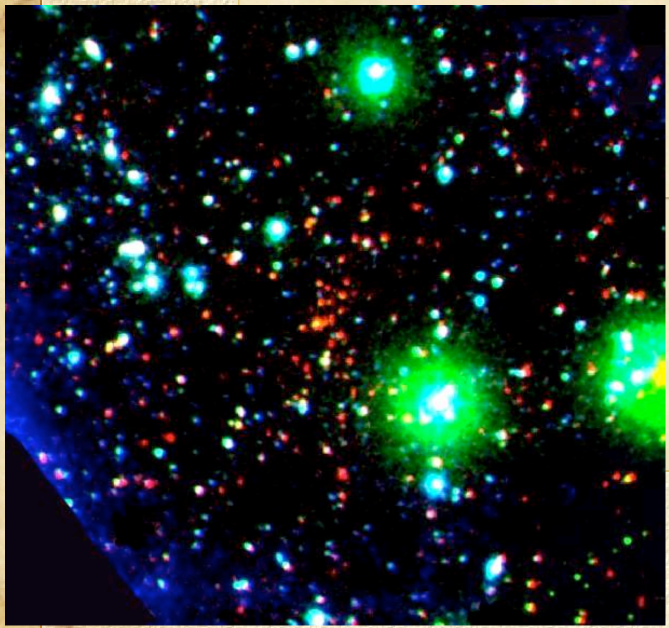
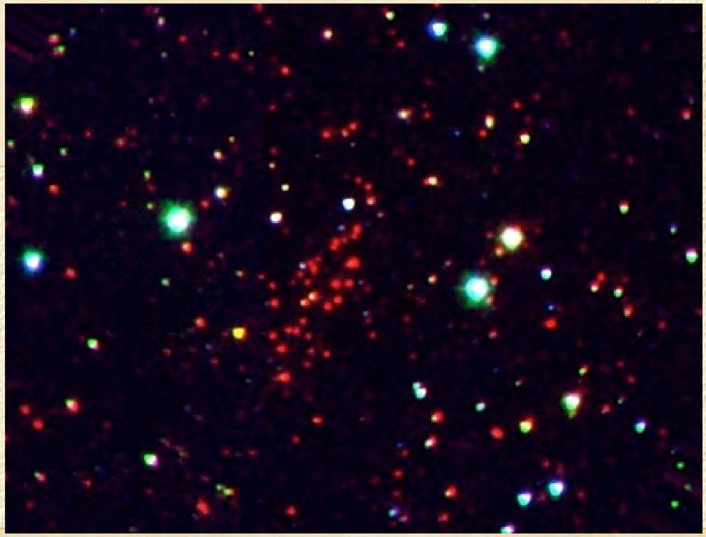
Kyoto, May, 2009

GMOS Spectroscopic Survey of z>1 SpARCS Galaxy Clusters

Howard Yee
University of Toronto
and
The SpARCS Survey collaboration





Outline:

- a brief summary of the SpARCS (**Sp**itzer **A**daptation of RCS) survey

- GCLASS (**G**emini **Cl**uster **A**strophysics **S**pectroscopic **S**urvey)
  - sample, observation technique

- preliminary GMOS spectroscopy results

Muzzin, et al. 2009, ApJ, in press (arXiv:0810.0005)
Wilson, et al. 2009, ApJ, in press (arXiv:0810.0036)

The SpARCS/CGLASS project:

US co-PI: Adam Muzzin (Yale),
Gillian Wilson (UC Riverside)

Cdn co-PI: Howard Yee (U. of Toronto)

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Subha Majumdar, TIFR;
Mike Balogh, U. Waterloo;
Doughlas Burke, Chandra Sc. Cent. ;
Erica Ellingson, U. Colorado;
Alexandro Rettura, JHU;
Renbin Yan, U. of Toronto

David Gilbank, U. Waterloo
Mark Lacy, Spitzer Science Center
Henk Hoekstra, Leiden
Mike Gladders, U. Chicago
Kris Blindert, MPIA
Shelley Bursik, U. Arkansas
Amalia Hicks; Michigan State
Tracy Webb, McGill U.

The search for high-redshift galaxy clusters:

- high-z (>~1) clusters provide a very significant lever-arm in the two major scientific motivations for galaxy cluster research:

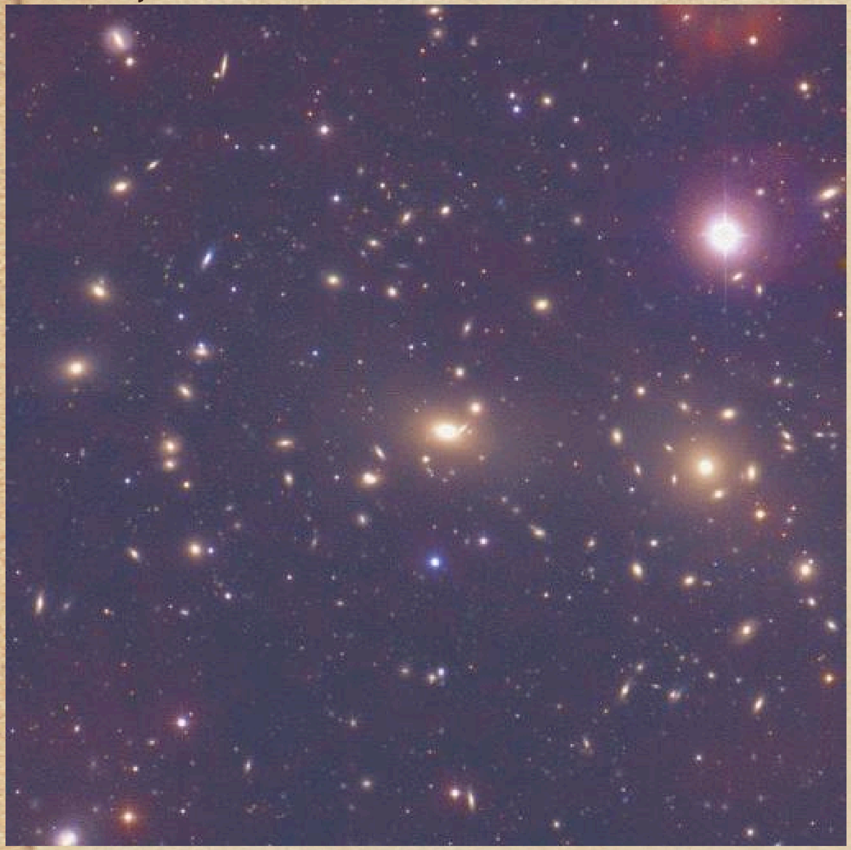
1. Growth of structures: the measurement of cosmological parameters.
2. Evolution and formation of clusters and cluster galaxies.

Cluster survey methods:

1. Optical/IR
2. X-ray
3. Sunyeav-Zeldovich effect

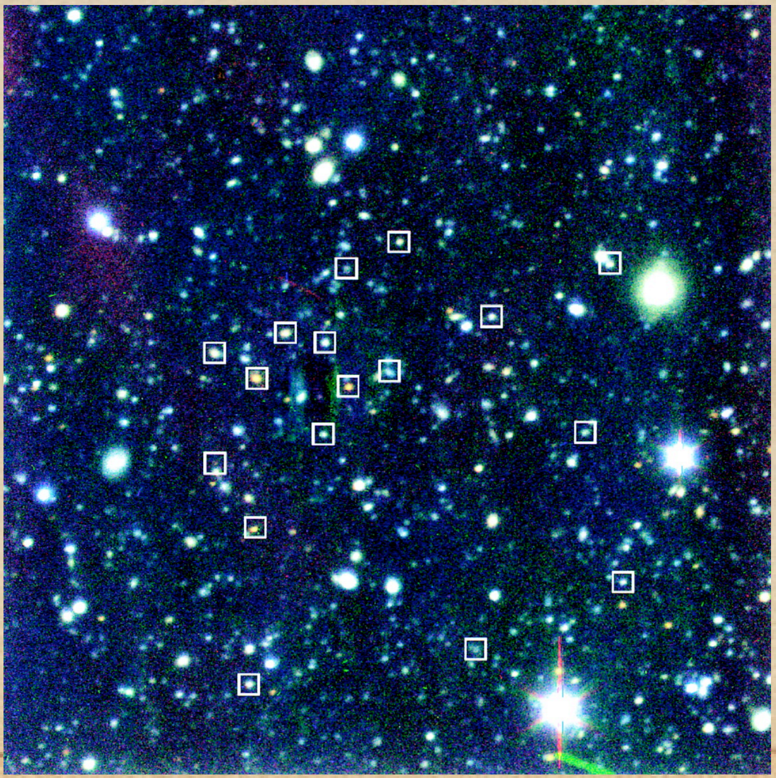
Each has advantages and disadvantages,
and its own problems in finding high-z clusters

Optical Search for Clusters



Coma
(A1656, z=.025) KPNO 0.9m,

Optical/IR searches are observational inexpensive, but suffer from increasing projection contaminations at higher z

