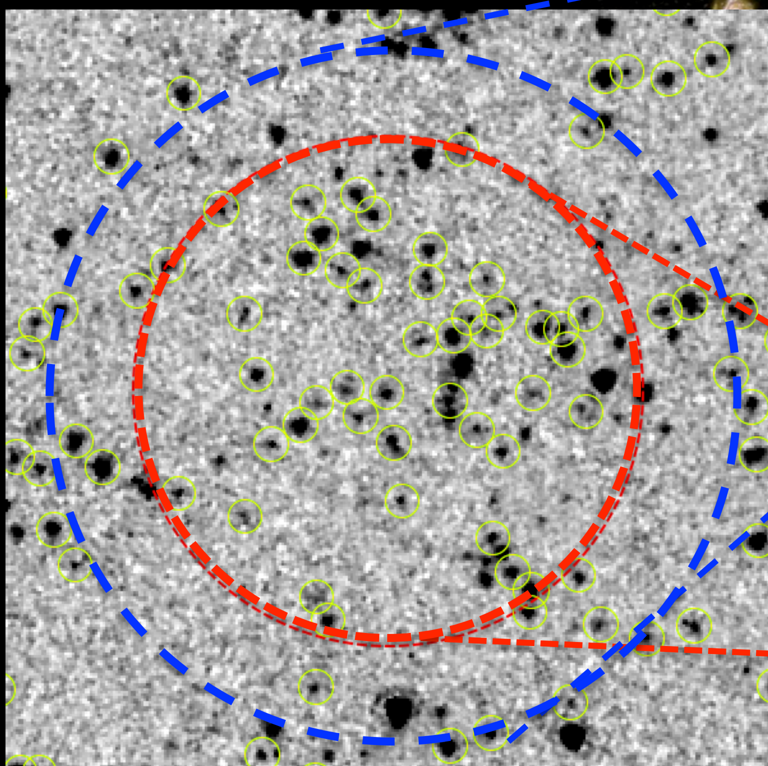
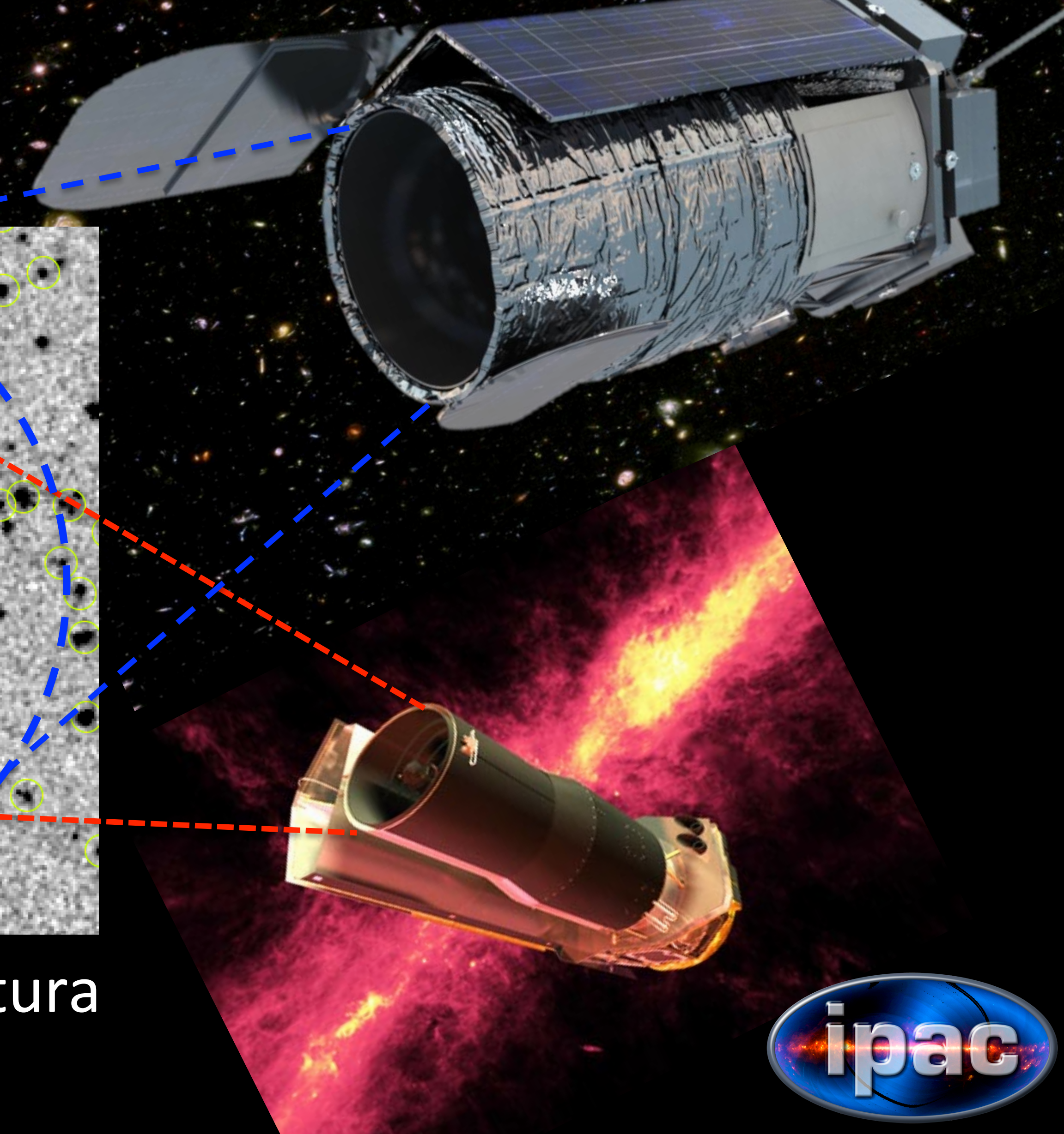
The search for the most distant clusters with *Spitzer*: synergies with *WFIRST~AFTA*





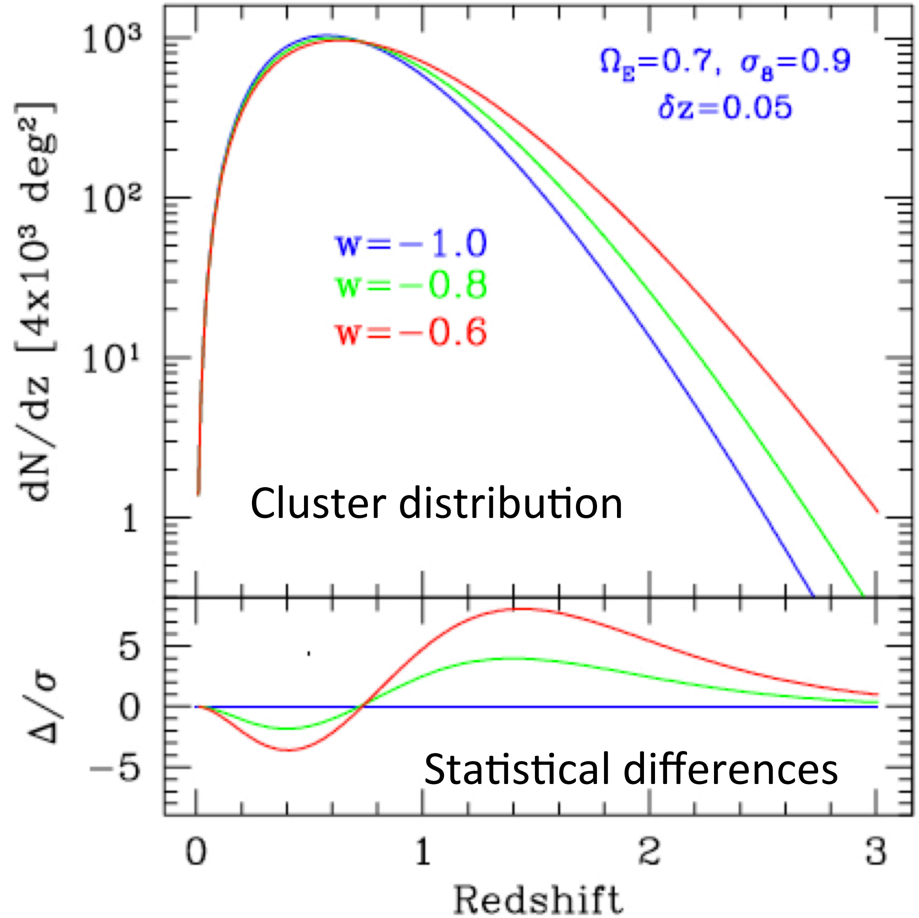
Alessandro Rettura

Caltech - IPAC

Galaxy clusters trace baryon and dark matter content and distribution

The redshift distribution of detected high redshift clusters in a deep, large survey is highly sensitive to the dark energy equation of state.

In combination with low-z clusters, following redshift evolution breaks parameter degeneracy



Mohr et al. 2003

Galaxy Clusters : Tools for WFIRST-AFTA cosmology

Abundance of rich clusters as a function of mass and redshift allows to trace the growth rate of structure.

Key uncertainty in this approach is accurate calibration of cluster mass scale.

WFIRST deep lensing observations will determine accurate mass determination of clusters.

Cluster abundances can then be used to determine the effects of dark energy on the growth rate.

Galaxy Clusters, tools for WFIRST-AFTA cosmology : hosts of Type Ia SNe

- Type Ia SNe provided the first strong evidence for cosmological acceleration (Riess et al. 1998; Perlmutter et al. 1999)

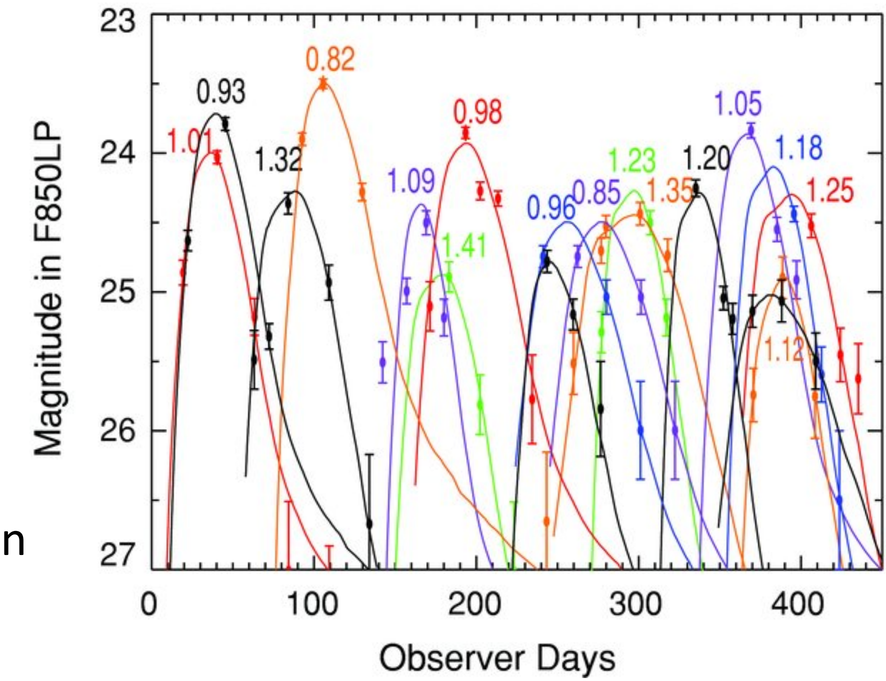
- By targeting massive galaxy clusters at $0.9 < z < 1.5$, a threefold improvement:

  – in the efficiency of finding SNe (compared to an HST field survey)

  – and a factor of three improvement in the total yield of SN detections in relatively dust-free red-sequence galaxies.

