Finding galaxy clusters in formation at redshifts > 3

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Edwin Retana-Montenegro (Leiden University)

HATLAS collaboration

Galaxy clusters at high-z: why?

Cluster Number Counts and masses

$$N(M,z) = \int\int \frac{dn(M,z)}{dM}\, dM\, dz\, \frac{dV_c}{dz}$$

T-M relation → N(T,z)

Y-M relation → N(Y,z)

$\theta = (\Omega_{M0}, \sigma_8)$

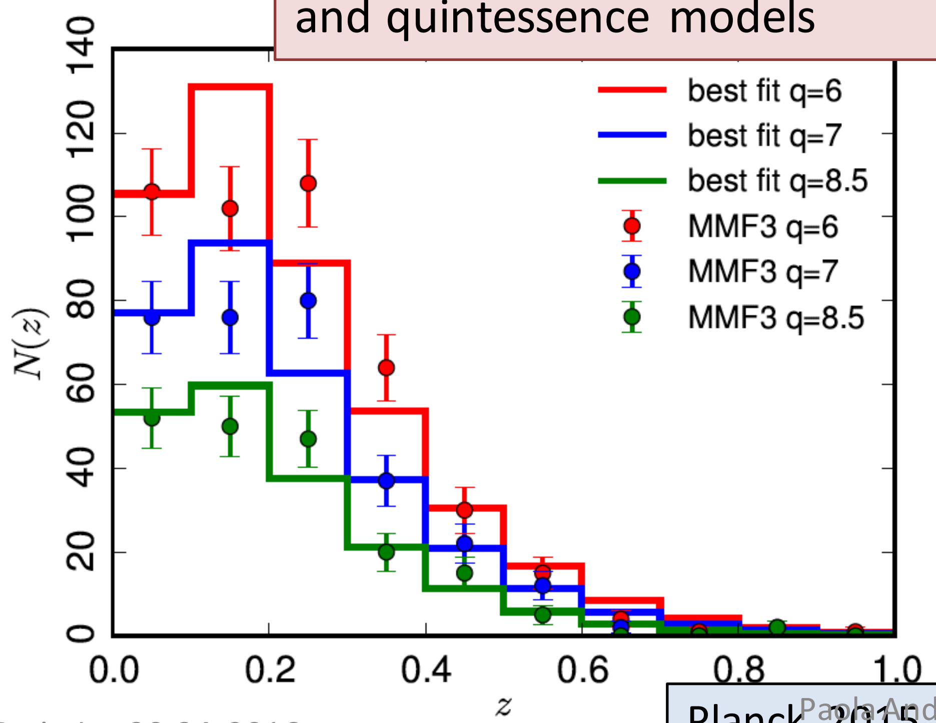
Geometry of the Universe

Growth of structure

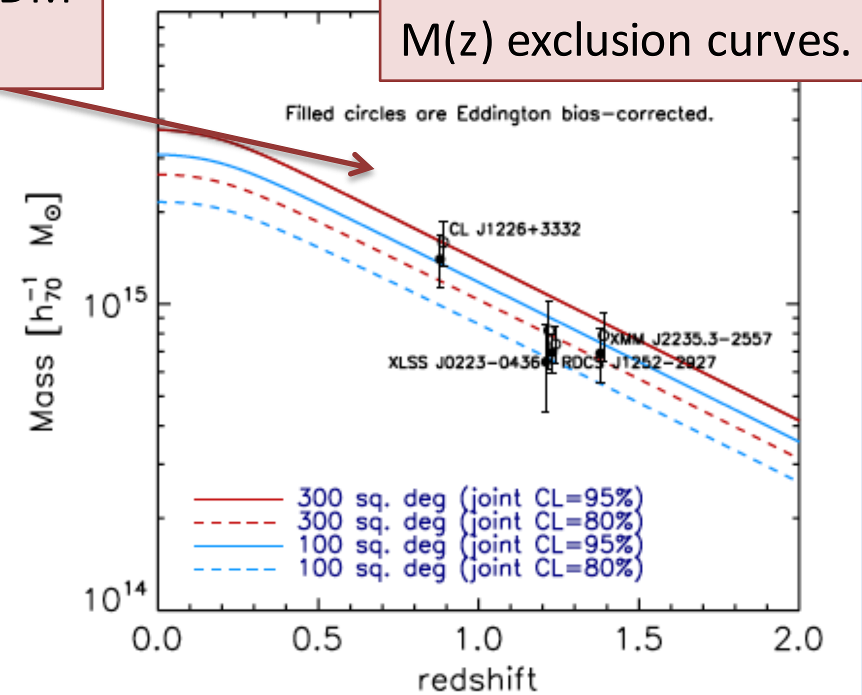
$\sigma_M(R=8\ h^{-1}Mpc,0) \equiv \sigma_8$

$\Omega_{M0} = \frac{\rho_{M0}}{\rho_{cr0}} = \frac{8\pi G}{3H_0^2}\rho_{M0}$

Even a single cluster with (M,z) above the curve would rule out ΛCDM and quintessence models



M(z) exclusion curves.

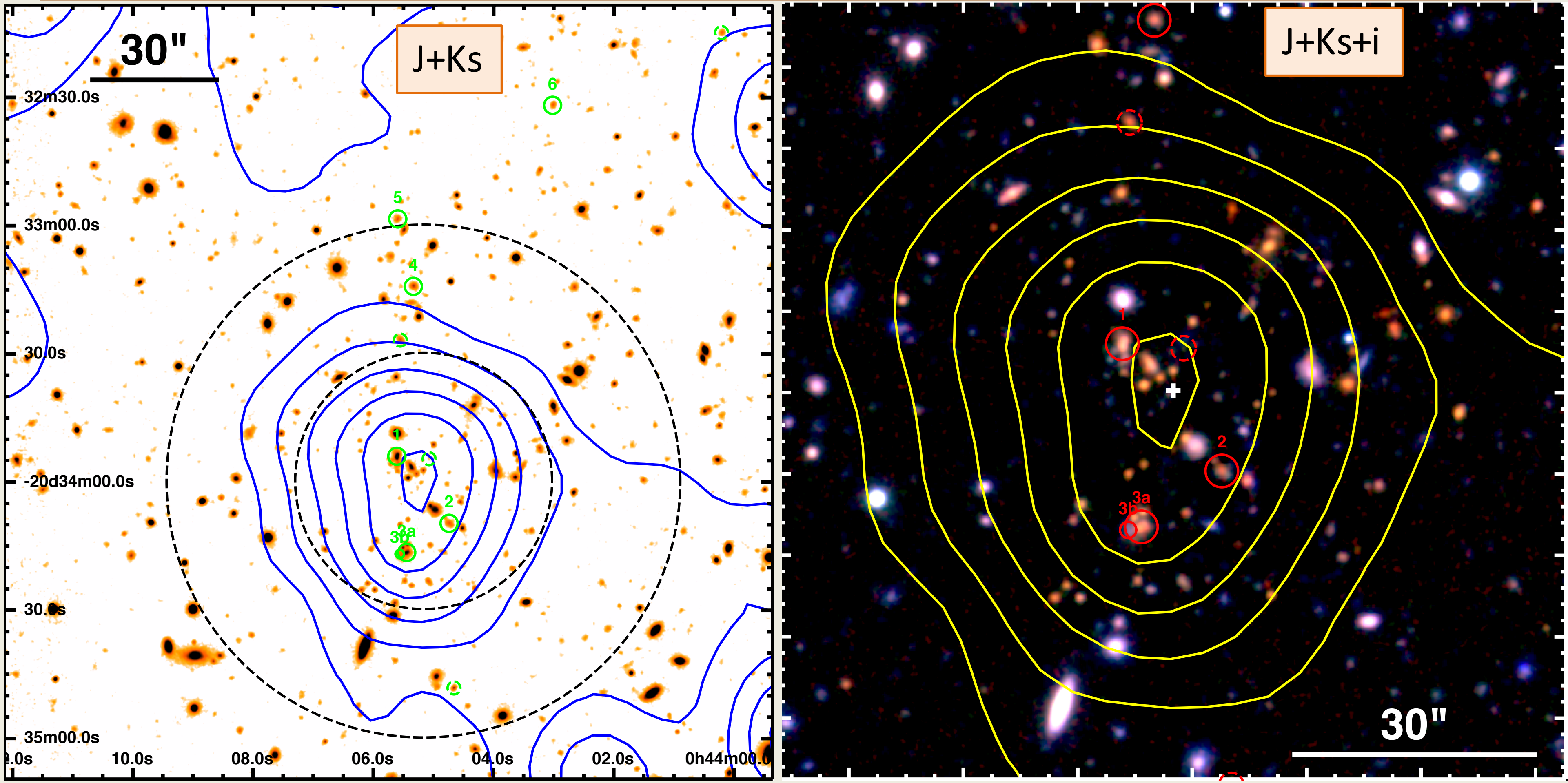


Planck, 2015

Mortonson et al., 2011; Jee et al., 2011

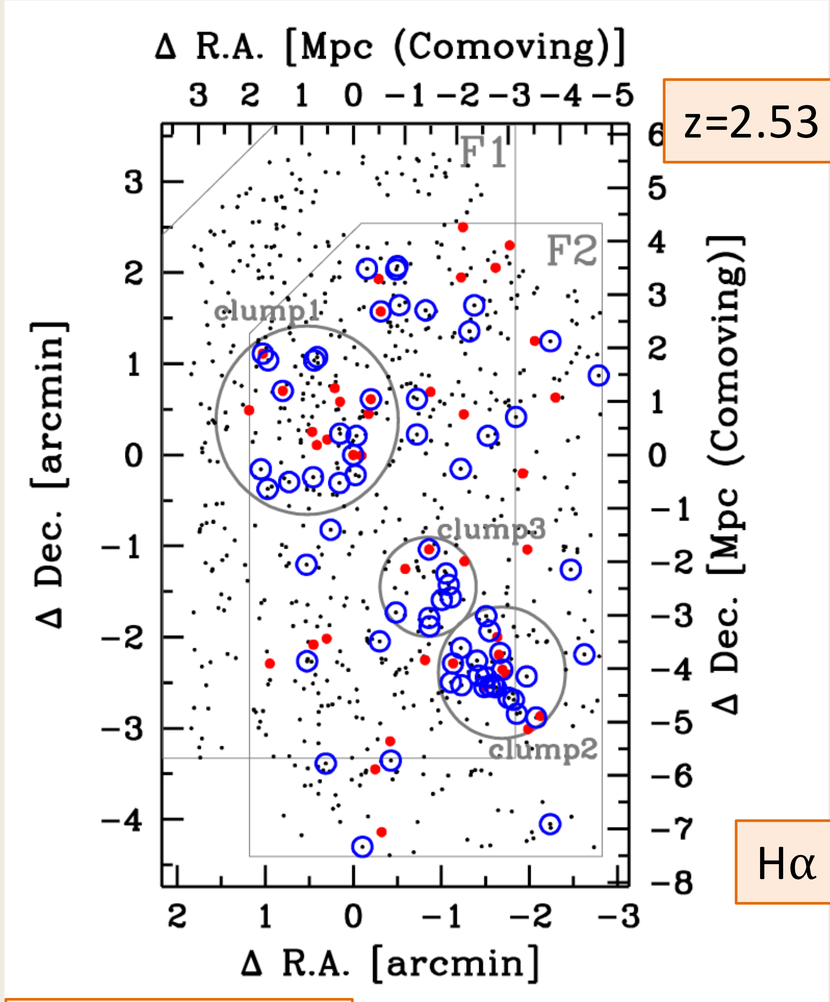
How to find first/proto clusters ?

