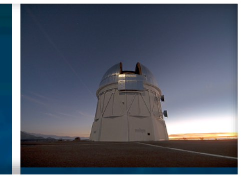
The SpARCS z > 1 Cluster Survey



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Current Generation of z > 1 Cluster Surveys

- Infrared
  - SpARCS
  - ISCS (IRAC Shallow Cluster Survey)
  - UKIDSS DXS (UKIRT Infrared Deep Sky Survey Deep Extragalactic Survey)
- Sunyaev-Zeldovich
  - APEX (Atacama Pathfinder Experiment)
  - ACT (Atacama Cosmology Telescope)
  - SPT (South Pole Telescope)
- X-ray
  - XMM-LSS (XMM Large-Scale-Structure Survey)
  - XCS (XMM Cluster Survey)
  - XDCS (XMM-Newton Distant Cluster Project)
  - eROSITA (extended Roentgen Survey with an Imaging Telescope Array)
  - WFXT (Wide-Field X-ray Telescope)

Ongoing/Completed   Planned/Proposed

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SpARCS Cluster Detection Technique

- Clusters are detected using an infrared adaptation of the efficient two-filter red-sequence technique “The Spitzer Adaptation of the Red-sequence Cluster Survey”.
- At z ~ 1, rest-frame 4000 Angstrom break passes into IR => SpARCS uses Spitzer [3.6] observations as “red’’ passband.
- SpARCS is a 25 night z’ (“blue” band) survey of the 50 square degree SWIRE fields.
- ~200 new z > 1 cluster candidates. z’-[3.6] color gives photo-z.

Survey summarized in

Wilson et al., 2009, ApJ, 698, 1943 — Southern Fields
Muzzin et al., 2009, ApJ, 698, 1934 — Northern Fields

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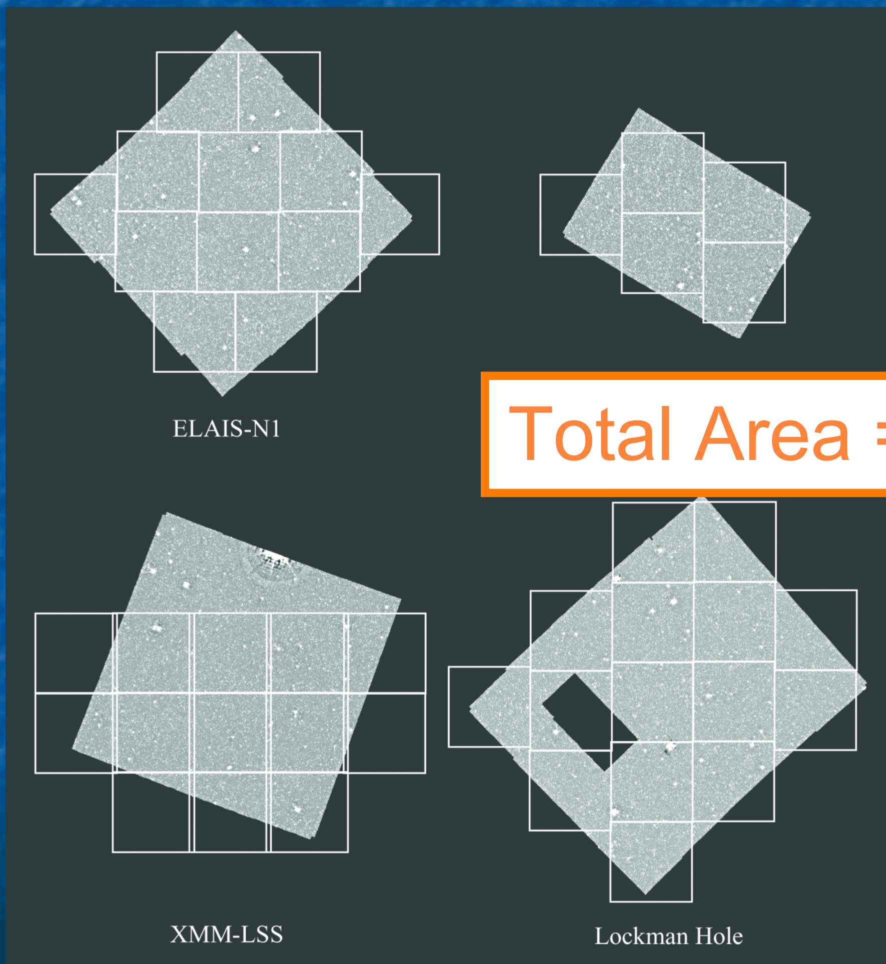
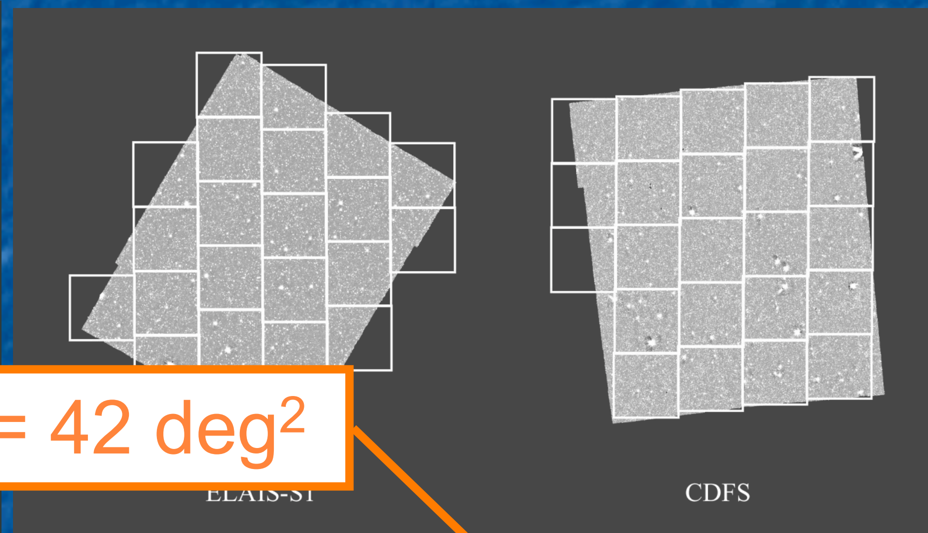
CFHT SpARCS fields CTIO

"Northern Fields"