  -Decouple the effects of host-galaxy extinction and intrinsic color in high-redshift SNe, reducing one of the largest systematic uncertainties in SN cosmology

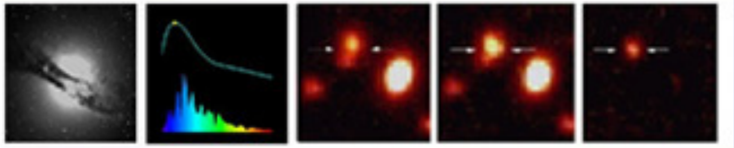
Sixteen new SNe were discovered at $z>0.95$!



Dawson et al. 2009, Suzuki et al. 2012

P.I.: Perlmutter

SCP Supernova Cosmology Project

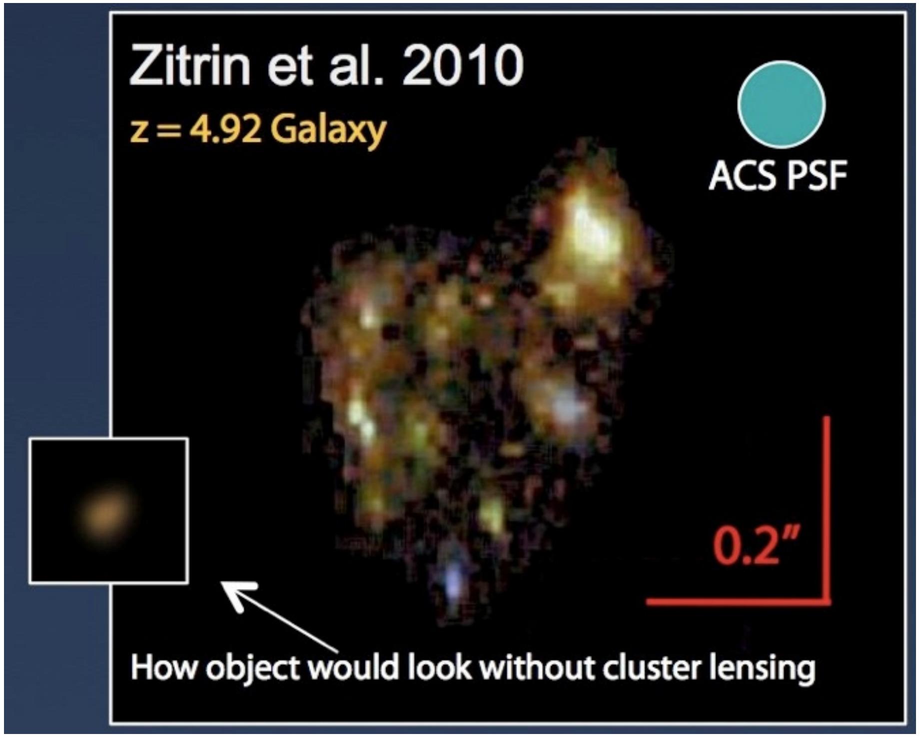


Galaxy Clusters as Cosmic telescopes: Discovery and study of first galaxies with WFIRST

CLASH has lead the way in coupling the gravitational lensing power of massive galaxy clusters with space-based enhanced panchromatic imaging capabilities

Test of structure formation models with unprecedented precision.

Discovery of very distant galaxies with unprecedented details



P.I.: Postman

Motivation

Tools for cosmology : **Redshift distribution, baryon and dark matter content**

$\sigma 8$, dark energy, universe's equation of state

Hosts of type Ia Supernovae, dark energy

Cosmic telescopes: Discovery and study of first galaxies

Tools for galaxy evolution studies: mode and epoch of massive galaxy formation

environmental effects, baryon-dark matter interaction

Goal

Finding large samples of mass-selected clusters at high-redshift (1.3 < z < 2)

Current Generation of $z \geq 1$ Cluster Surveys

- **Infrared**
  - ISCS/IDCS (IRAC Shallow/Distant Cluster Survey)
  - SpARCS (Spitzer Adaptation of Red-sequence Cluster Survey)
  - UKIDSS DXS (UKIRT Infrared Deep Sky Survey Deep Extragalactic Survey)
  - SSDF (Spitzer SPT Deep Field Survey)
  - CARLA (Clusters around Radio-Loud AGN)
  - MaDCoWS (Massive Distant Clusters of WISE Survey)

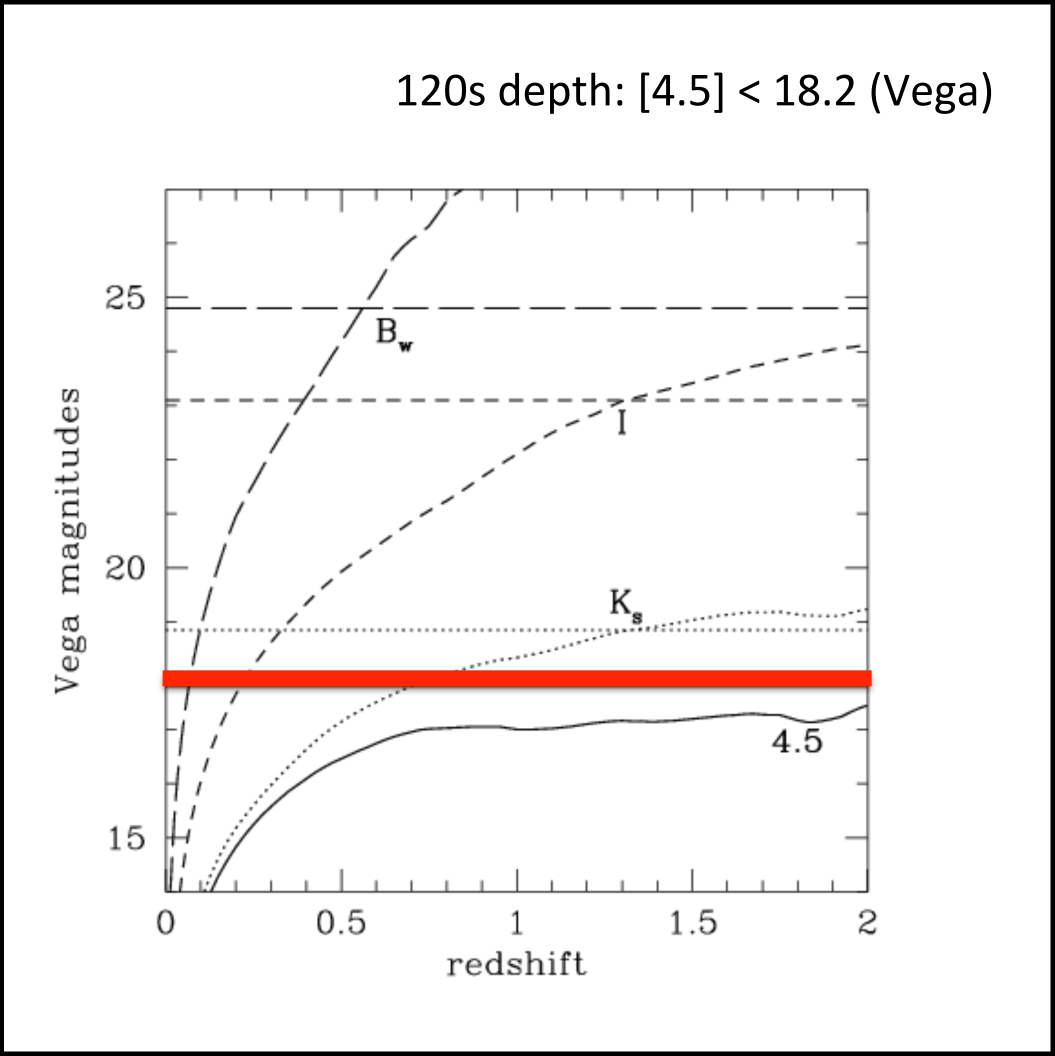
- **Optical**
  - DES (DARK ENERGY SURVEY)

- **Sunyaev-Zel'dovich Effect**
  - ACT (Atacama Cosmology Telescope)
  - SPT (South Pole Telescope)
  - Planck

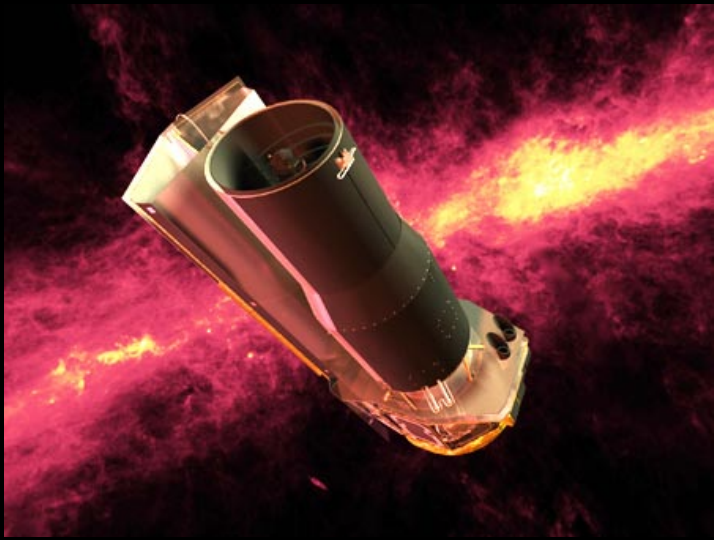
- **X-ray**
  - XMM-XXL
  - XMM-LSS (XMM Large-Scale-Structure Survey)
  - XCS (XMM Cluster Survey)
  - XDCP (XMM-Newton Distant Cluster Project)
  - eROSITA (extended Roentgen Survey with an Imaging Telescope Array) (Launch 2015)

- **Future Near-Infrared Survey**
  - EUCLID
  - WFIRST

Spitzer Space Telescope



Eisenhardt et al. 2008



Large, homogeneous Spitzer high redshift cluster surveys:

-provide exciting targets for WFIRST

-provide a training set to identify additional clusters outside of the Spitzer footprint

SSDF: Spitzer-SPT Deep Field survey

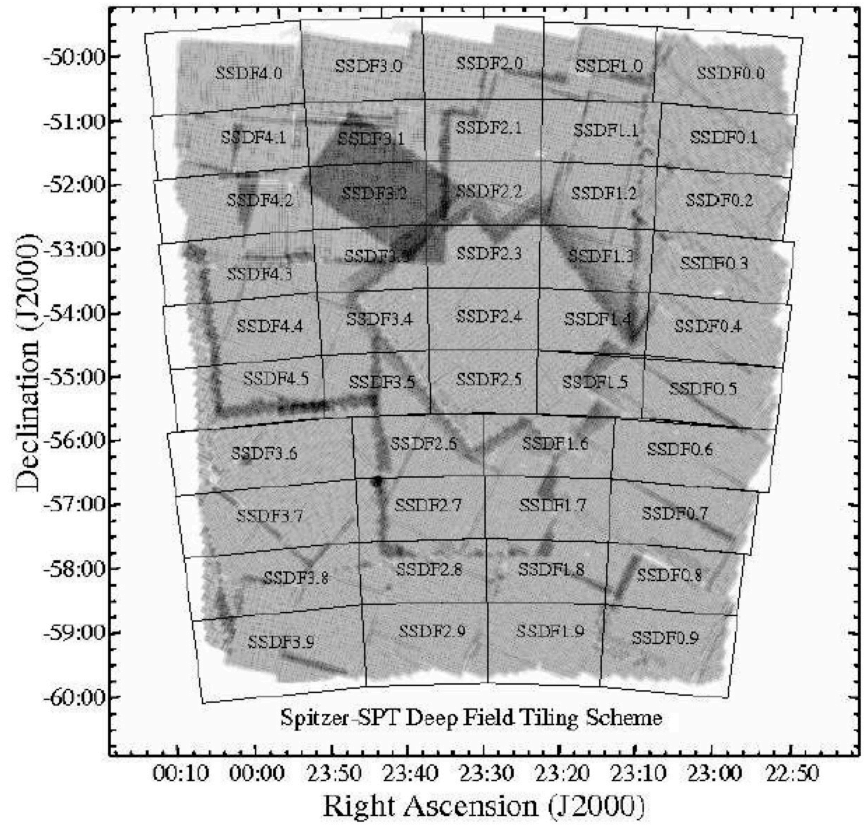
Cycle-8 *Warm-Spitzer* Exploratory Program PI: Stanford (UC-Davis)

- 94deg^2
- [3.6], [4.5] mag
- 120s depth
- 5σ lim: [4.5]<21.46 AB ; [3.6]<21.75 AB

- Coverage of 23h field of the SPT Survey

- Why SPT ?