XMMUJ0044.0-2033 @ z = 1.58



Santos et al, 2011;
Fassbender et al, 2014

Overdensities around Radio-loud AGN @1.3<z<3.2

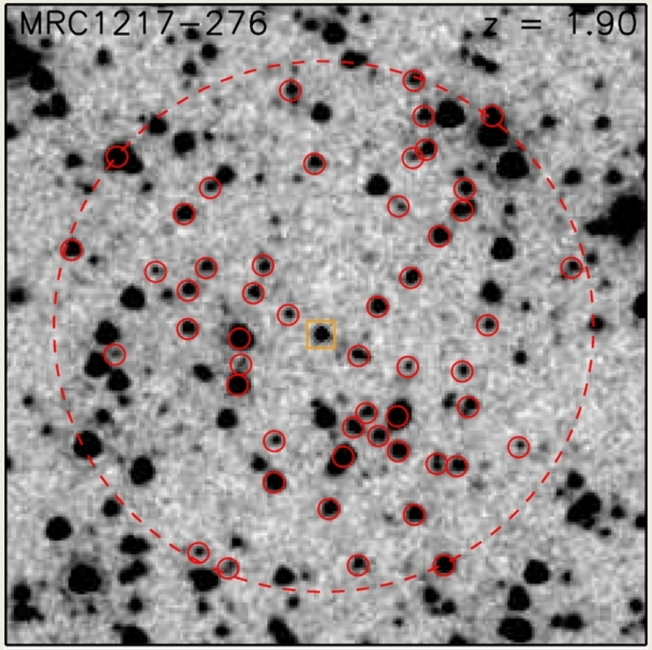


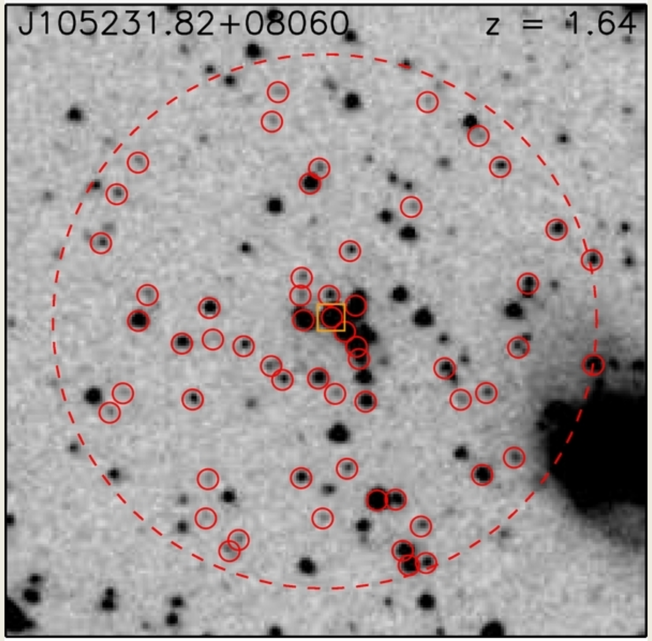
z=2.53

Hα emitters

Hayashi et al, 2012

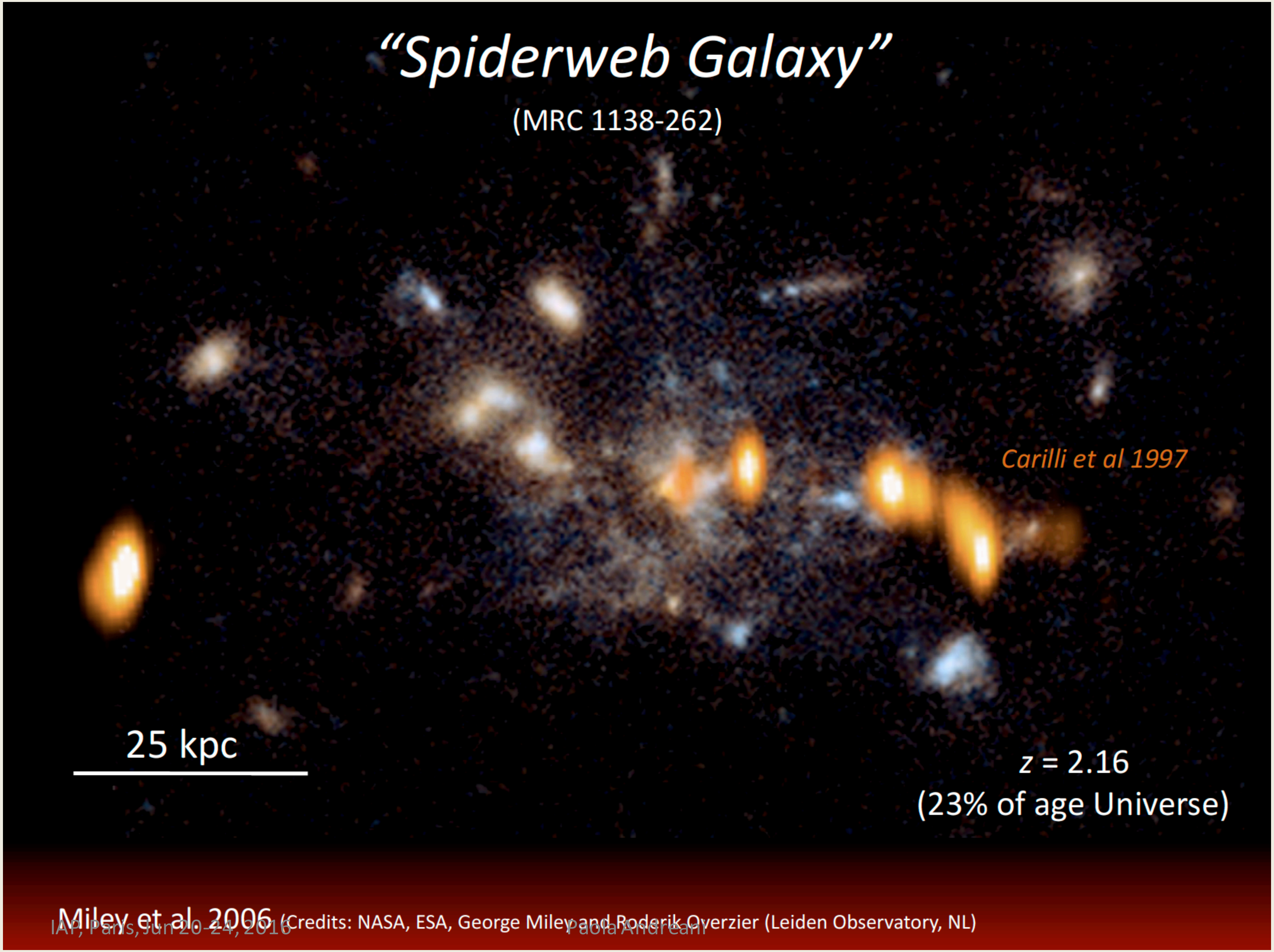
Spitzer

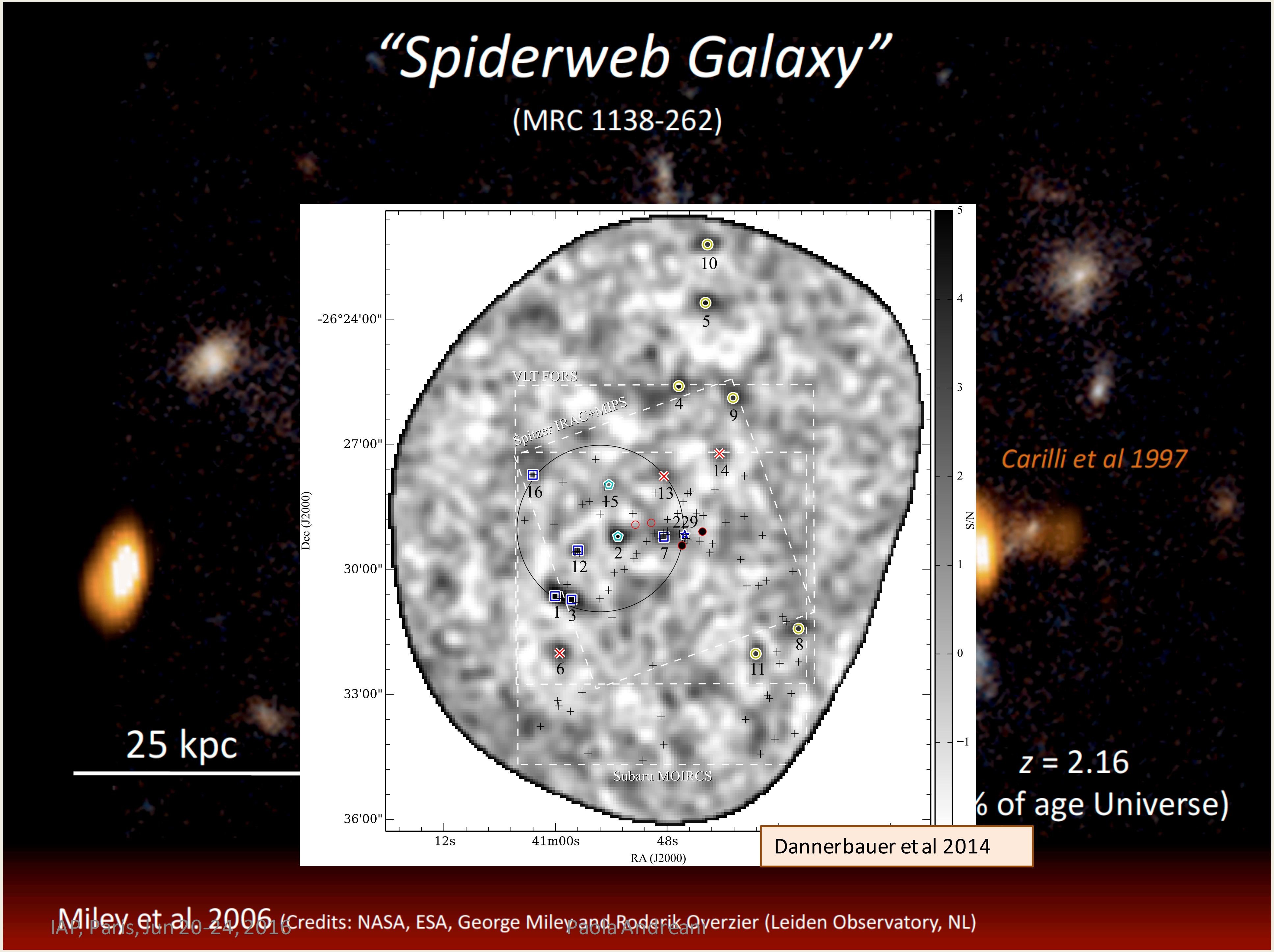




Dominika Wylezalek et al. 2013 ApJ 769 79

See also, Kurk et al, 2004; Hatch et al, 2011; Rigby et al 2014


"Spiderweb Galaxy"
(MRC 1138-262)
Carilli et al 1997
25 kpc
z = 2.16
(23% of age Universe)
Miley et al. 2006 (Credits: NASA, ESA, George Miley and Roderik Overzier (Leiden Observatory, NL)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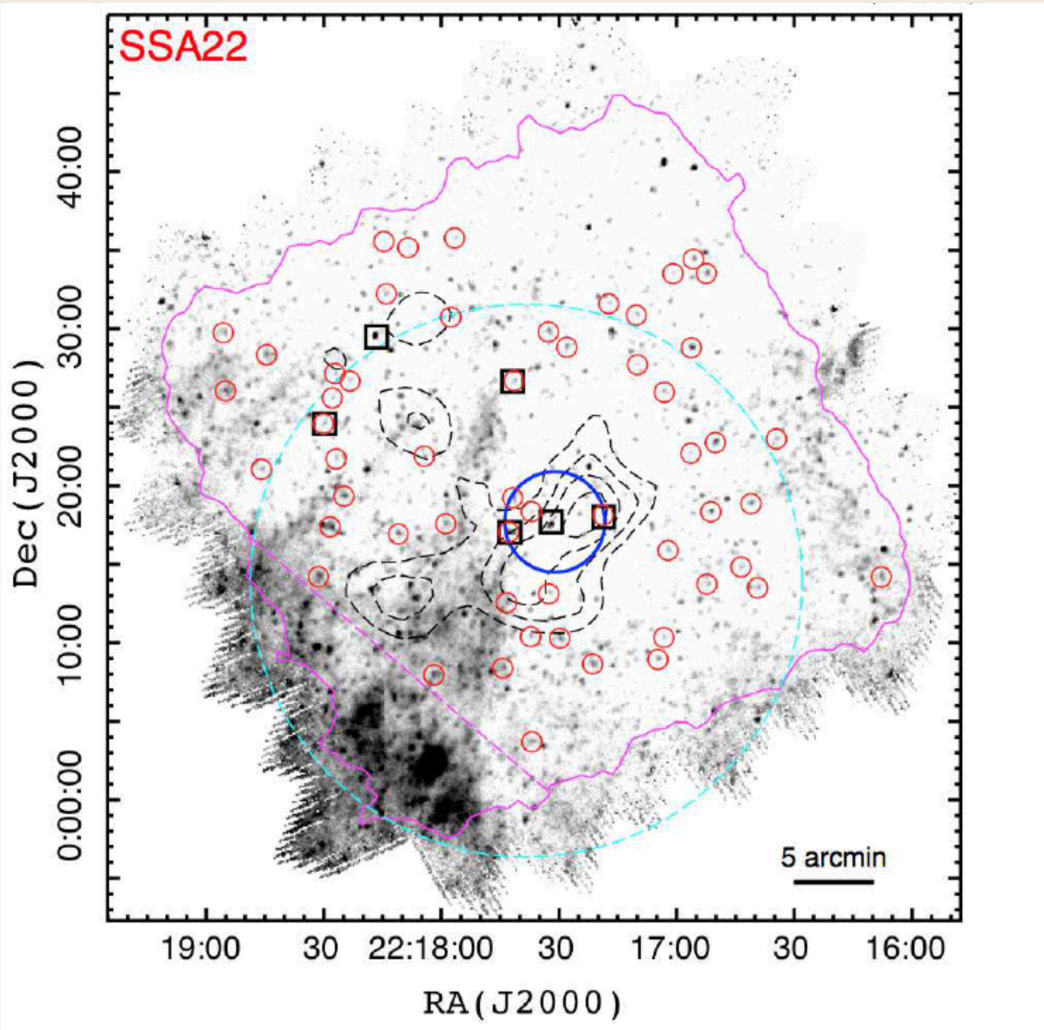
Carilli et al 1997
25 kpc
z = 2.16
% of age Universe)
Dannerbauer et al 2014
VLT FORS
Spitzer IRAC+MIPS
Subaru MOIRCS
-26°24'00"
27'00"
30'00"
33'00"
36'00"
Dec (J2000)
12s
41m00s
48s
RA (J2000)
S/N
Miley et al. 2006 (Credits: NASA, ESA, George Miley and Roderik Overzier (Leiden Observatory, NL)
IAP, Paris, Jun 20-24, 2016
Paola Andreani