"Southern Fields"





Total Area = 42 deg^2

Field	R.A. J2000	Decl. J2000	SWIRE 3.6 μm Area (deg^2)	SpARCS z' Area (deg^2)	Usable Area (deg^2)
ELAIS-S1[a]	00:38:30	−44:00:00	7.1	8.3	6.5
XMM-LSS	02:21:20	−04:30:00	9.4	11.7	7.3
Chandra-S[a]	03:32:00	−28:16:00	8.1	7.9	7.1
Lockman	10:45:00	+58:00:00	11.6	12.9	9.7
ELAIS-N1	16:11:00	+55:00:00	9.8	10.3	7.9
ELAIS-N2	16:36:48	+41:01:45	4.4	4.3	3.4
Total			50.4	55.4	41.9

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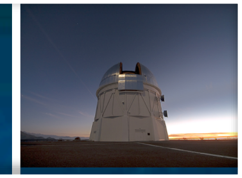
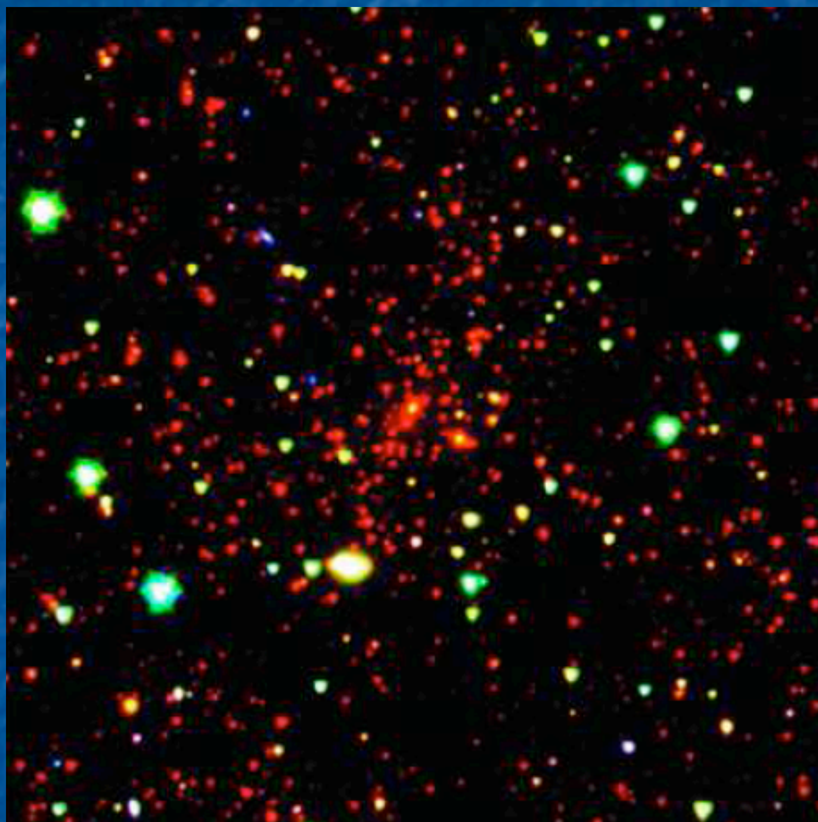
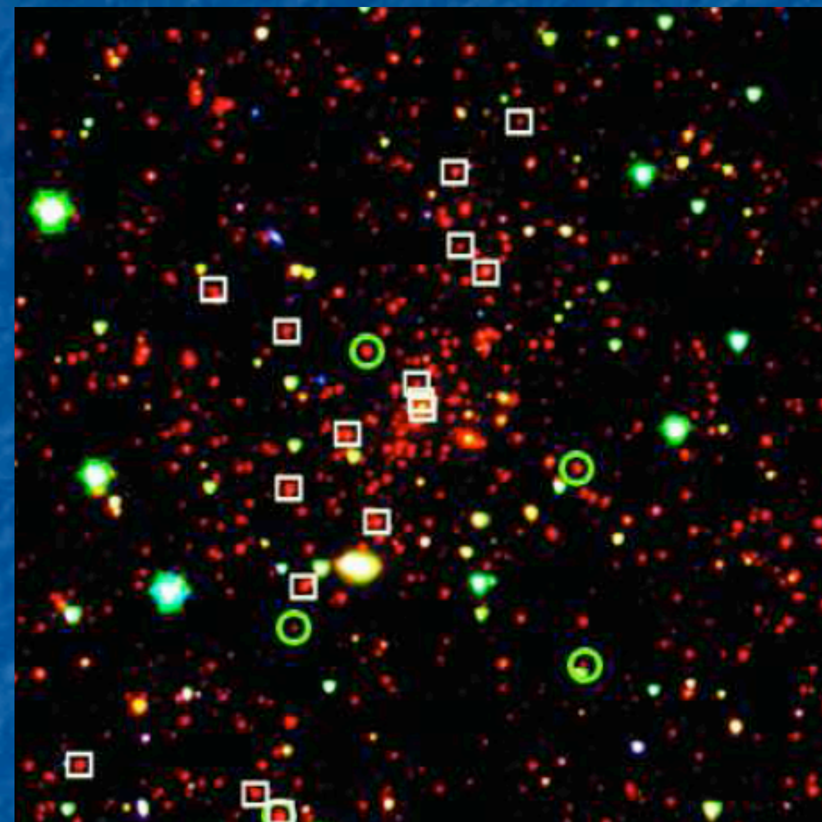
SpARCS J161315+564930 (z = 0.87)