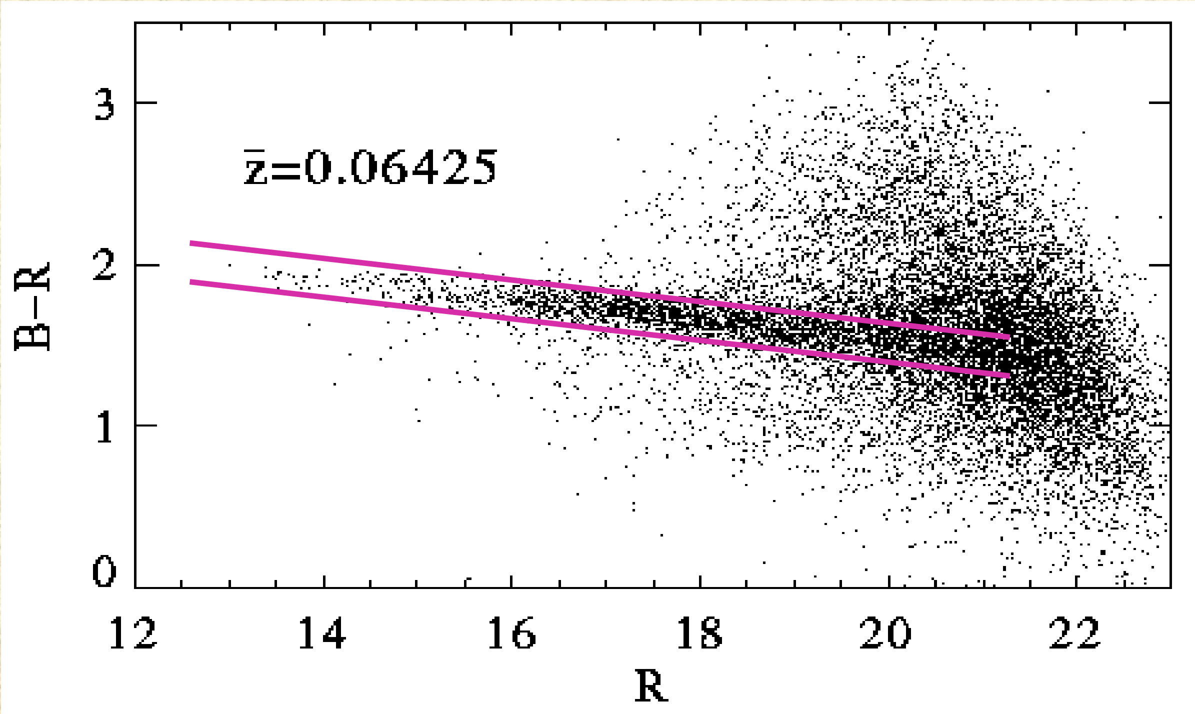


PDCS, z=0.83

The Cluster Red-Sequence Method

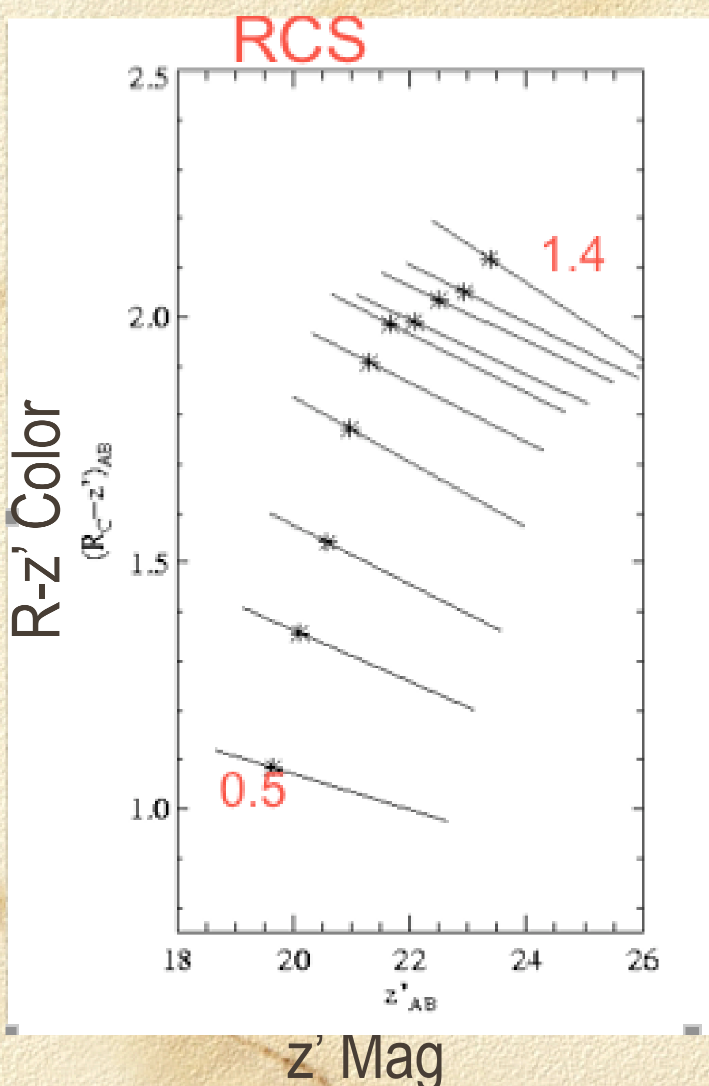
Gladders & Yee 2000, AJ, 120, 2148

Uses the early-type (red) galaxies as markers for cluster detection to eliminate most of the projection contaminations



Requires only 2 filters: Inexpensive

Color-magnitude relation of Ellipticals as a function of redshift



The RCS1

- 92 sq deg, CFHT 12k, CTIO mosaic-cam

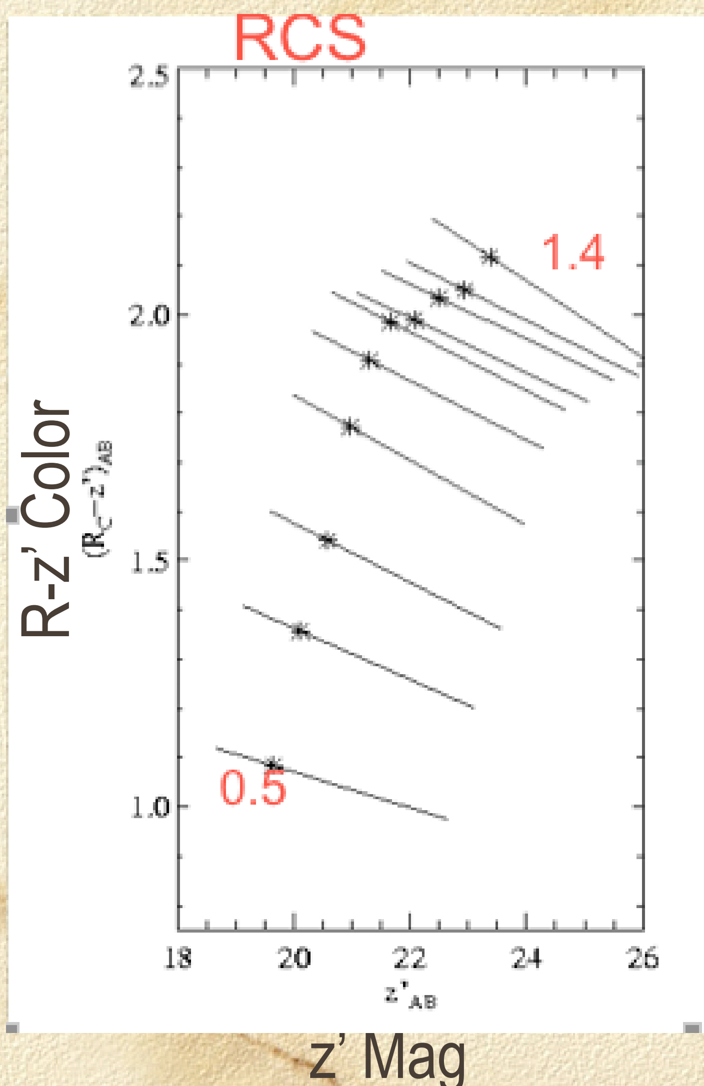
(Gladders & Yee, 2000, 2005)

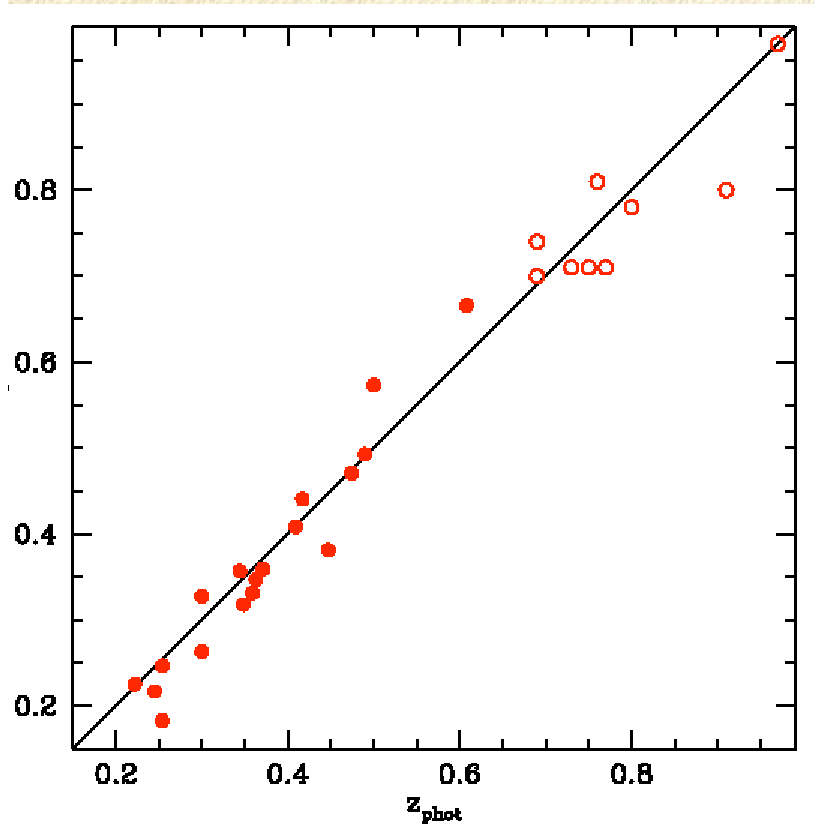
The RCS2

- 920 sq deg, CFHT Megacam

(www.rcs2.org; Yee et al, 2007, astro-ph)

Cluster photo-z from the red-sequence



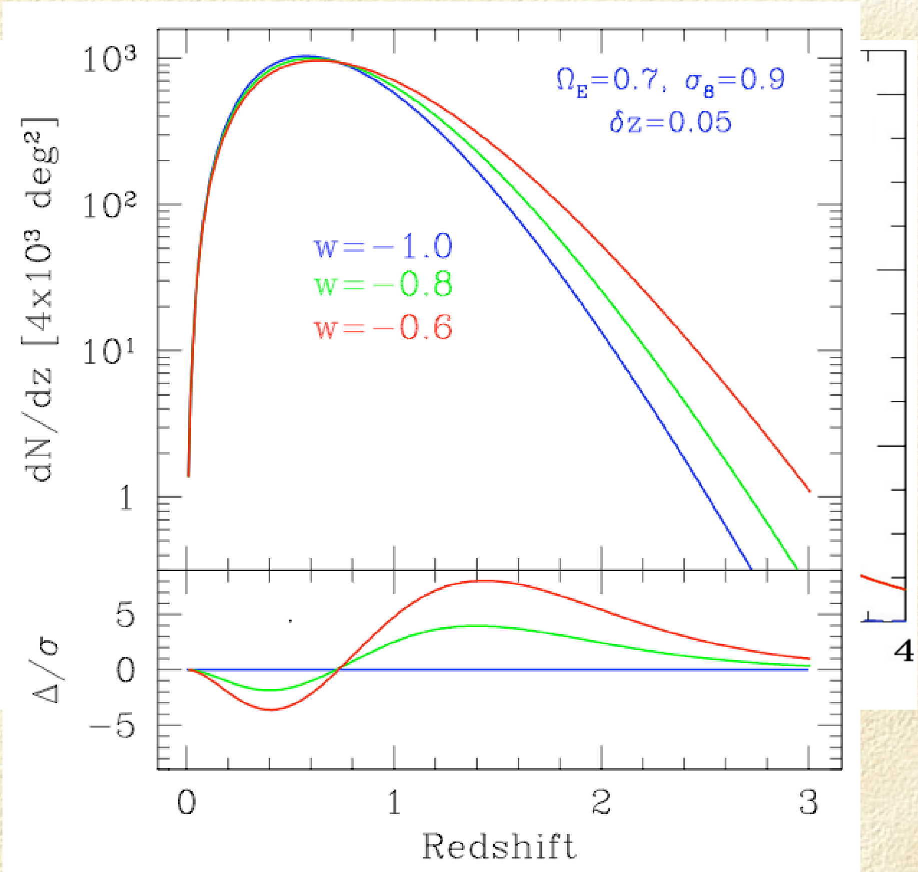


Red-sequence photo-z (2 filters) vs spectral z (RCS1 data);
$\Delta z \sim 0.03$ to 0.06;
as good as <0.02 for RCS2

At Higher z:

