with time.

De Lucia 2007

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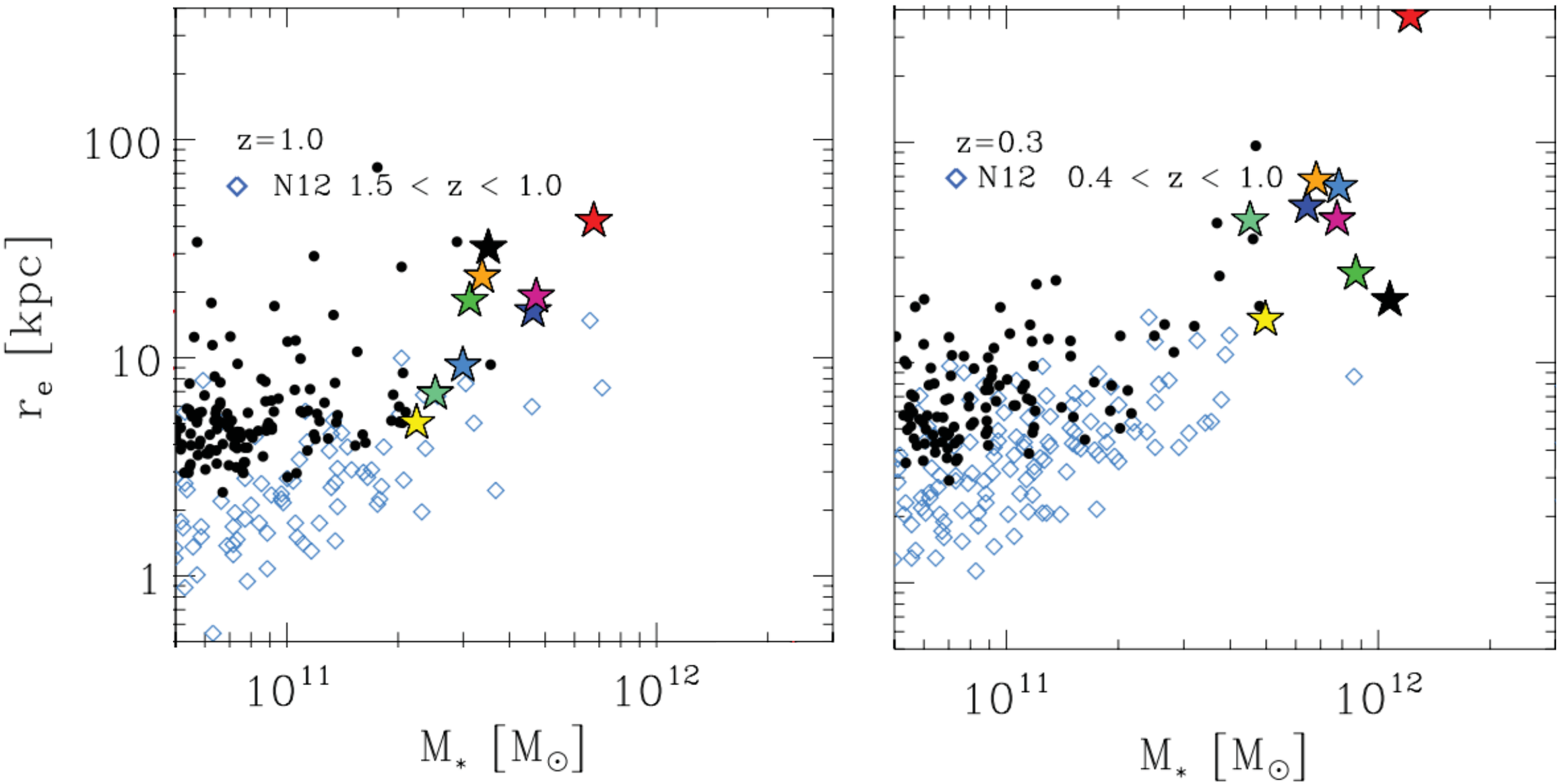
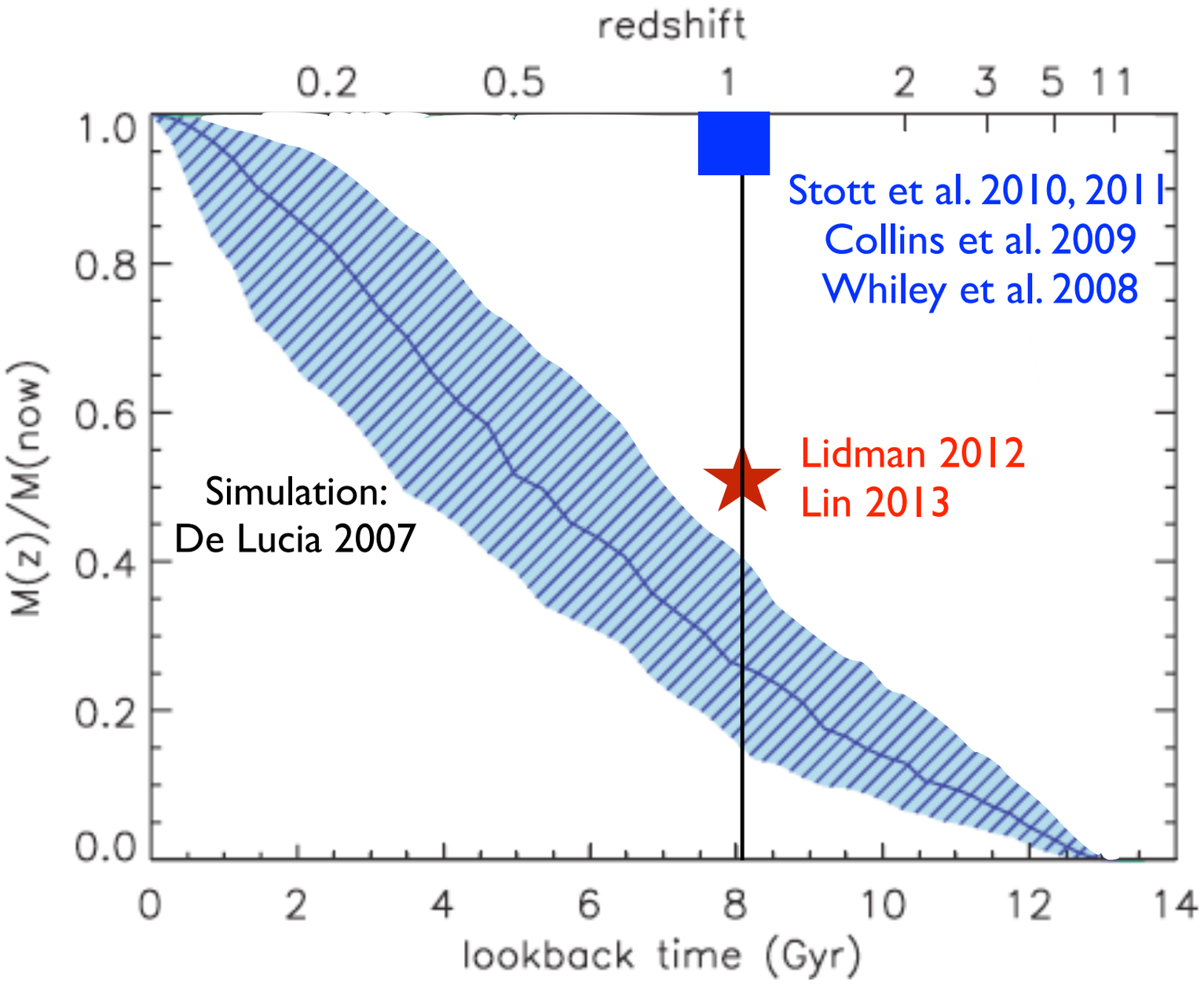


Laporte 2013

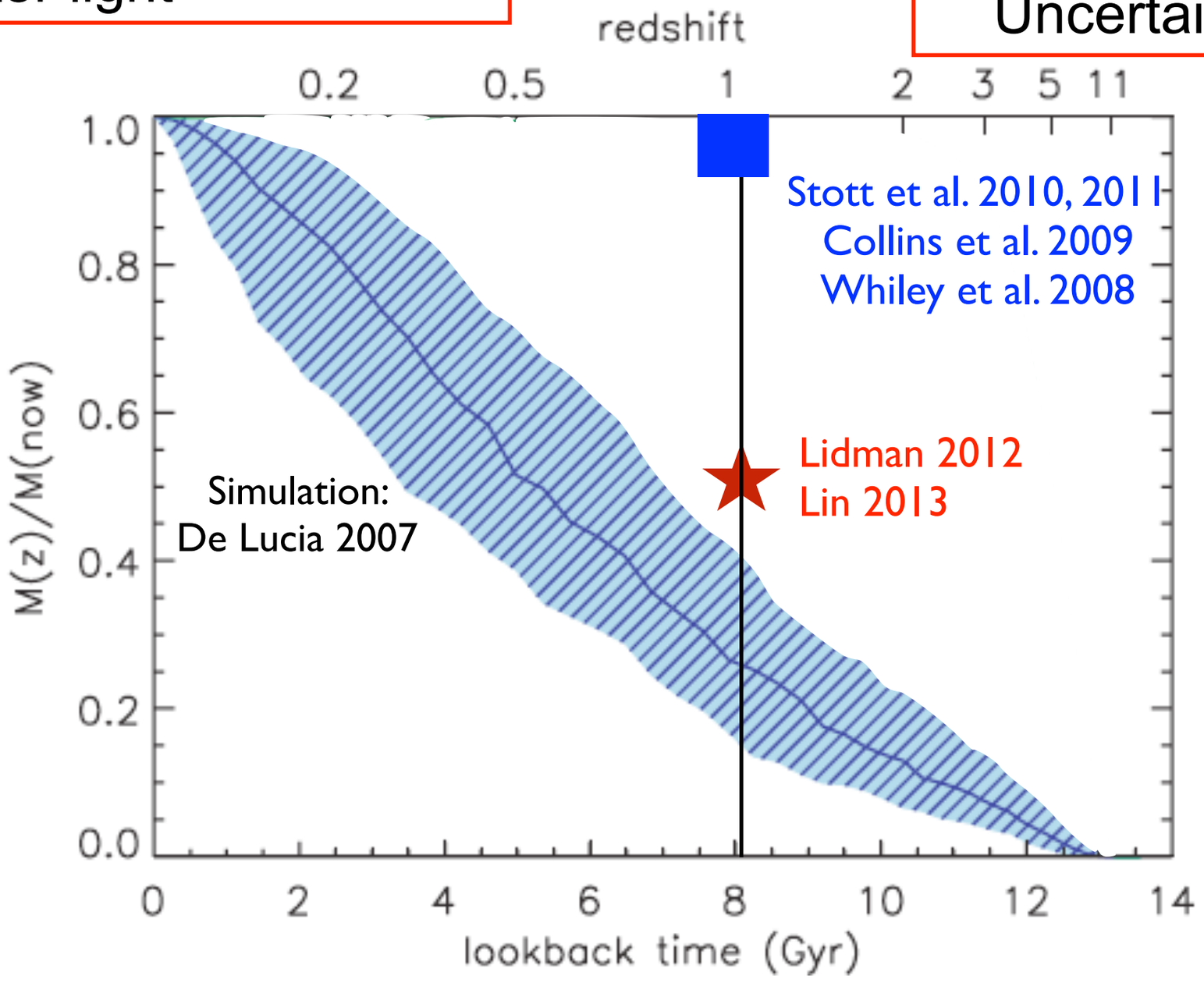
But merging does not seem to explain all…



Observations do not agree with a simple merging prediction on BCG growth.
Observations also do not agree with each other.