Demarco et al., 2009, ApJ, submitted (Keck/LRIS observations)





$$\sigma = 1230 \pm 320 \mathrm{km\ s^{-1}}$$

$$M_{200} = (2.0^{+2.0}_{-1.2}) \times 10^{15}\, M_{\mathrm{Sun}}$$

□ 16 members ○ non-member

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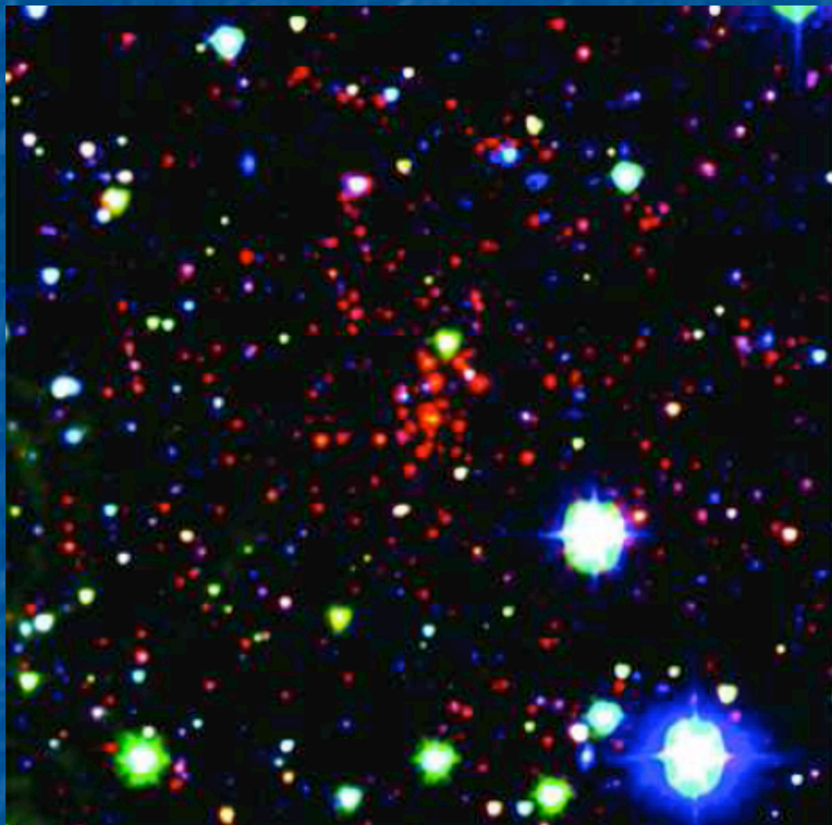
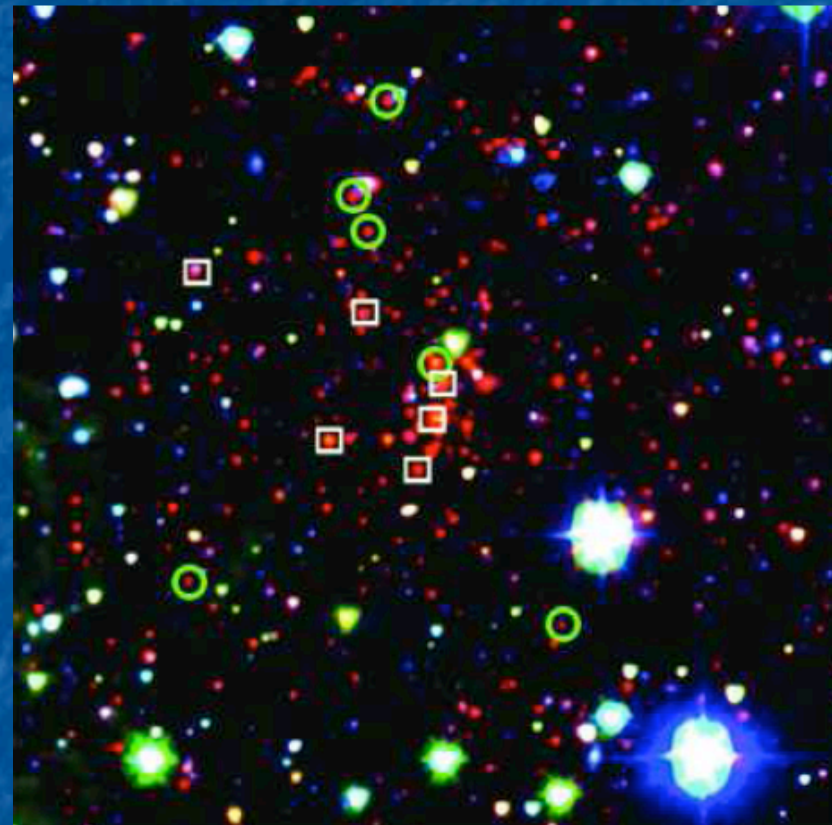
SpARCS J161641+554513 (z = 1.16)

Demarco et al., 2009, ApJ, submitted (Keck/LRIS observations)