- SZ-effect Masses – (Reichardt+2013)
- SPTpol (ongoing) will provide SZ-masses up to z~2



Ashby+2013

SSDF Clusters Working Group

M. Ashby (Harvard)
J. Bartlett (Paris – JPL)
M. Brodwin (UMKC)
P. Eisenhardt (JPL)
D. Gettings (U.Florida)
A. Gonzalez (U.Florida)
F. Ardila (U. Florida)
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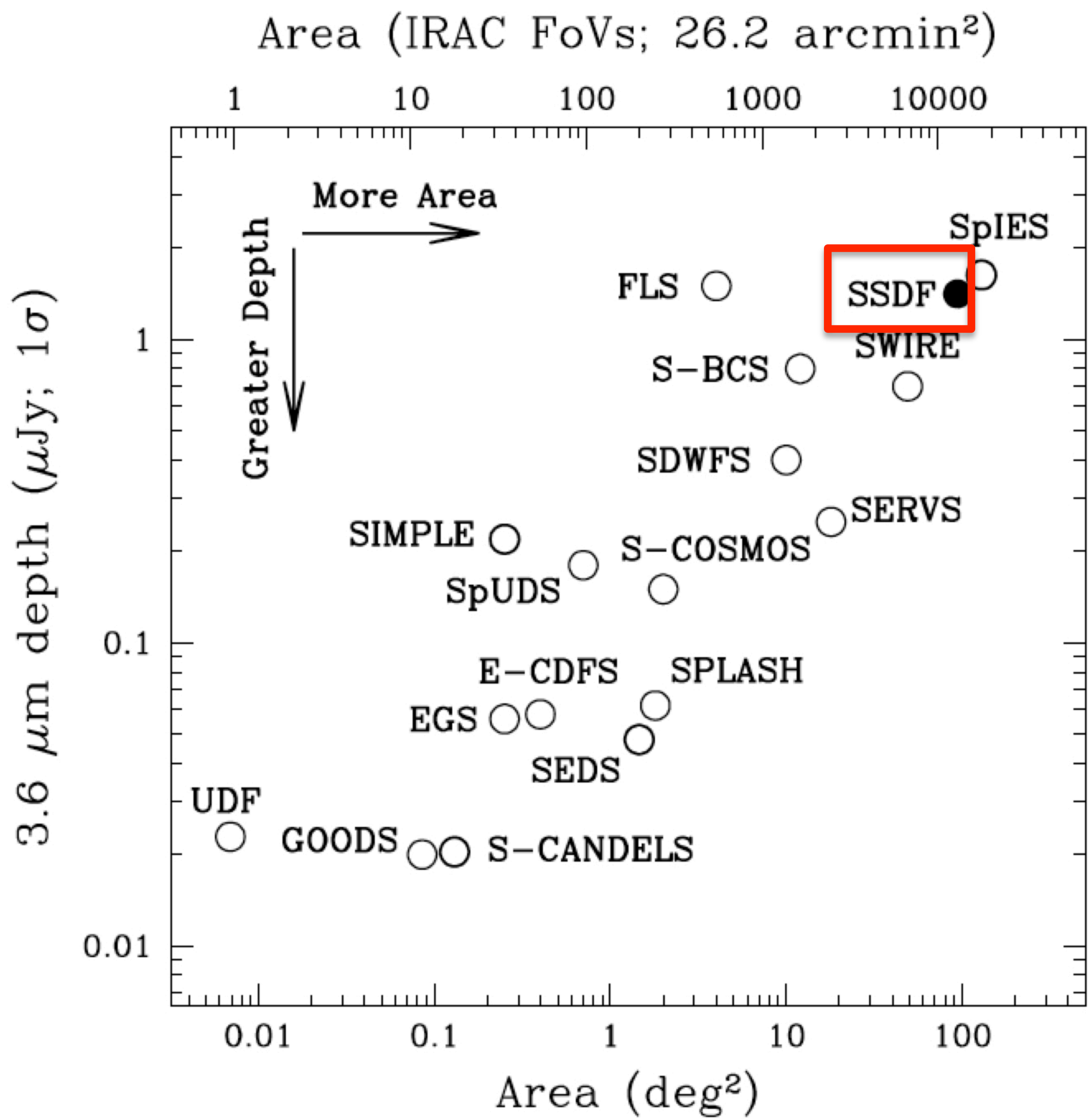
J. Martinez-Manso (U.Florida)
S. Mei (Paris Obs.)
P. Rosati (U.Ferrara-Italy)
S.A. Stanford (UC-Davis) (*Spitzer*-PI)
D. Stern (JPL)

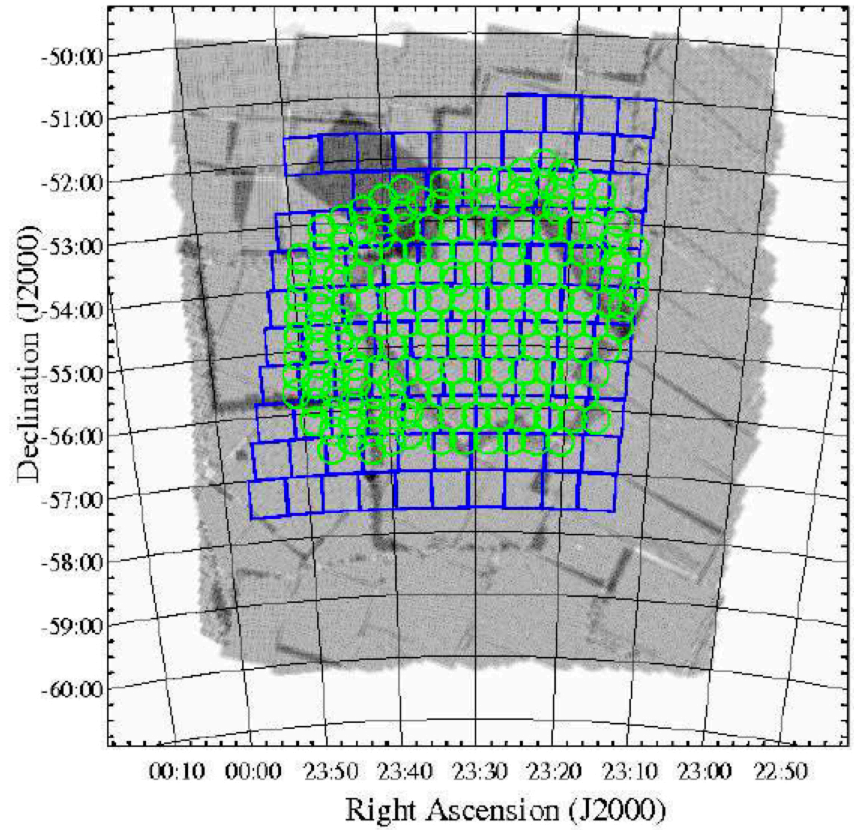
+ SSDF Team

Large Area *Spitzer* Surveys



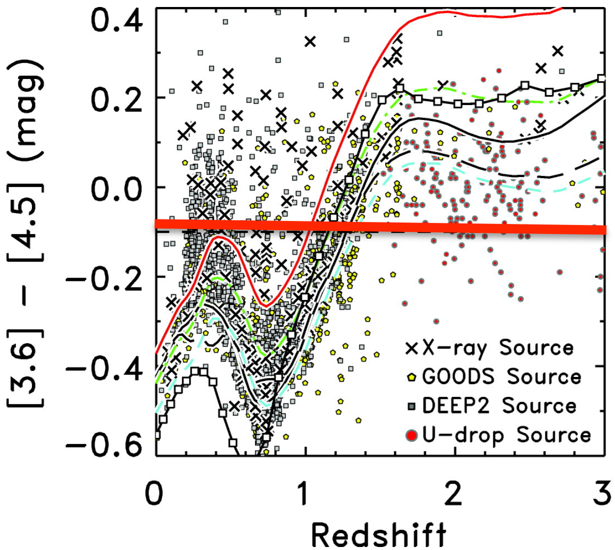
Ashby+2013

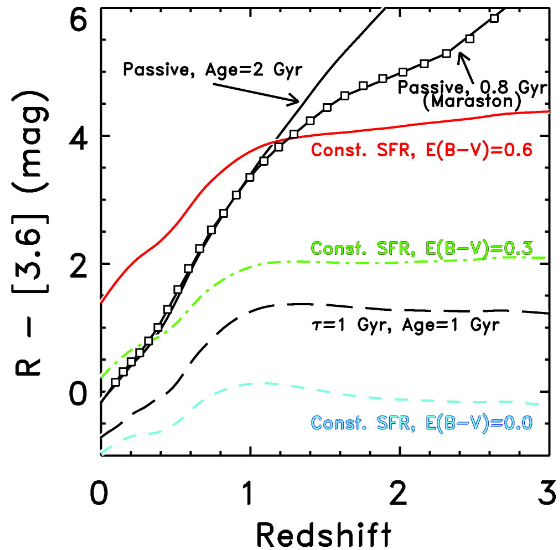
Ancillary Data



- BCS survey ~50deg (PI: Desai– griz photometry, 23 AB mag , Bleem et al. 2014)
- *XXM*-XXL survey ~25deg^2 (PI: Pierre – Xray Masses)
- XXL-DECam survey ~25deg2 (PI: Lidman –ugriz photometry, 25 AB mag)
- VISTA (VHS Survey ((McMahon et al. – shallow JHK photometry, ~20-21 AB mag)
- Herschel/SPIRE (Holder et al. 2013)
- ATCA (16cm, down to 40μJy/beam)
- DES Survey (24 AB mag)

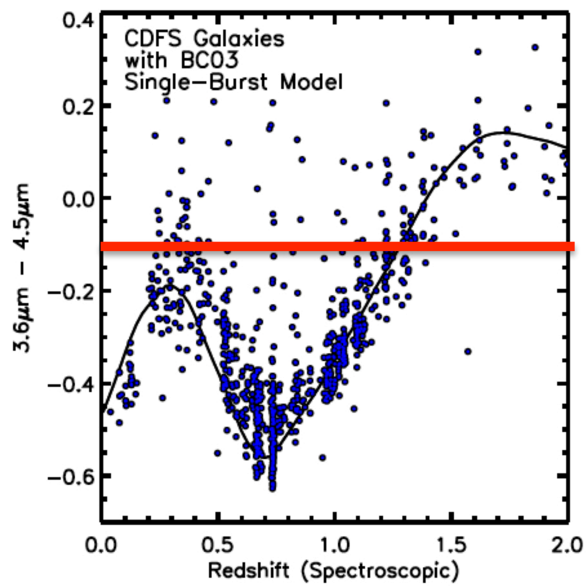
Spitzer selection of z> 1.3 galaxies : 1.6 μm stellar 'bump'