Overdensity of Ly-break Gs - Ly-α-emitters z=3.09

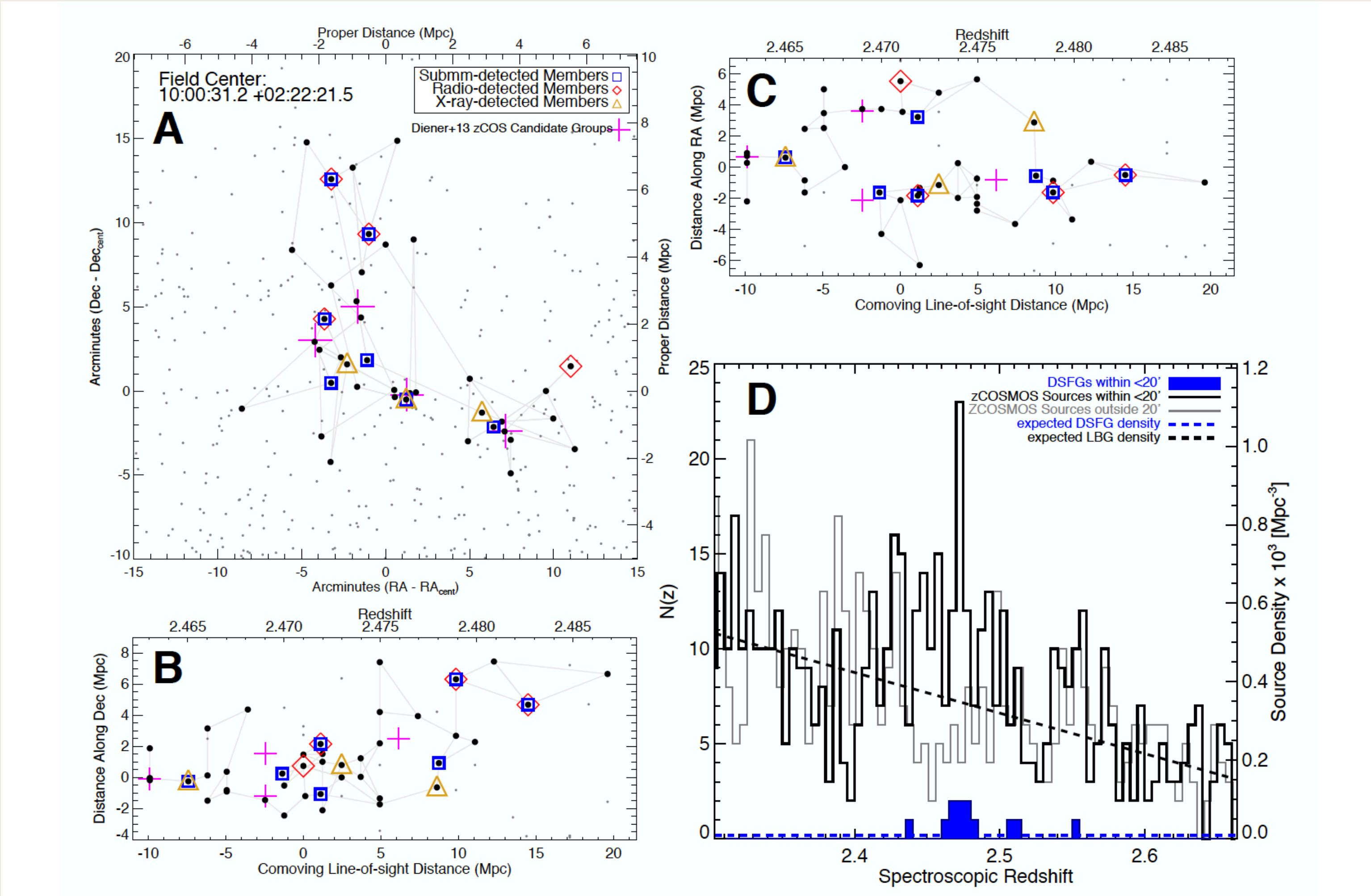
60Mpc comoving

Total SFR ~ 5600 $M_{\odot}$/yr



Steidel et al 1998, Hayashino et al 2004, Matusa et al. 2005, Yamada et al, 2012, Kubo et al 2016

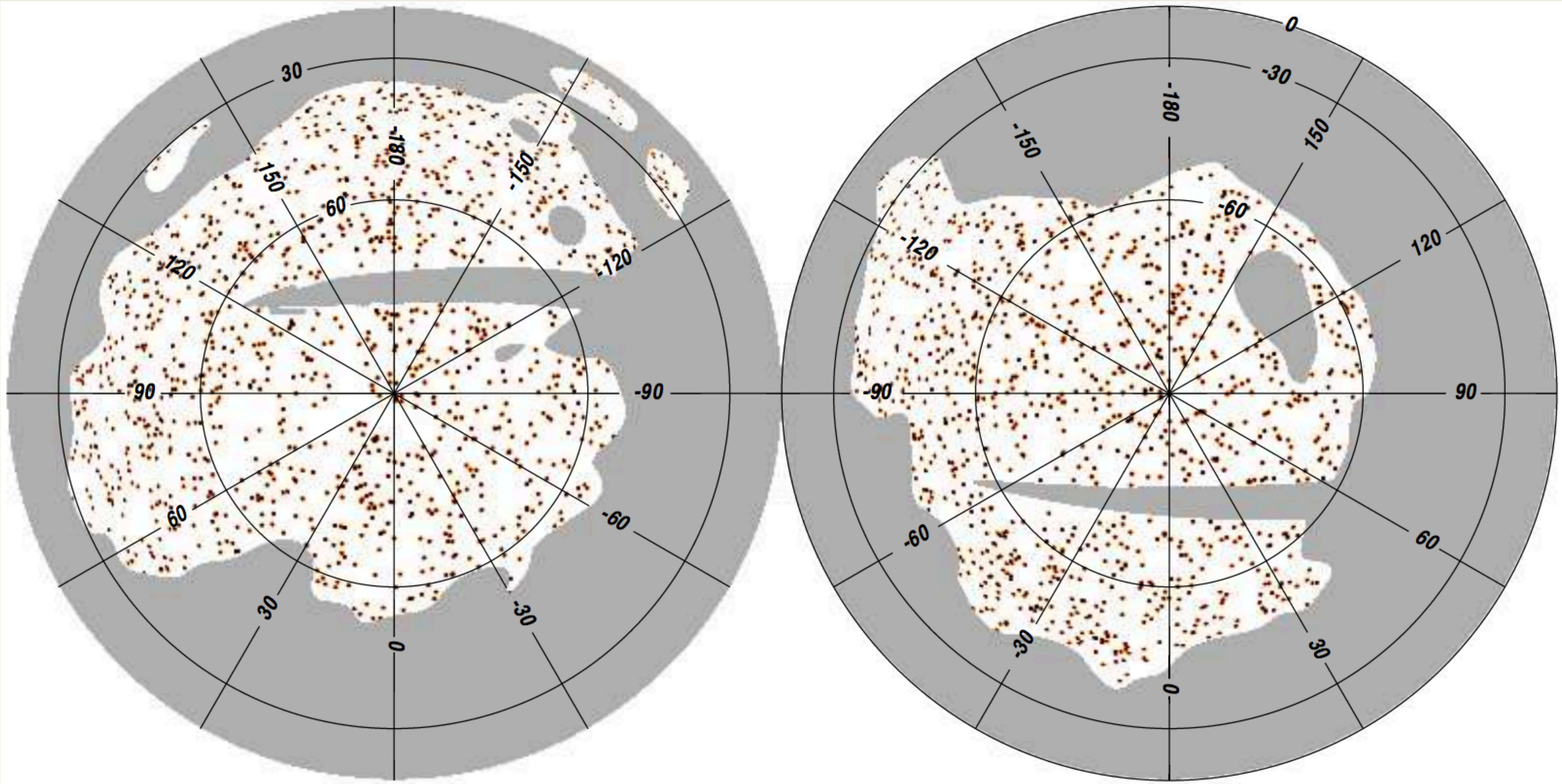
z=2.47 PCL1002 proto-cluster



Casey et al, 2015;

Why FIR/submm?
Protoclusters as dusty sources

High-redshift infrared galaxy overdensity candidates in Planck



Planck Collaboration, 2015, arXiv:1508.04171

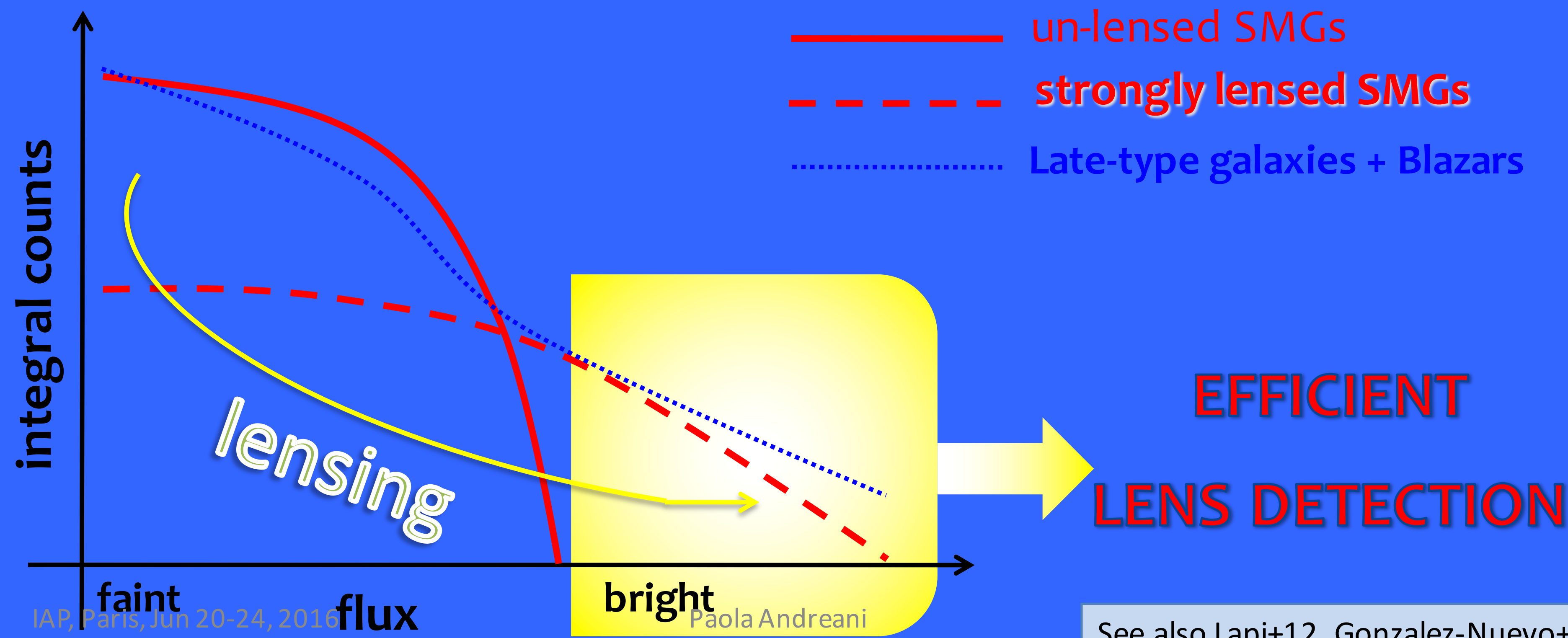
a Lensing science case for large FIR surveys (H-atlas)

Sub-mm surveys are ideal for finding lenses

Blain (1996), Perrotta et al. (2003), Negrello et al. (2007)

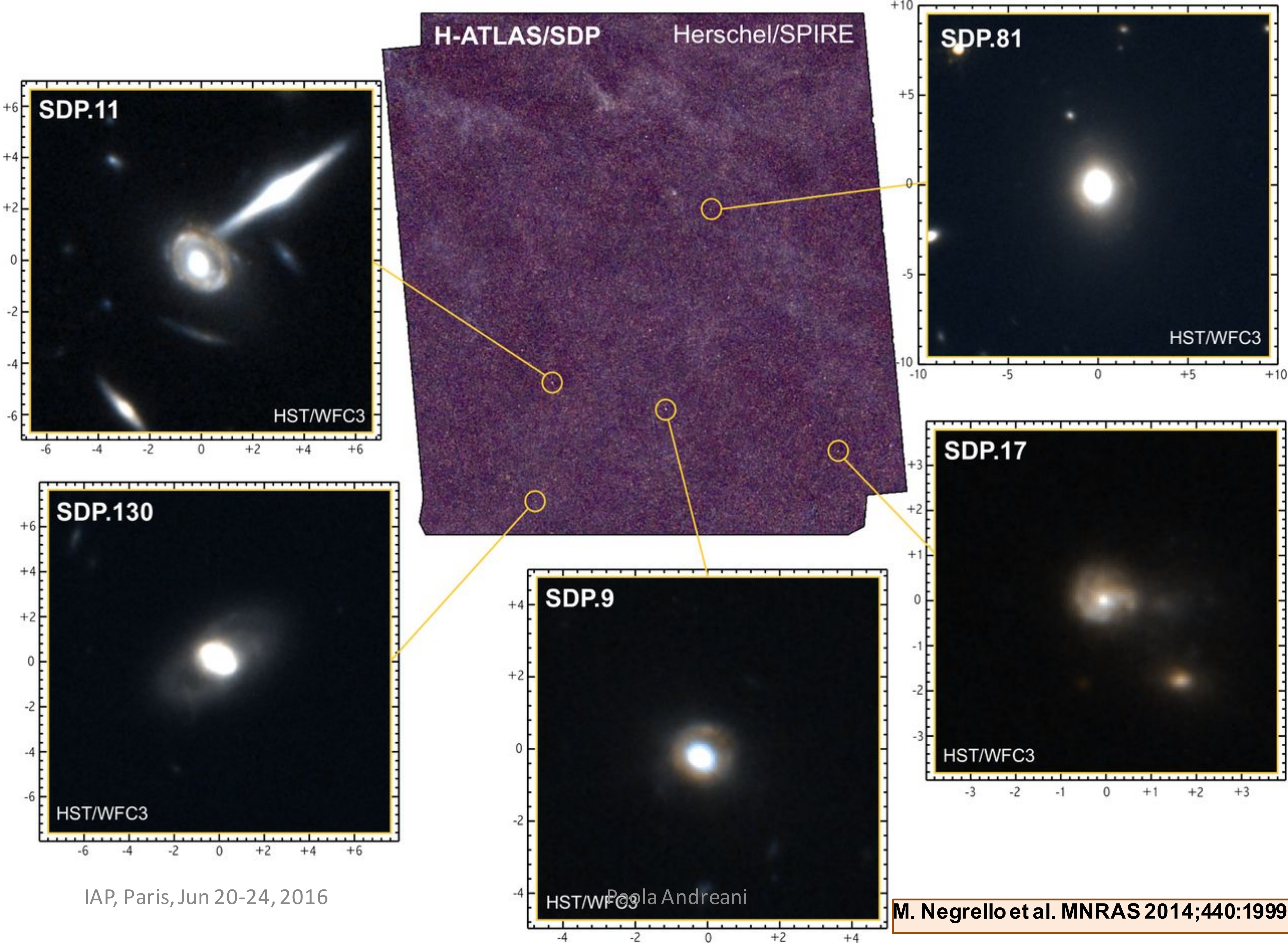
- **high redshift** → high efficiency for lensing
  Chapman et al. (2005)
- **steep counts** → strong *magnification bias*
  Coppin et al. (2006)

Negrello, 2010



See also Lapi+12, Gonzalez-Nuevo+12

HST/WFC3 images of the first five confirmed gravitational lensing systems discovered by H-ATLAS (blue for F110W and red for F160W).