$$\sigma = 950 \pm 330 \text{km s}^{-1}$$

$$M_{200} = (7.7^{+11}_{-5.5}) \times 10^{14} M_{Sun}$$

□ 10 members

○ non-member

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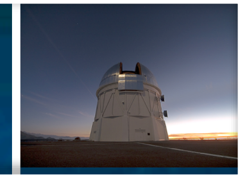
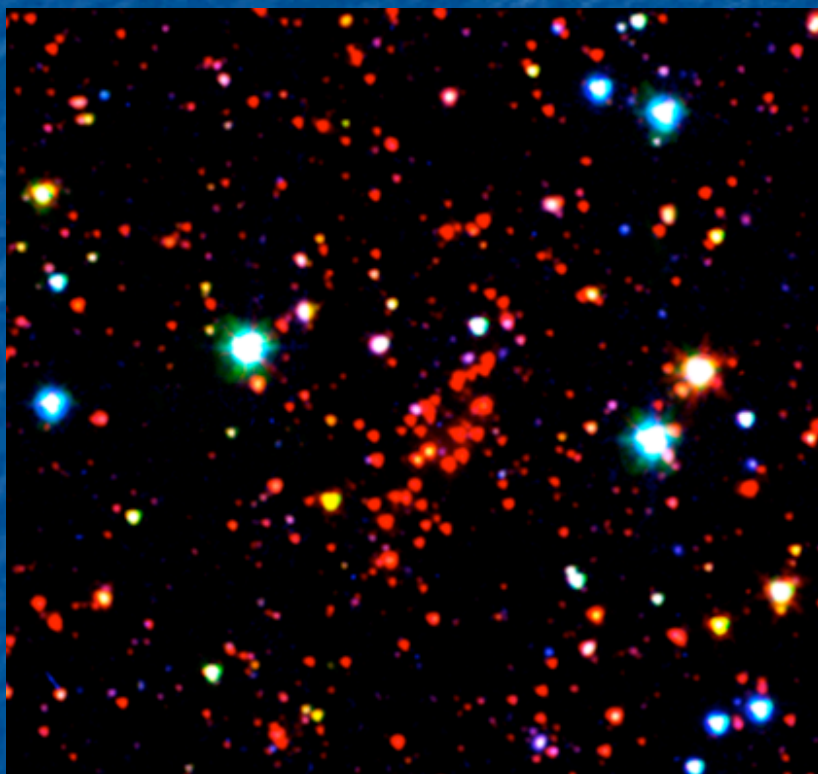
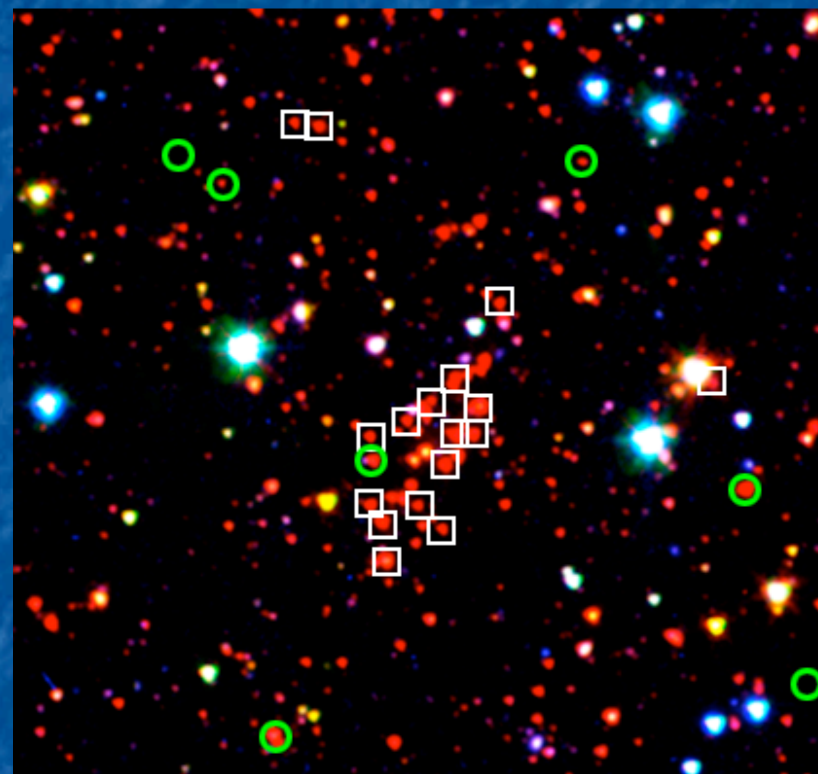
SpARCS J163435+402151 (z = 1.18)



Muzzin et al., 2009, ApJ, 698, 1934 (Gemini/GMOS-N observations)





$$\sigma = 490 \pm 140 \mathrm{km\ s^{-1}}$$

$$M_{200} = (1.0 \pm 0.9) \times 10^{14} M_{\mathrm{Sun}}$$

□ 17 members

○ non-member

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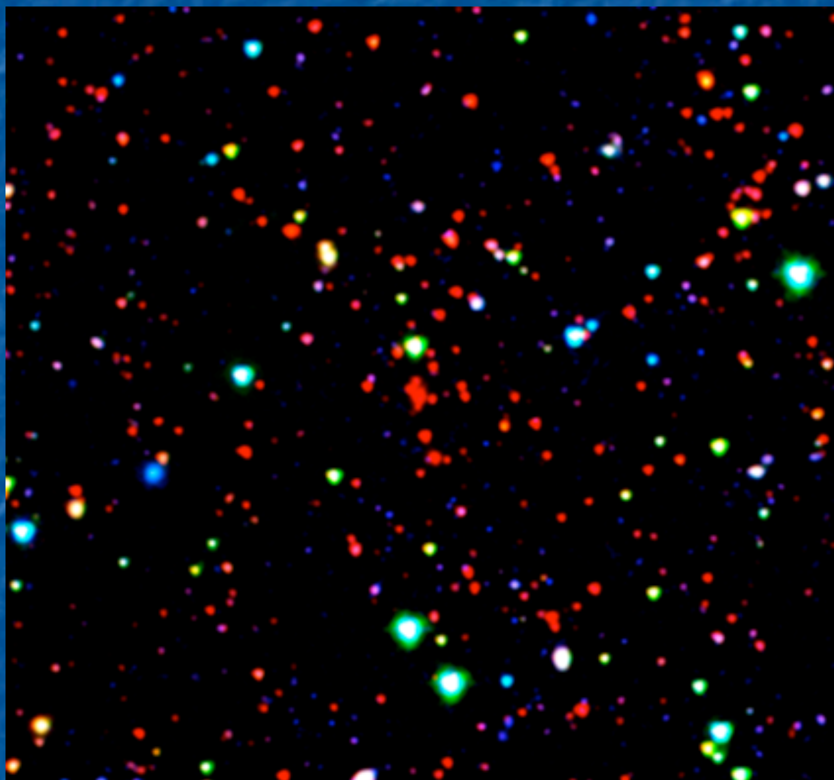
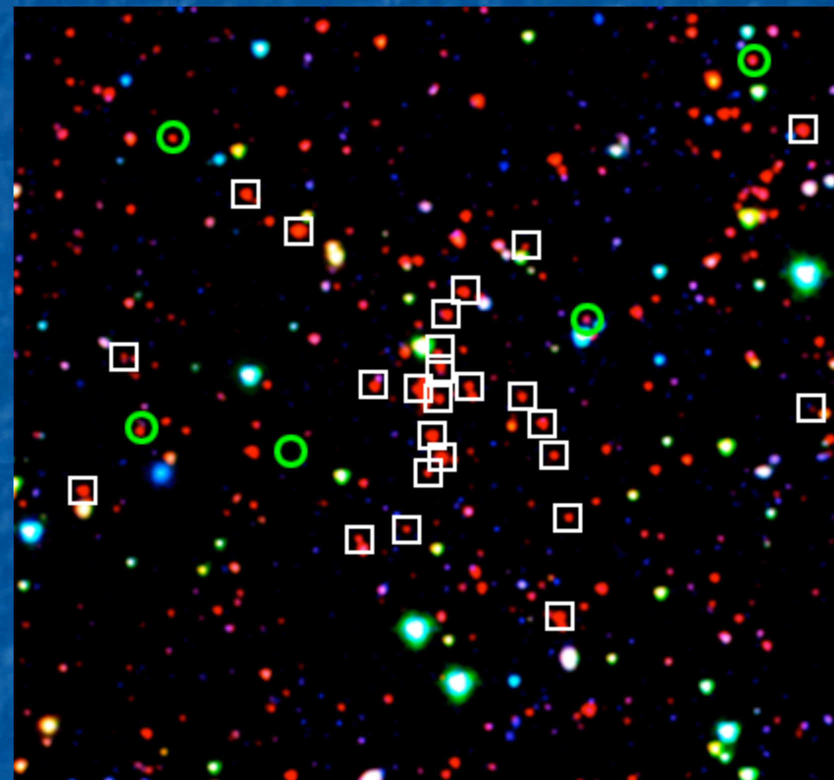
SpARCS J163852+403843 (z = 1.20)