Issues with the merging theory:
BCG star formation
Intra-cluster light

Issues with observations:
BCG photometry
Sample selection
Uncertainty estimation



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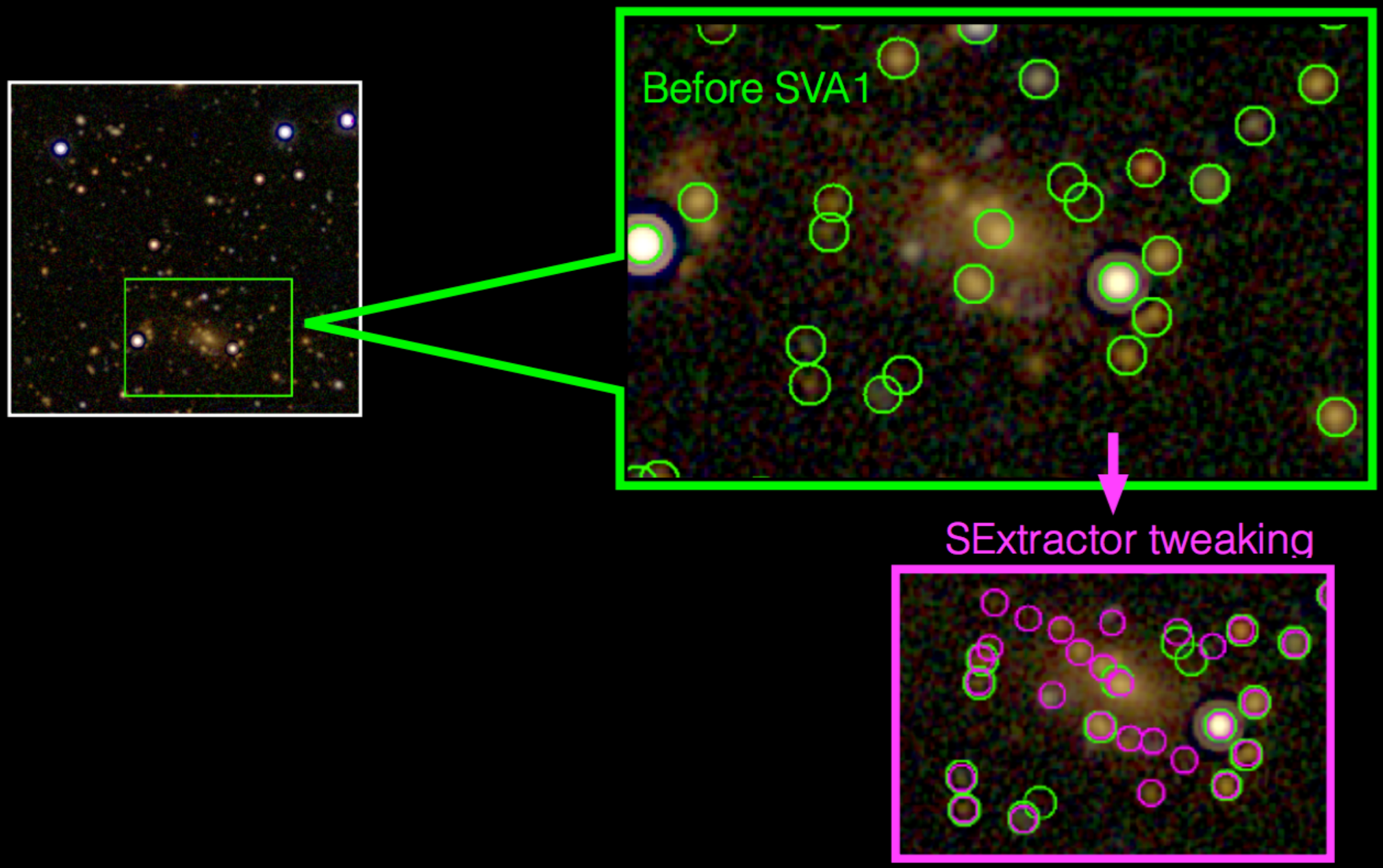
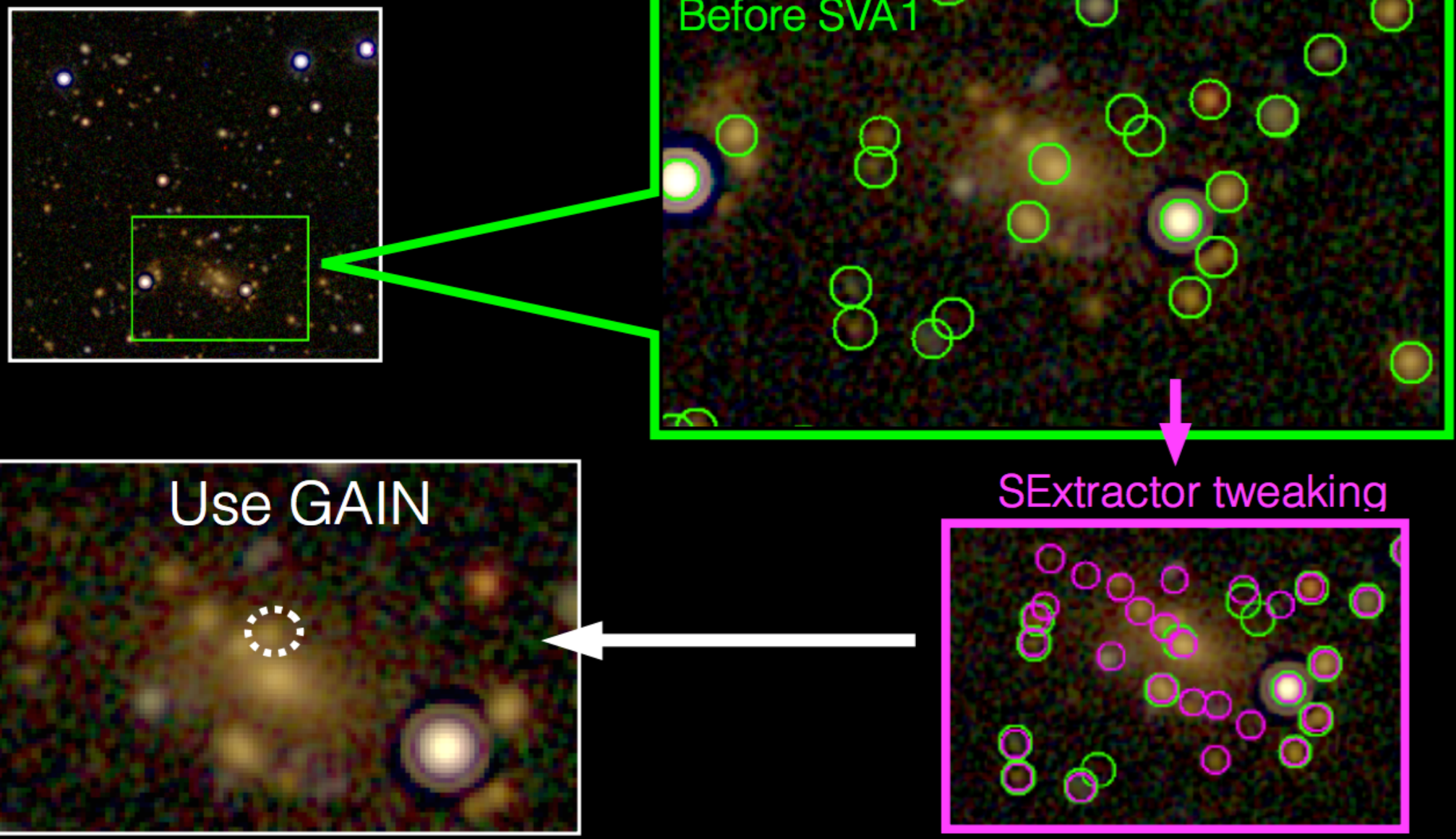
BCG photometry:

optical data processing pipeline struggles with object detection around BCGs.



BCG photometry:

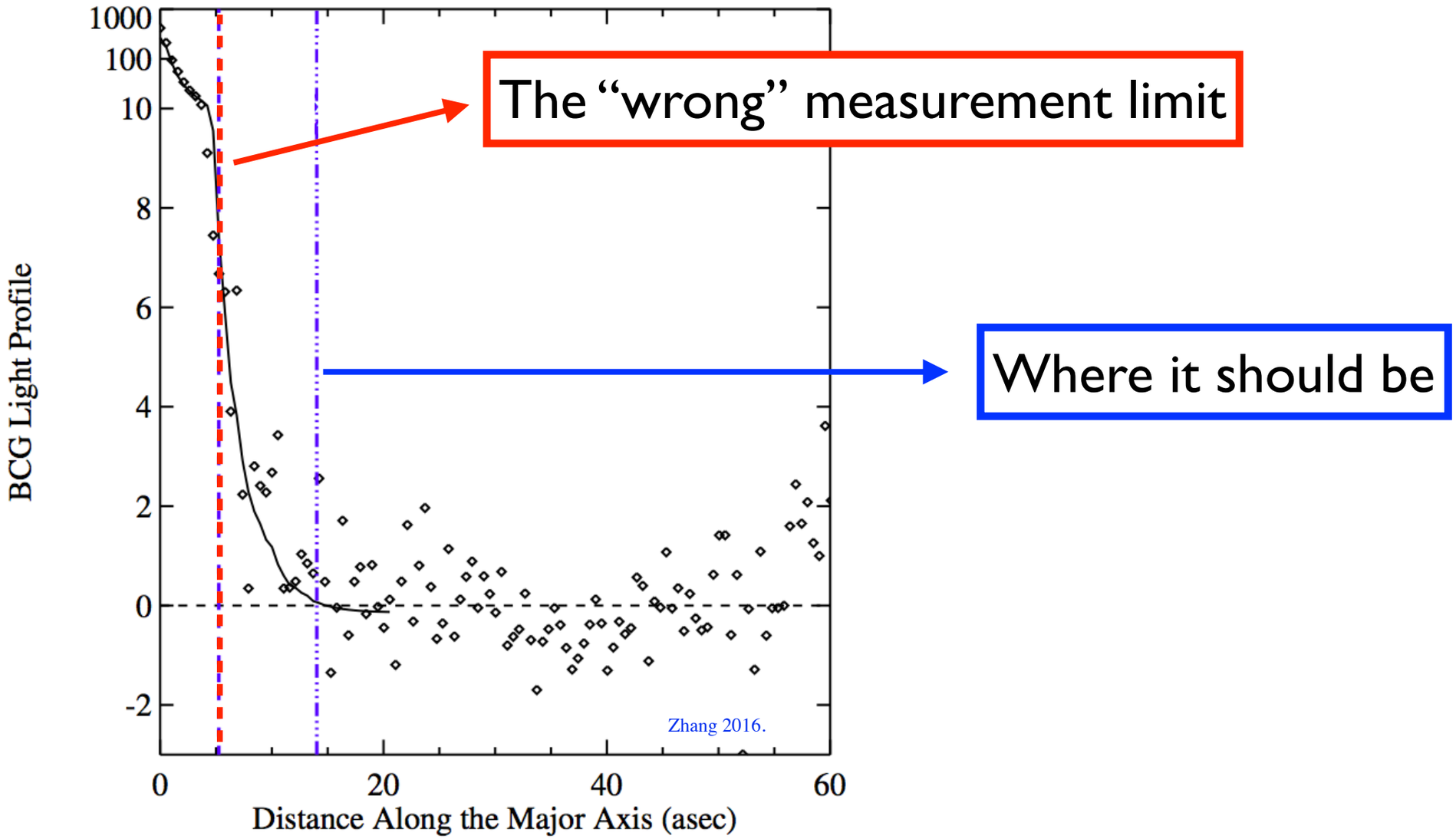
we wrote a package to help with object detection around BCGs.



The **G**radient **A**nd **IN**terpolation Based Deblender
(GAIN deblender)

BCG photometry:

optical data processing pipeline struggles with measuring quantities around BCGs.