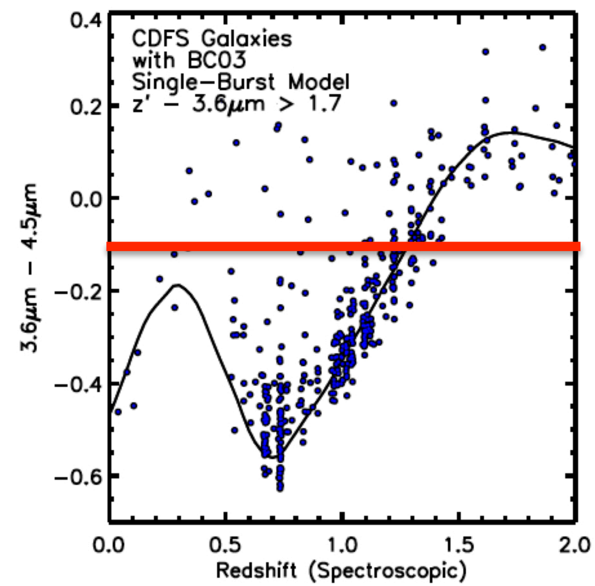




Papovich (2008)

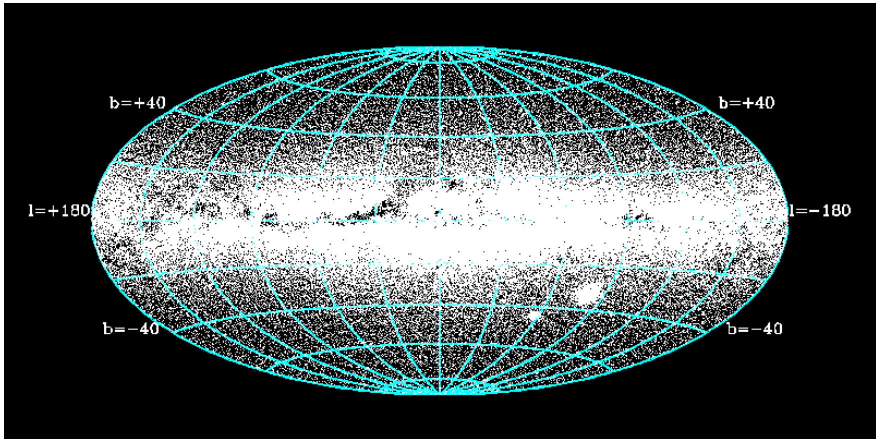
Simple color cut:
[3.6]-[4.5] > -0.1 (AB)

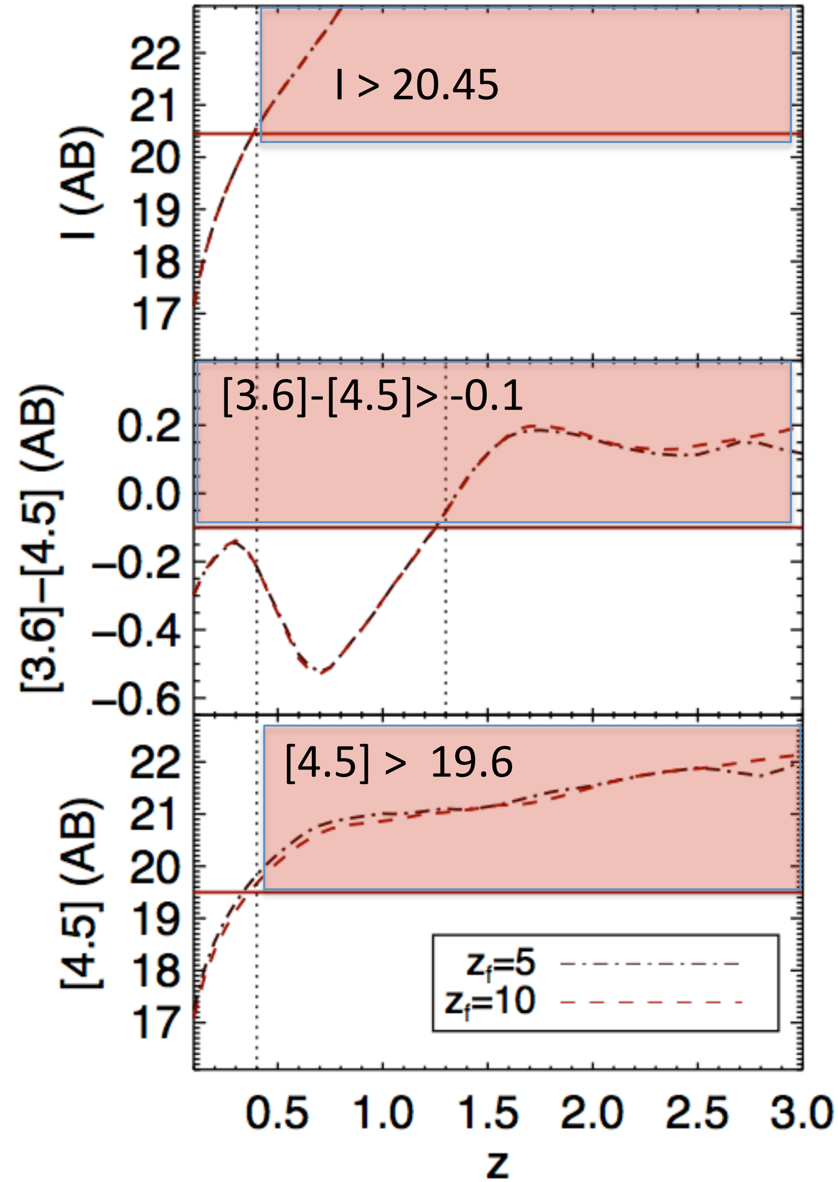




Muzzin+2013a

SSDF implementation: [3.6], [4.5] color + All-sky SuperCosmos I-band





Rettura et al. 2014

The SuperCOSMOS Sky Surveys (SSS) archive holds the object catalogue data extracted from scans of photographic Schmidt survey plates (i.e., POSS II + UKST) in B, R, I bands.

Homogeneous coverage over the entire 94 deg2 Spitzer survey down to I = 20.45 (AB)

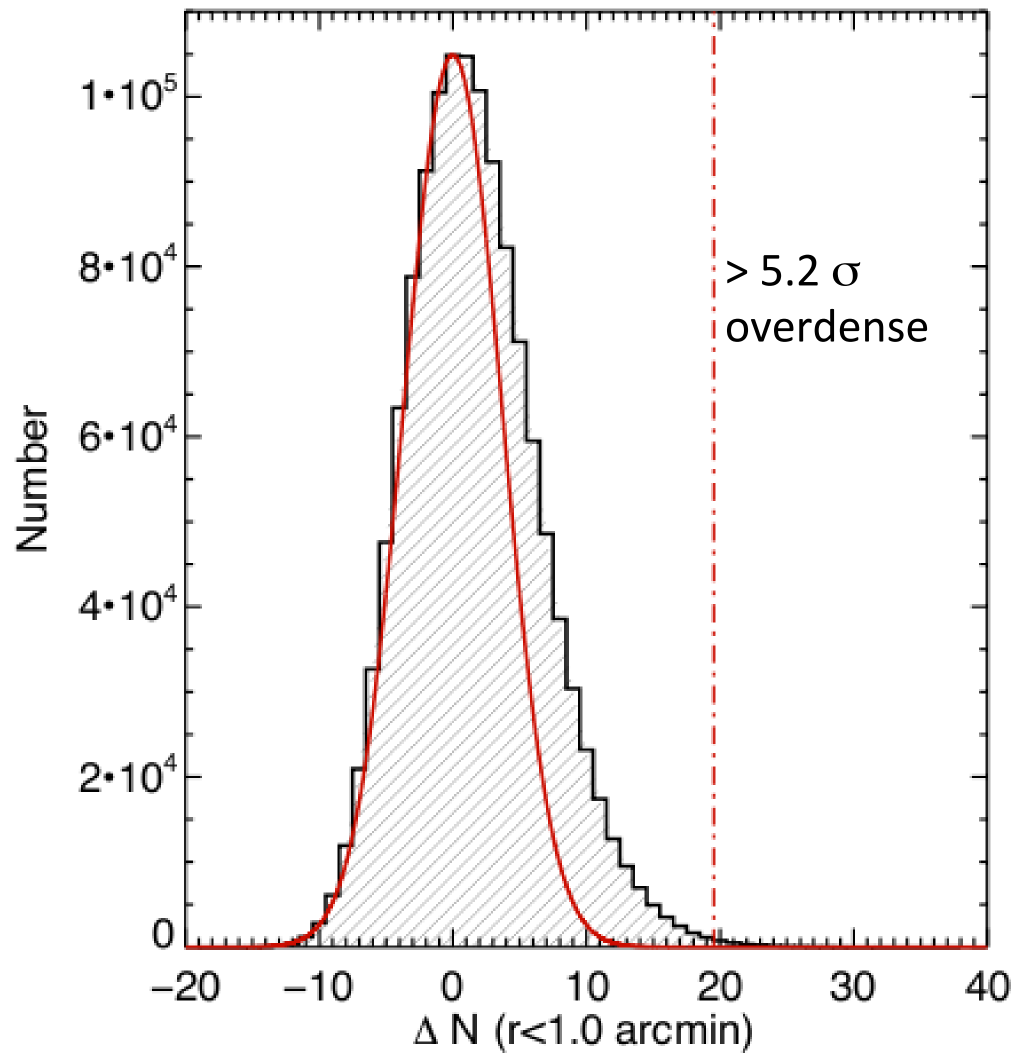
High-z Clusters Search Algorithm

- Counts in cell analysis

- **ΔN** = Completeness-corrected excess number of objects with respect to the local background with:

- [3.6] – [4.5] **>** –0.1,
- 19.5 **<** [4.5] **<** 21.46
- **I >** 20.45

within 1.0′ radius



Rettura et al. 2014

Sample Purity

- Determine purity, $\mathbf{f}_{\mathrm{pure}}$ as a function of the detection significance $\mathbf{X}_{\mathrm{f}}$, defined as:

$$f_{\mathrm{pure}}(X_f) = \frac{N_{\mathrm{real}}}{N_{\mathrm{tot}}} = 1 - \frac{N_{\mathrm{false}}}{N_{\mathrm{tot}}},$$

- We run our cluster finding algorithm on comparable-depth observations from the IRAC Shallow Cluster Survey (ISCS) (Eisenhardt et al. 2004), matched with SuperCOSMOS data.