- closer to formation time
  → larger evolutionary effects

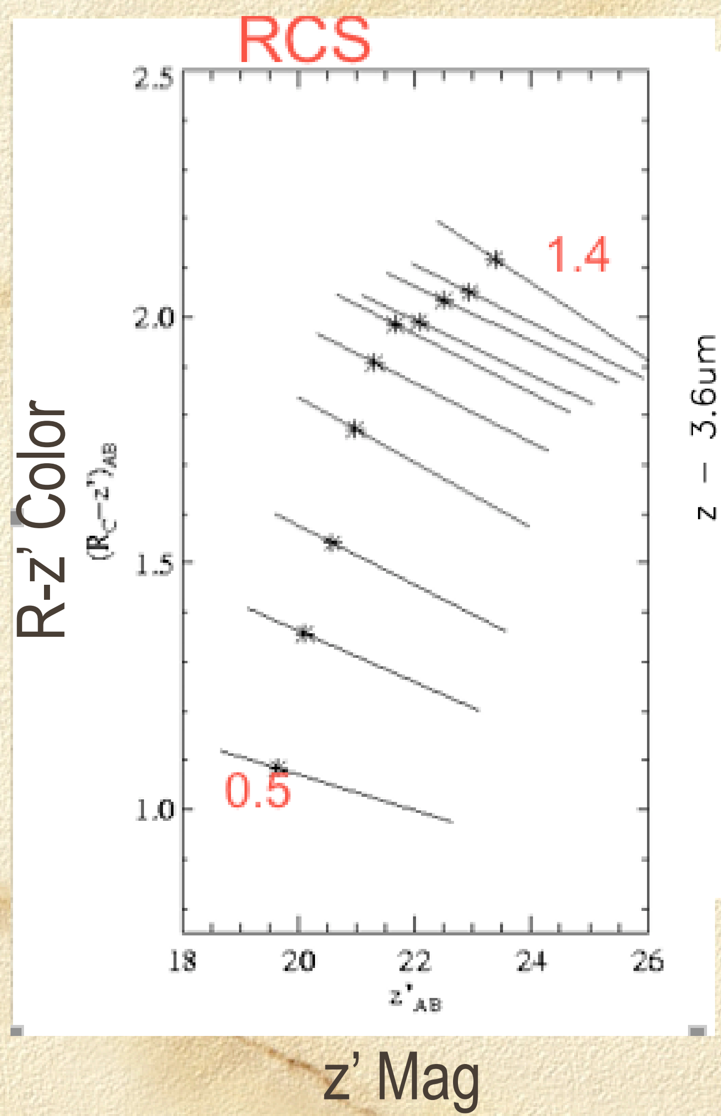
- larger differences in N(m) between different cosmological models

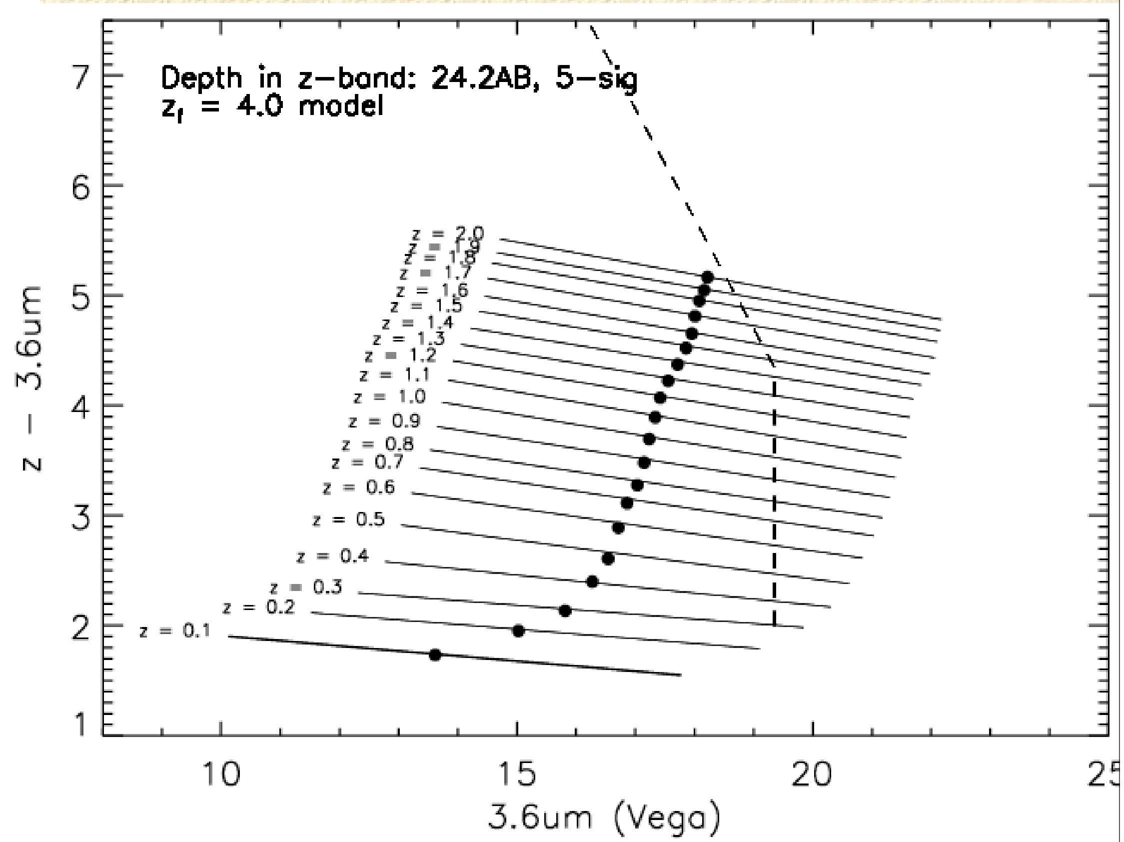


The Search for z >1 Clusters

- the RCS technique is optimized when the 2 filters straddle the 4000A break
- requires IR images for z>~1.1
  - the cluster redshift "desert": 1.2<z<2

Color-magnitude relation of Ellipticals as a function of redshift





IRAC channel 1 + z' band provides separations in the red-sequence to z~1.8

The SpARCS survey (Adam Muzzin, G. Wilson, Yee, +...)

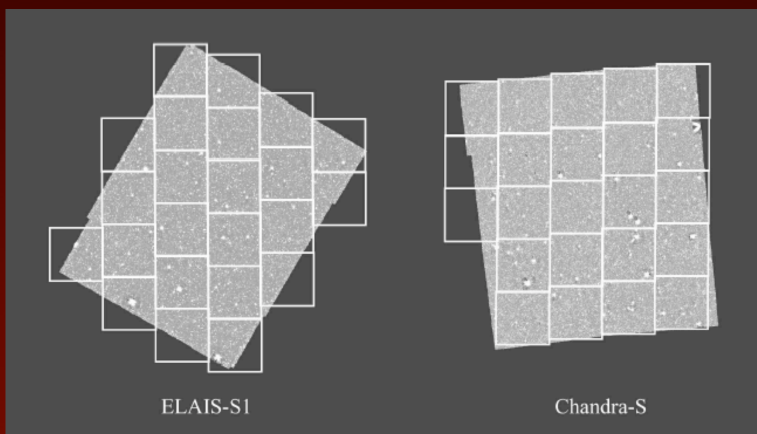
(Spitzer Adaptation of RCS)

- combine (public) Spitzer SWIRE 3.6μm data (50 sq deg) with deep ground-based z' band (~2hr integration)

- CFHT (8 nights) + CTIO (15 nights); 6 patches
  -- search for clusters to z~1.8
  -- expect ~200 clusters with z>1

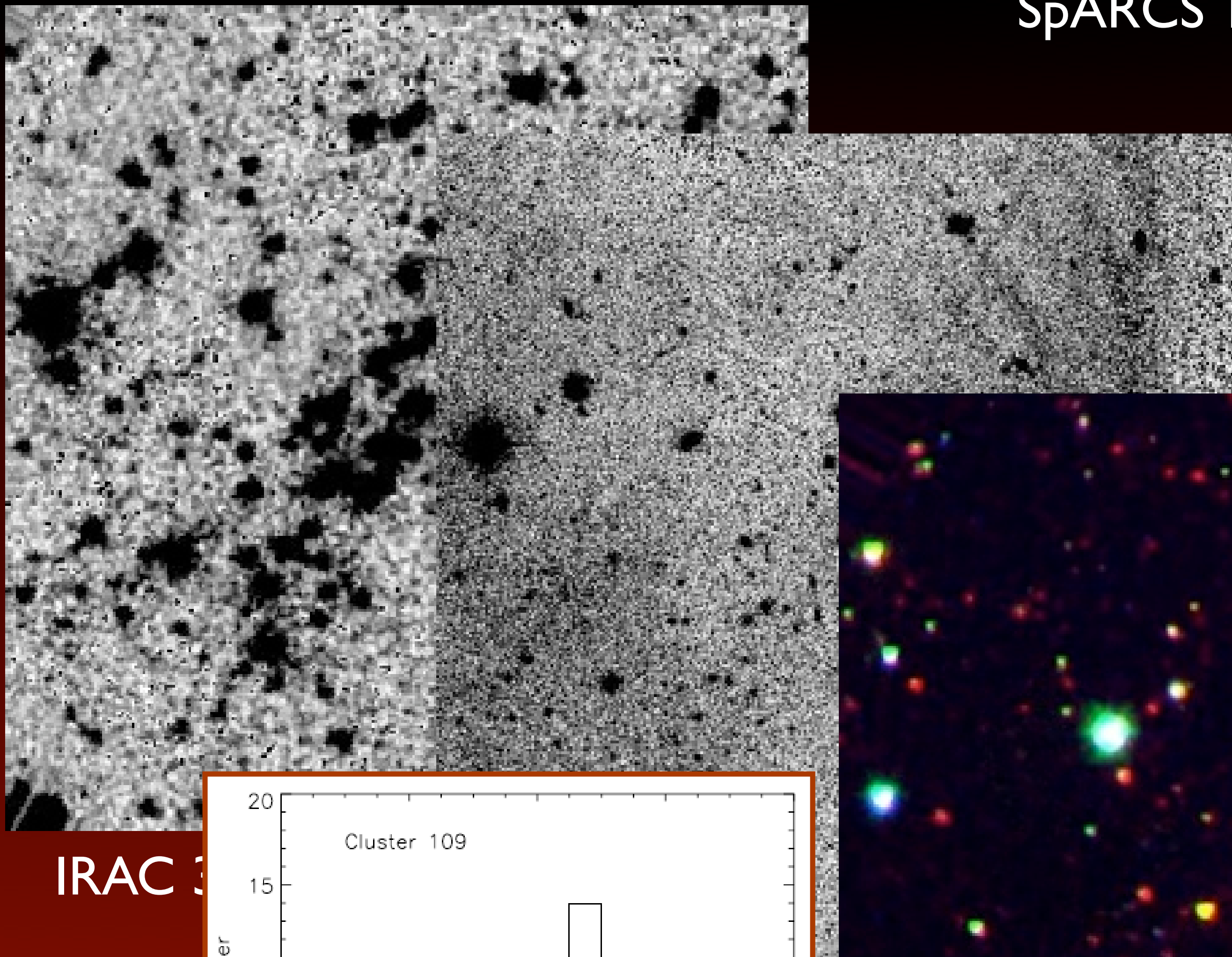
SpARCS fields: North (CFHT), 28.3 sq deg