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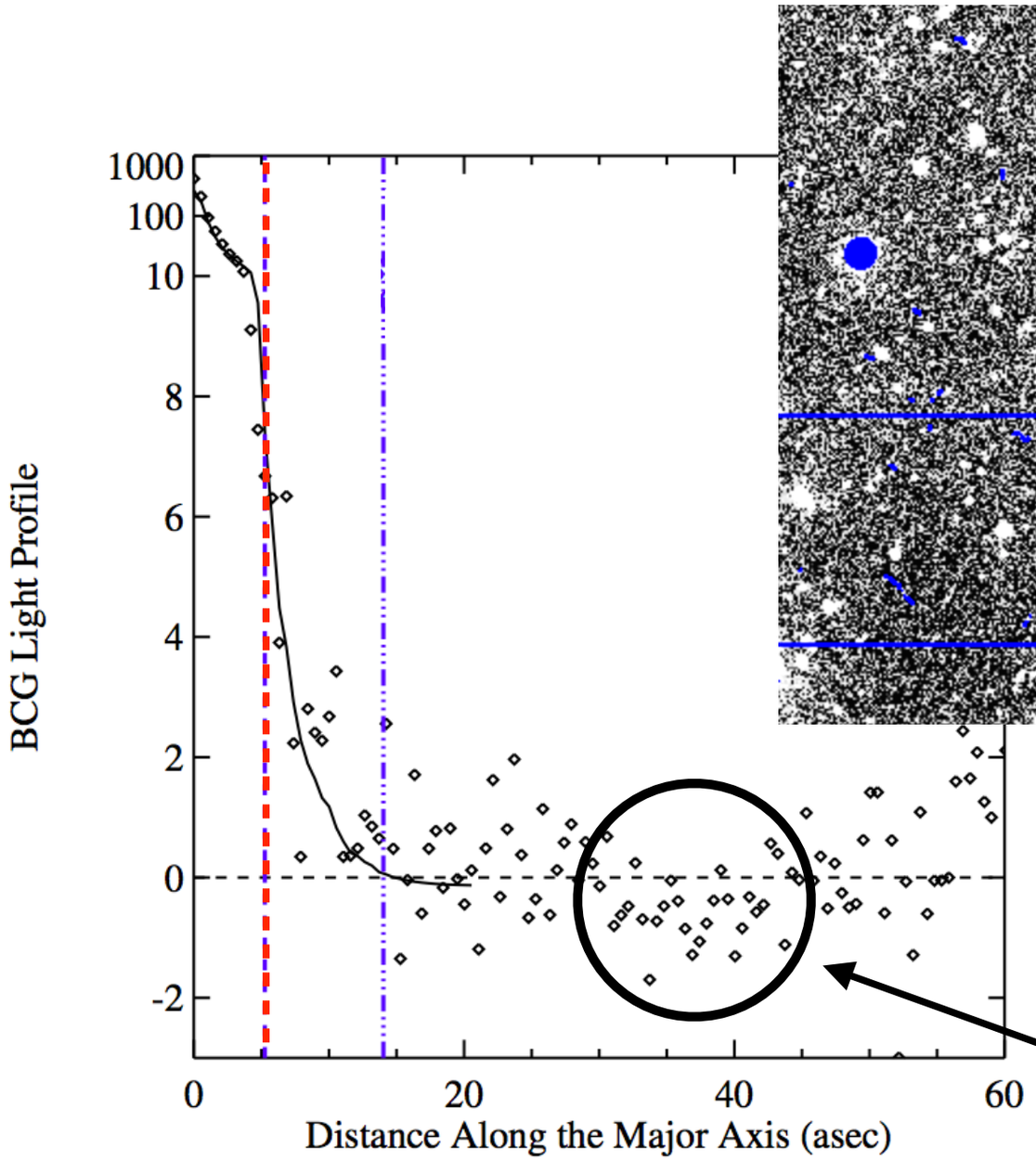
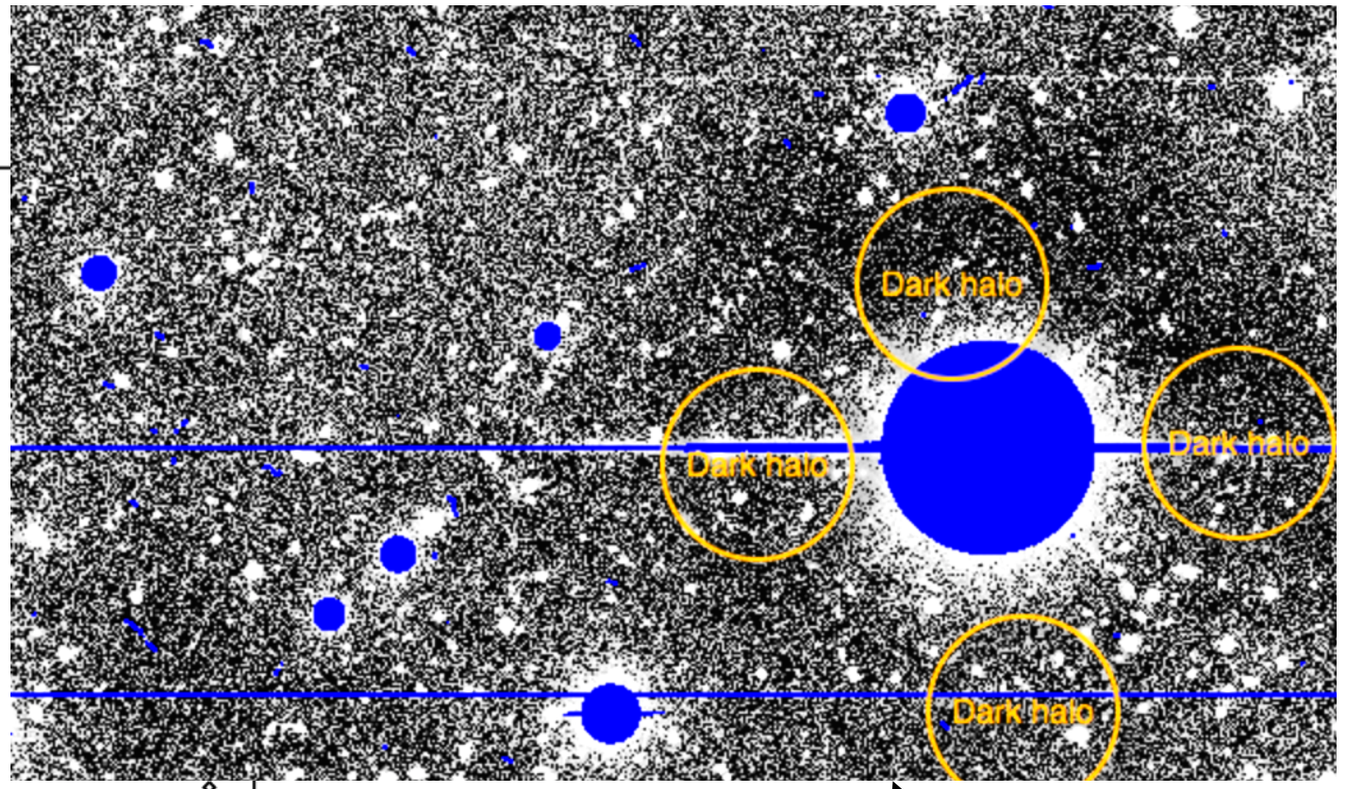




In-accurate background subtraction

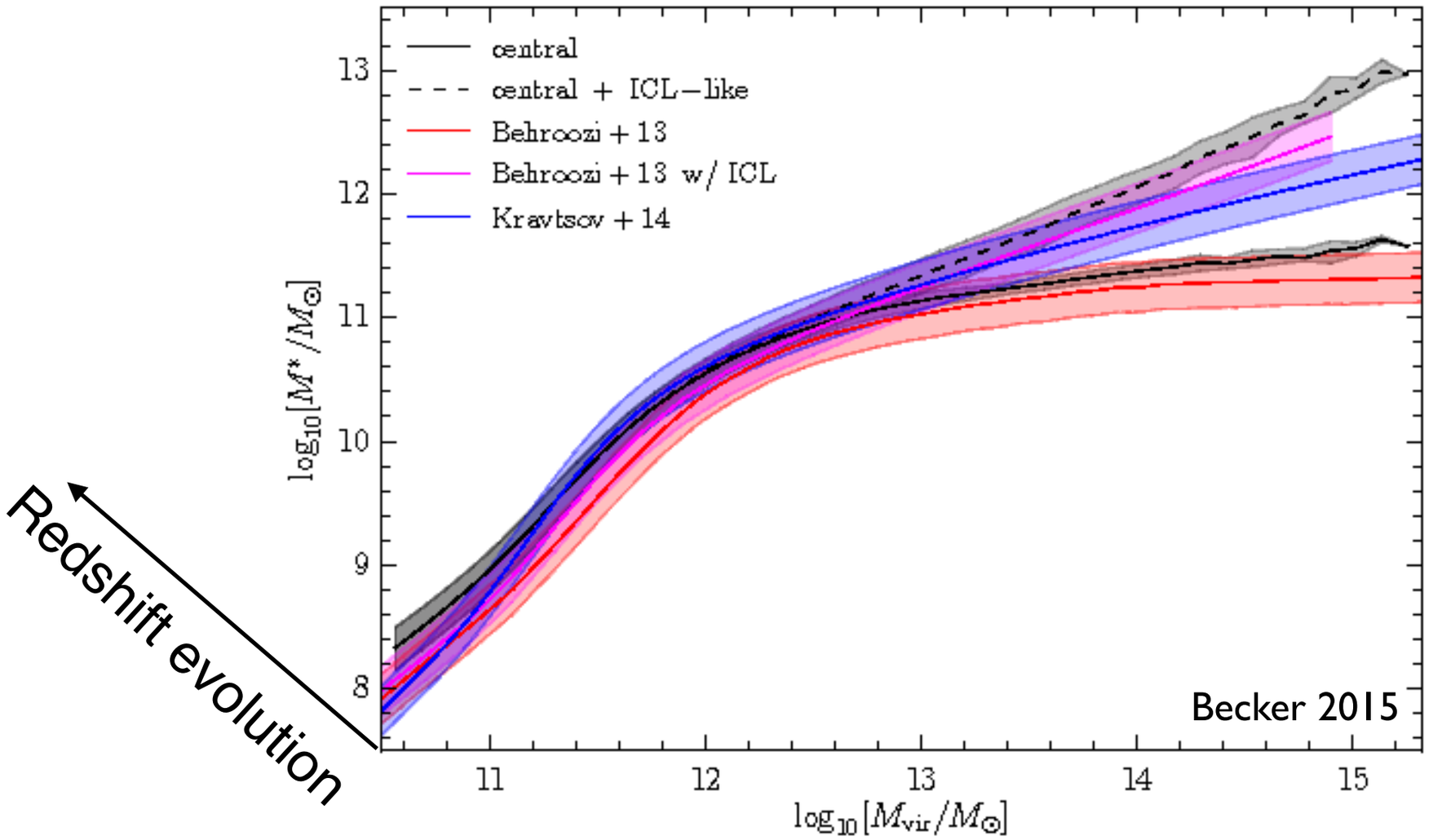
Issues with observations:

BCG photometry

Sample selection

Uncertainty estimation

Mass dependence effect:
mass range is important.



Issues with observations:

BCG photometry

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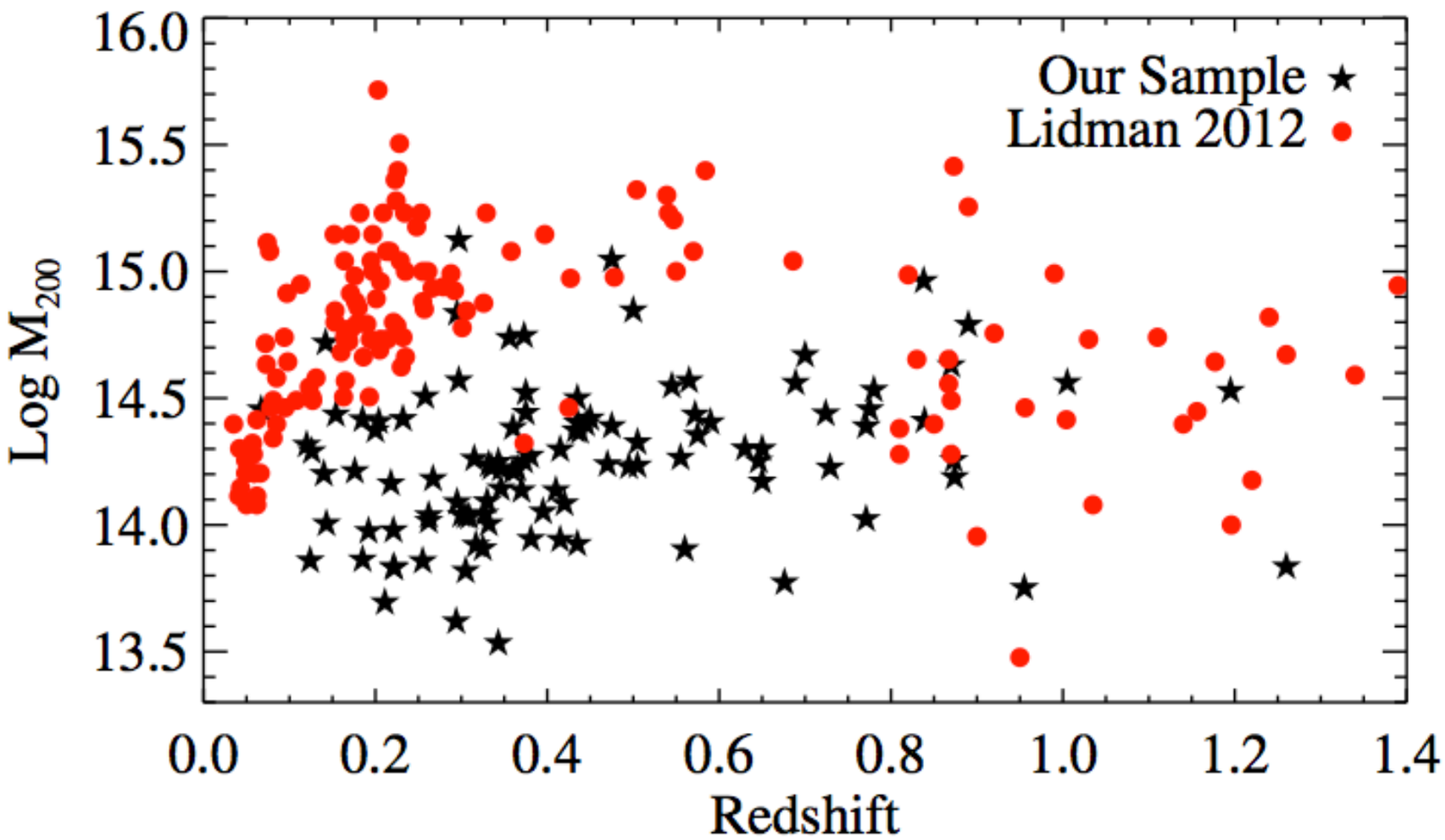
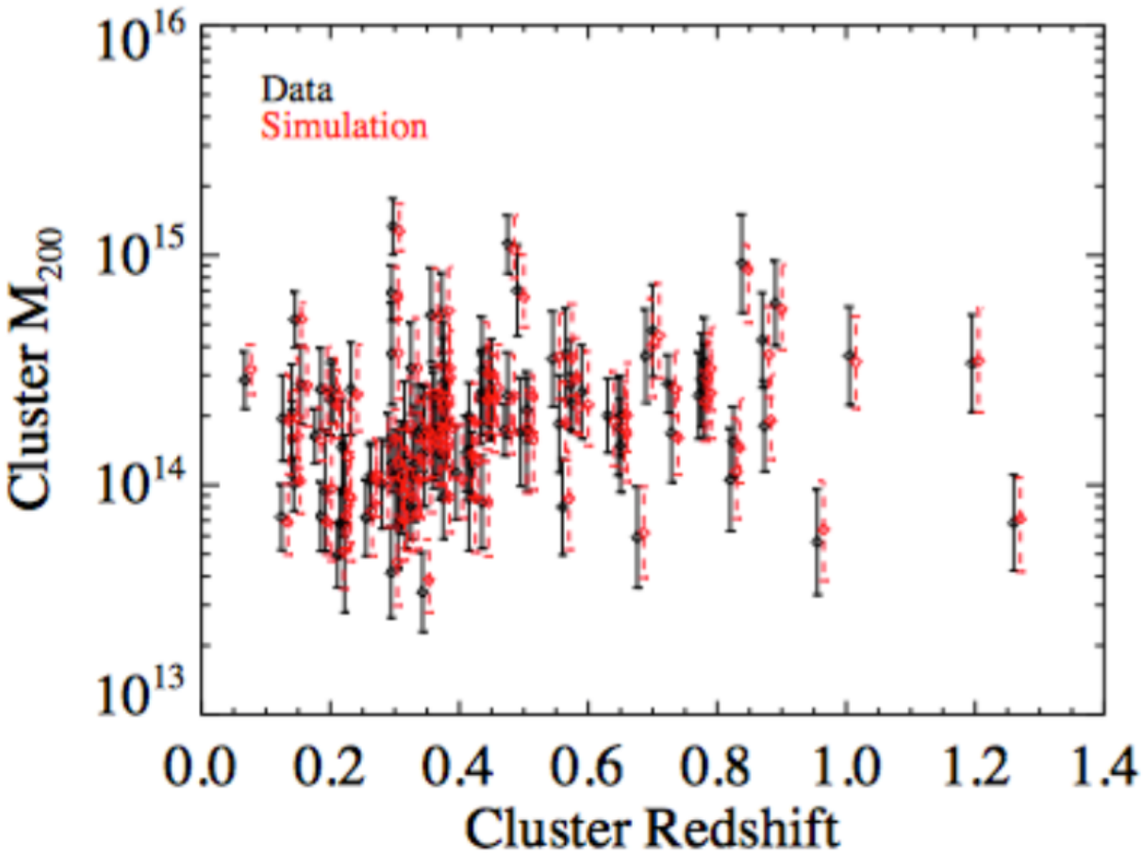
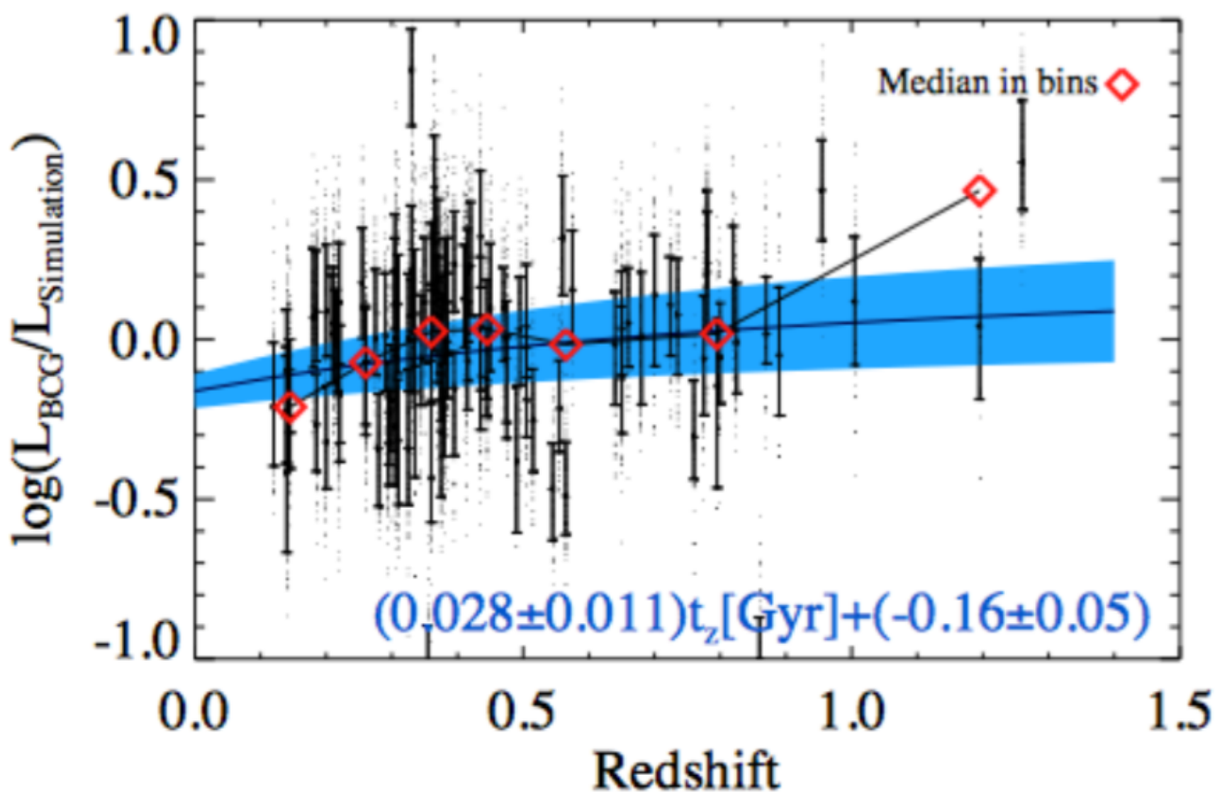