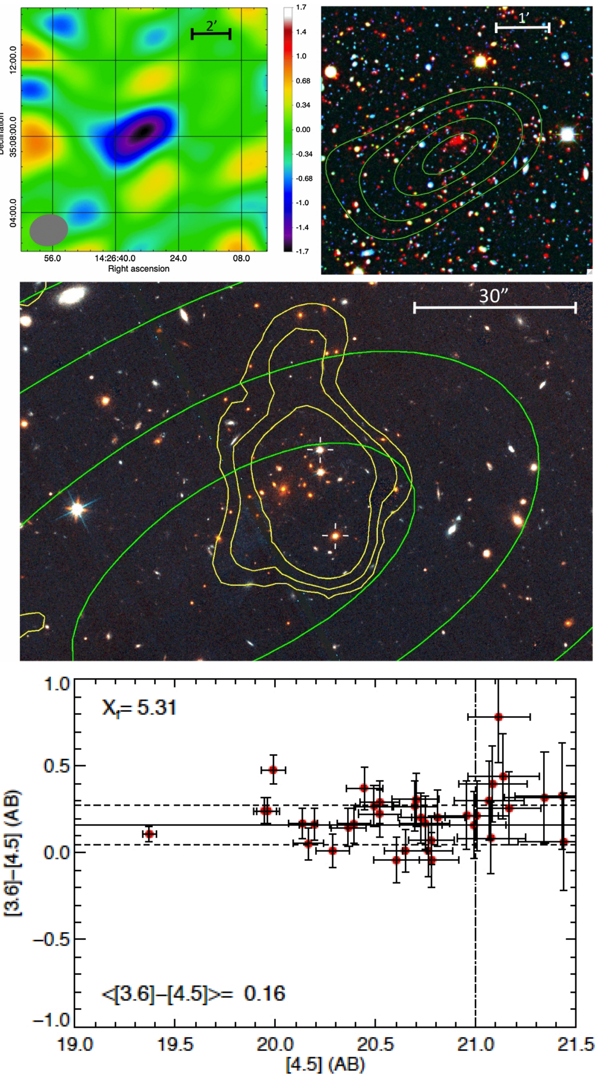
- The ISCS is a wide-field IR-selected galaxy cluster survey carried out using 90s Spitzer /IRAC imaging of the 8.5 deg2 Boötes field of the NOAO Deep, Wide-Field Survey (NDWFS, Jannuzi & Dey 1999).

- We estimate a purity of ~80% at $z>1.3$ from comparison with accurate photozs (11bands) and large specz campaign in Boötes that resulted in 18 confirmed $1.0 < z < 1.9$ clusters (Brodwin+11).

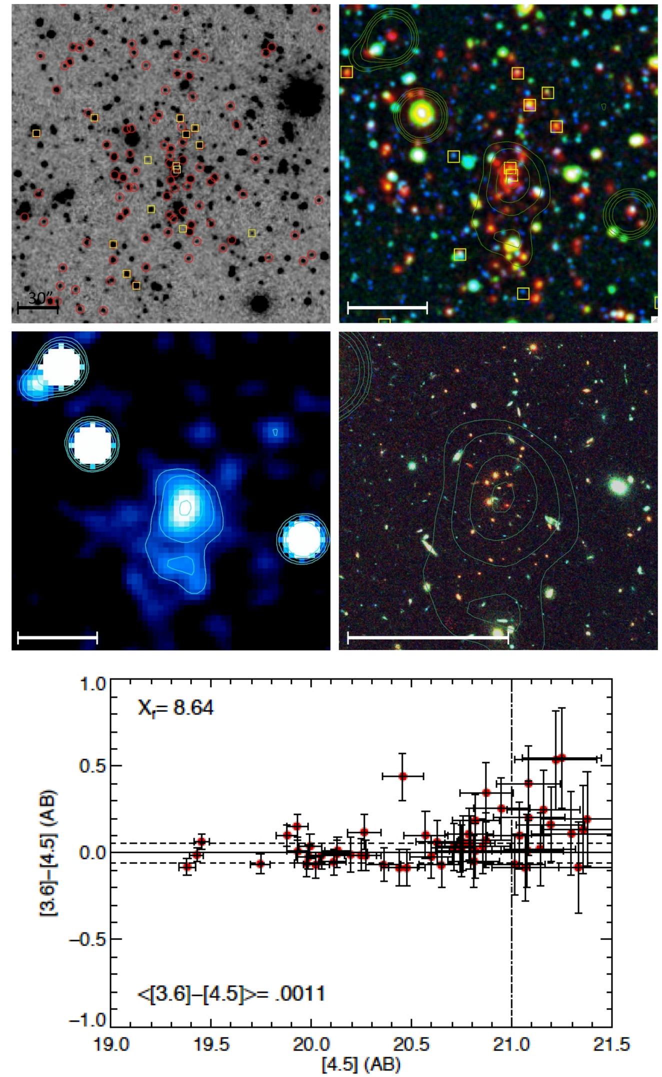
$$X_f = 5.2 \rightarrow f_{\mathrm{pure}} = 0.80$$

SSDF cluster finding algorithm applied to Boötes field

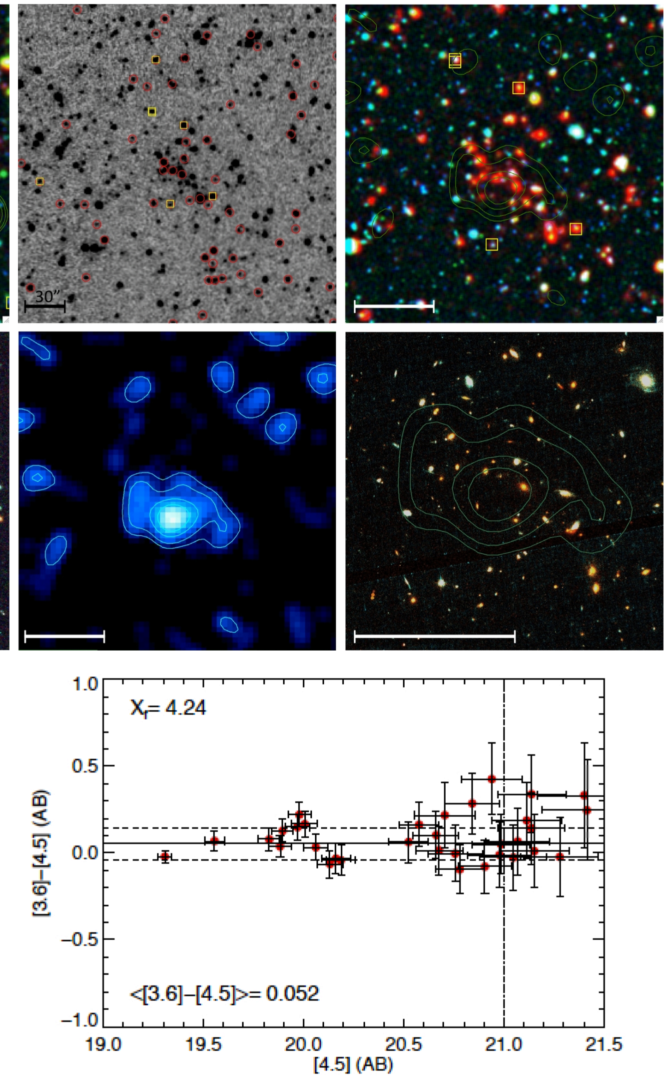
IDCS J1426.5+3508 @ z=1.75



ISCS J1438.1+3414 @ z = 1.41

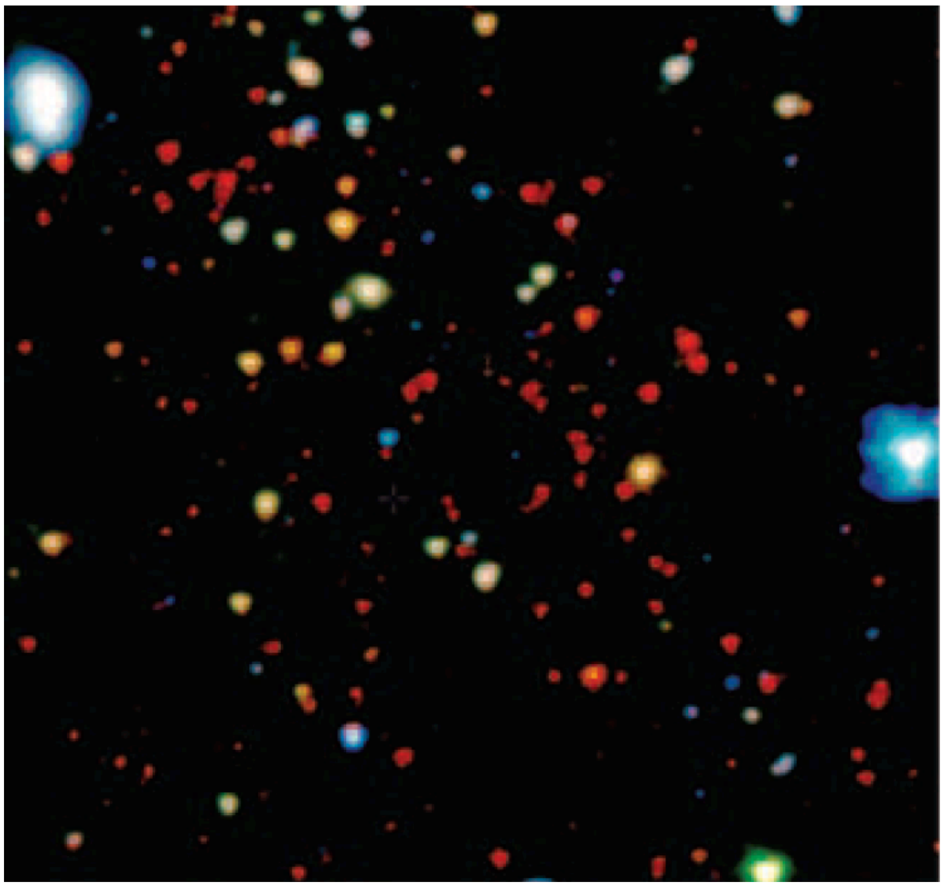


ISCS J1432.4+3250 @ z=1.49



SSDF cluster finding algorithm applied to SWIRE

SWIRE-CDFS (7.8deg^2)

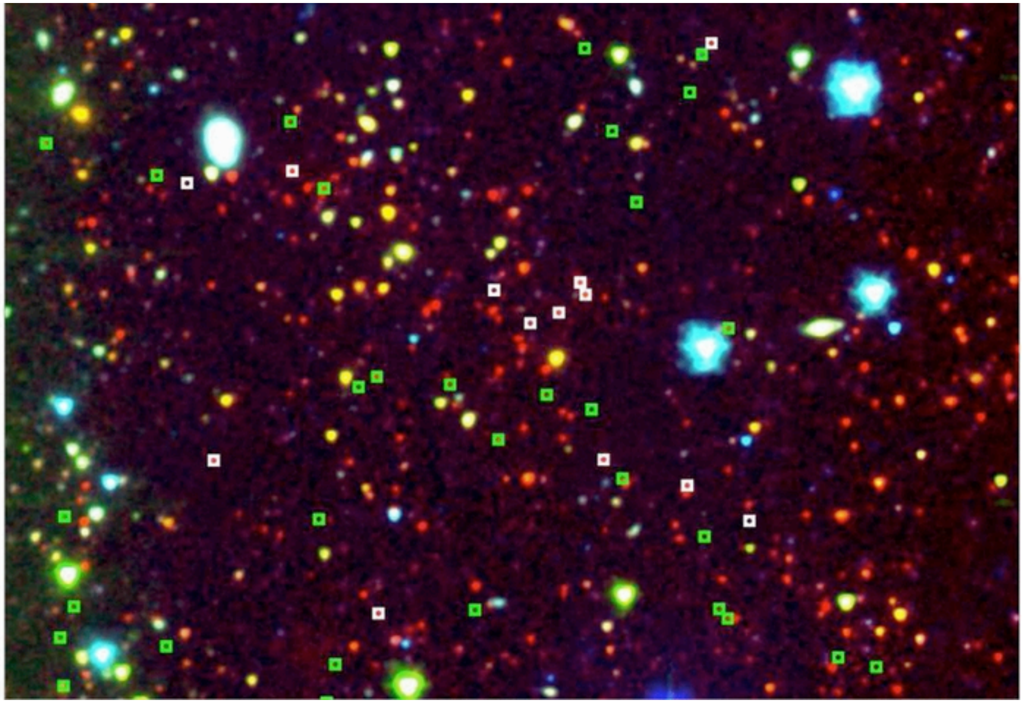


- SpARCS CDFS-44 (left)
  - z_spec= 1.626
  - 2nd most significant overdensity in field
- SpARCS CDFS-41
  - z_spec= 1.368
  - 6th most significant overdensity in field

Lidman et al. 2012, Wilson et al. 2014, in prep.