South (CTIO), 13.6 sq deg

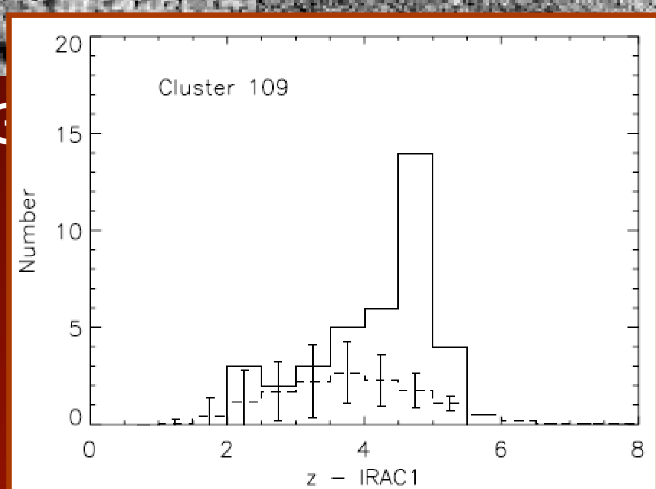


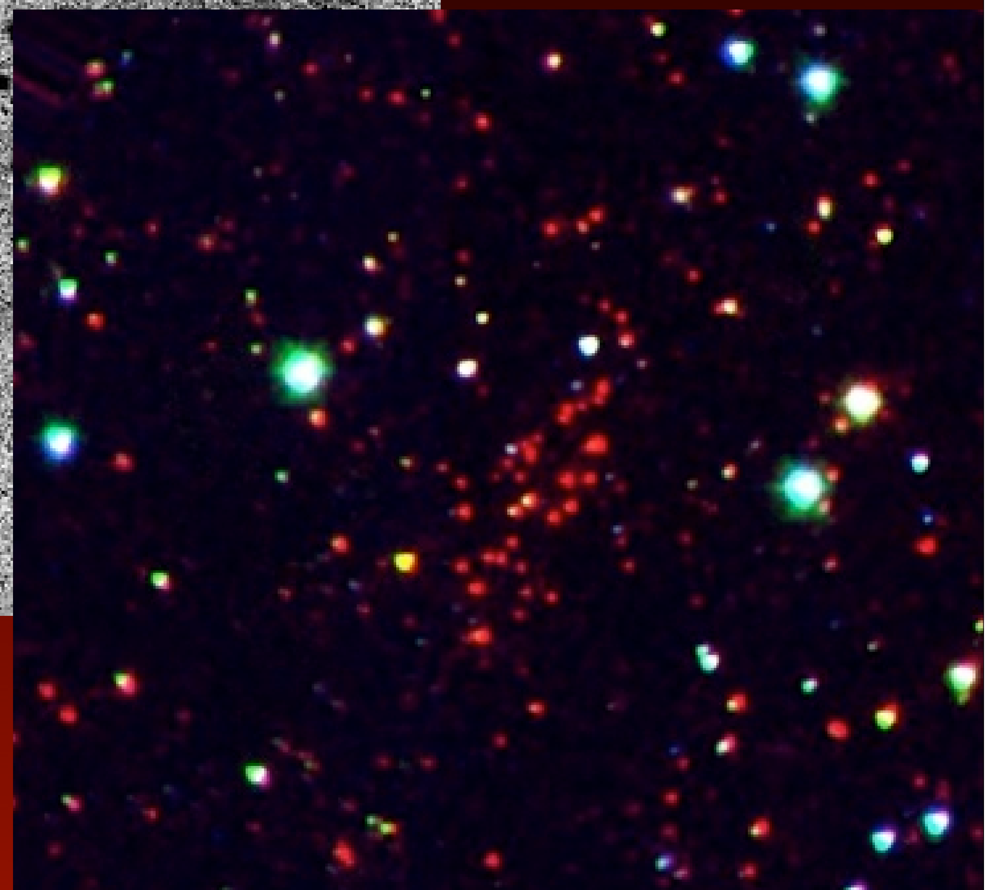
SpARCS 163435+402151`

$z_{phot} = 1.25$



IRAC 3





Spectroscopically Confirmed High-z Clusters as of end of 2007

Most distant X-ray clusters	Most distant IR clusters
z = 1.45, XMMXCS J2215.9-1738	z = 1.41, ISCS J143809+3414
z = 1.39, XMMU J2235.3-2557	z = 1.34, SpARCS J0035.7-4312
z = 1.27, RDCS J0849+4452	z = 1.24, ISCS J1434.5+3427
z = 1.24, RDCS J1252.9-2927	z = 1.20, SpARCS J1638.8+4039
z = 1.22, XLSS J022303-043622	z = 1.18, SpARCS J1634.5+4021

Spitzer has nearly doubled the number of known distant clusters in just a few years!

The Gemini GMOS Survey of High-Redshift SpARCS Clusters

The anchor of a comprehensive mulit-wavelength program to study 10 rich hight-z SpARCS clusters (nine at z>1, one at z=0.9);

including:

- ~50 spectroscopic members per cluster
- multi-band opt/IR imaging
- MIPS, SCUBA2, radio imaging
- Chandra X-ray imaging
- HST imaging

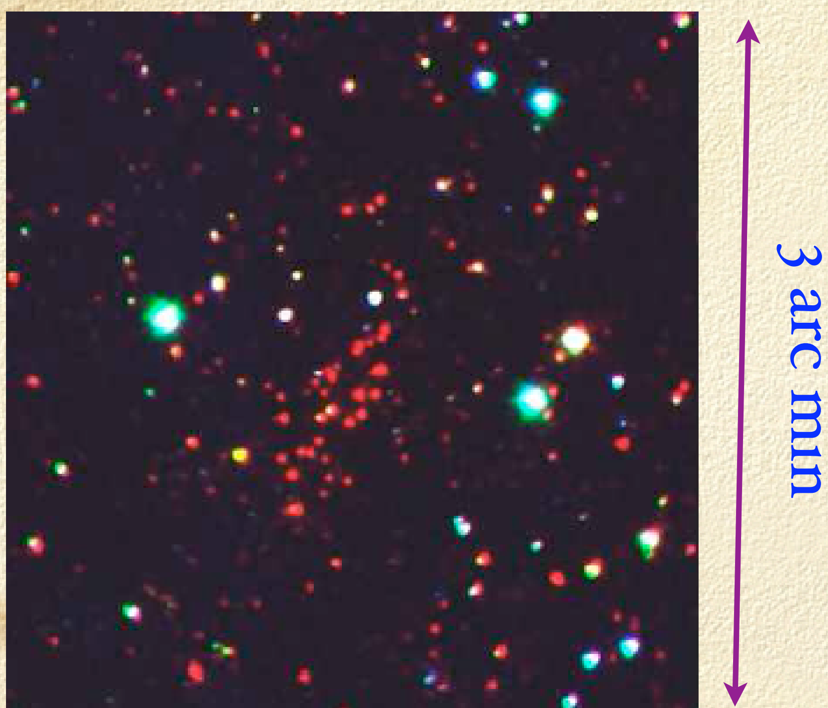
Observation:

GMOS: band nod-&-Shuffle mode
R150 grism, 1.74Å per pixel
1" slit, giving a resolution of 17Å (~200km/s)

Each cluster: 4 masks,
integration time: ~3 hrs/mask;
(4 hrs for the highest z)
S/N~ 3-4 per pixel (z'<22.5)

Total time (including N&S overhead, pre-imaging etc):
197 hrs, split equally Canada/USA

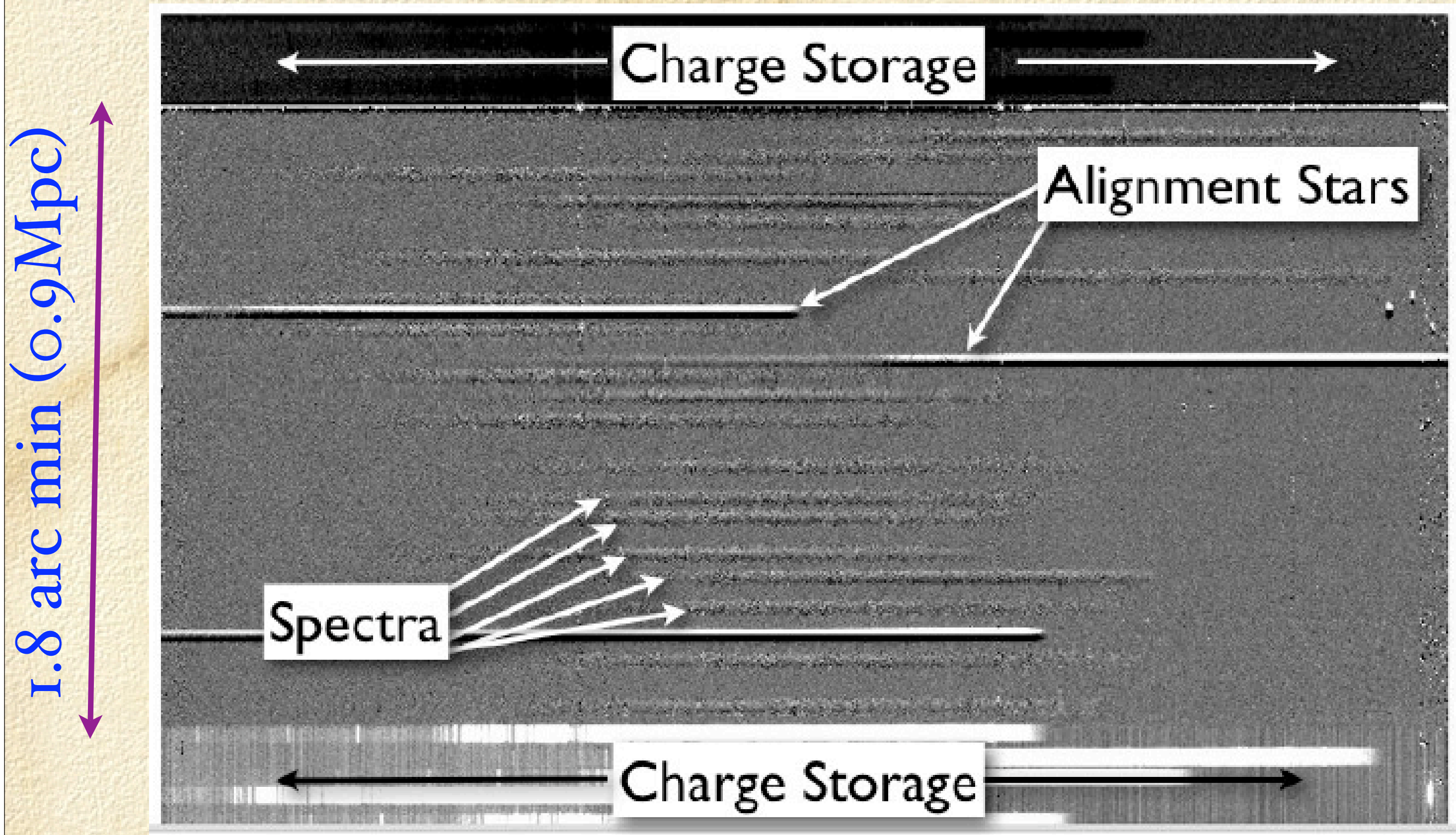
Galaxy clusters at $z>\sim1$ are compact on the sky, with the core subtending ~1-2 arcmin