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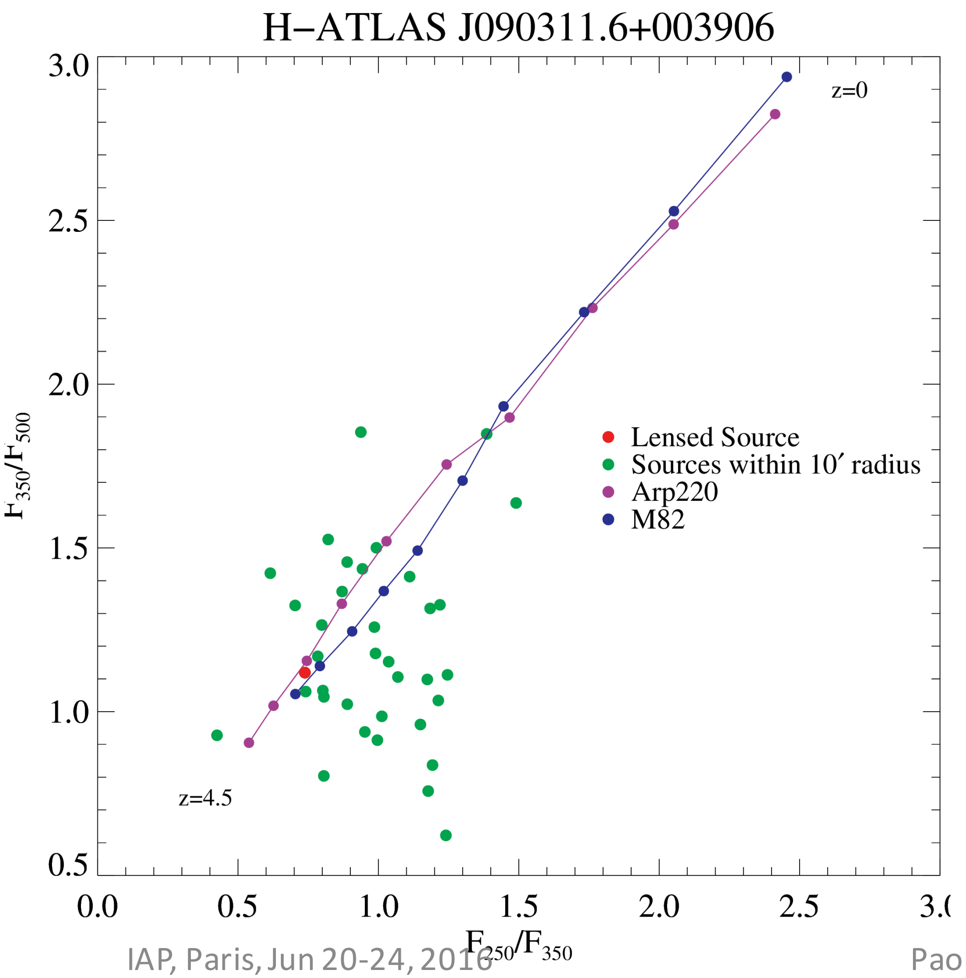
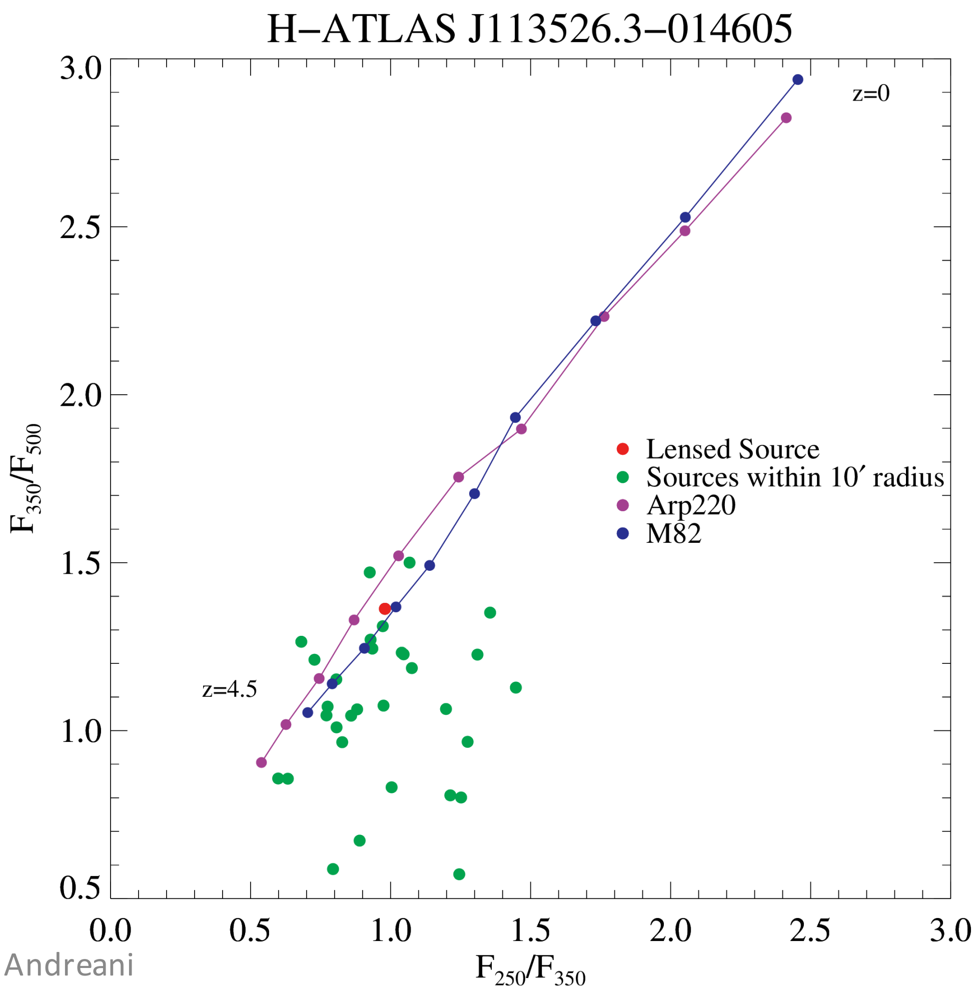
M. Negrello et al. MNRAS 2014;440:1999

Selecting candidates from col-col plots

SDP81: HATLAS J090311.6+003906

G12v2.43: HATLAS J113526.3-014605



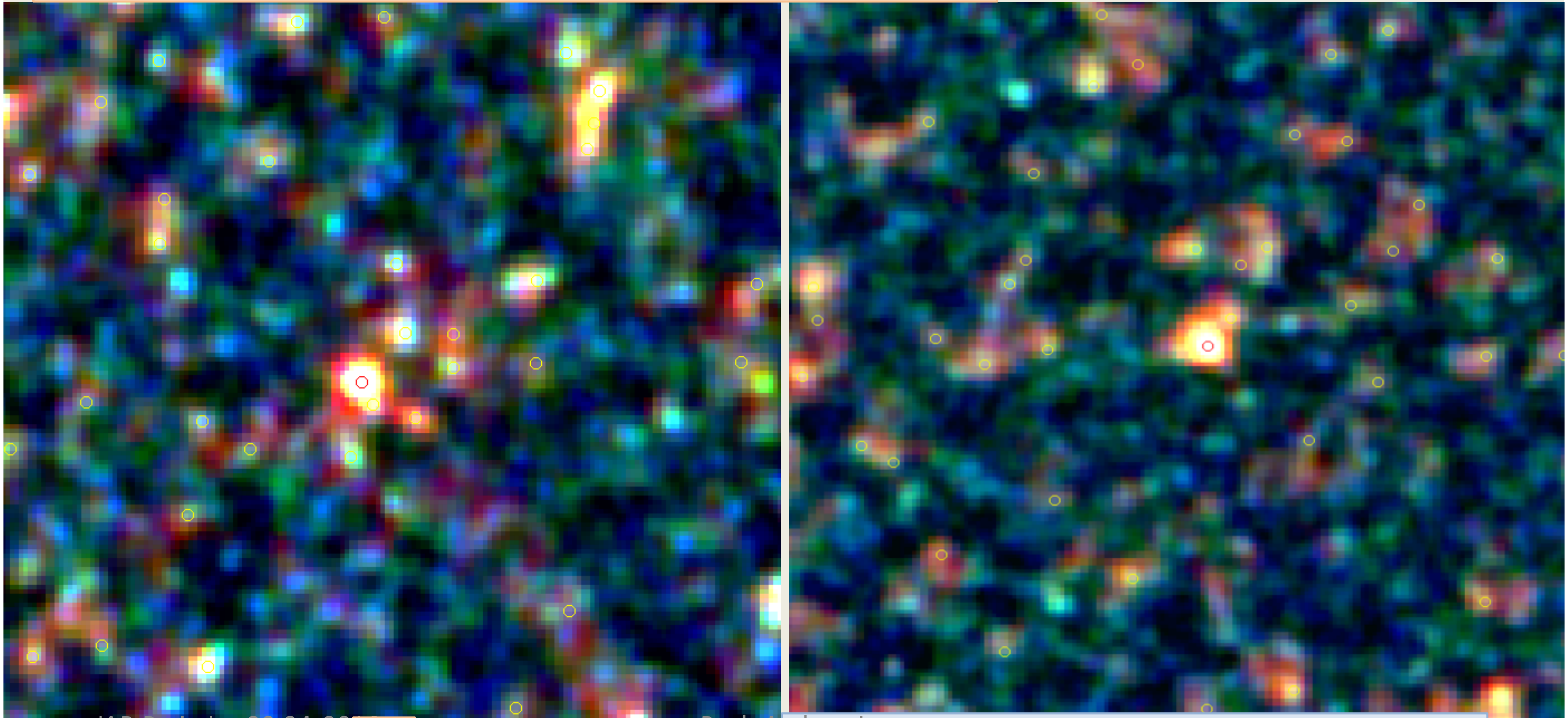


Overdensities in H-ATLAS fields

3 colour maps of the overdensity fields

candidate protoclusters around the lenses H-ATLAS J09+00 at z=3.04 and H-ATLAS J11-01 at z=3.12