The DES-XCS sample covers a large redshift and mass range.

A simple matching Method:
Match simulation BCGs with observations, considering uncertainties.

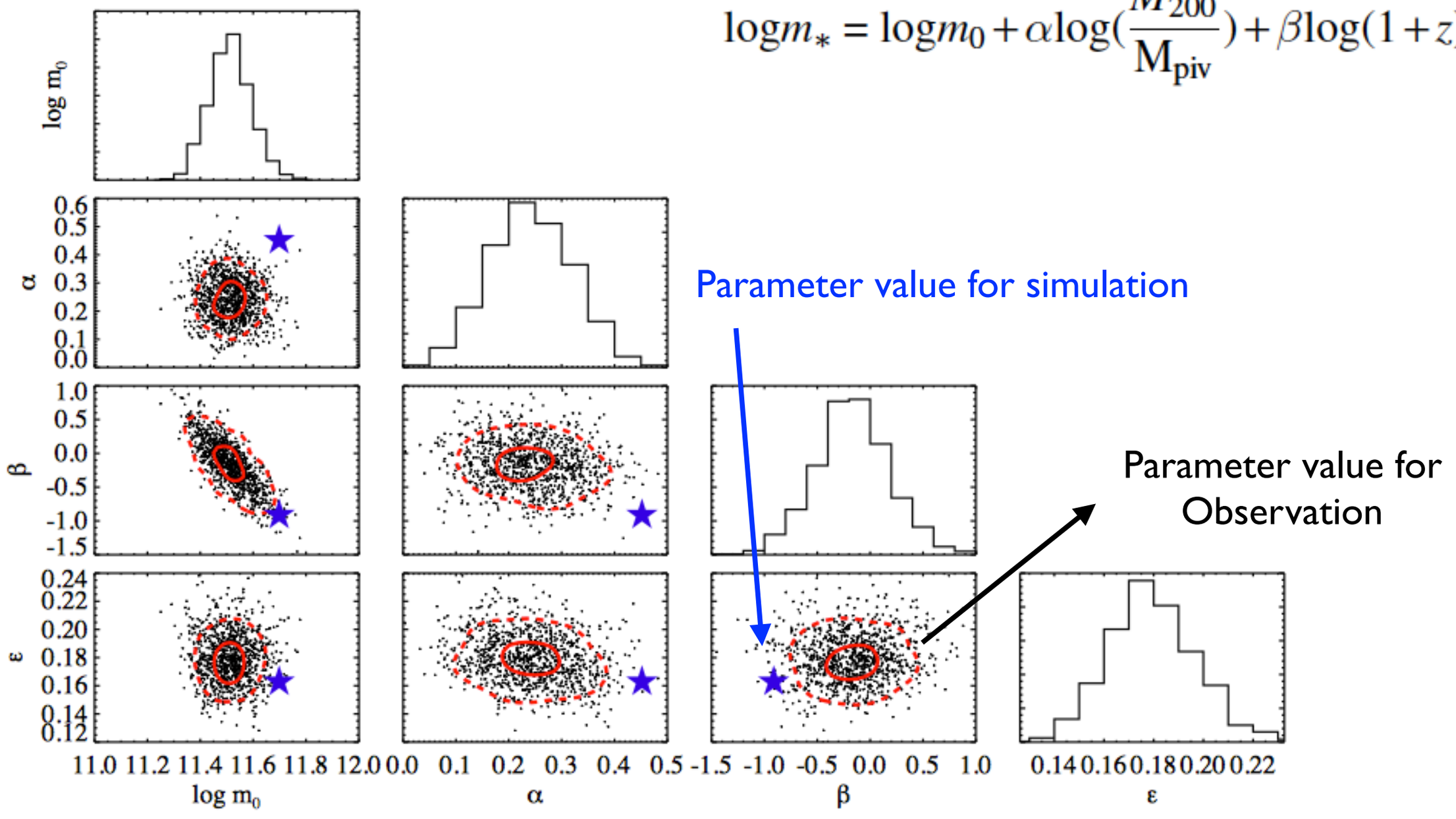


Result:
The observed BCGs are under-luminous/massive at low redshift.

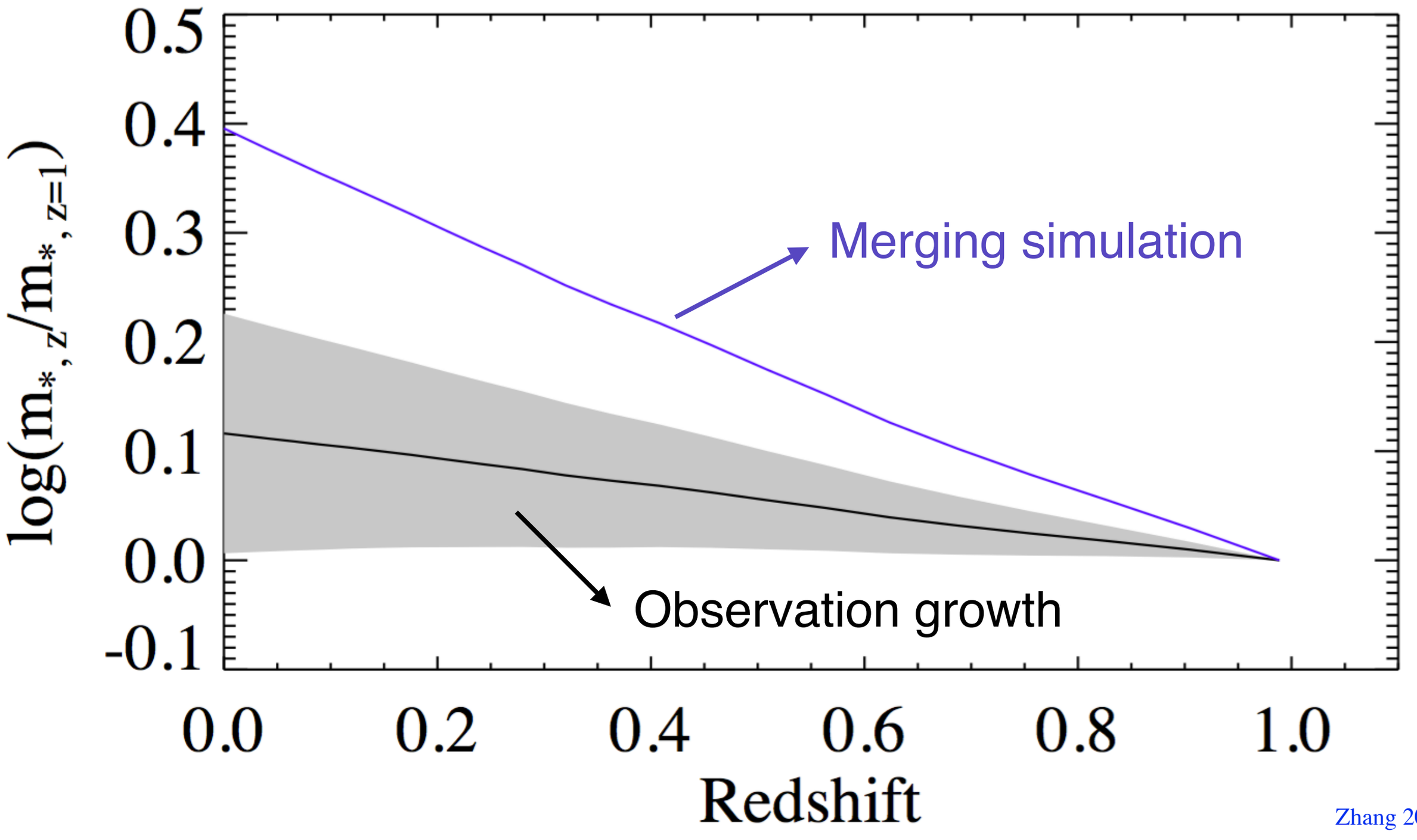


A modeling method: Model BCG evolution for both simulation and observation — convenient to incorporate all measurement uncertainties.