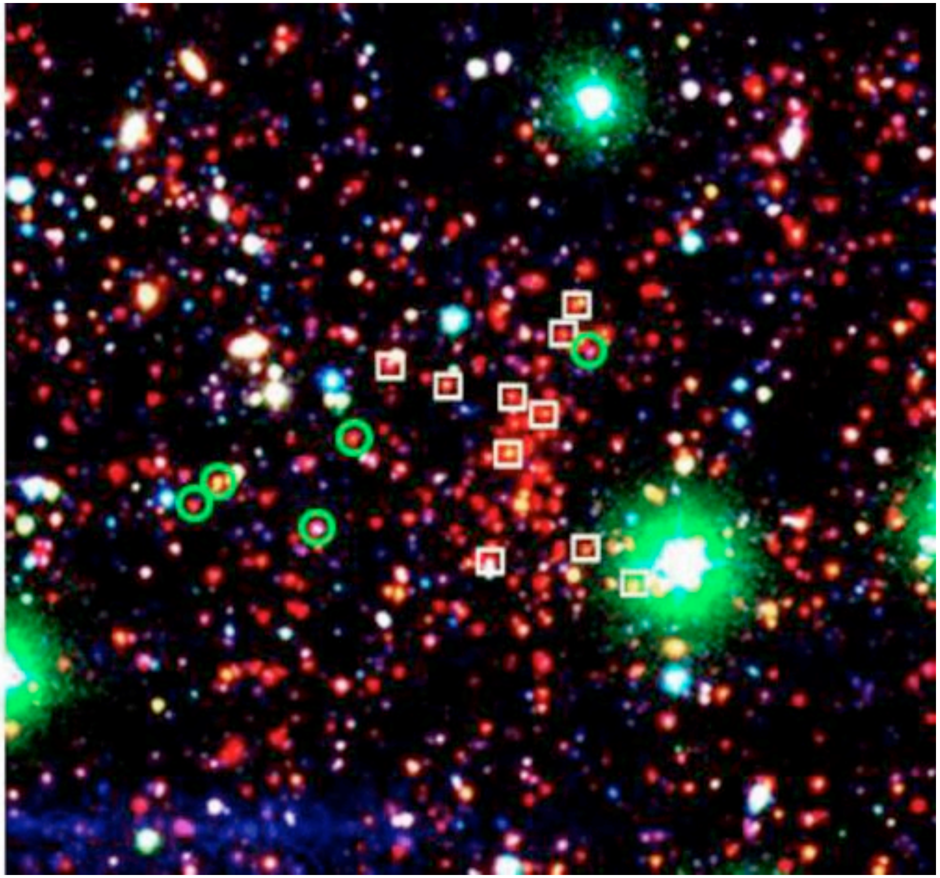
SWIRE XMM (9.1 deg^2)

- J022427-032354 (right)
  - z_spec= 1.63
  - 1st most significant overdensity in field.



Muzzin et al. 2013

SWIRE ELAIS-S1 (6.8 deg^2)



Wilson et al. 2009

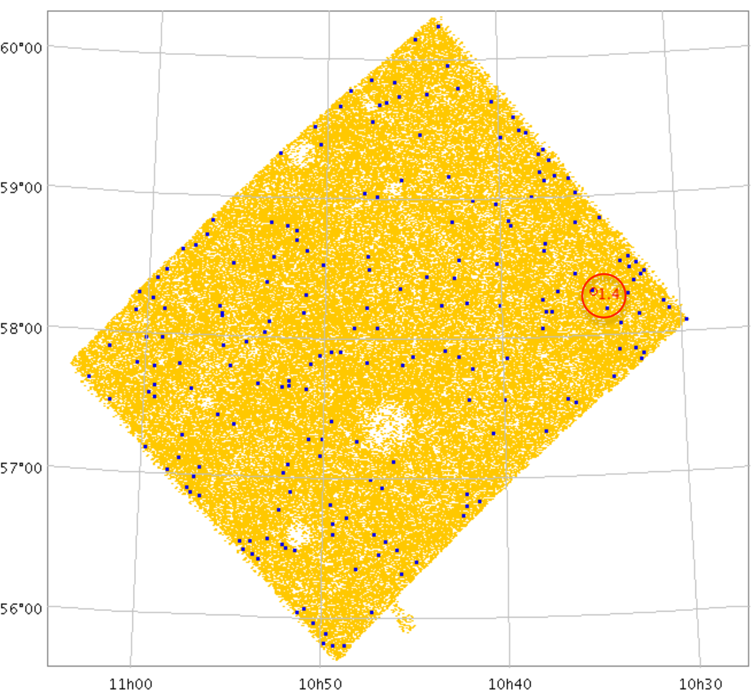
- GCLASSJ0035
  - z_spec =1.335
  - 1st most significant overdensity in field.

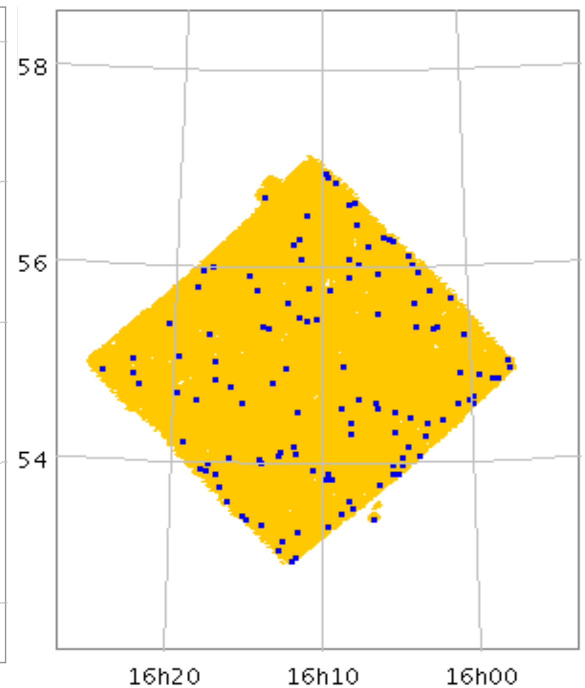
Other SWIRE fields

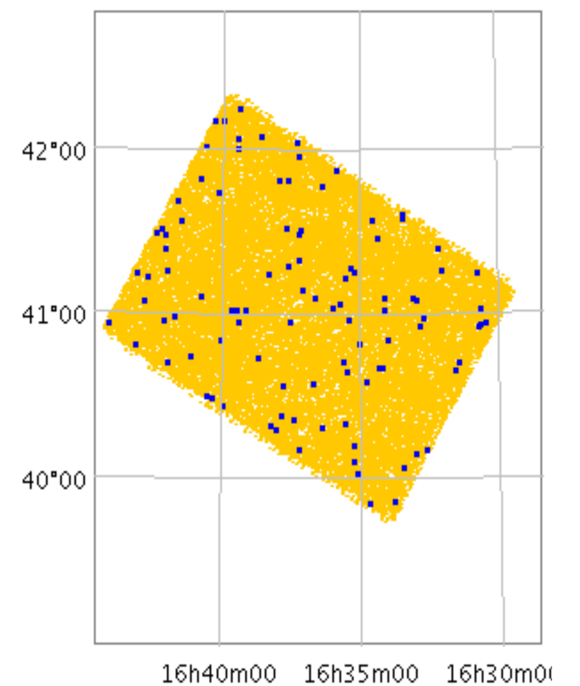
- Lockman Hole
  - 11.1 deg²
  - SpARCS Lockman-77
    - z_spec= 1.4

- ELAIS-N1
  - 9.3 deg²
  - No z > 1.3 spectroscopically confirmed clusters yet.

- ELAIS-N2
  - 4.1 deg²
  - No z > 1.3 spectroscopicall y confirmed clusters yet.