Lenses: red circles, Herschel high-z sources: yellow circles

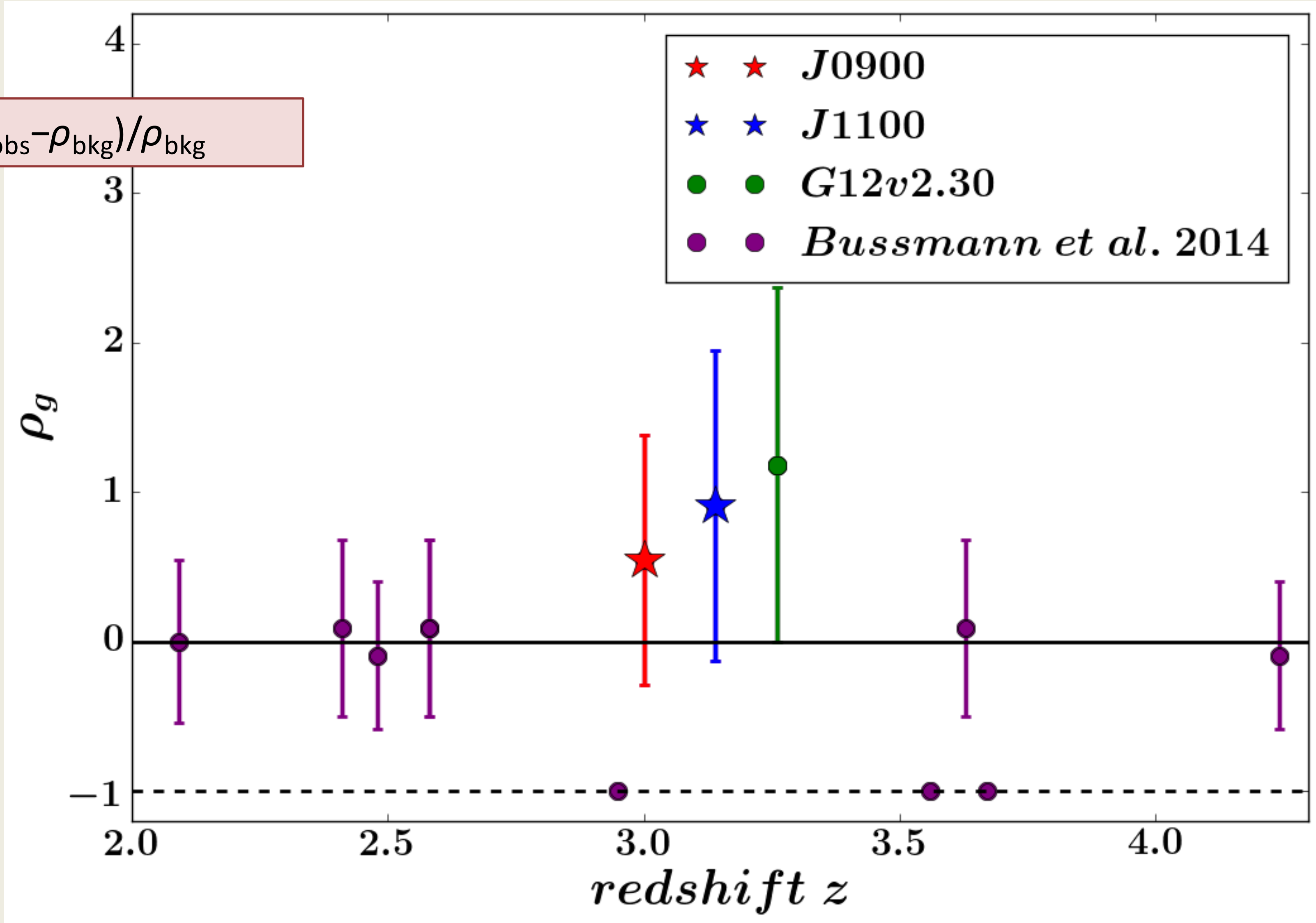


8′

Blue = 250μm Green=350μm Red=500μm

Surface density of sources in the targeted fields

$\rho_g = (\rho_{obs} - \rho_{bkg})/\rho_{bkg}$

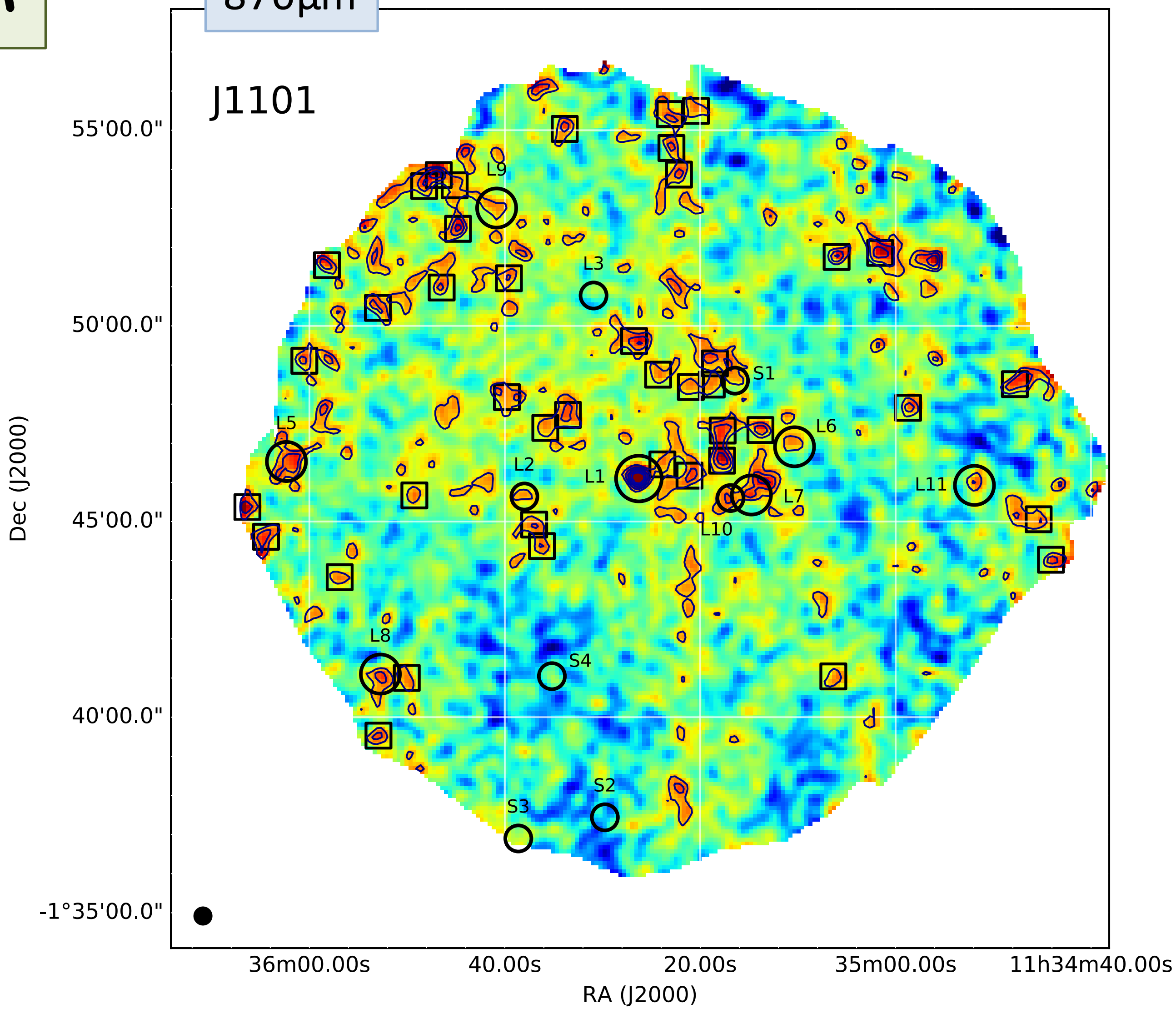


Follow-up APEX/LABOCA

Field of G12v2.43

HATLAS J113526.3-014605

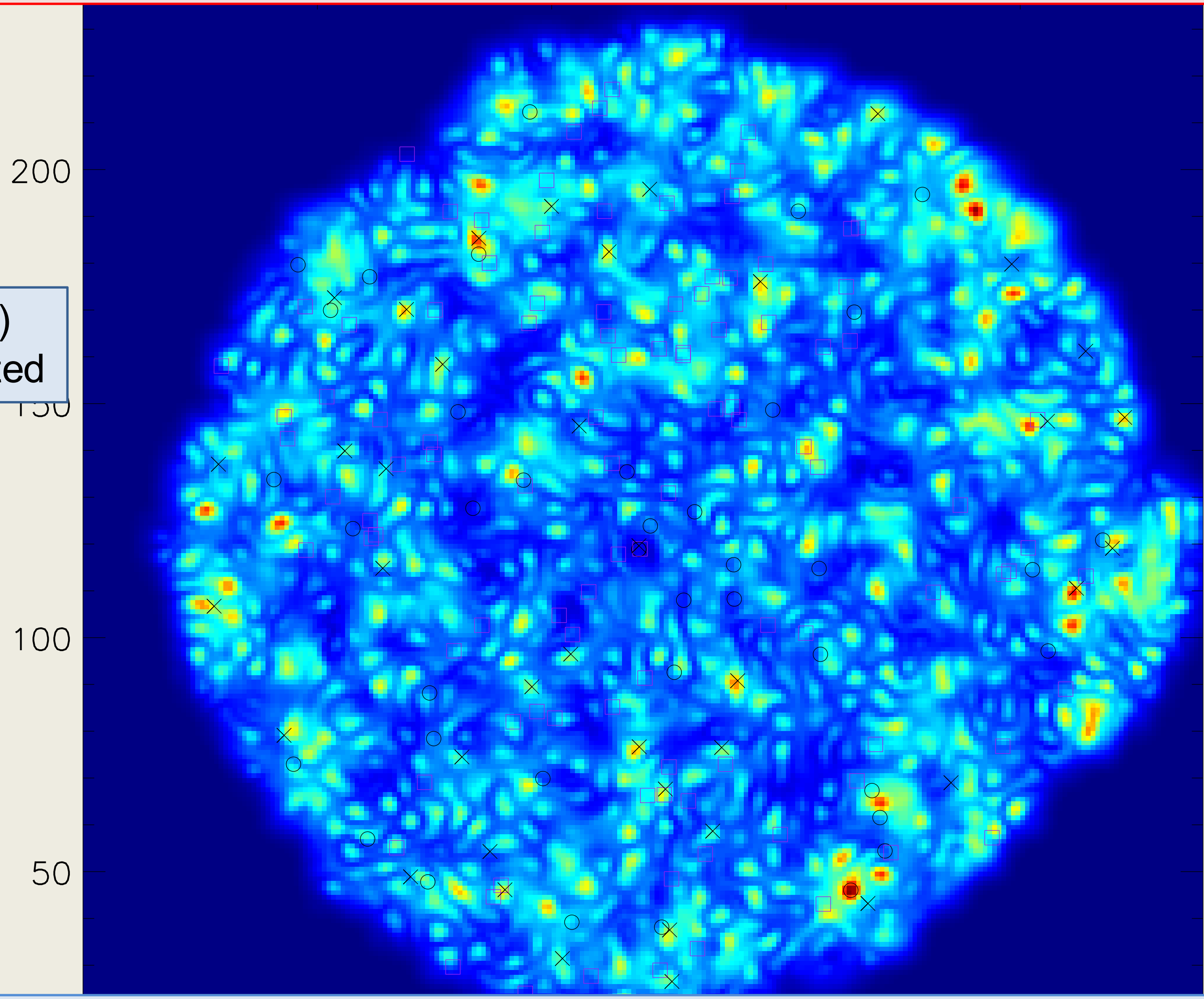
870µm



SPIRE
LABOCA

Retana-Montenegro, P.A., et al, 2016 (submitted)

A more accurate subtraction of the background noise



Central (lensed) source subtracted

Detections through a mean-squared fit of the function p(x,y)= A g(x,y)
A is the amplitude of the flux
g(x,y) is a Gaussian function (LABOCA/APEX psf) with FWHM=3 pixels and peak value=1
The detection threshold = sigma of fit residuals

A more accurate subtraction of the background noise

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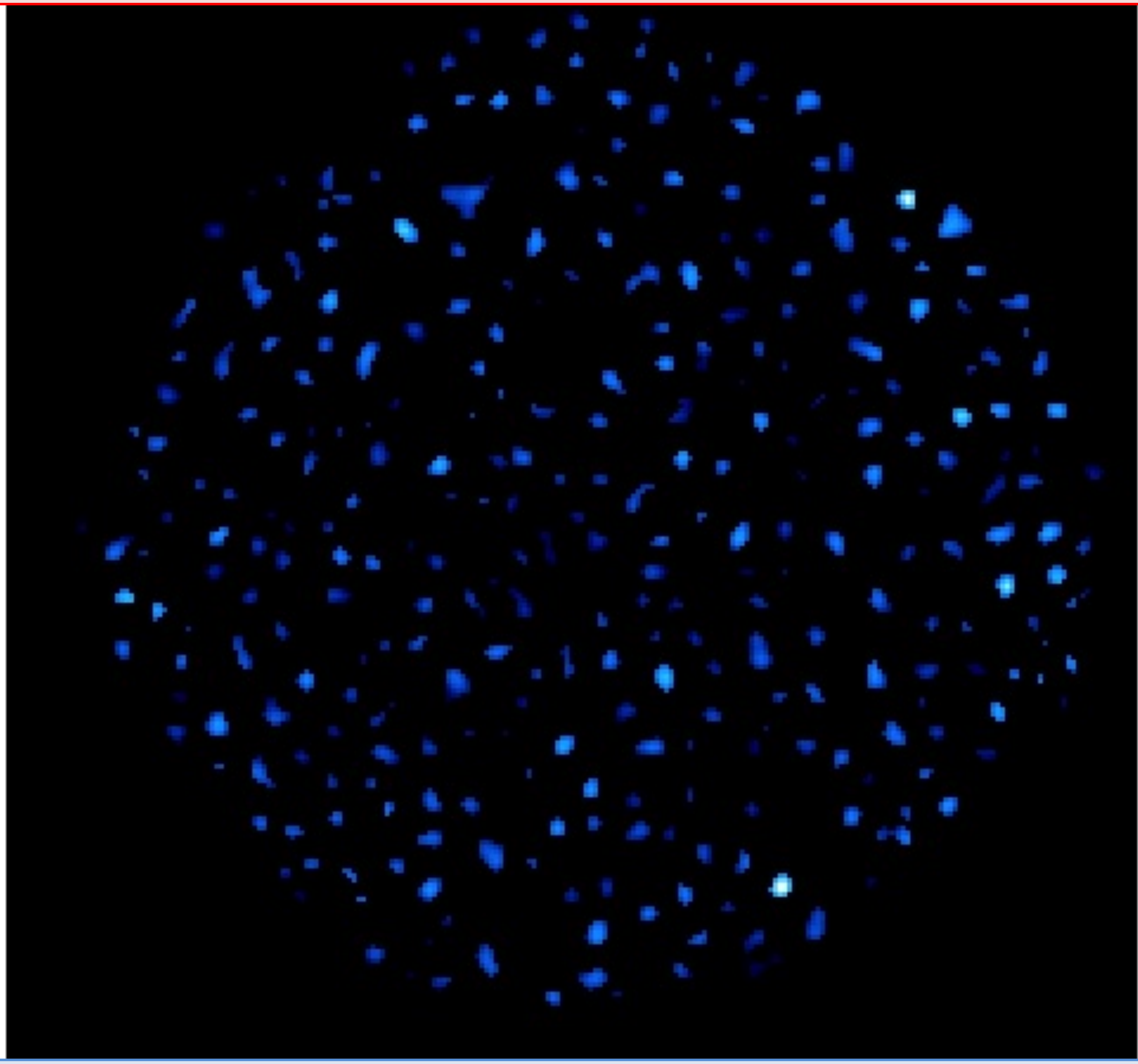

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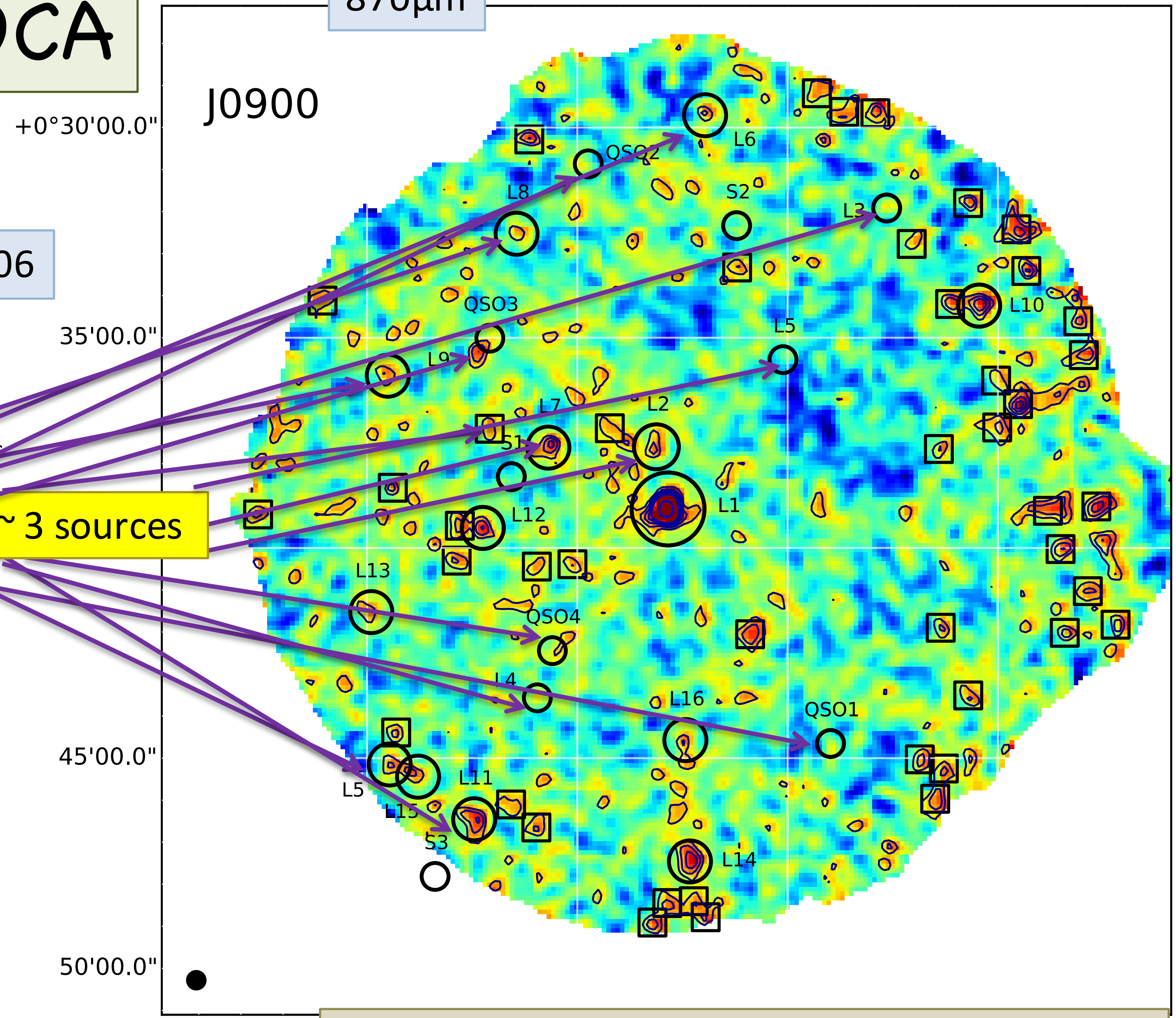
Follow-up APEX/LABOCA