$$\log m_* = \log m_0 + \alpha \log(\frac{M_{200}}{M_{piv}}) + \beta \log(1+z)$$

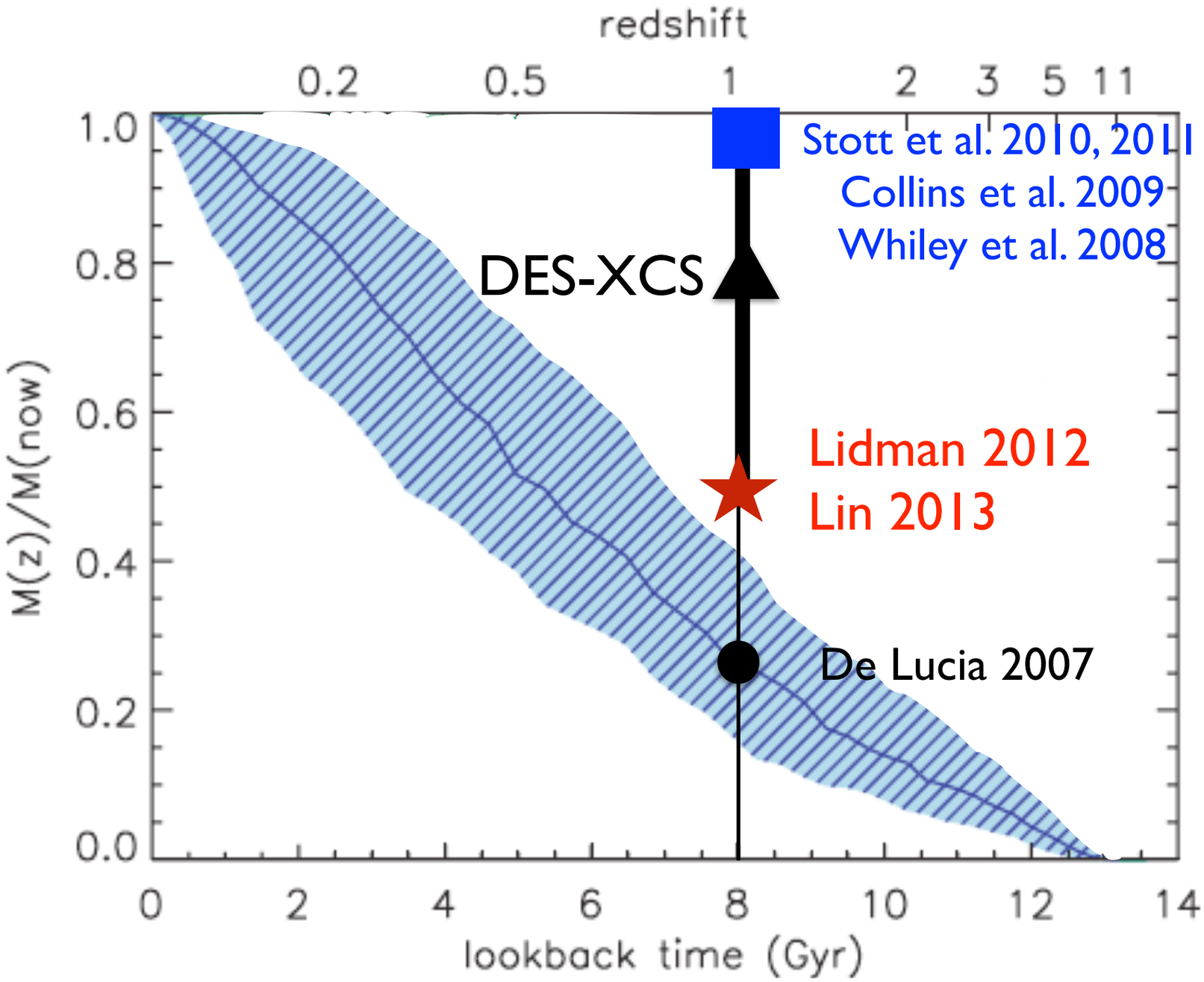


There indeed exists a discrepancy between the merging prediction and the observation.



Zhang 2016.

There indeed exists a discrepancy between the merging prediction and the observation.
The disagreement between previous observations is gone after considering measurement uncertainties.



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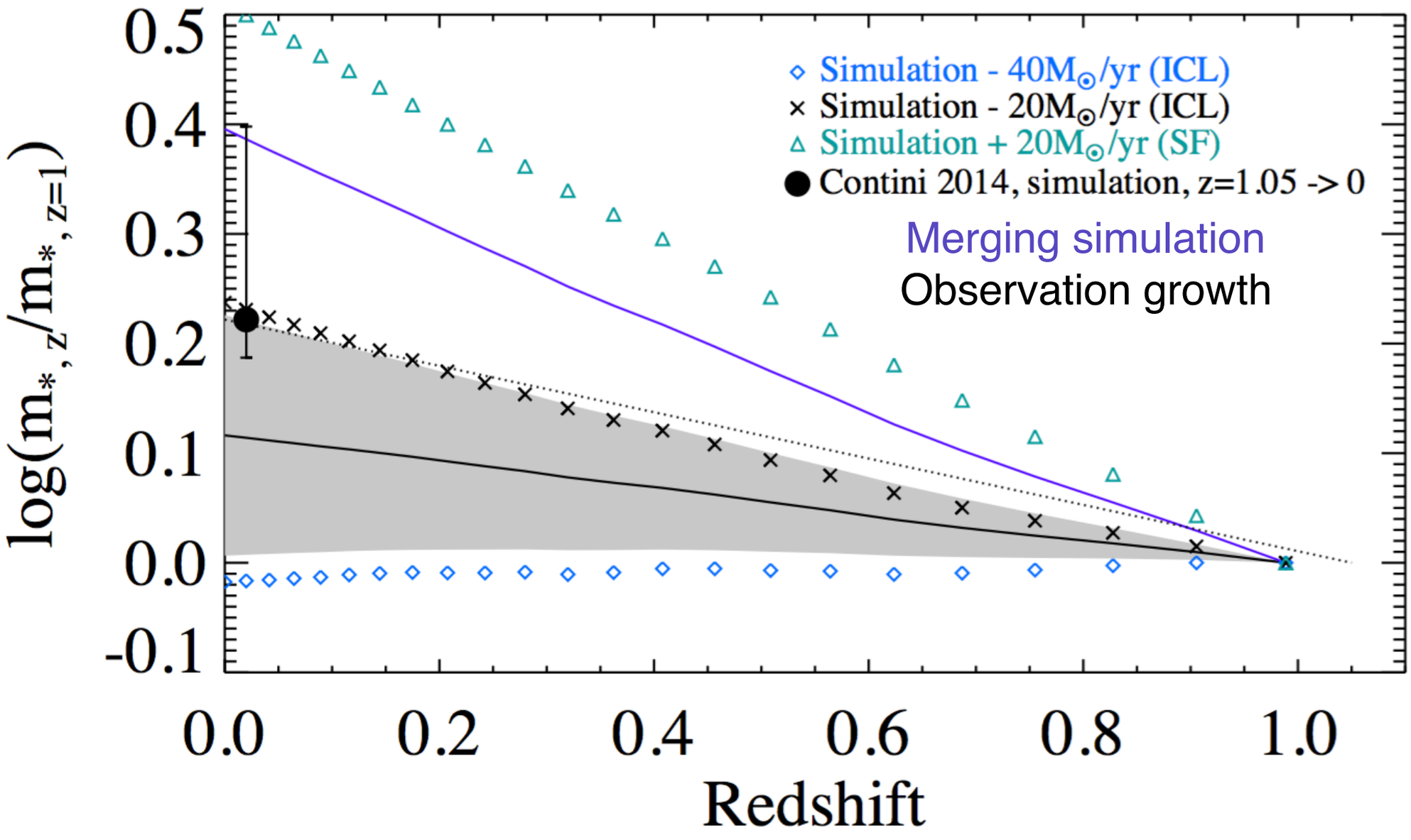
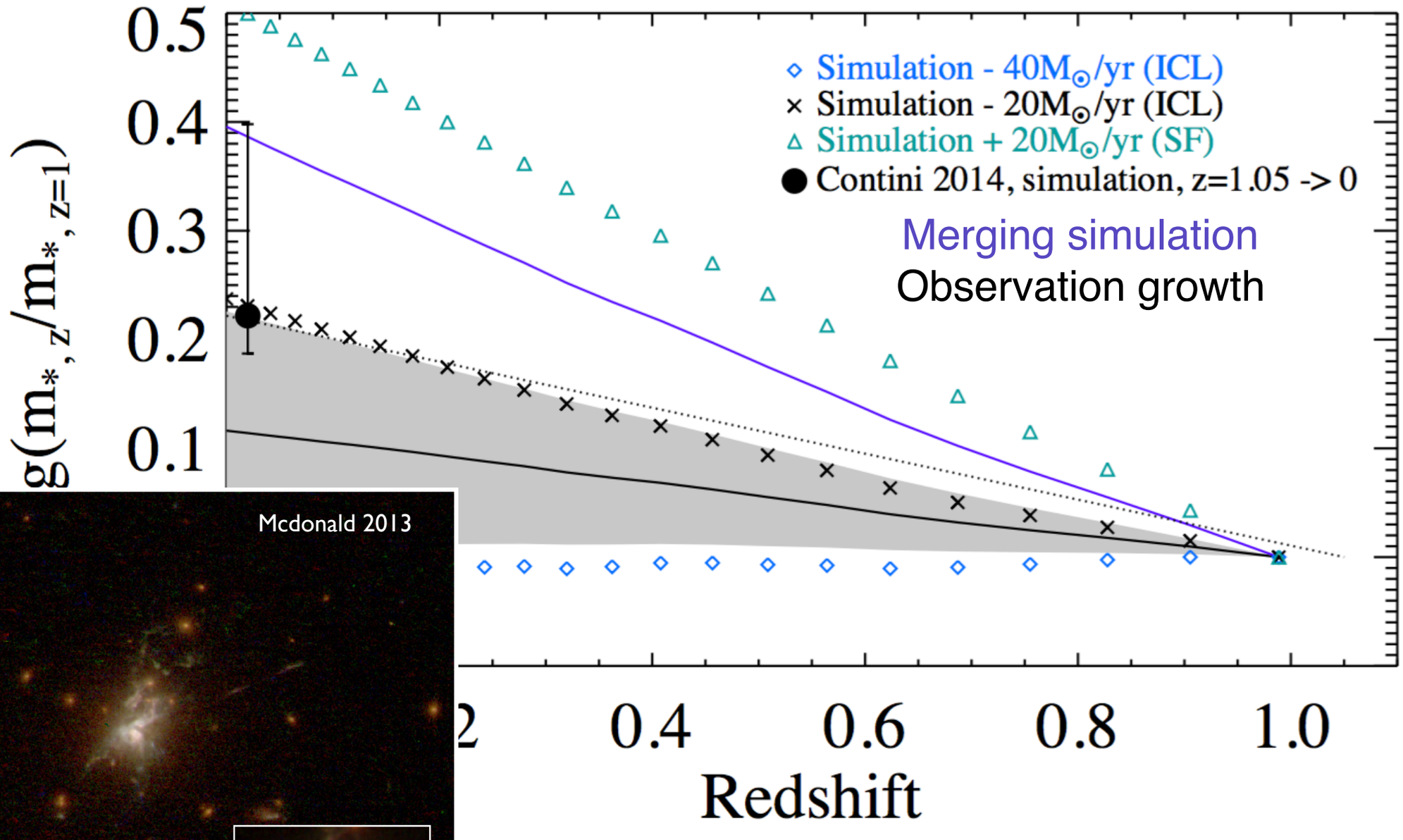
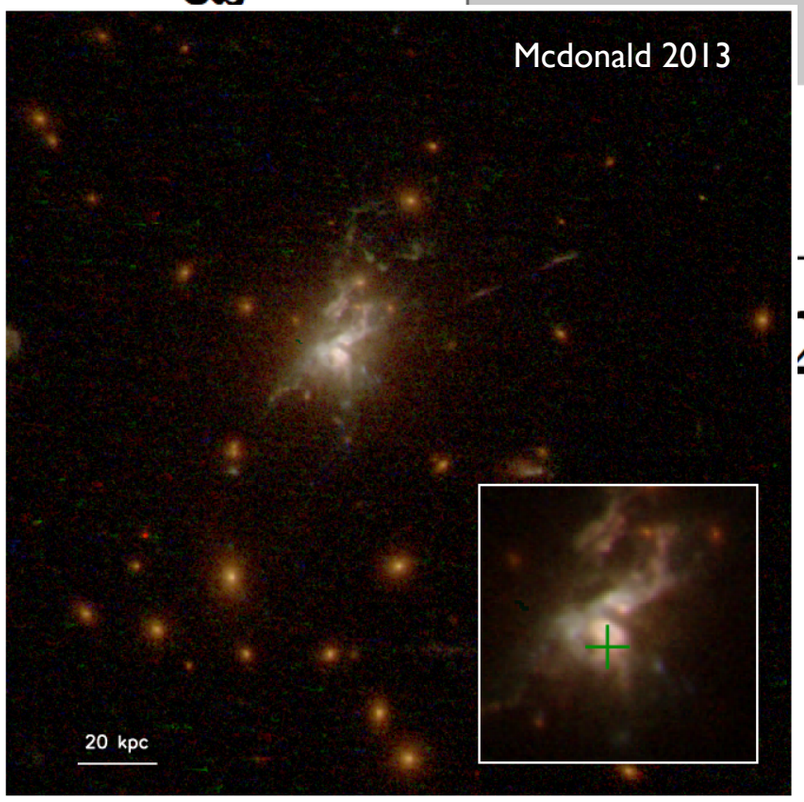


There exists other processes that affect BCG formation.