→ can only place a limited number of slits in the region with the highest excess number of galaxies,

even with nod&shuffle

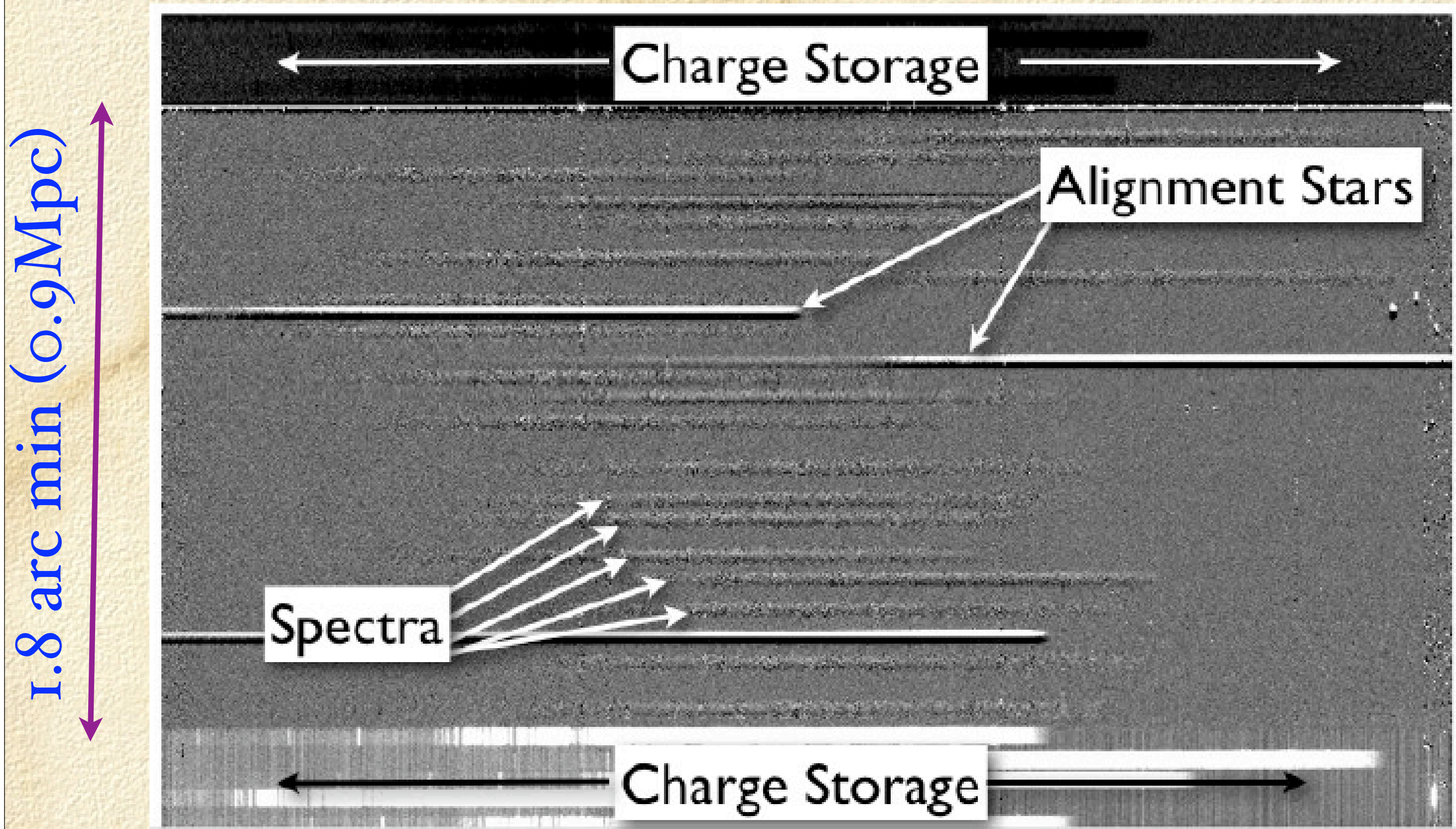
Nod & Shuffle, with band-shuffling



3” micro-slits (1.5” on; 1.5” off)

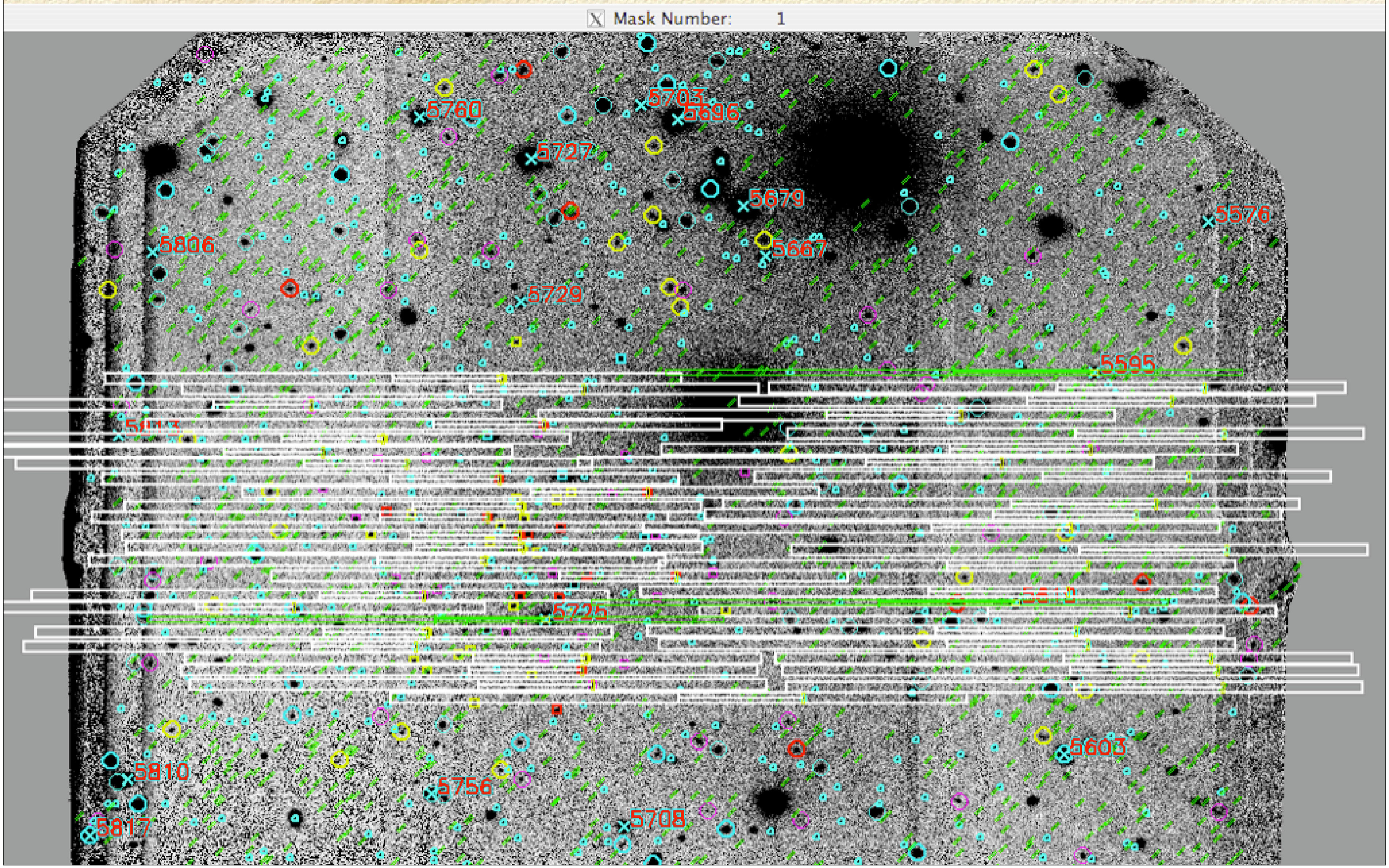
charges are shuffled and stored in the top and bottom 3rd
(as oppose to storing immediately adjacent to the slits)

Nod & Shuffle, with band-shuffling



- typically 25 slits within the 1 Mpc core of the clusters; compared to standard mask design/N&S: 10-15 slits
- able to obtain 20-30 member redshifts using 3 to 4 masks
- factors of 2 to 3 more efficient (in comparison with similar VLT/Keck programs).

New strategy/ more efficient (own) mask design program for 09A: 50+ slits per mask

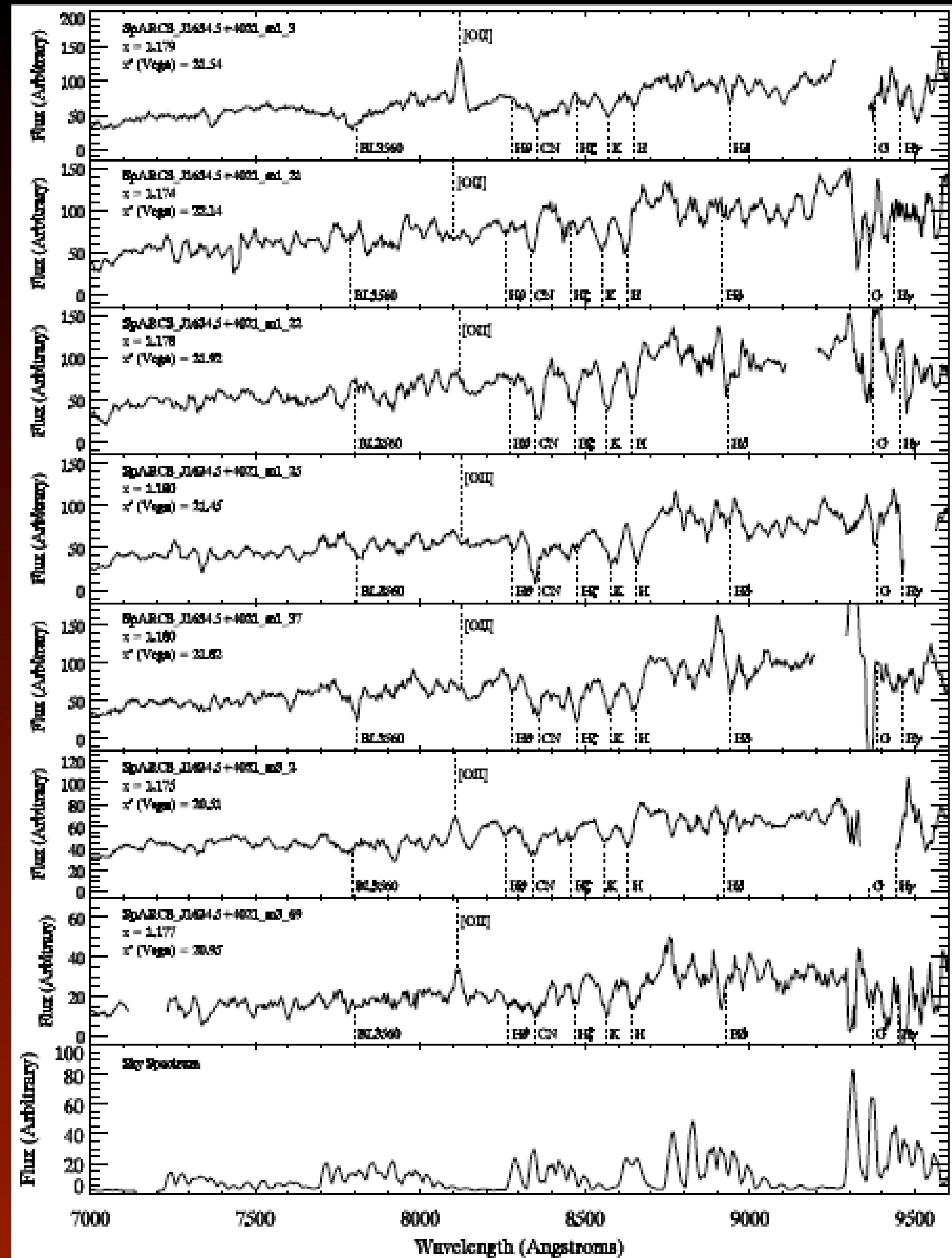


A 48 slit mask

- more efficient double-tiering by placing the center of the cluster to one side (and reverse the position for the next mask)