Field of SDP81

870μm

HATLAS J090311.6+003906

Candidate redshift z ~ 3 sources

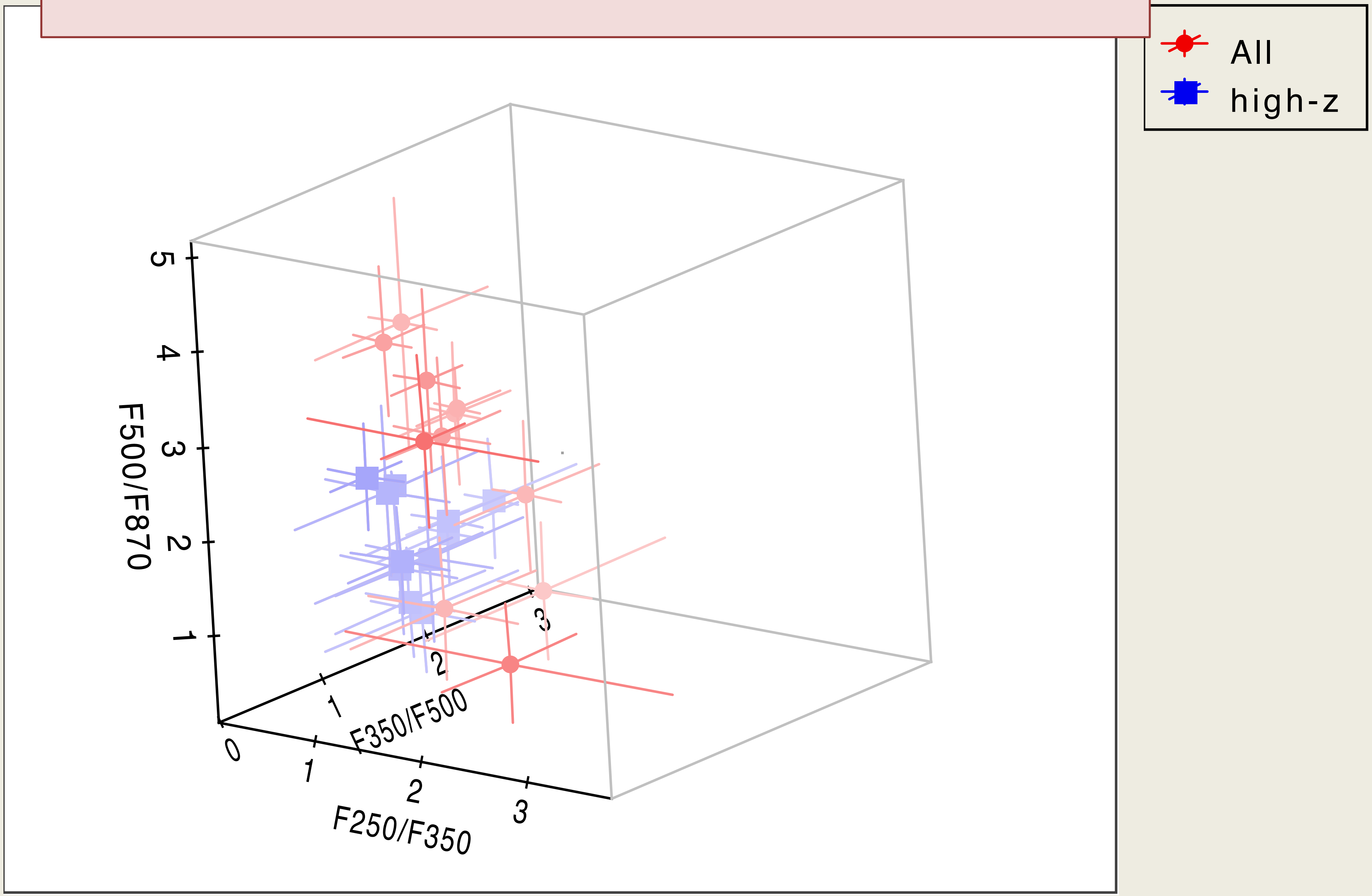


SPIRE
LABOCA

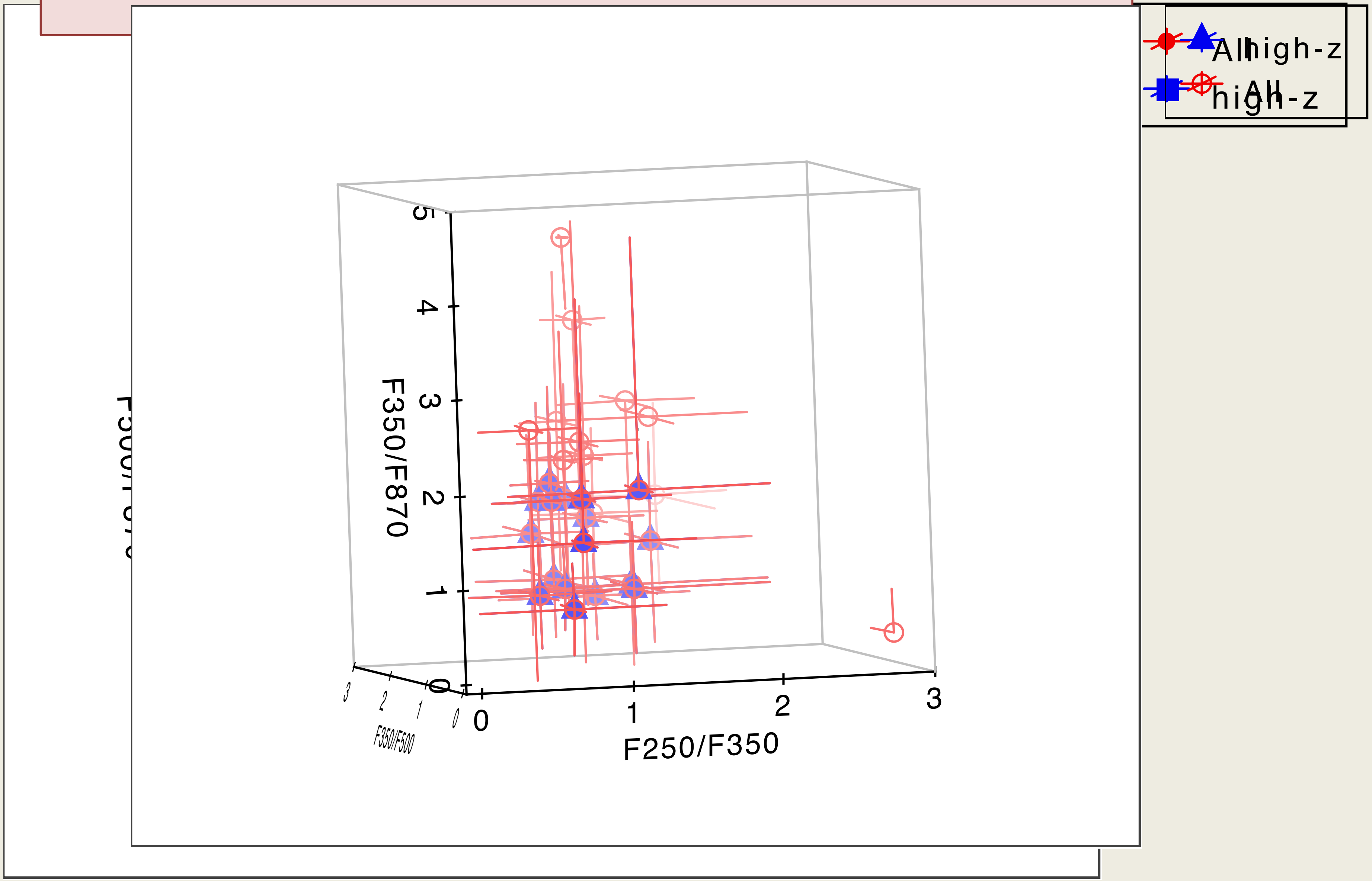
IAP, Paris, Jun 20-24, 2016

Retana-Montenegro, P.A., et al, 2016 (in HATLAS-wiki)