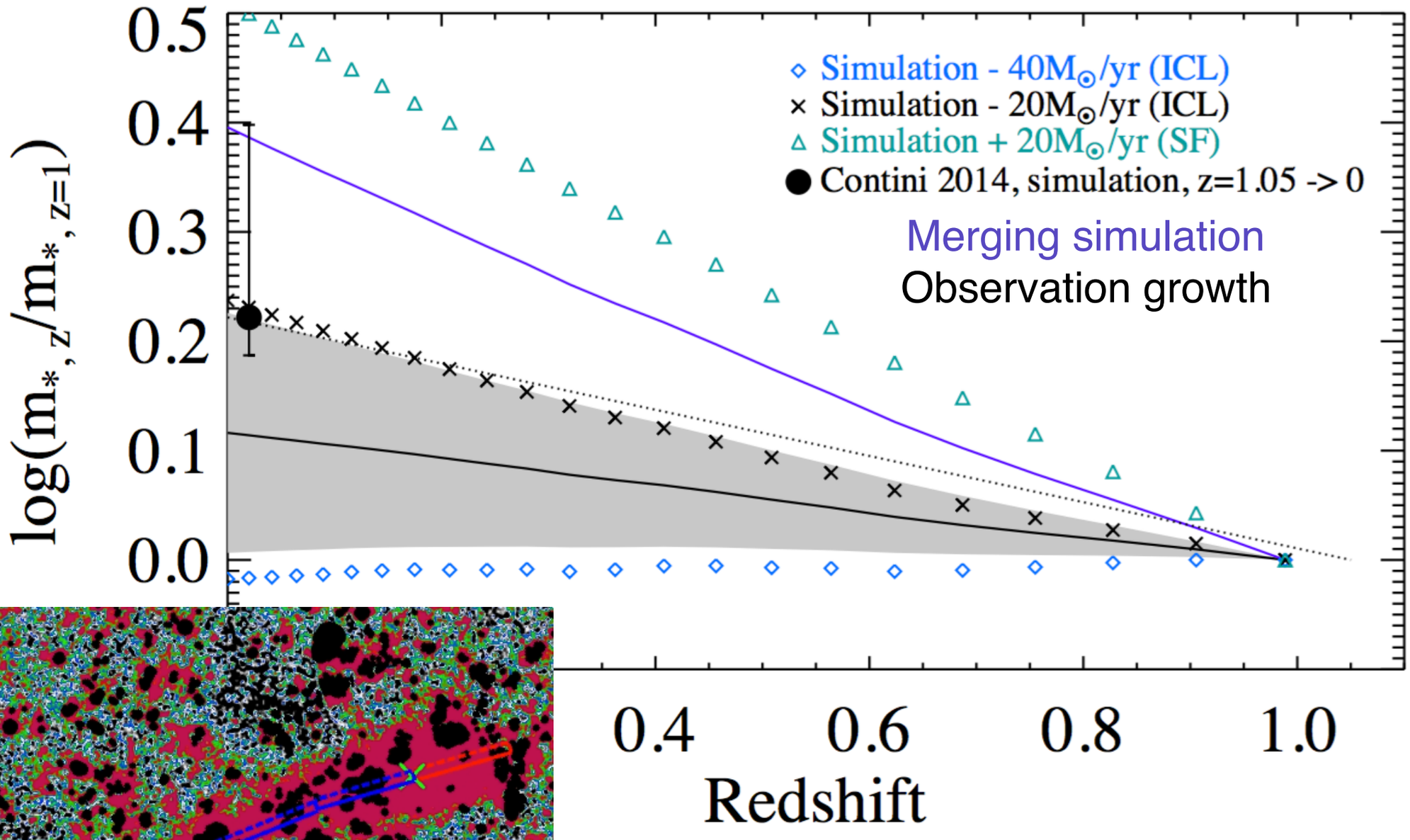
Star formation makes the simulated BCGs grow even faster.

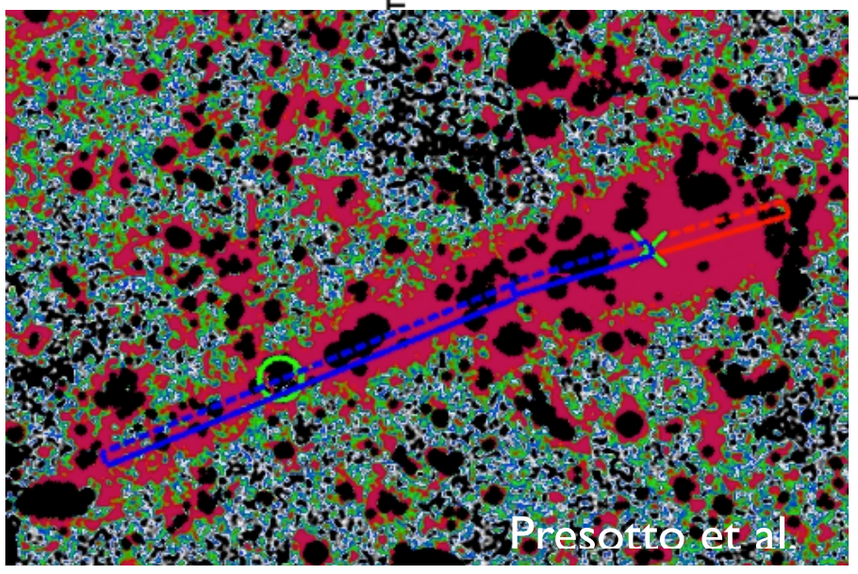




There exists other processes that affect BCG formation.

ICL can make the simulated BCGs grow slower.



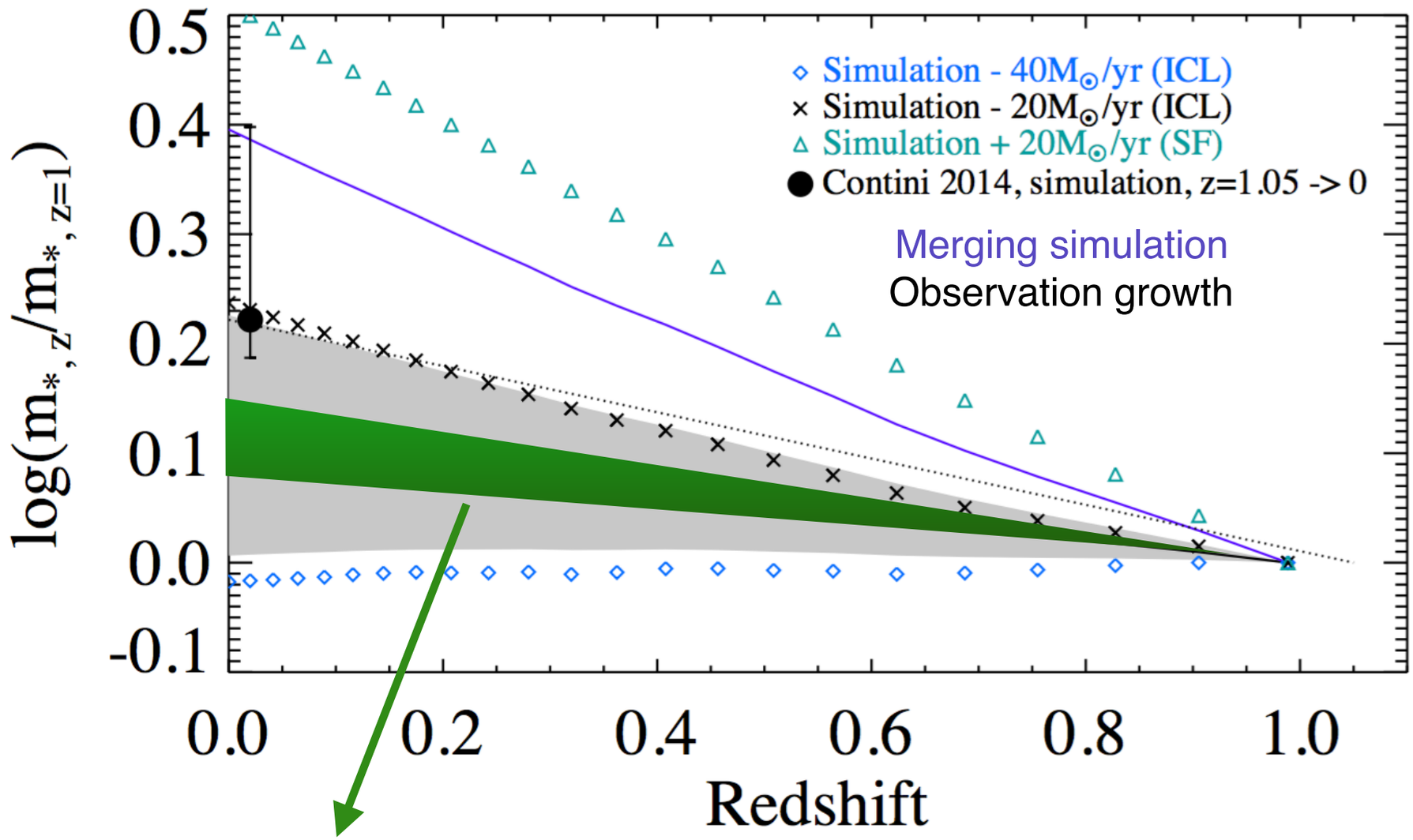


~ 10 to 50 $M_{\odot}/\mathrm{yr}$ after z = 1.0.
~ 10% to 40% the total of BCG+ICL stellar masses.

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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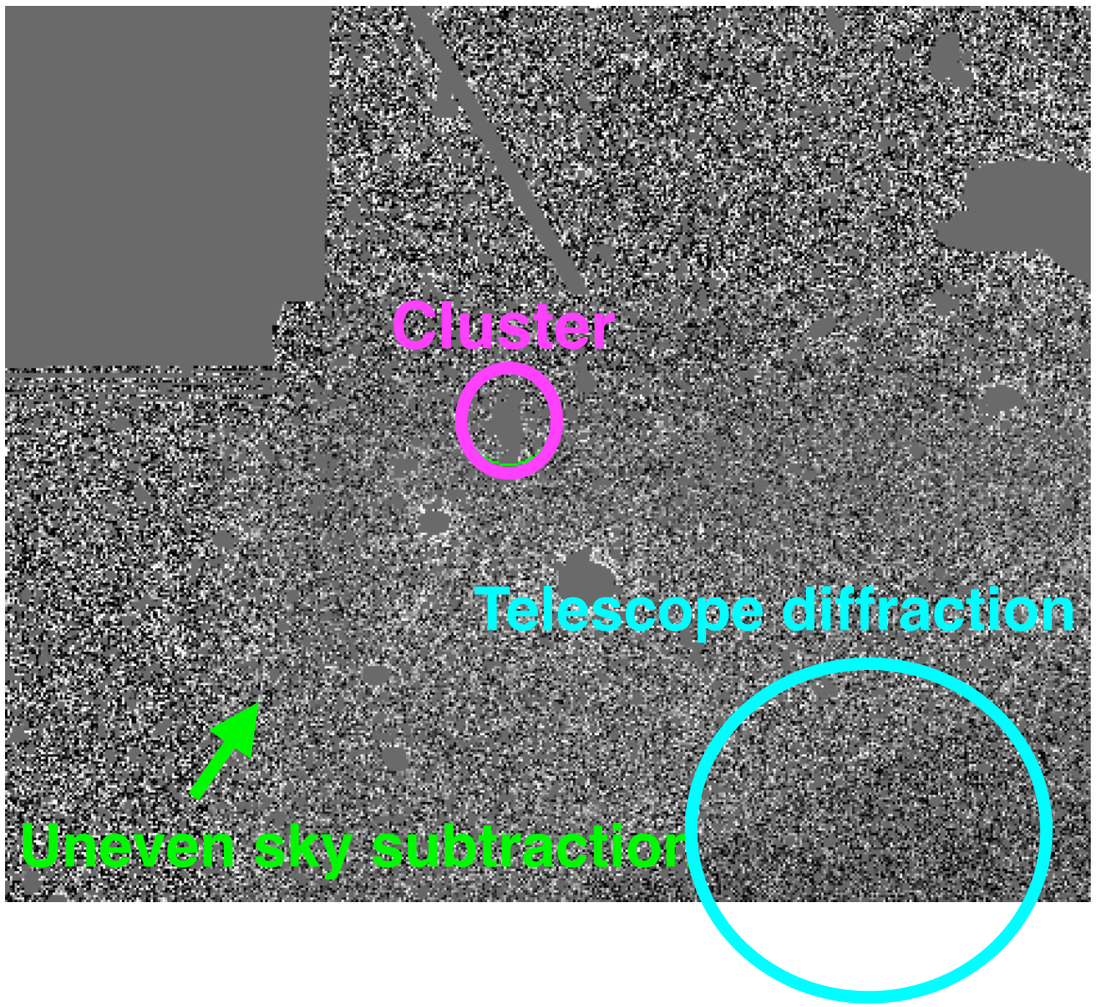
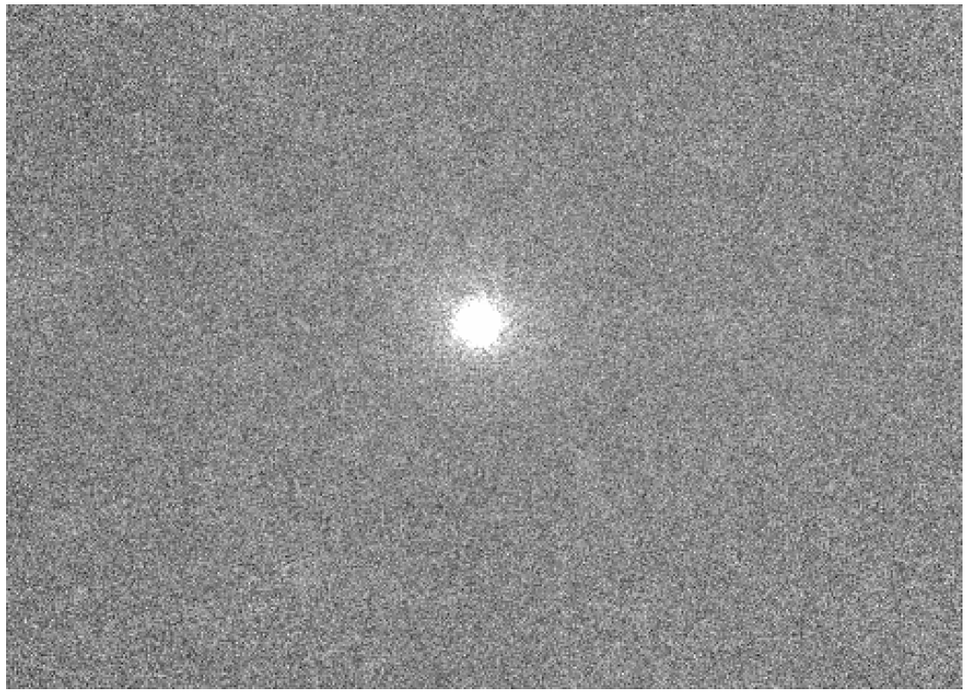


Stack



Wide fields surveys makes it possible to **stack** hundreds of clusters to detect faint diffused light.