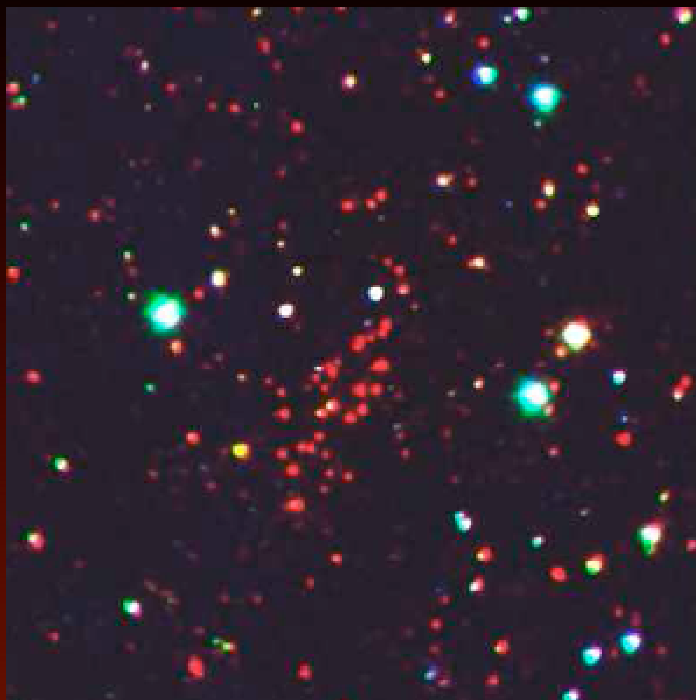
- own mask design program (Muzzin) to overcome inefficiencies in the Gemini-provided program:
  - arbitrary number of priority bins (instead of max 3)
  - tighter placements of slits
  - more flexible placements/choices of alignment stars