A 3 D colour-colour plot

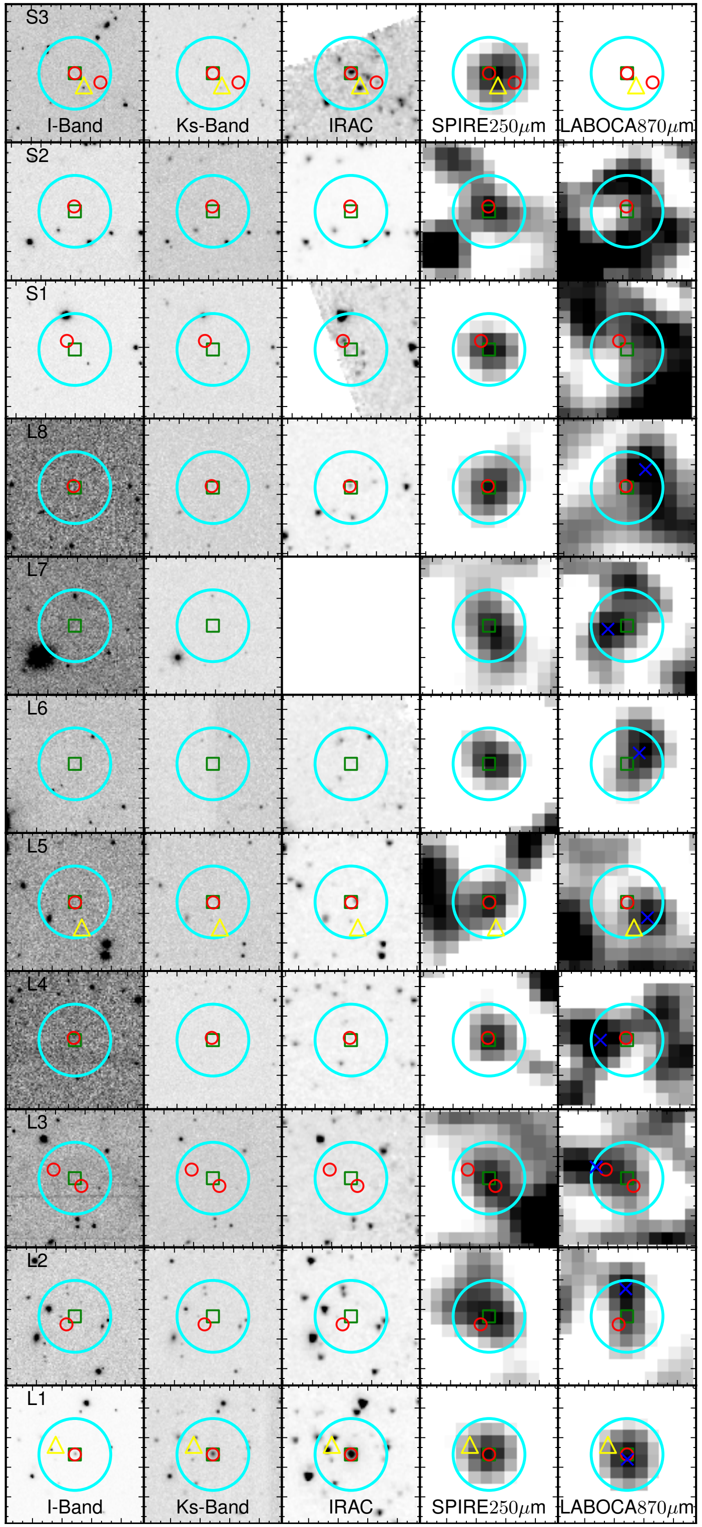


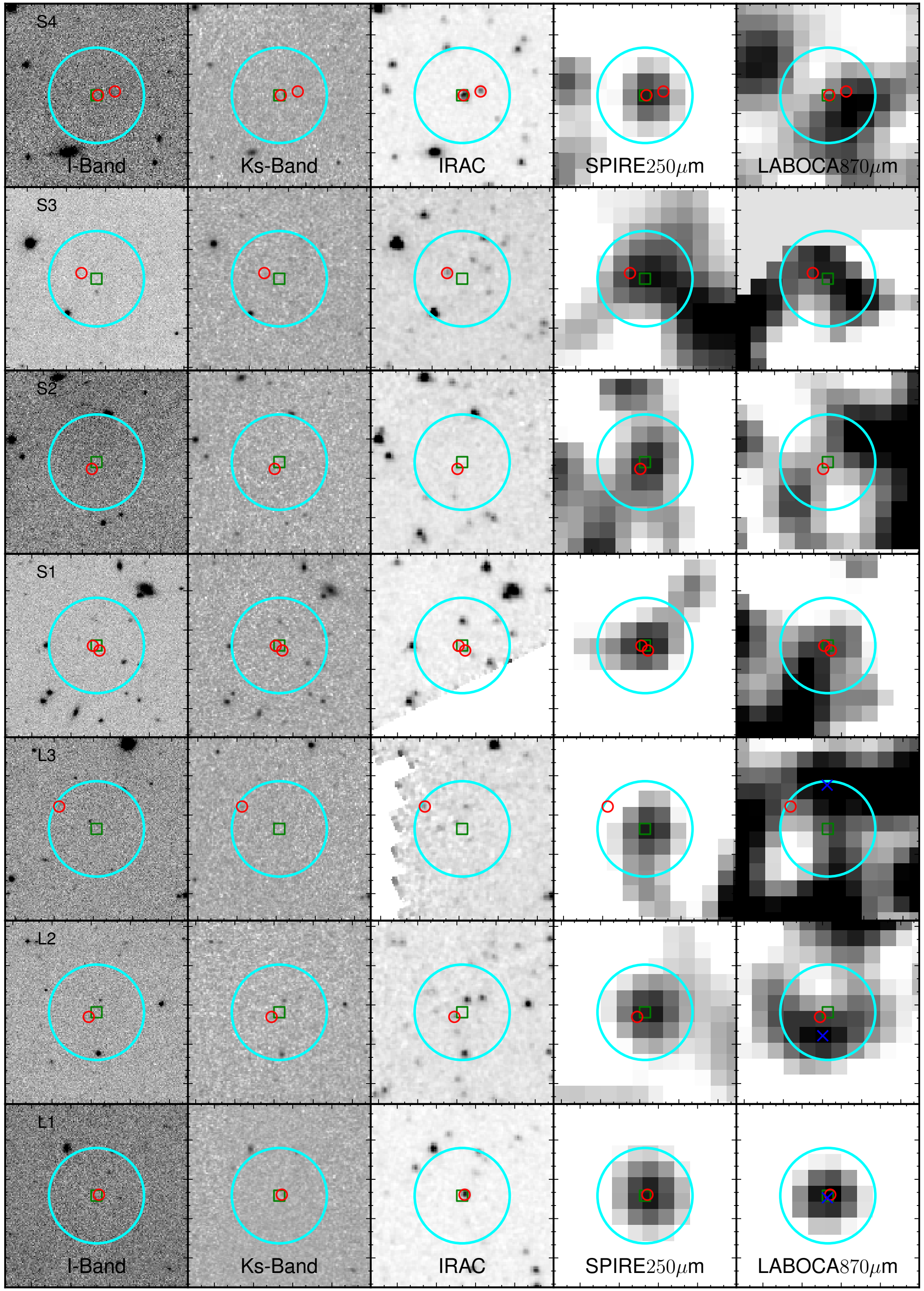
A 3 D colour-colour plot



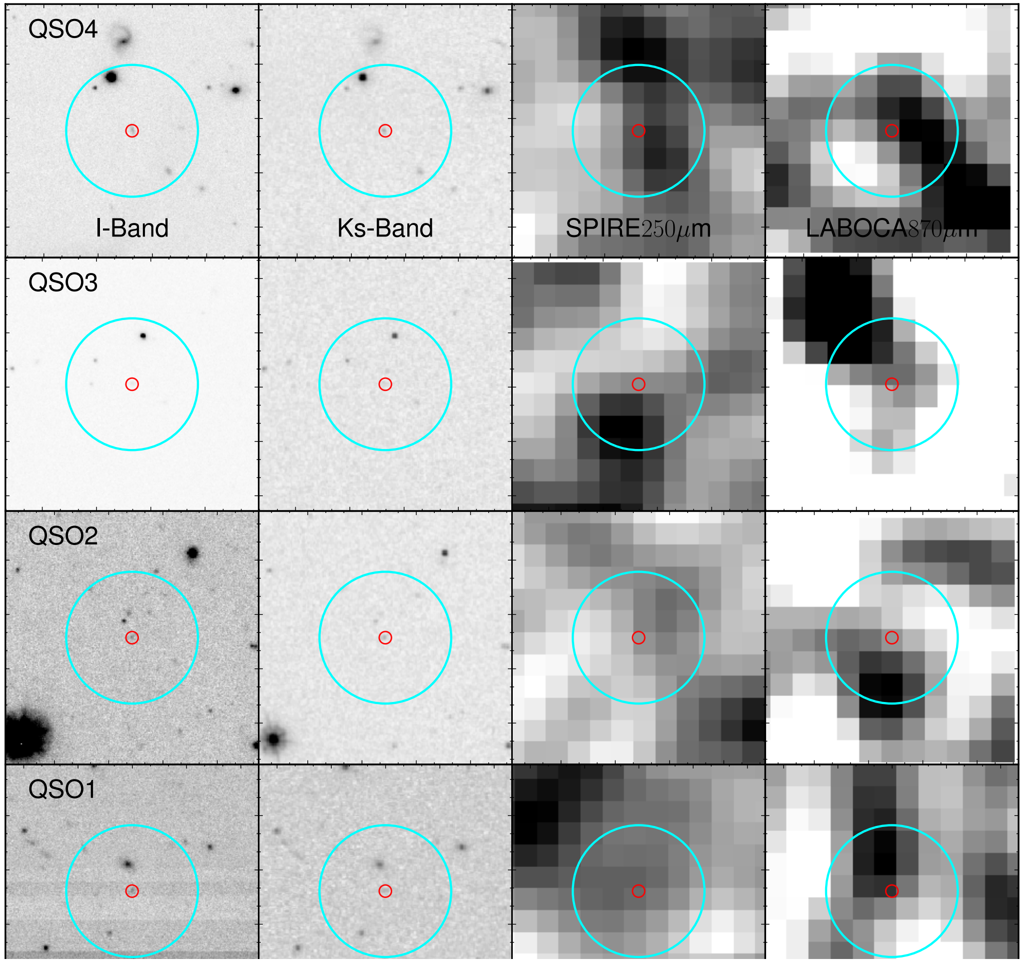
Source identification: archival research

HATLAS Herschel/SPIRE + PACS
Spitzer IRAC 3.6 and 4.5um (rms~0.4uJy)
HAWK-I data (too shallow): no detections
KIDS: u'=24.8, g'=25.4, r'=25.2, i'=24.2 (5σ)
VIKING: Z=23.1 Y=22 J=22.1 H=21.5 Ks=21.3 (5σ)
XMM Newton of GAMA9 (Ranalli et al, 2015):
    too shallow: only 3 sources found
Radio: non detections

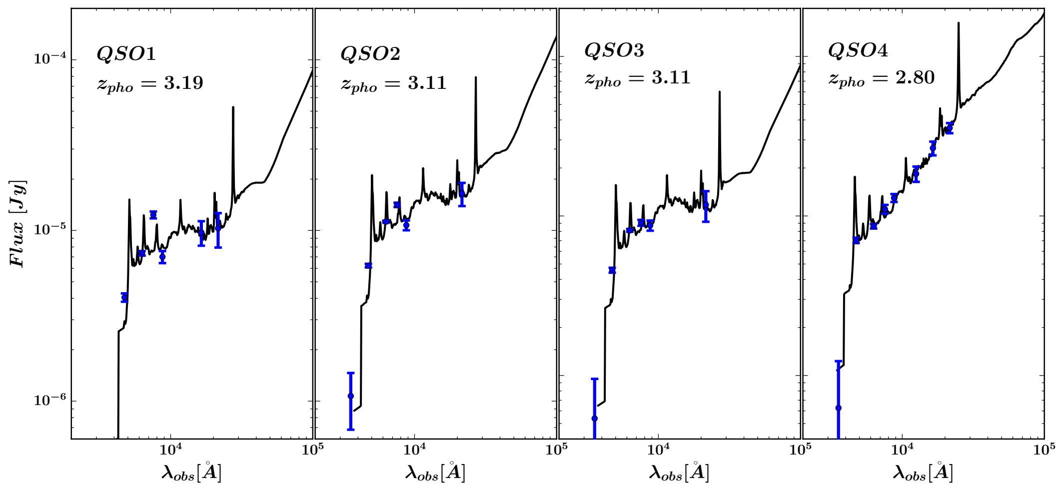

S3
S2
S1
L8
L7
L6
L5
L4
L3
L2
L1
I-Band
Ks-Band
IRAC
SPIRE250μm
LABOCA870μm


S4
S3
S2
S1
L3
L2
L1
I-Band
Ks-Band
IRAC
SPIRE250μm
LABOCA870μm

QSOs at z~3

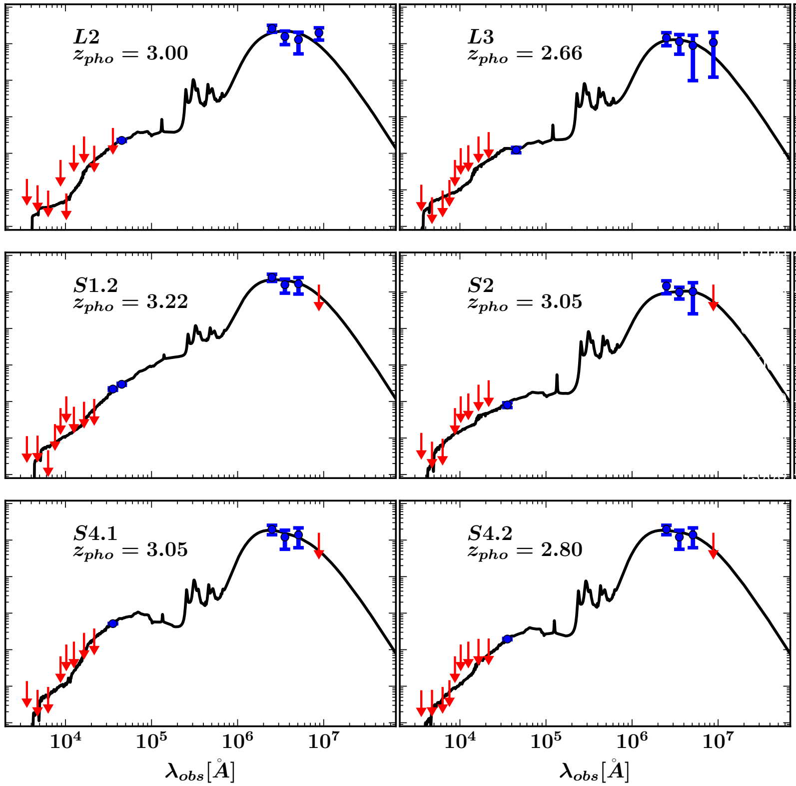


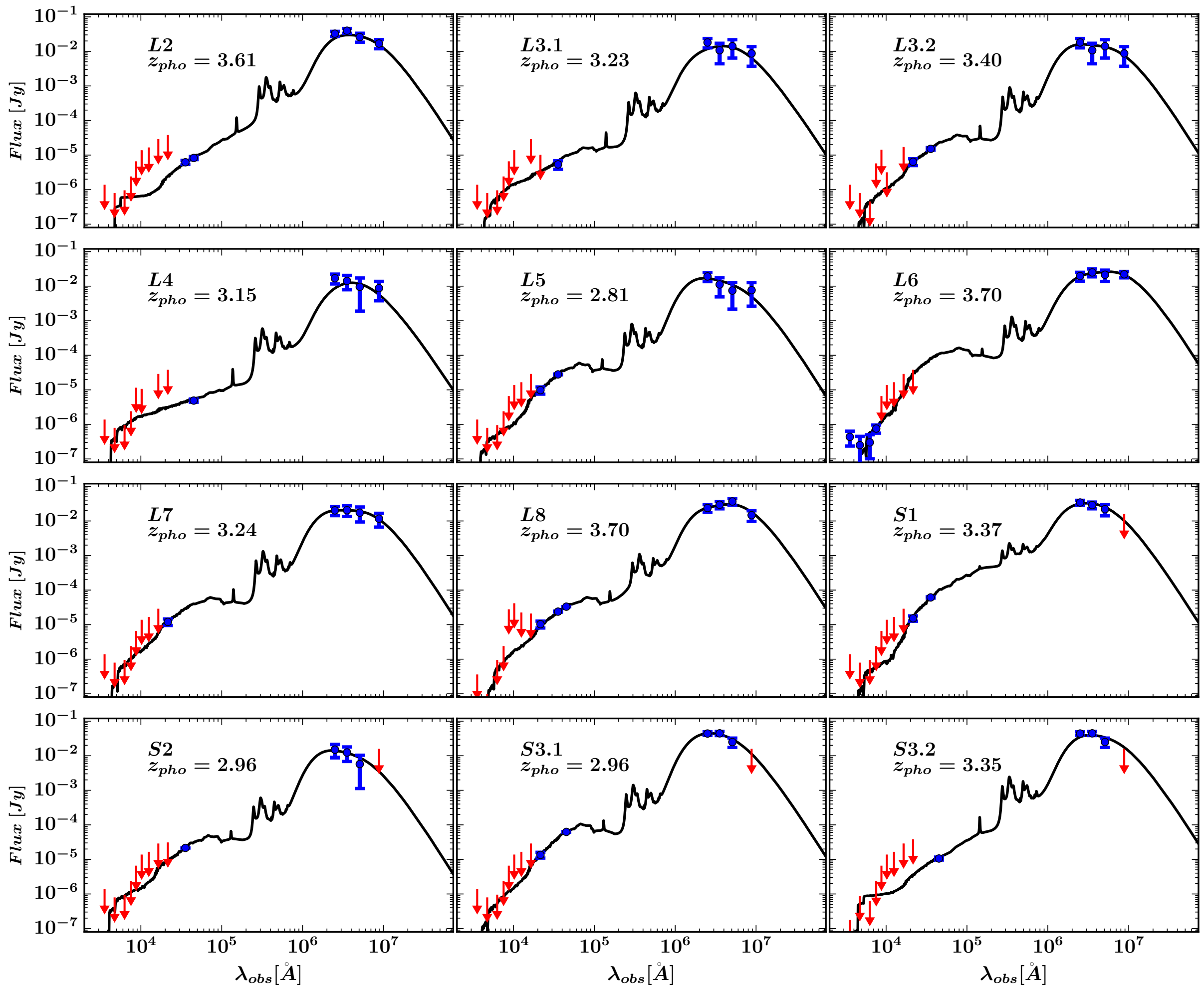
QSO4
I-Band
Ks-Band
SPIRE250μm
LABOCA870μm
QSO3
QSO2
QSO1