Muzzin et al., 2009, ApJ, 698, 1934 (Gemini/GMOS-N observations)





$$\sigma = 650 \pm 160 \mathrm{km\ s^{-1}}$$

$$M_{200} = (2.4 \pm 1.8) \times 10^{14} M_{\mathrm{Sun}}$$

□ 28 members

○ non-member

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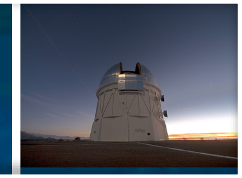
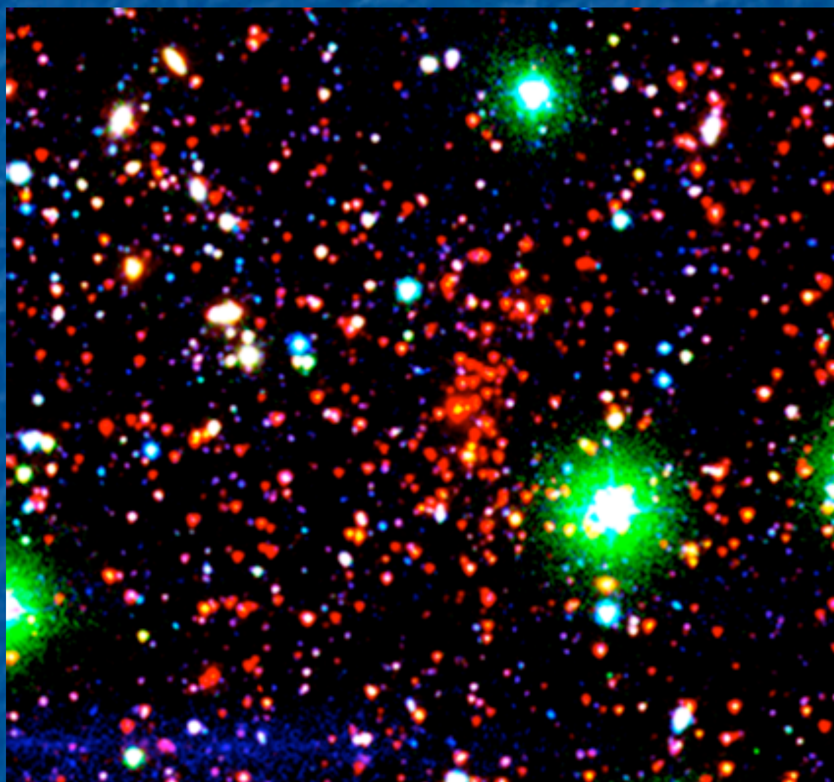
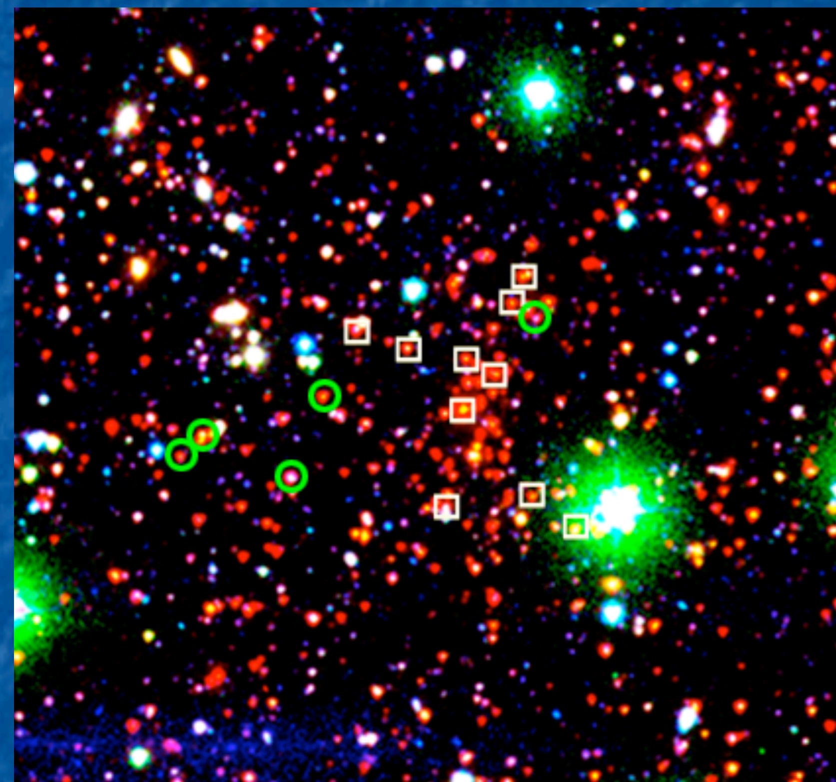
SpARCS J003550-431224 (z = 1.34)



Wilson et al., 2009, ApJ, 698, 1943 (Gemini/GMOS-S observations)





$$\sigma = 1050 \pm 230\,\mathrm{km\ s^{-1}}$$

$$M_{200} = (9.4 \pm 6.2) \times 10^{14}\, M_{\mathrm{Sun}}$$

□ 10 members ○ non-member

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Clusters as Cosmological Probes

At $z < 1$, RCS & SDSS surveys (Gladders et al. 2007, Rozo et al., 2009) have measured constraints on Ω_m and σ_8 from the evolution of the cluster mass function.

To do this efficiently, ***the survey data itself*** is used, not only to detect clusters, but also to estimate:

- redshift (from red-sequence color)
- mass (from optical richness)

The strongest constraints on ω, the equation of state of dark energy, are expected to come from cluster abundances at $z > 1$.