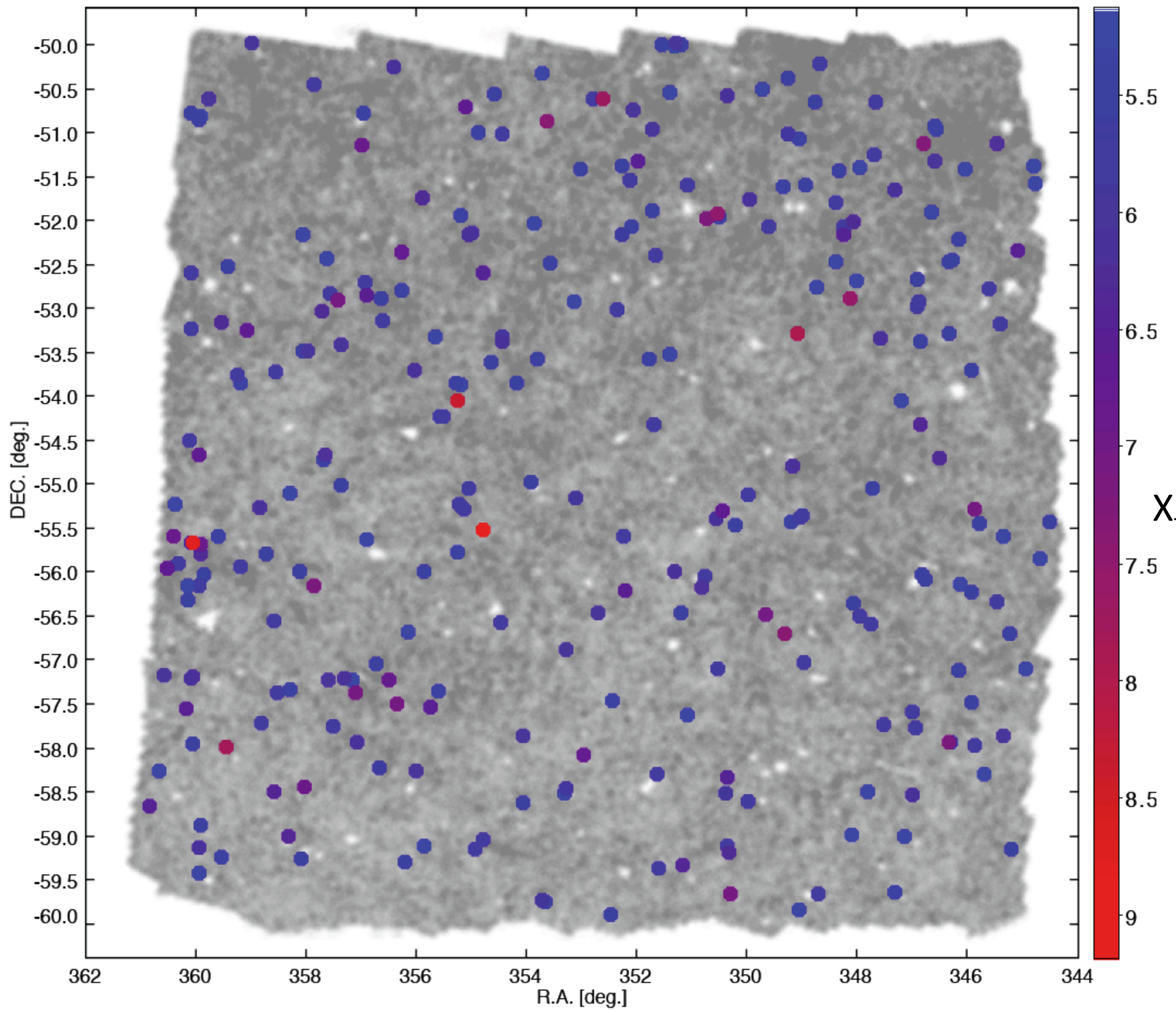




Cluster Candidates at z>1.3 in the SSDF

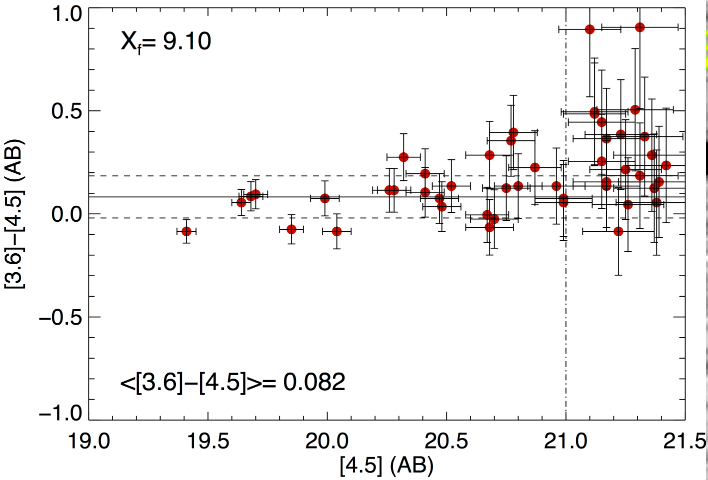
279 candidates

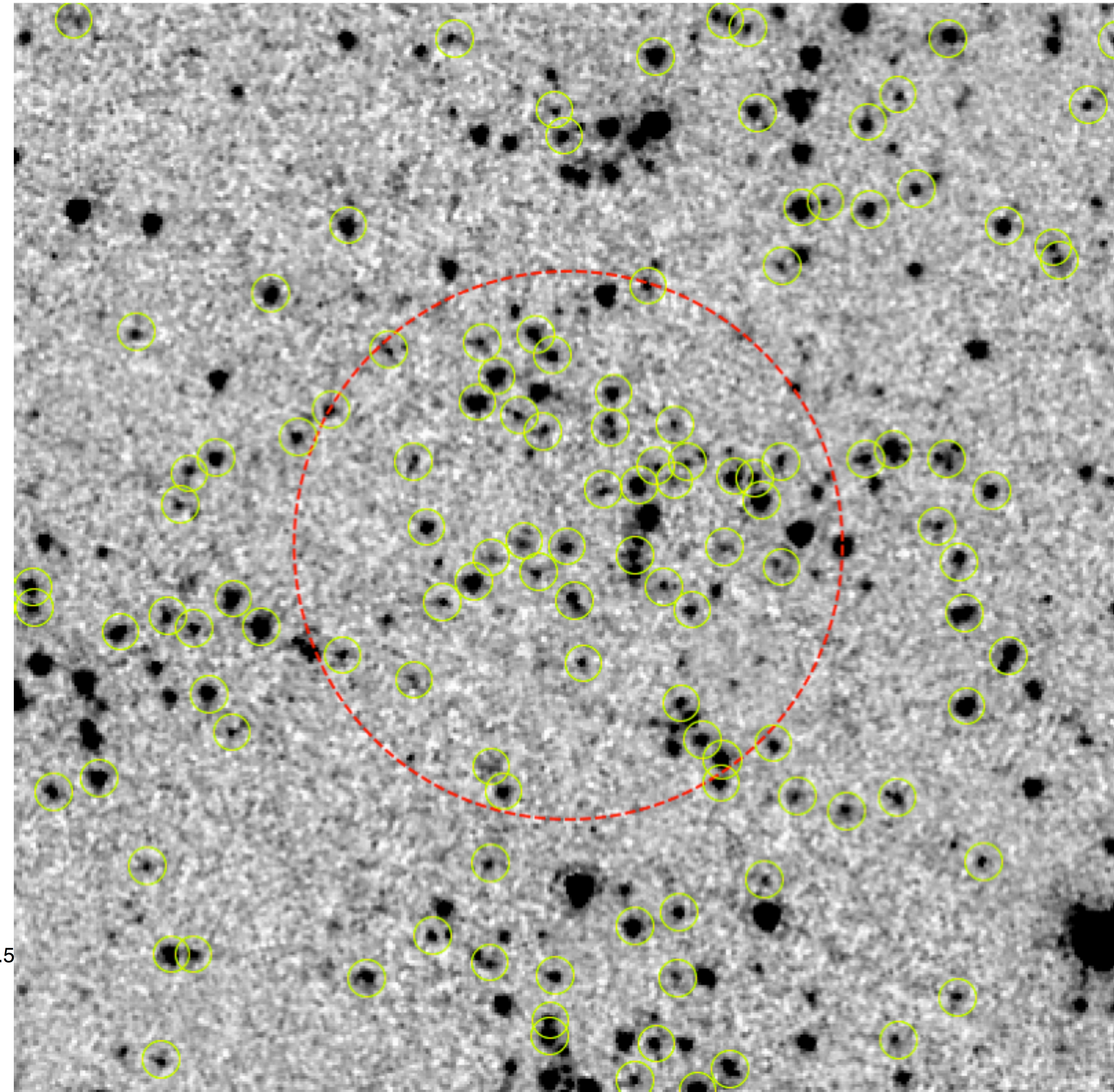
$X_f > 5.2$



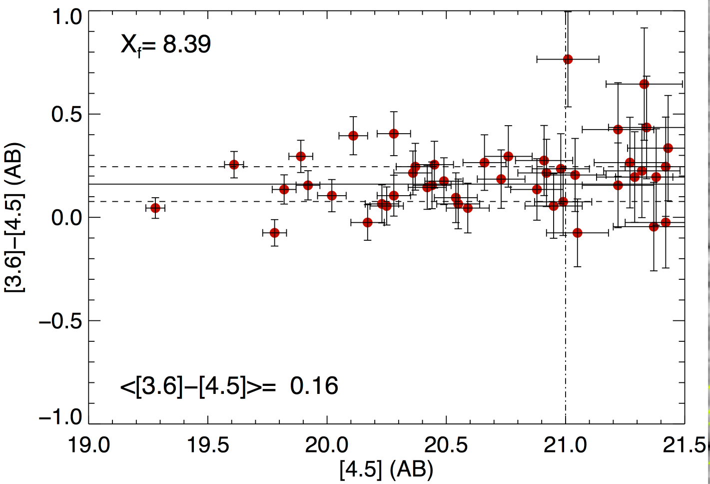
Rettura et al. 2014

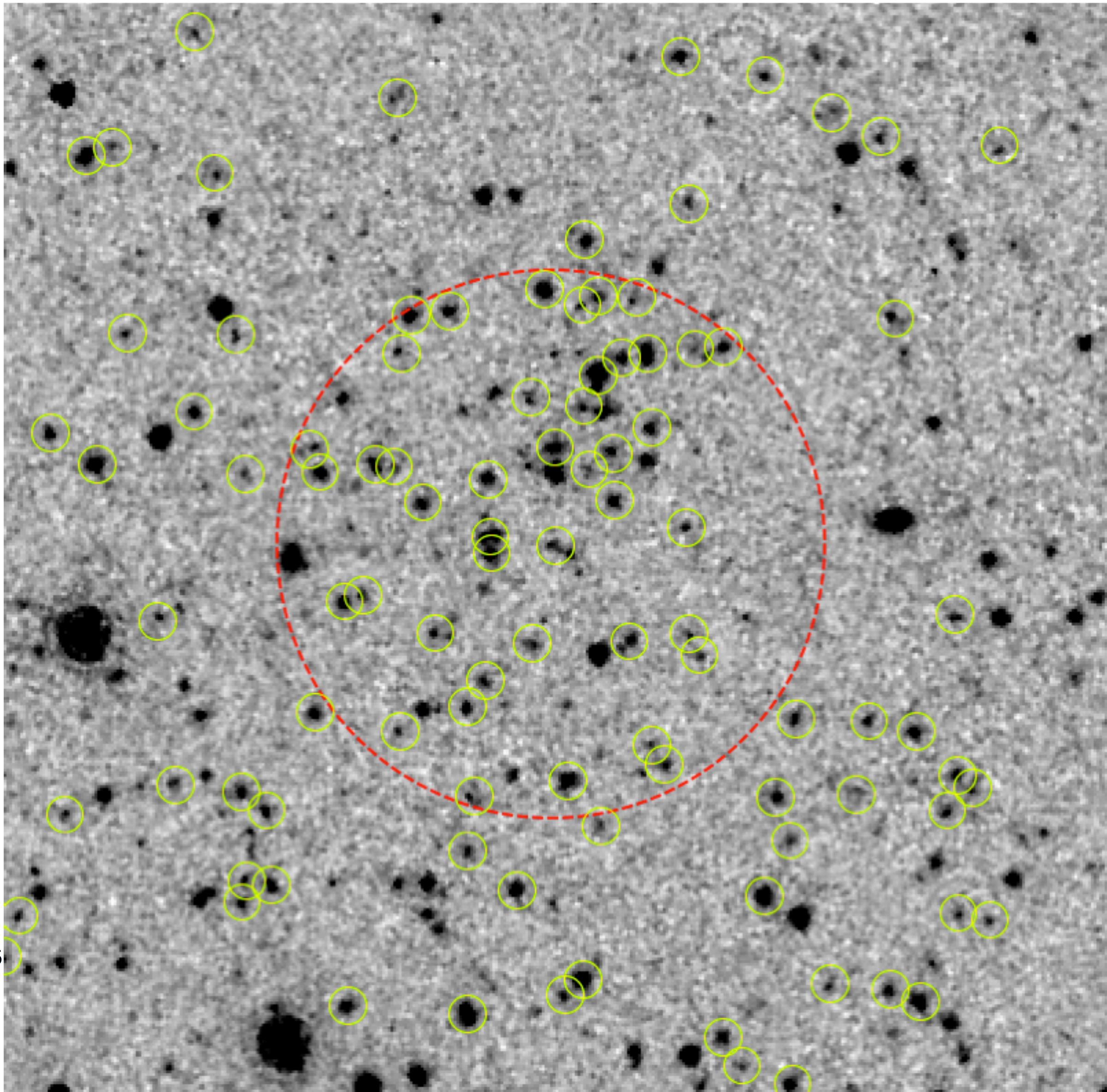
SSDF-CL J2339-5531



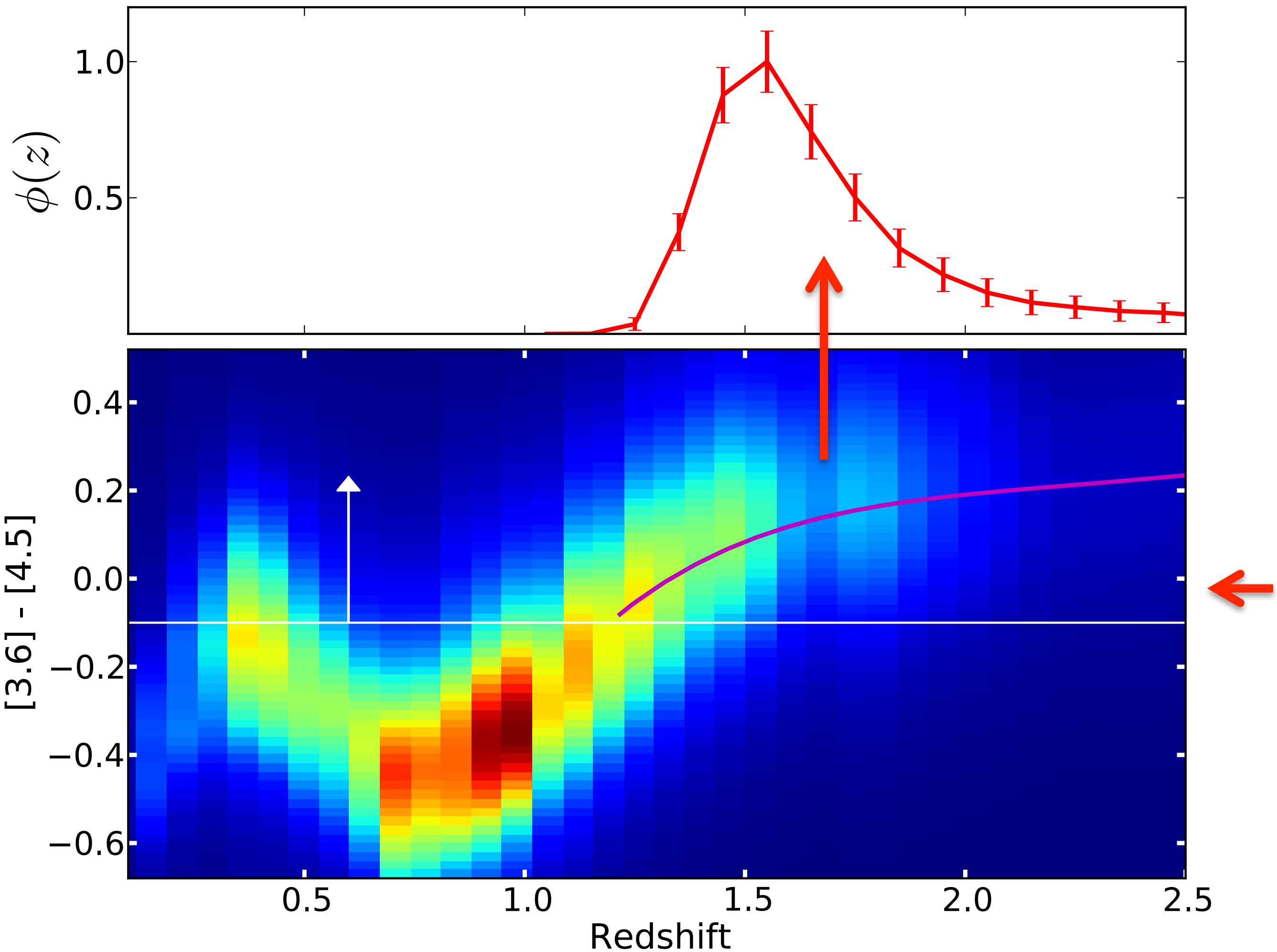


SSDF-CL J2340-5403





Sample properties : Redshift Distribution

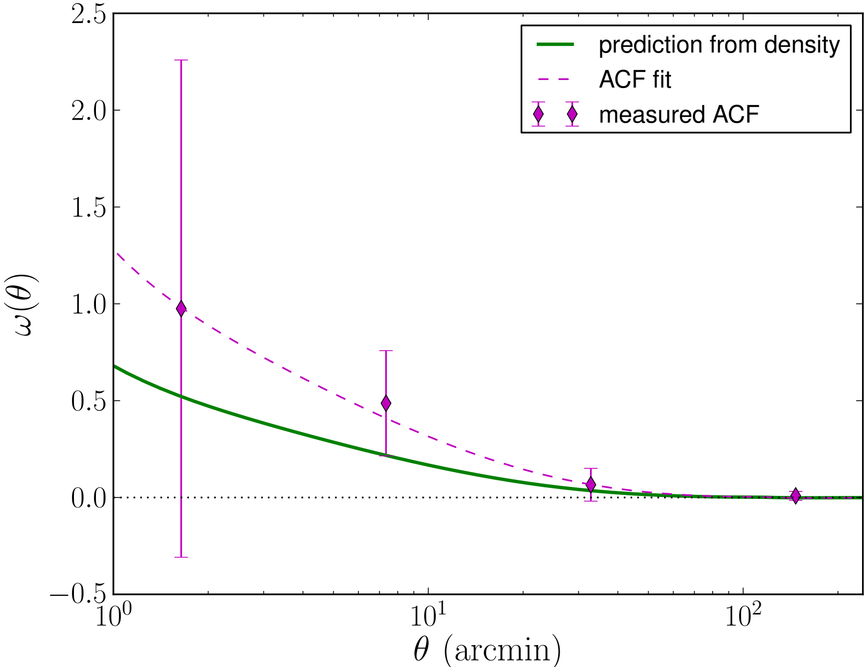


Derived SSDF clusters redshifts distribution

Spectroscopic and Photometric Data from COSMOS UltraVista Catalog (Muzzin et al. 2013b)

Rettura et al. 2014

Sample properties : Clustering (of Clusters) Analysis



Angular Correlation Function

Best-fit results for the number density, the characteristic minumum mass, the mean mass, the bias and the angular correlation length of the SSDF cluster sample as found by the density and the clustering fits.

	Clustering
n_c $(10^{-7}h^3\mathrm{Mpc}^{-3})$	$0.7^{+6.3}_{-0.6}$
$M_{\rm min}$ $(10^{14}h^{-1}M_\odot)$	$1.5^{+0.9}_{-0.7}$
$M_{\rm mean}$ $(10^{14}h^{-1}M_\odot)$	$1.9^{+1.0}_{-0.8}$
b_c	10.8 ± 2.5
r_0 $(h^{-1}\mathrm{Mpc})$	32 ± 7

Strong clustering signal

Number density and r0 are consistent with ΛCDM predictions (Springel et al. 2005)

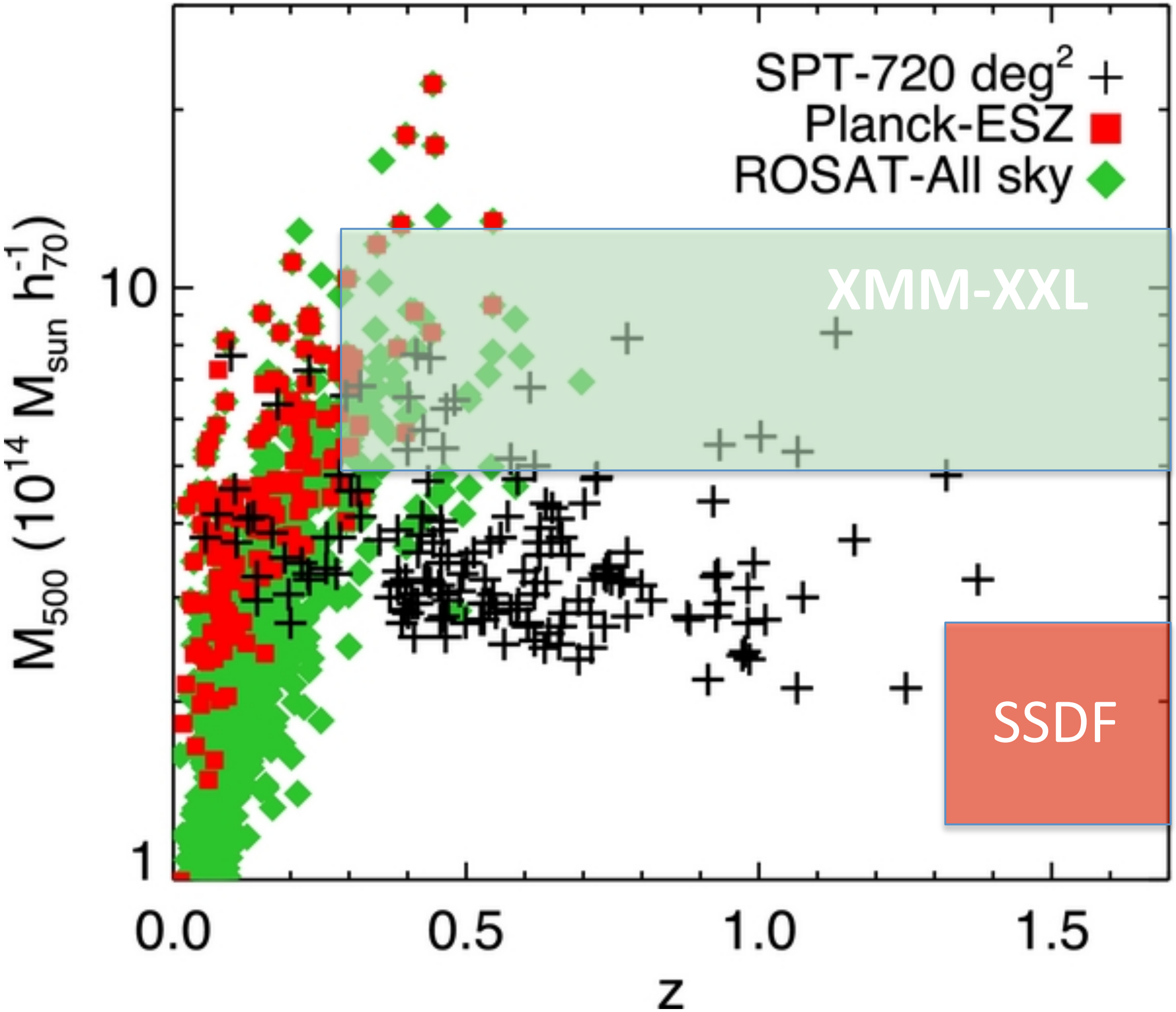
Rettura et al. 2014