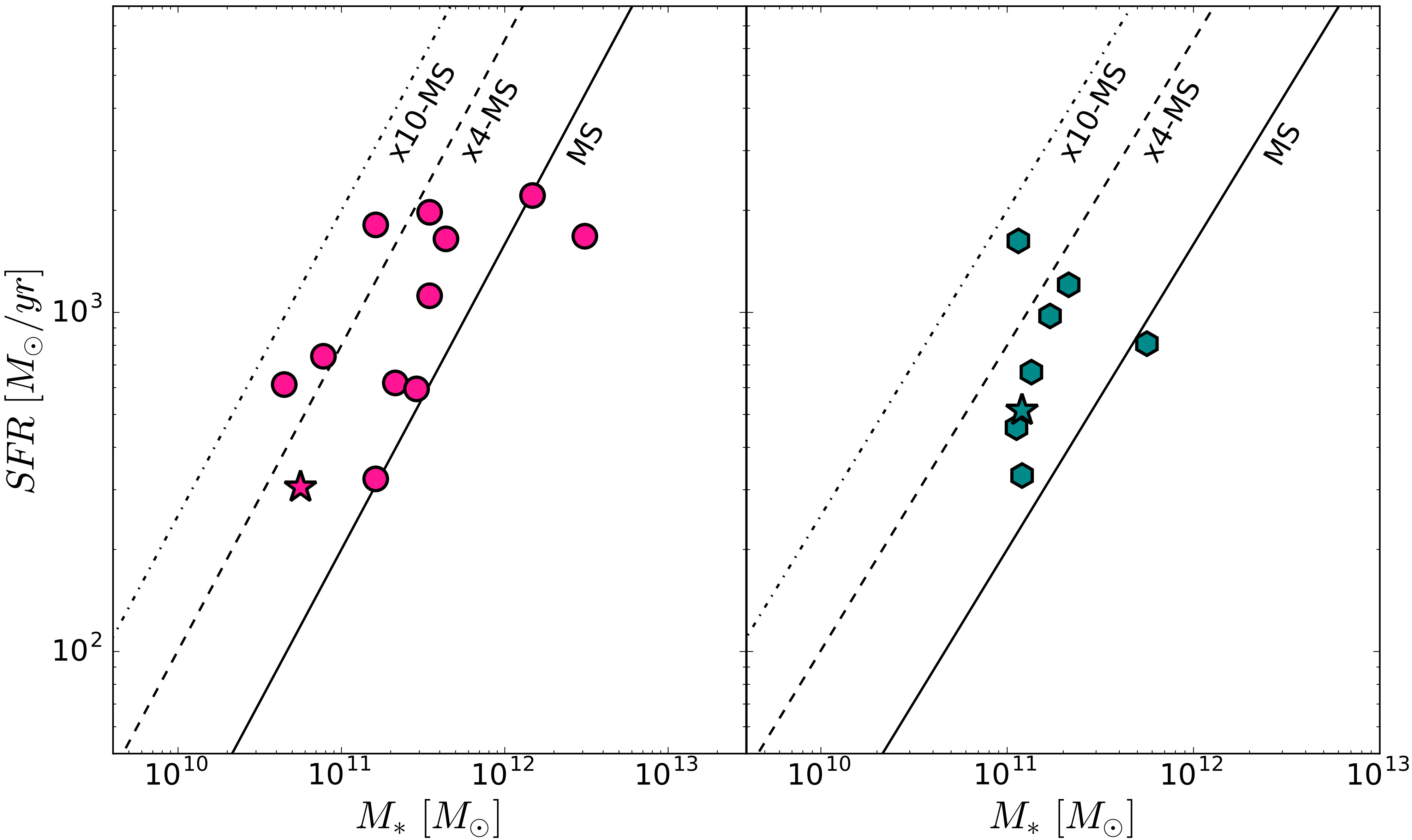
QSO1
$z_{pho} = 3.19$
QSO2
$z_{pho} = 3.11$
QSO3
$z_{pho} = 3.11$
QSO4
$z_{pho} = 2.80$
$Flux\ [Jy]$
$\lambda_{obs}[\AA]$

SEDs fitting

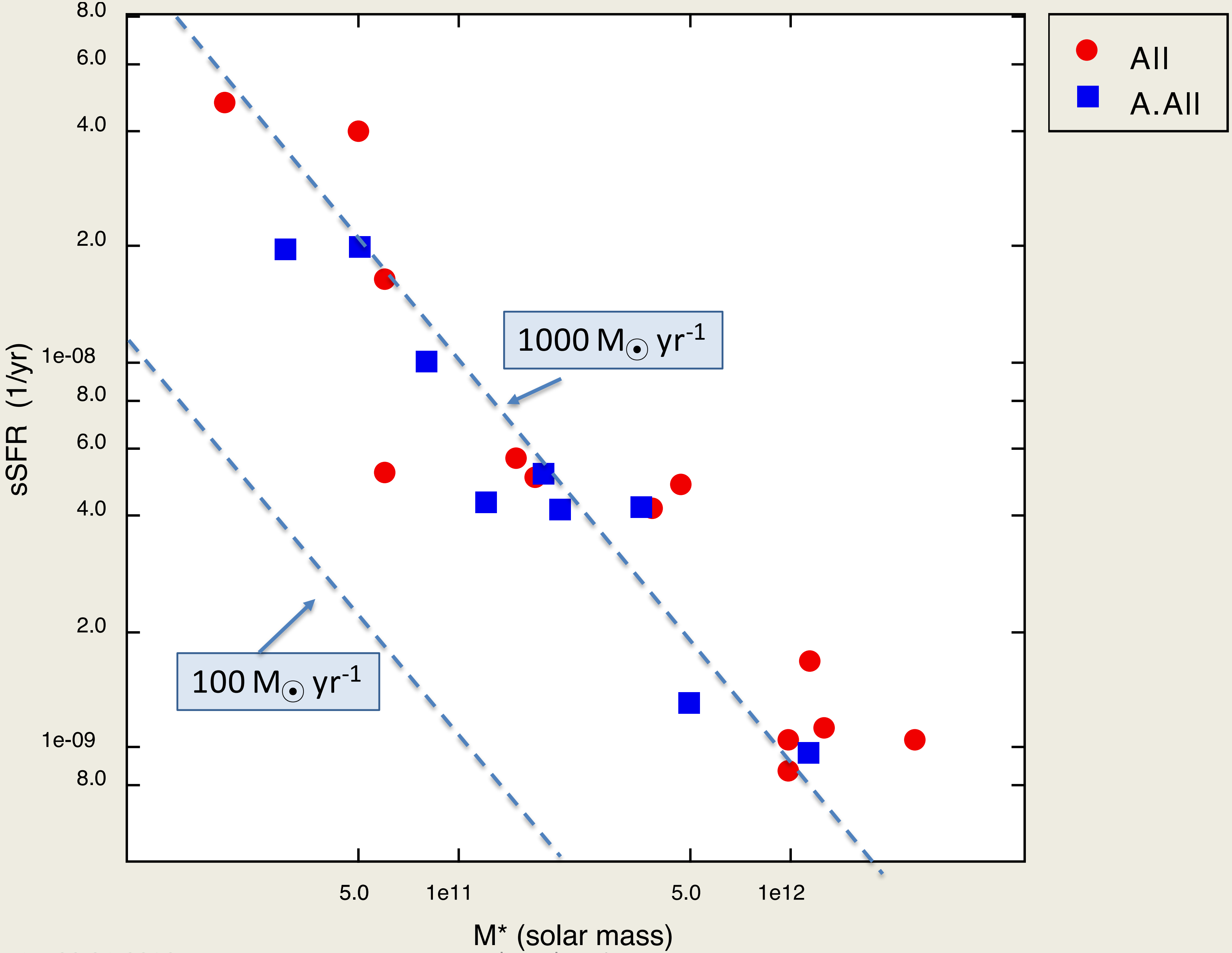




Retana-Montenegro, P.A., et al, 2016 (subr



x10-MS
x4-MS
MS
$SFR\ [M_\odot/yr]$
10^3
10^2
10^{10}
10^{11}
10^{12}
10^{13}
$M_*\ [M_\odot]$
x10-MS
x4-MS
MS
10^{10}
10^{11}
10^{12}
10^{13}
$M_*\ [M_\odot]$



8.0
6.0
4.0
2.0
1e-08
8.0
6.0
4.0
2.0
1e-09
8.0
sSFR (1/yr)
All
A.All
1000 M⊙ yr-1
100 M⊙ yr-1
5.0
1e11
5.0
1e12
M* (solar mass)

Masses of the overdensity

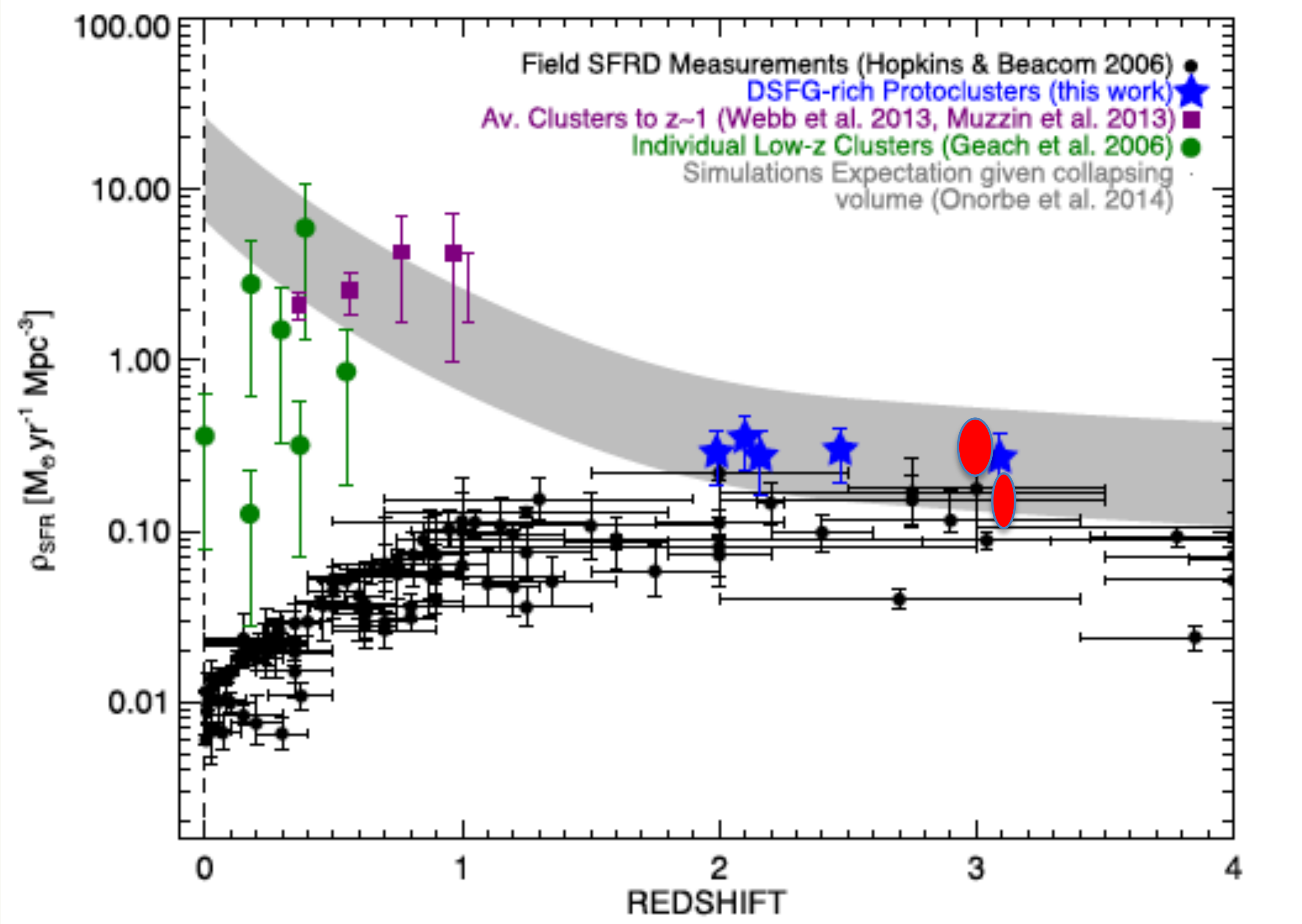
- The total mass in stars: $M_* \sim 2\text{-}7 \times 10^{12}\ M_\odot$
  The mass of the DM halo
- ➔ $M_{\text{DM halo}}$ - SFR relation

$$\mathrm{SFR} = 35 \left(\frac{M_\mathrm{H}}{10^{12}\, M_\odot}\right) \left(\frac{1+z}{2.5}\right)^{2.1} M_\odot\, \mathrm{yr}^{-1},$$

(Lapi et al, 2011)

- $M_{\text{DM halo}} \sim 7.3\ 10^{13} - 1.6\ 10^{14}\ M_\odot$

SFRD of clusters



Casey 2016

Summary

- Colour selection of candidate z>3 Herschel lenses' fields with overdensity of sources
- Follow-ups + archival research: confirm the overdensity of sources at the same z as the lens
- AGN at the same redshift found
  - A few DSFG host a Xray source (likely an AGN)
  - High-z proto-clusters contain rare DSFGs and luminous AGN in 10arcminutes
- These structures are rare and short-lived
- Observations of protoclusters over large regions of sky will shed light on the assembly of galaxy clusters
  - Will these structure eventually collapse?
  - Which are the nowadays counterpart?