Can we estimate cluster redshift and mass at $z > 1$?

Yes !!

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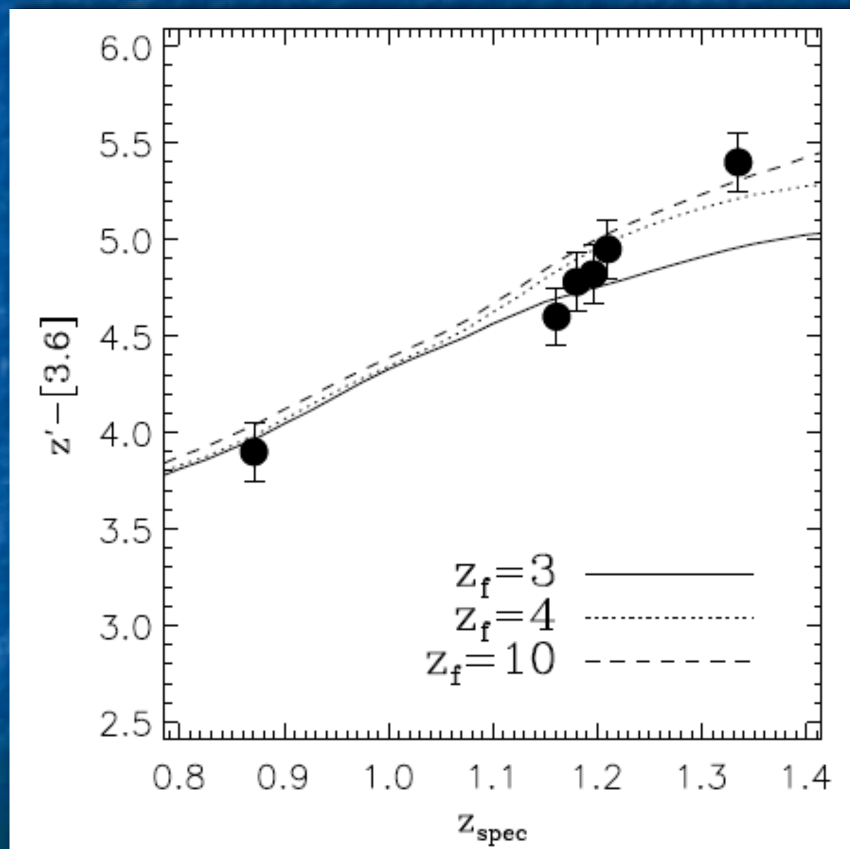
Cluster Redshift from z’-[3.6] color

Agreement is good between predicted BC03 color and spectroscopic z

SpARCS clusters



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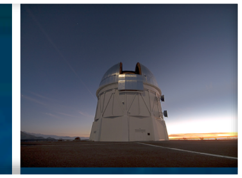
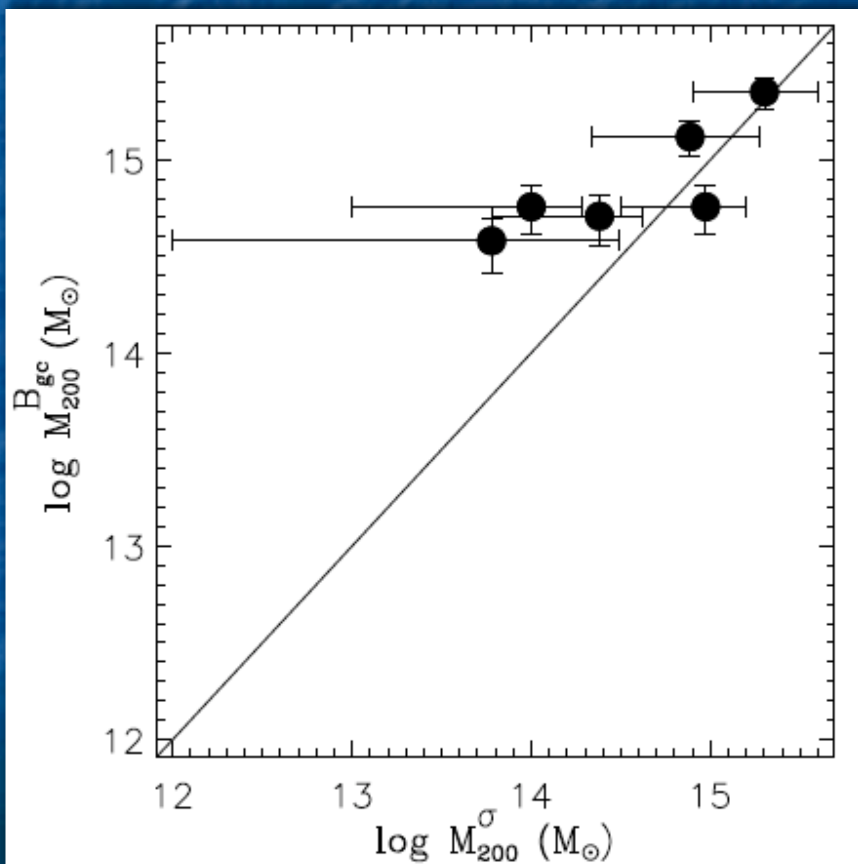
Cluster Mass (from Richness)



Agreement is good between Mass estimated from Richness (Bgc parameter) and Mass estimated from Galaxy Velocity Dispersion (σ)



"GCLASS" : The Gemini Cluster Astrophysics Spectroscopic Survey will measure 50 spectroscopic redshifts in ***each*** of 10 rich SpARCS clusters at z~1.1 (200 hour, six semester program, ending in 2010B)

See next talk by Adam Muzzin & poster by Erica Ellingson

Prospects are good for current generation of surveys aiming to estimate cluster redshifts and masses at z > 1 ***directly*** from optical-infrared imaging.

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SpARCS Cluster Candidates at z > 1.34

Using z'-[3.6] red sequence method, SpARCS detected fewer cluster candidates at z > 1.4 than expected.

Bruzual & Charlot model predictions and observations in good agreement to z = 1.2, but disagreement grows with increasing z.