SpARCS 163435+402151

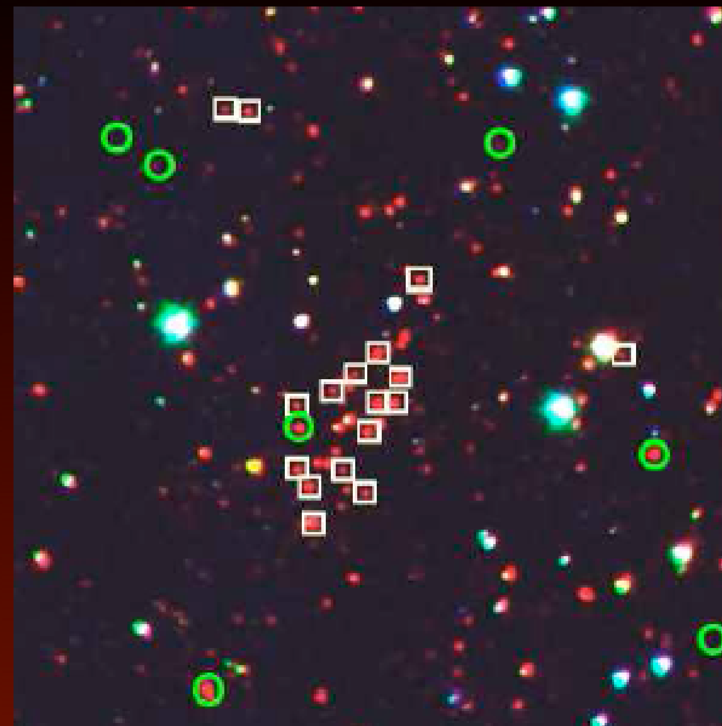


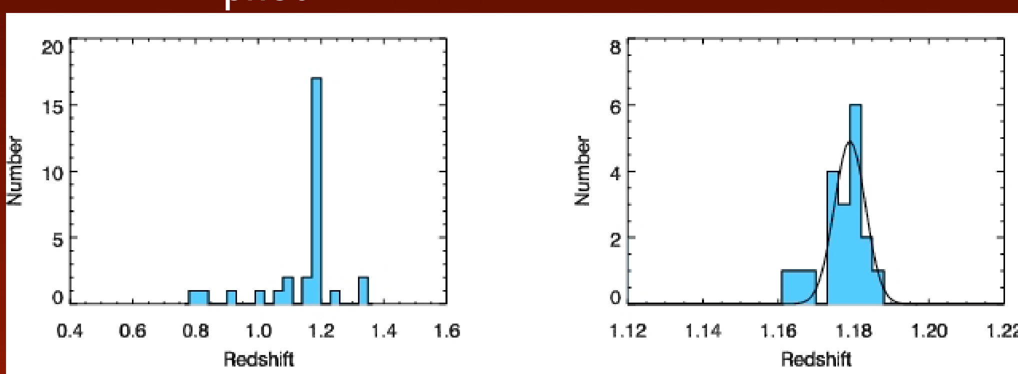
z_{phot} = 1.25

SpARCS 163435+402151`



$z_{phot} = 1.25$





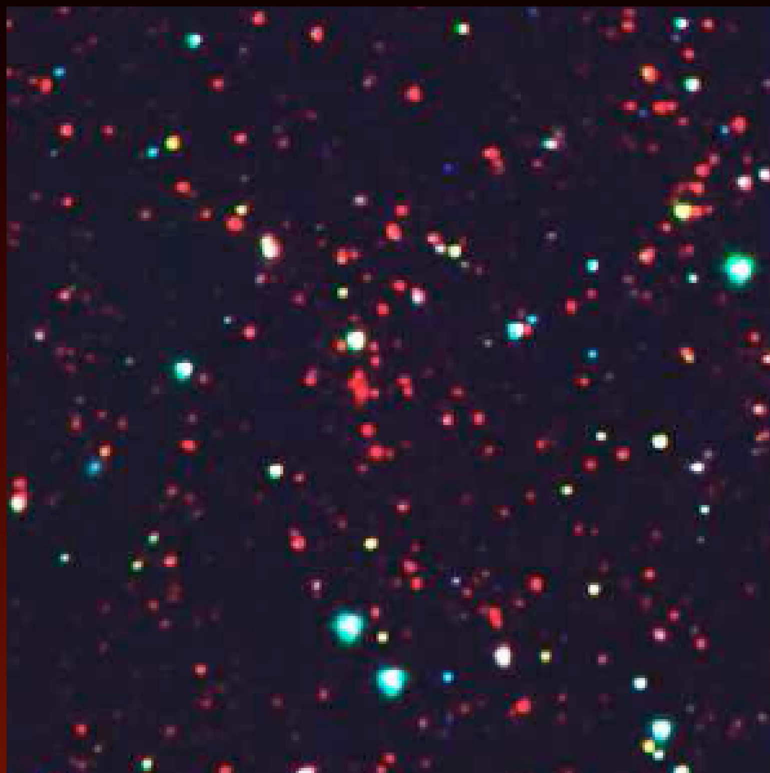
17 spectroscopic members

$z = 1.1798$

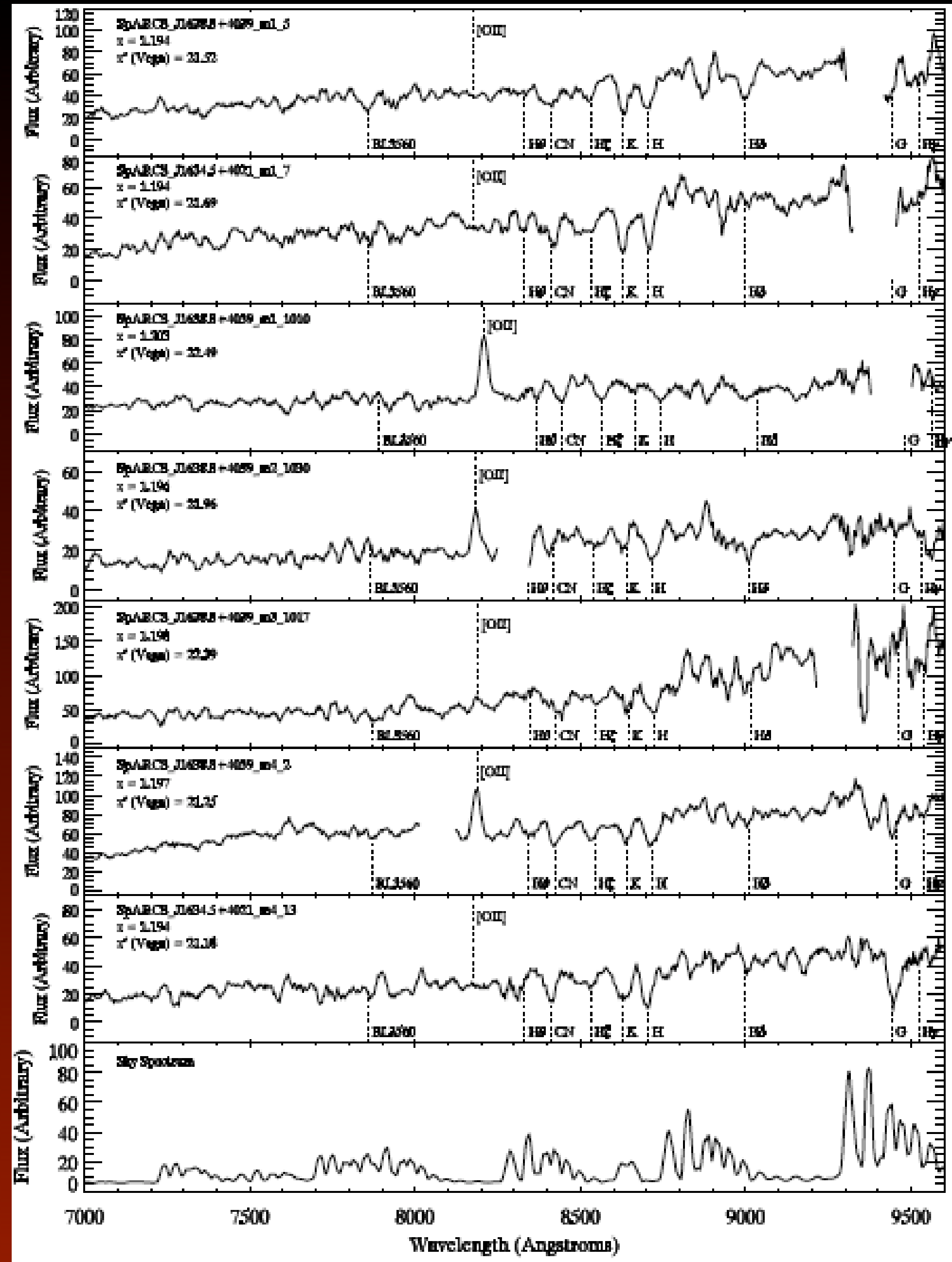
$\sigma = 490 \pm 140$ km/s

$M_{200}=1.0^{+1.1}_{-0.6} \times 10^{14} M_{sun}$

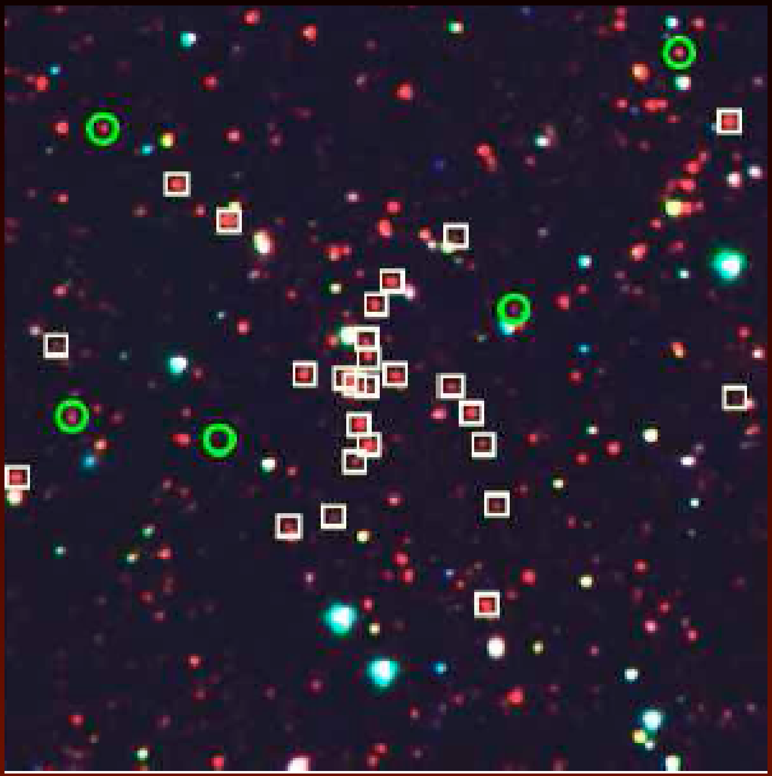
SpARCS 163852+403843



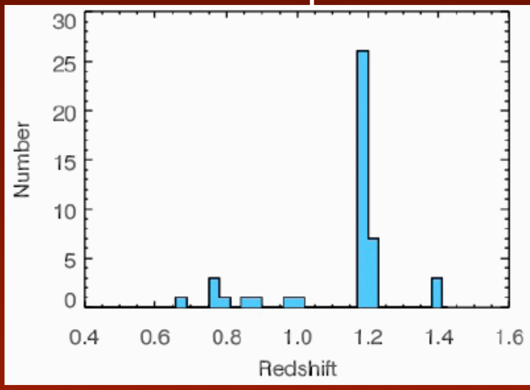
$z_{phot} = 1.3$

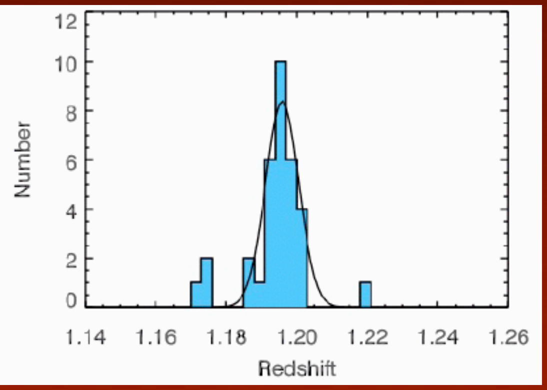


SpARCS 163852+403843



z_{phot} = 1.3





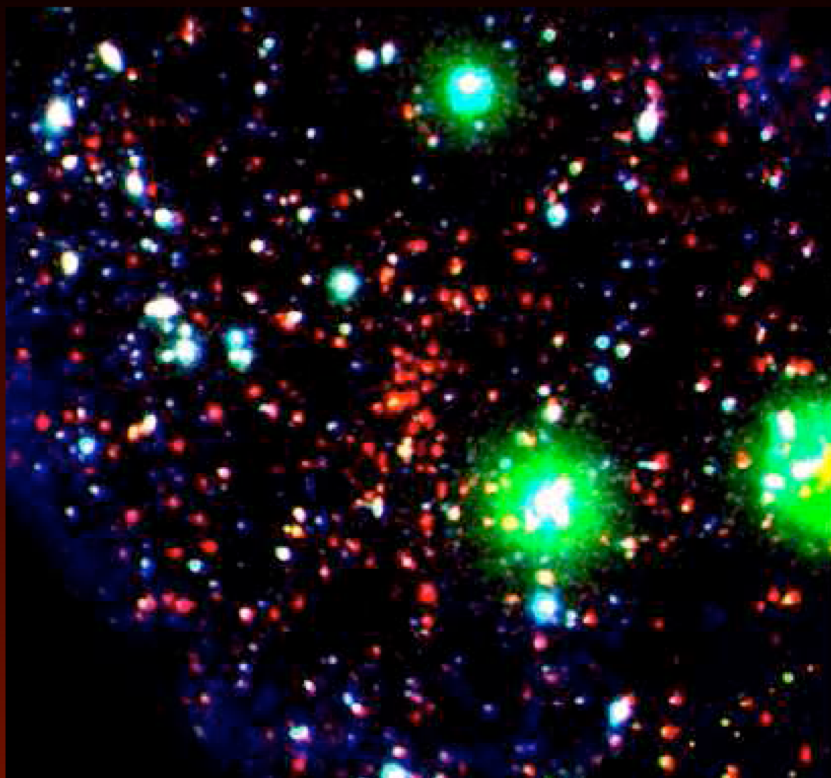
28 spectroscopic members

$z = 1.1963$

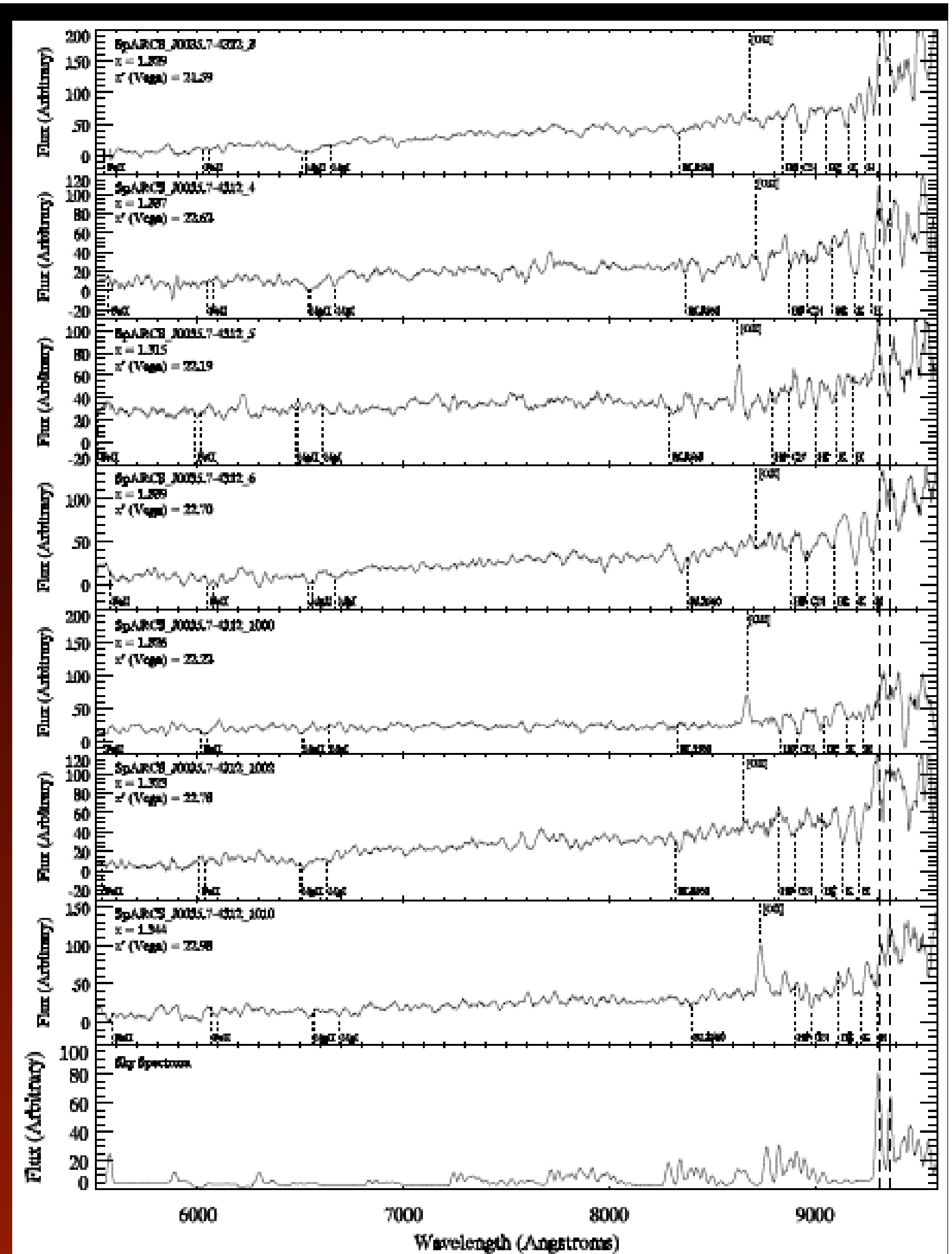
$\sigma = 650 \pm 150$ km/s

$M_{200} = 2.4^{+2.2}_{-1.4} \times 10^{14} M_{sun}$

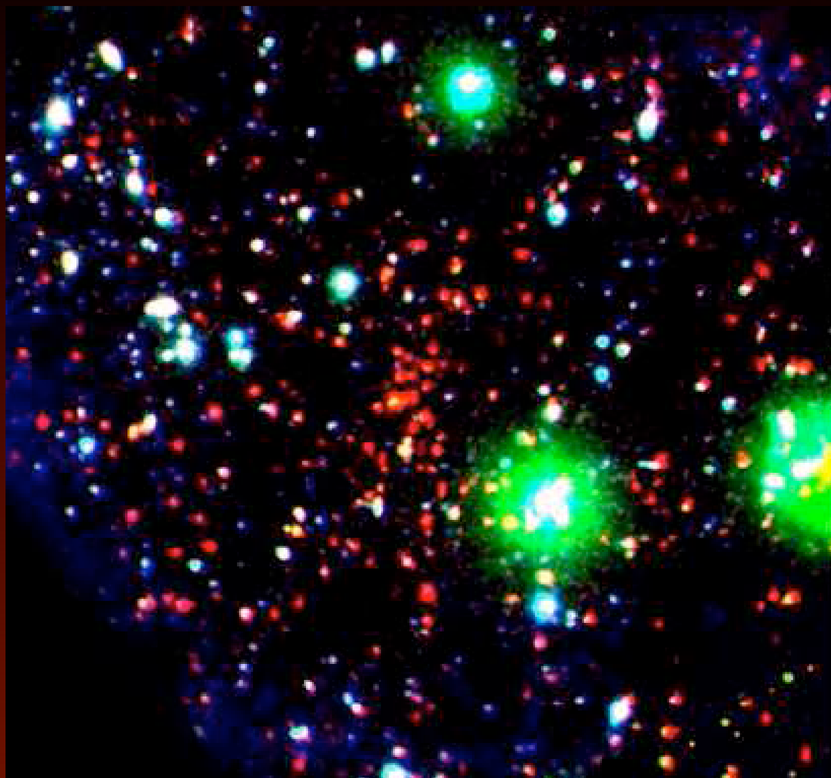
SpARCS 003550-431124

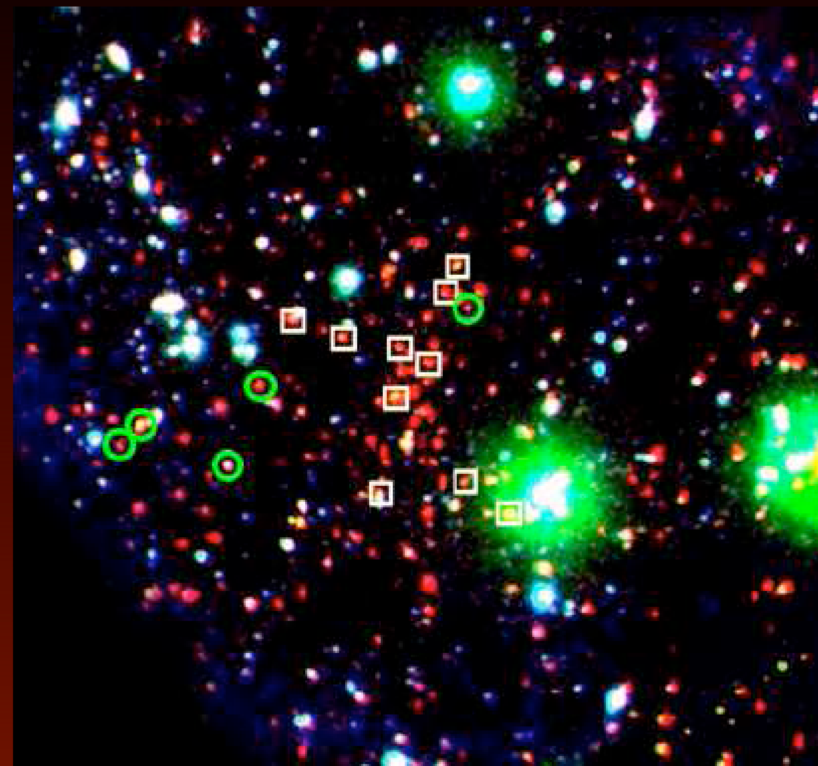


$z_{phot} = 1.6$