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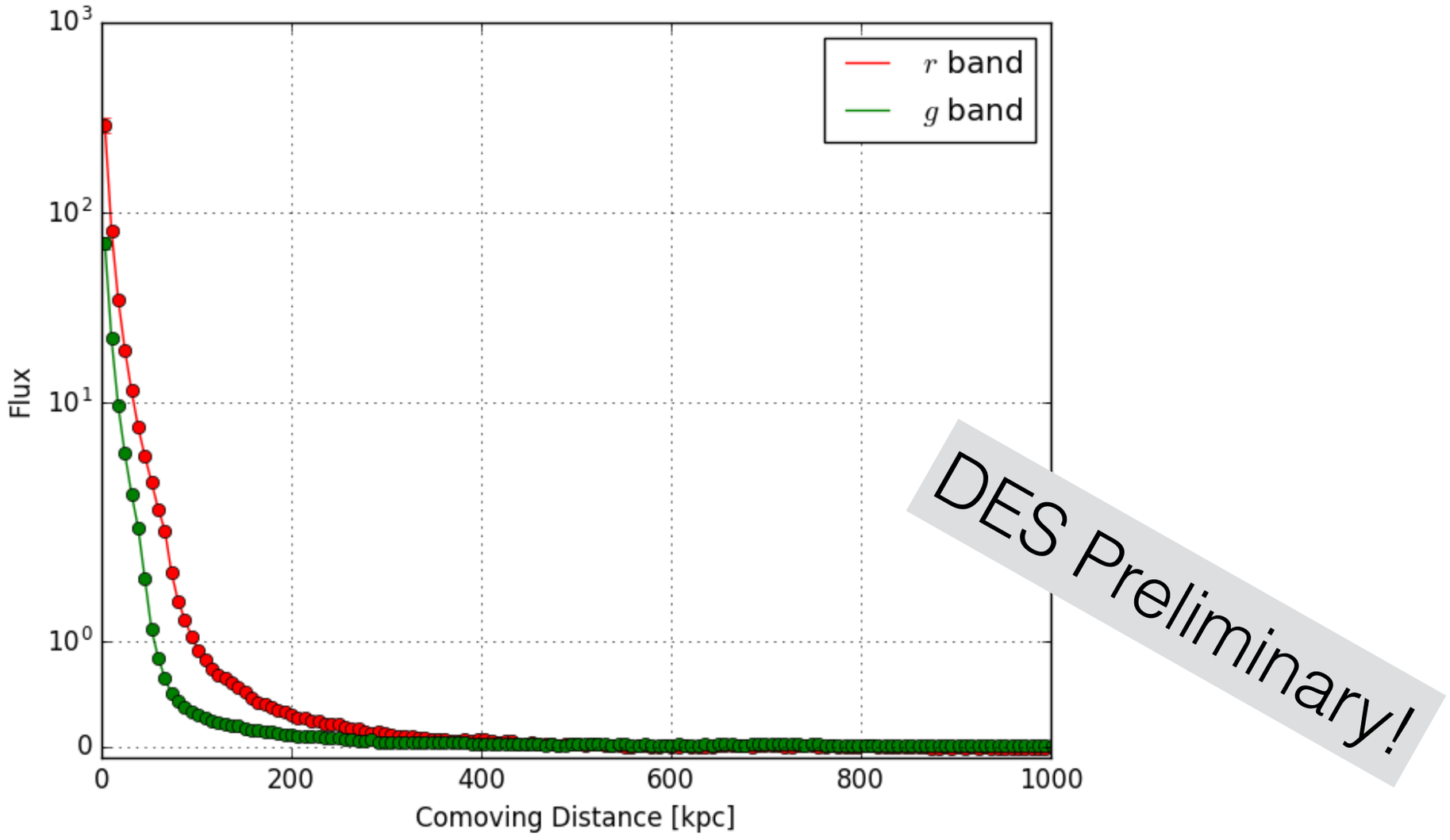
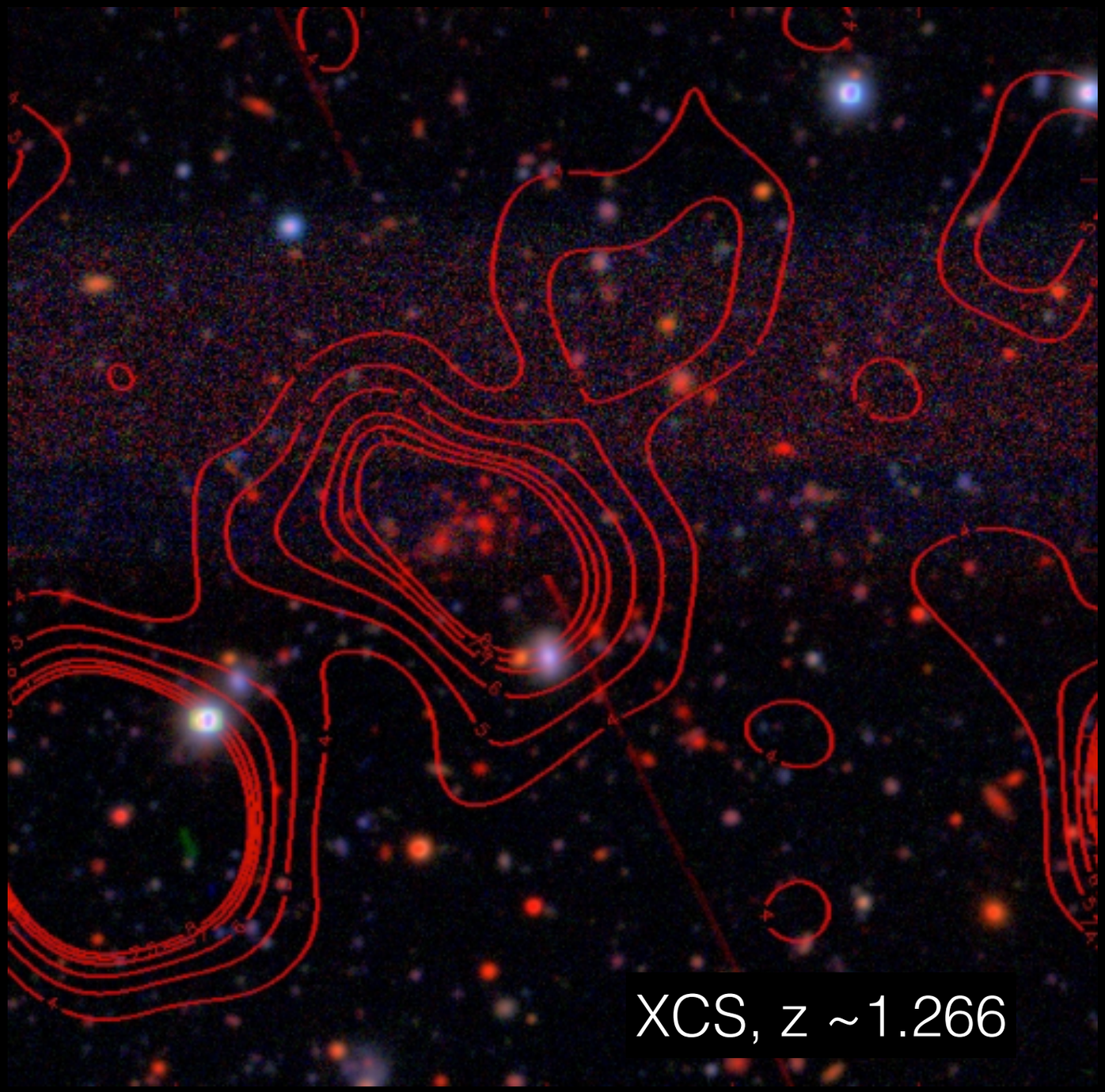


Wide fields surveys makes it possible to stack hundreds of clusters to detect faint diffused light.

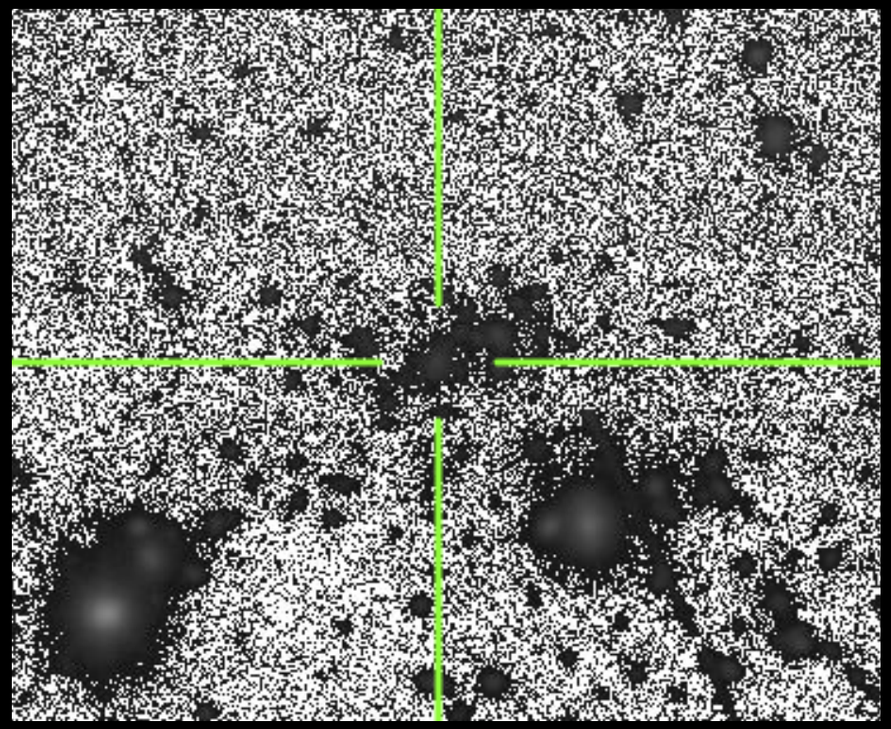
DES has the capacity for conducting ICL analysis to z ~ 0.7

Can we go beyond redshift 1.0?
Does DES have clusters beyond redshift 1.0?



