Clusters at z > 1.5 from the SpARCS Infrared Cluster Survey

Ricardo Demarco
Department of Astronomy
Universidad de Concepción
The SpARCS collaboration

Gillian Wilson (UCR)
Howard Yee (Toronto)
Chris Lidman (AAO)
Julie Nantais (Concepciòn)
Alireza Farahmandi (UCR)
Michael Balogh (Waterloo)
Erica Ellingson (Colorado)
Mike Gladders (Chicago)
Hendrik Hilldebrandt (UBC)
Mark Lacy (NRAO)
Allison Noble (McGill)
Remco van der Burg (Leiden)

Adam Muzzin (Leiden)
Alessandro Rettura (Caltech)
Ricardo Demarco (Concepciòn)
Andrew DeGroot (UCR)
Joseph Cox (UCR)
Douglas Burke (SAO)
David Gilbank (Waterloo)
Amalia Hicks (MSU)
Henk Hoekstra (Leiden)
Jean-Christophe Mauduit (Caltech)
Jason Surace (Caltech)
Tracy Webb (McGill)
Searching for Galaxy Clusters

X-ray

Rosati et al. (2004)

Gobat et al. (2011)
Searching for Galaxy Clusters

Sunyaev-Zel’dovich

Menanteau et al. (2011)
Searching for Galaxy Clusters

Optical

Abell (1958)

Abell catalog: $Z < 0.2$ (Abell et al. 1989)

Red Sequence technique: $Z \leq 1$

Gladders & Yee (2000)

Abell 2390, $z = 0.231$

$I$-band
Searching for Galaxy Clusters

Optical, Optical-NIR

Gladders & Yee (2005)

Muzzin et al. (2008)
Searching for Galaxy Clusters

Optical, Optical-NIR

Gladders & Yee (2005)

Muzzin et al. (2008)

Red sequence at high-z limited by depth in optical

Spitzer FLS
optical-NIR, MIR

**SpARCS**

Instead of the R-band, z’-band is used to go deeper in the optical.

By $z \sim 1.1$ the z’-band is no longer redward of the rest-frame 4000Å-break. Using the z’-band and the [3.6]-band allow us to identify red galaxies and discover $z \gtrsim 1$ galaxy cluster candidates.

Total area $\sim 45$ deg$^2$, z’-band (CTIO, CFHT) and [3.6]-band (Spitzer). $\sim 200$ cluster candidates at $z \gtrsim 1$, 15 spec. confirmed at $z > 0.85$ (2 at $z > 1.6$).

See: Wilson et al. (2009), Muzzin et al. (2009, 2012), Demarco et al. (2010a)
The Stellar-Bump Sequence method

See also: Muzzin’s talk
The Stellar-Bump Sequence method

Muzzin et al., in prep
The Stellar-Bump Sequence method

- SpARCS J021524–034331
  - $z = 1.004$
  - Muzzin et al. (2012)

- XLSSC 048
  - $z = 1.00$
  - Pacaud et al. (2007)

- XLSSC 029
  - $z = 1.05$
  - Pacaud et al. (2007)

- XLSSC 046
  - $z = 1.22$
  - Bremer et al. (2006)

Muzzin et al., in prep

XMM-LSS SWIRE FIELD
FOV ~ 3 x 2 degrees
zphot = 1.0 color slice
High Redshift Stellar-Bump Cluster Candidates:

SpARCS J0331-2843: **CDFS-44**, \(z_{\text{phot}} \sim 1.7\)
SpARCS J0224.5-0323.5: **XMM-113**, \(z_{\text{phot}} \sim 1.7\)

Multi-wavelength dataset:

<table>
<thead>
<tr>
<th></th>
<th>FORS2 spec.</th>
<th>HAWK-I</th>
<th>IMACS/FORS2</th>
<th>Spitzer</th>
<th>CTIO/CFHT</th>
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</thead>
<tbody>
<tr>
<td><strong>CDFS-44</strong></td>
<td>6000-10500Å</td>
<td>Y J K(_s)</td>
<td>g’r’i’z’</td>
<td>3.6(\mu)m, 4.5(\mu)m</td>
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<td>z’</td>
</tr>
</tbody>
</table>