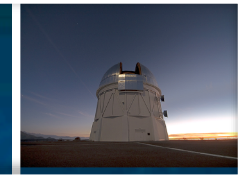
Early type galaxies are about half a magnitude fainter at z = 1.5 than pre-survey models predict, assuming:

- No dust
- Single burst solar metallicity with formation redshift $z_f = 4$
- BC03 models

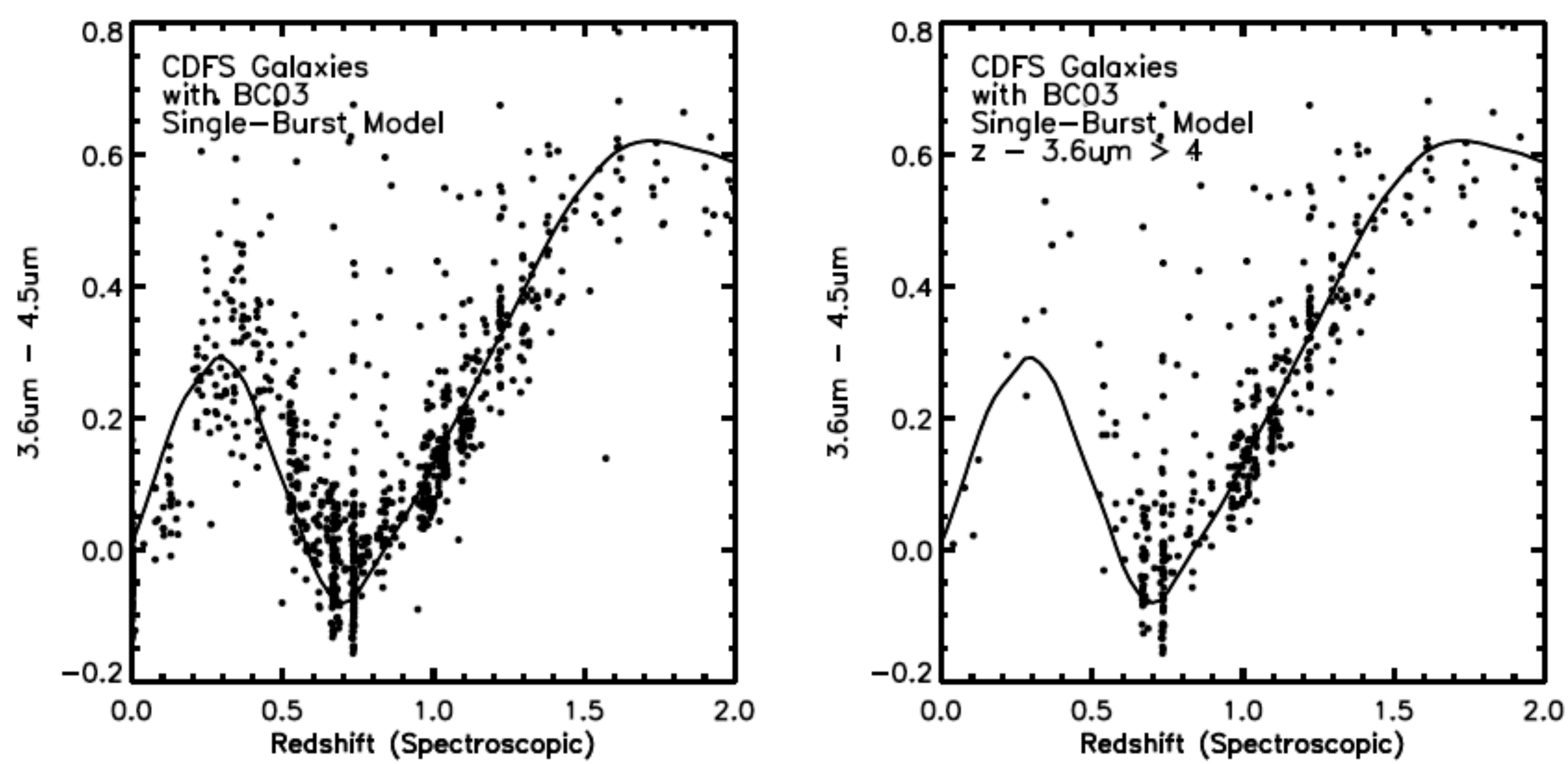
L* galaxies are only marginally detected at the limiting magnitude of the survey (z' = 24.0 Vega)

Need a new method to detect z > 1.5 clusters

The Stellar Bump Sequence (SBS) Method



1) Note in right panel how red color cut (z’- [3.6] > 4 Vega) successfully excludes almost all z < 1 galaxies.