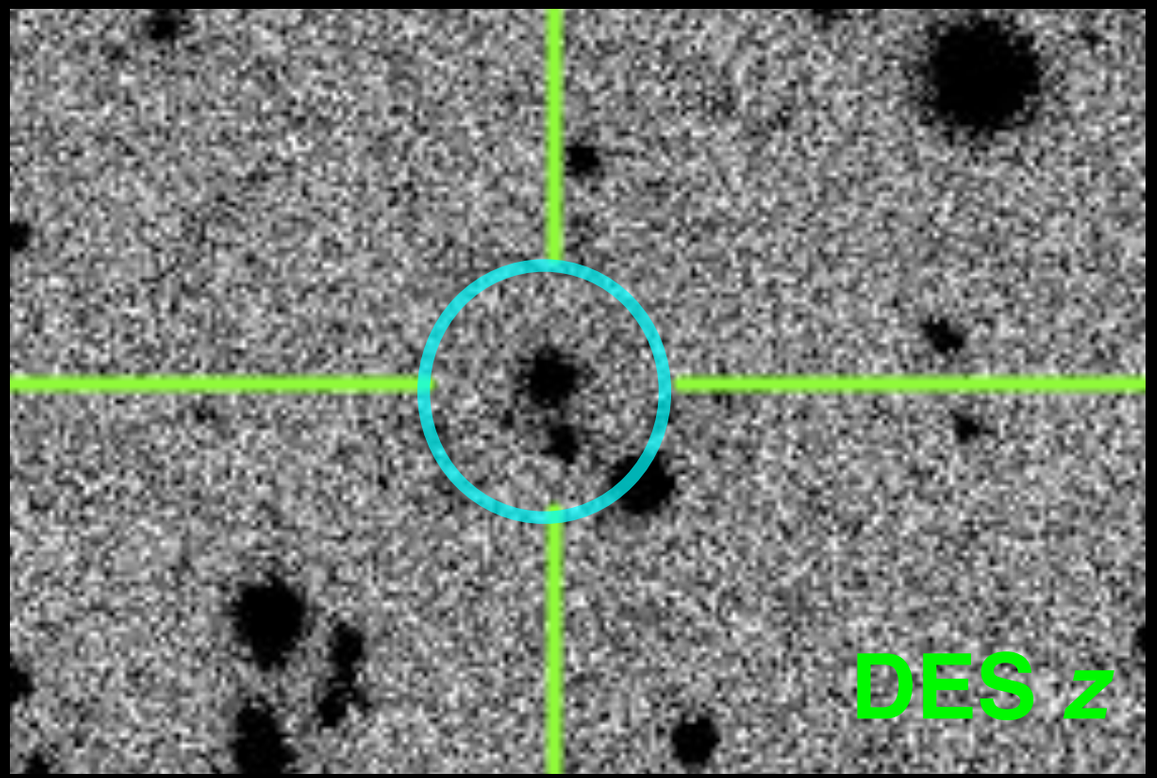
XCS, z ~1.266

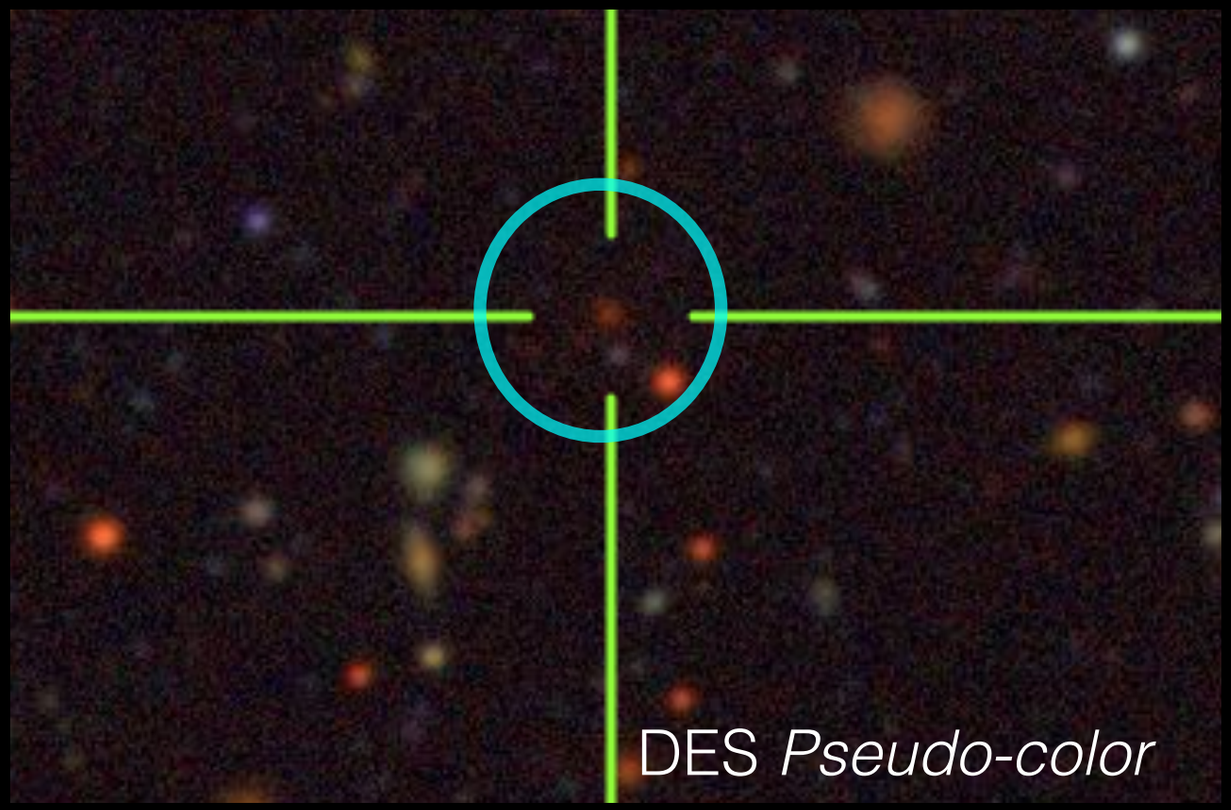
DES SN field
Depth: m*+ 2 mag



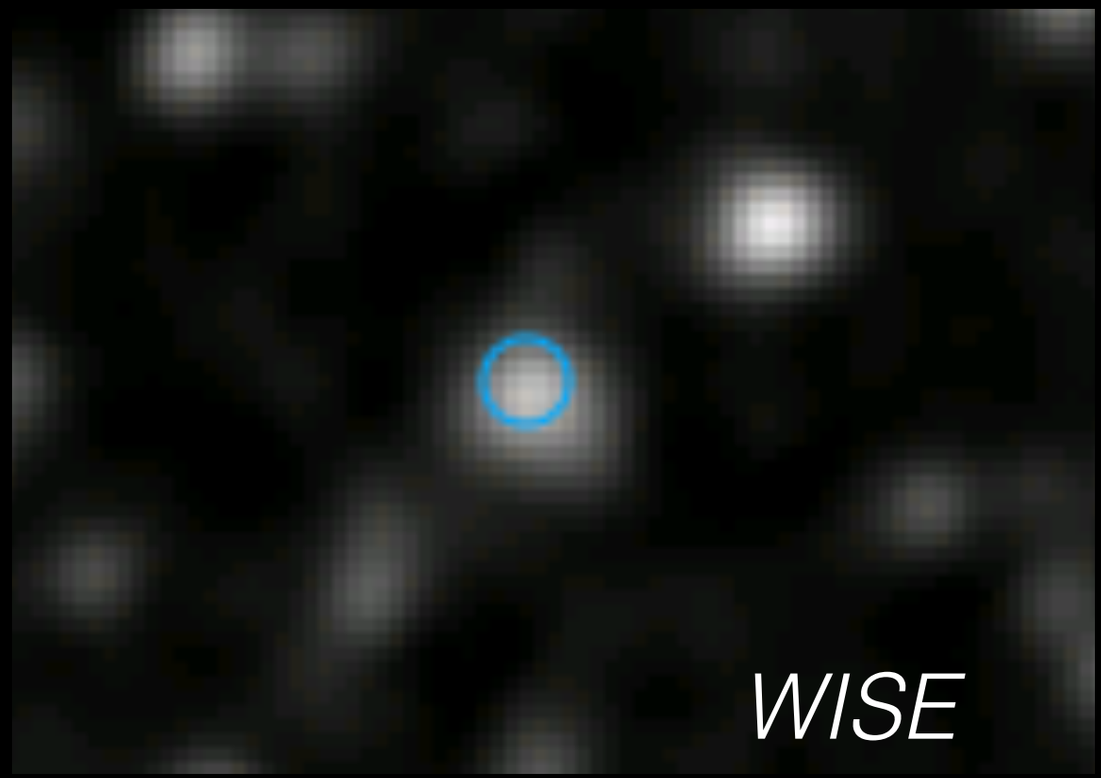
DES *z*

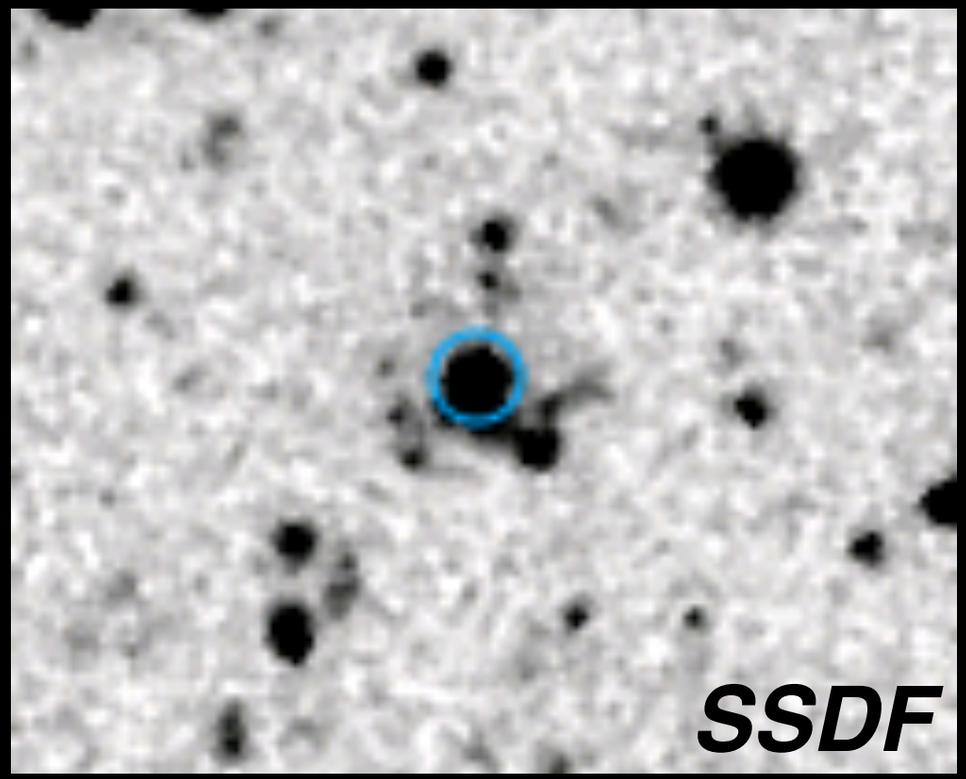
XCS, z ~1.2
DES wide field. Depth: m*





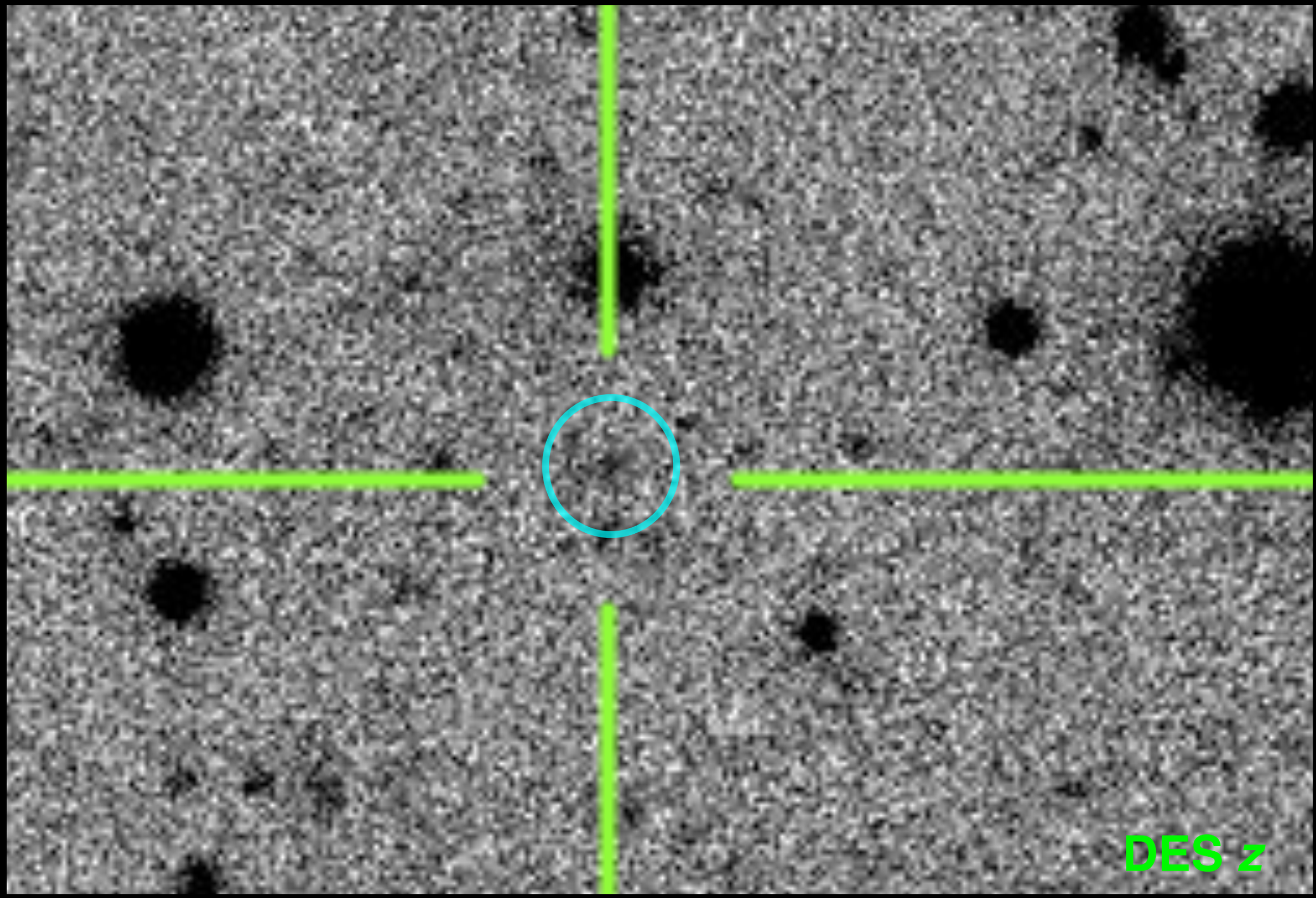
Public Infrared data available





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 *WISE* data?
- DES supernovae: making use of the deep *z* band data and public *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).