**FORS2 color-color selection for spectroscopy:**

Class 1: SBS with \(z’ < 22.5\)
Class 2: SBS with \(z’ > 22.5\) and MIPS detection
Class 3: SBS with \(z’ > 22.5\) and no MIPS detection
Classes 4 to 6: in classes 1 to 3 and \(R > 700\) kpc
Class 7: anything else with detection in \(z’\) and IRAC
Class 8: anything else with detection in \(z’\) (FORS2)
Spectroscopic FORS2 observations

**CDFS-44**: 2 masks (3.75 h/mask), 37 and 39 slits targeted: 39 emission line: 25 redshifts: 26

**XMM-113**: 2 masks (3.75 h/mask), 32 slits each targeted: 32 emission line: 28 redshifts: 29

**ESO P85**: 21 hours awarded MXU mode with 300I grism (~ 6000 - 10500 Å, R~600)
CDFS-44

$\sim 3.5' \times 2.5' \ (1.8 \ \text{Mpc} \times 1.3 \ \text{Mpc}), \ z' \text{YKs}$

$2' \rightarrow 1 \ \text{Mpc}$
CDFS-44

\[ \sim 3.5' \times 2.5' \ (1.8 \ Mpc \times 1.3 \ Mpc), \ z'YKs \]

\[ 2' \rightarrow 1 \ Mpc \]
CDFS-44 (sample spectra)

Members: 12  Emission line: 10

Wilson et al., in prep
CDFS-44 (sample spectra)

Members: 12  Emission line: 10

Wilson et al., in prep
Members within 2 Mpc from BCG. Velocity distribution consistent with one single gaussian (KS test). There is no evidence for substructure (DS test).

<z> = 1.626, \( \sigma_v \lesssim 700 \) km/s

\[ z_{\text{cl}} = 1.6259^{+0.0020}_{-0.0017} \quad \sigma_v = 695^{+84}_{-192} \text{ km/s} \]
Large Scale Structure around CDFS-44

Springel et al. 2006

Excess of galaxies with \([3.6] - [4.5] \approx 0.6\) (\(z \sim 1.6\))

FORS2/MXU and IMACS multiband imaging pending

Excess of galaxies with \([3.6] - [4.5] \approx 0.6\) (\(z \sim 1.6\))
XMM-113

SpARCS J022427-032355
z = 1.623
This Paper

CIG J0218.3–510
z = 1.625
Papovich et al. (2010)

XMM-LSS SWIRE FIELD
FOV ~ 3 x 2 degrees
zphot = 1.6 color slice

Muzzin et al., in prep
XMM-113

30'' → 0.25 Mpc

3.8' × 2.4'(1.9 Mpc × 1.2 Mpc)

Y-band
XMM-113

Member

Non member

30” → 0.25 Mpc
XMM-113 (sample spectra)

Members: 12  Emission line: 8

Wilson et al., in prep
XMM-113 (sample spectra)

Members: 12    Emission line: 8

Wilson et al., in prep
Members within 1.5 Mpc from BCG. Velocity distribution consistent with one single gaussian (KS test). There is no significant evidence for substructure (DS test). $<z>=1.633$, $\sigma_v \approx 400$ km/s.

$z_{cl} = 1.6332^{+0.0010}_{-0.0010}$

$\sigma_v = 393^{+19}_{-101}$ km/s
Conclusions

- The Stellar-Bump Sequence (SBS) method is an efficient and effective algorithm to find $z>1.5$ clusters.

- The SBS algorithm is unbiased against lower-mass and more common clusters, allowing us to find structures that will become Coma-like clusters by $z=0$.

- Two clusters spectroscopically confirmed at $z\sim1.63$ (CDFS-44 [12] and XMM-113 [12]).

- These clusters have velocity dispersions $\sigma_v<700$ km/s and their cores are populated by galaxies with on-going star formation. These systems may be representative of “more common” clusters that will become Coma-like by $z=0$.

**Next:** to survey the surrounding (<10’) region around clusters in search for groups and filaments (pre-infall cluster pop.)