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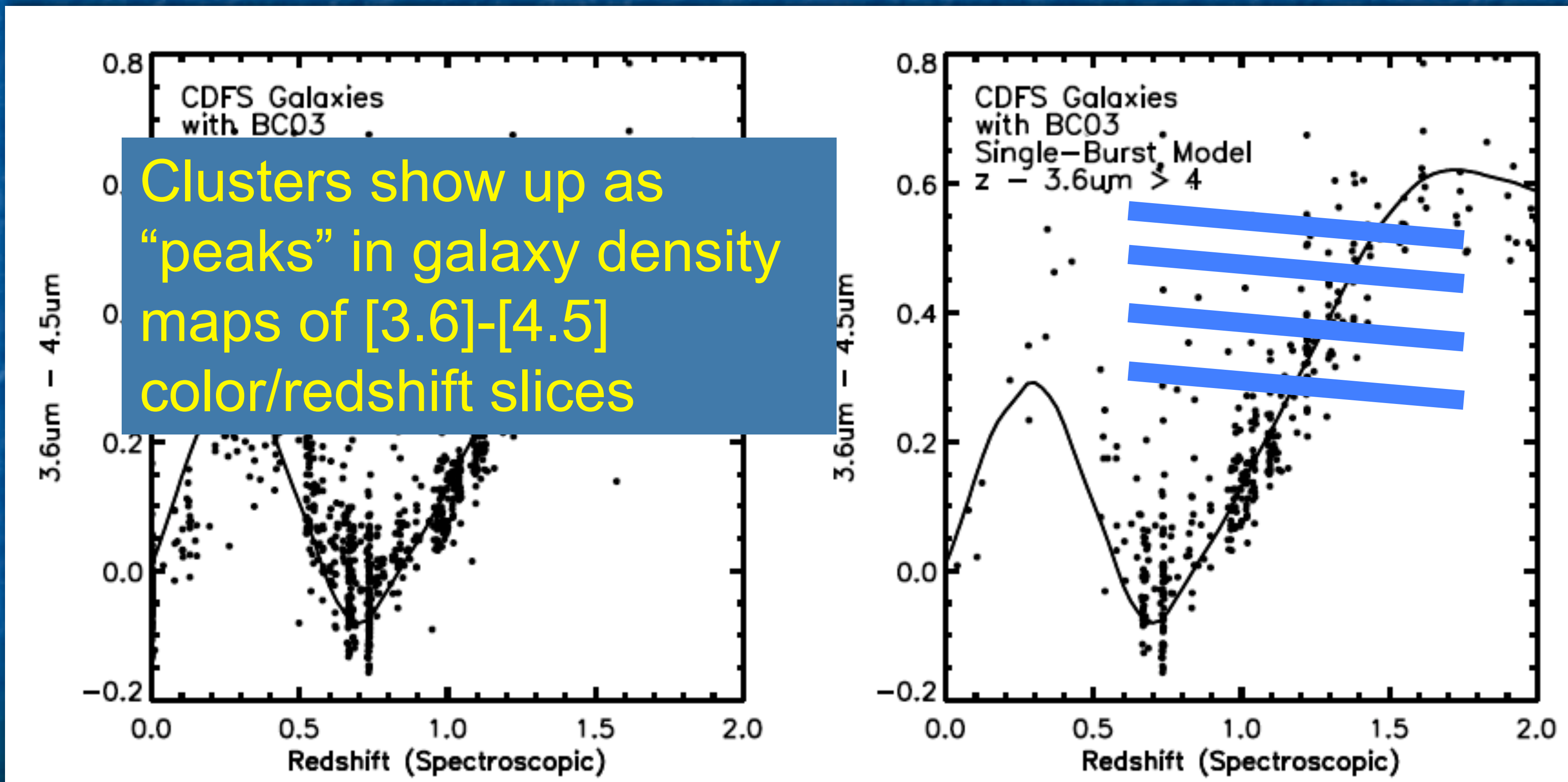
The Stellar Bump Sequence (SBS) Method

2) At z > 1, [3.6]-[4.5] color is an effective redshift indicator, because it is monotonically increasing.



Clusters show up as "peaks" in galaxy density maps of [3.6]-[4.5] color/redshift slices

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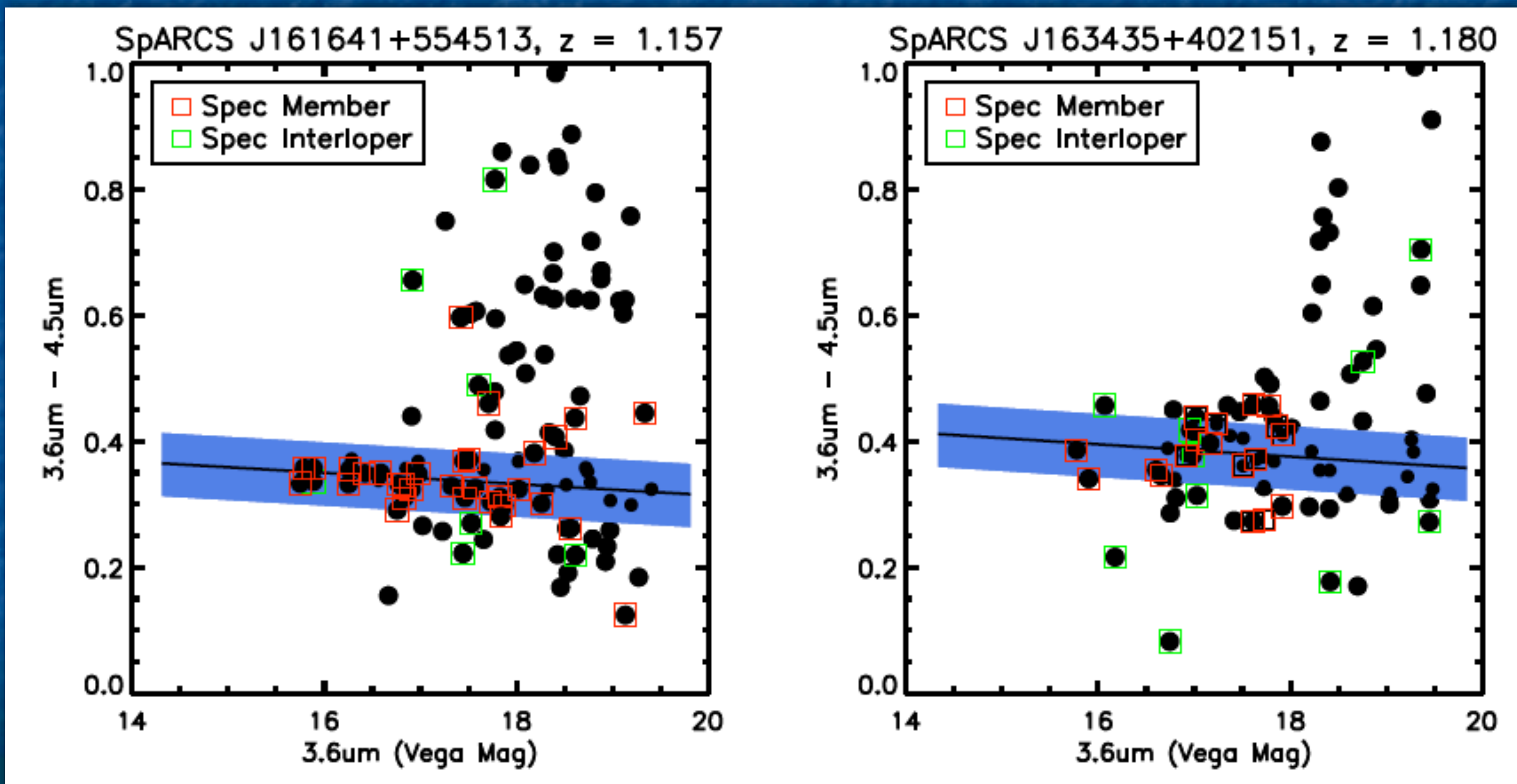
SBS Method : Sanity Check

Confirmed clusters, detected using z’-[3.6] red-sequence method,

also show [3.6]-[4.5] stellar bump sequence



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