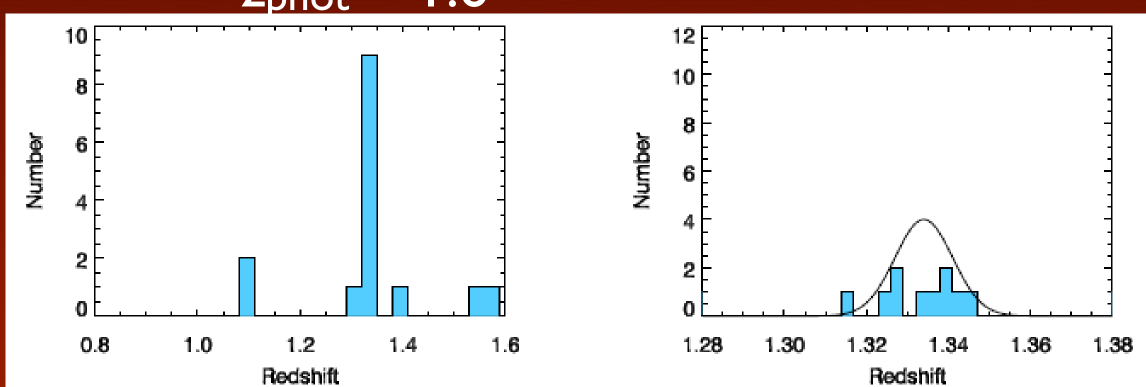


SpARCS 003550-431124





z_{phot} = 1.6

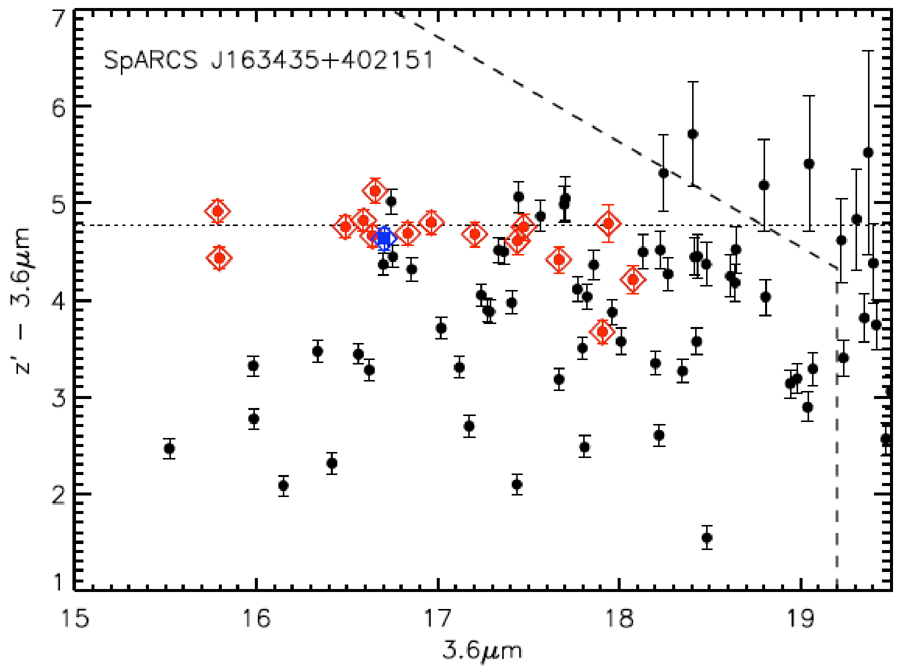


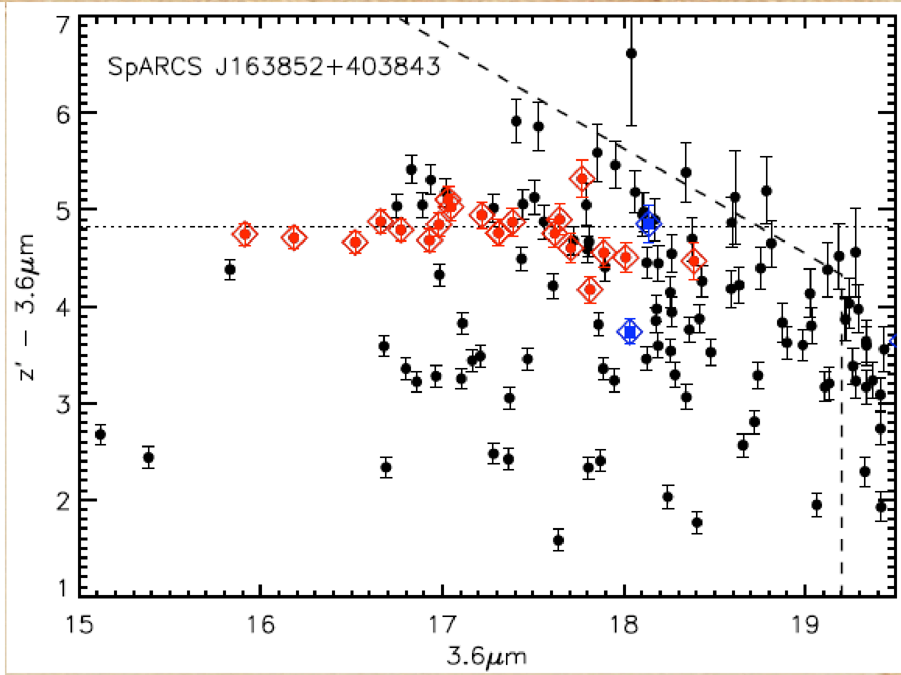
10 spectroscopic members

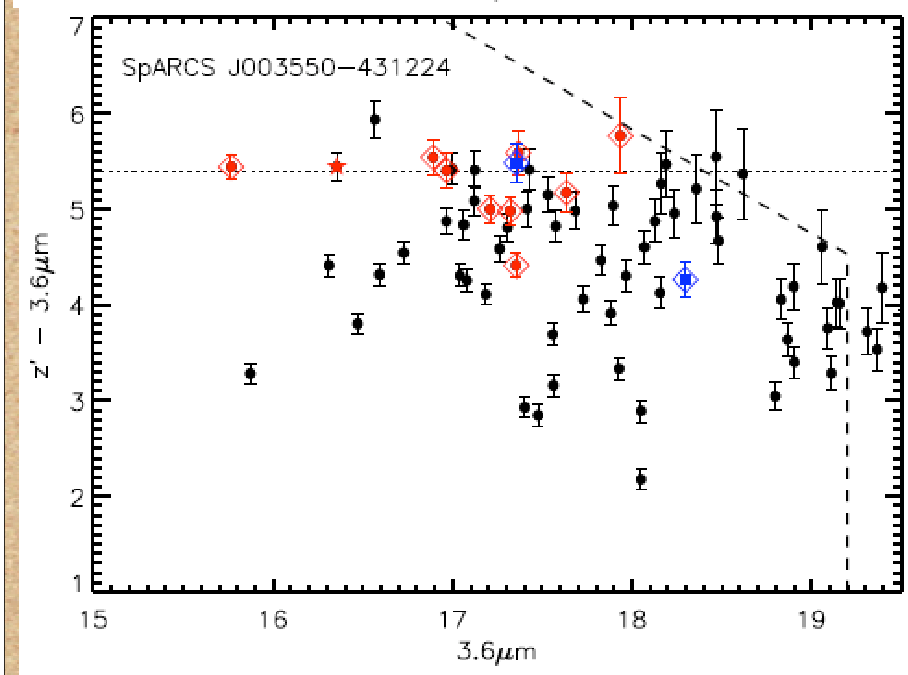
z = 1.335

σ = 1050 ± 230 km/s

$M_{200} = 9.4^{+4.5}_{-1.4} \times 10^{14} M_{sun}$







Cluster CDMs

Summary:

- The extension of the optical red-sequence method to the IR is a powerful technique in discovering galaxy clusters at $z>1$, and potentially to $z\sim2$.

- Gemini GMOS with the band Nod-&-Shuffle technique provides arguably the most efficient combination for multi-object spectroscopy of high-redshift clusters; allowing an useful number of cluster member redshifts to be obtained in a reasonable time

- spectroscopic confirmation of SpARCS high-z clusters:
  so far 100% confirmation;
  dynamical mass consistent with richness;
  well-established red-sequence galaxies