Sample properties : Mass-Redshift Distribution

- No detections in 1st generation SPT cluster catalog (Reichardt et al. 2013)

→ The two samples do not overlap in mass-redshift space

- SPTpol will soon detect most of them?



Reichardt et al. 2013

Present:

- New sample of cluster candidates of galaxies at $1.3 < z < 2.0$ over the 94 deg^2 Spitzer survey of the SPT field.
- 120s of Spitzer data and Scans of photographic plates finds clusters up to z~2 with an 80% purity.
- Strong clustering
- n_c , r_0 values are consistent with previous observational studies and match expectations based on ΛCDM high-resolution simulations.
- The sample has a mean mass $\mathbf{M}_{mean}$ =1.9 x 10^{14} $M_\odot$.

→ Will evolve into massive clusters (> 5 x 10^{14} $M_\odot$) at **z** = 0. 2

Near Future Directions:

- Magellan/IMACS spectroscopy data taken to assign cluster membership (data reduction ongoing)
- VLT/KMOS spectroscopy (Mei's talk) of Photoz-selectted in the 25deg2 overlapping area with deep DECam optical data (data reduction ongoing)

CONCLUSION:

Ongoing large Spitzer cluster surveys will provide high-redshift targets for WFIRST:

- enabling unique, exciting, synergic, multi-wavelength studies of the Spitzer-selected sample
- providing training sets to identify additional high-redshift clusters outside of the Spitzer footprint.