Evolution of the Interstellar Gas Fraction Over Cosmic Time

CANDELS and ALMA

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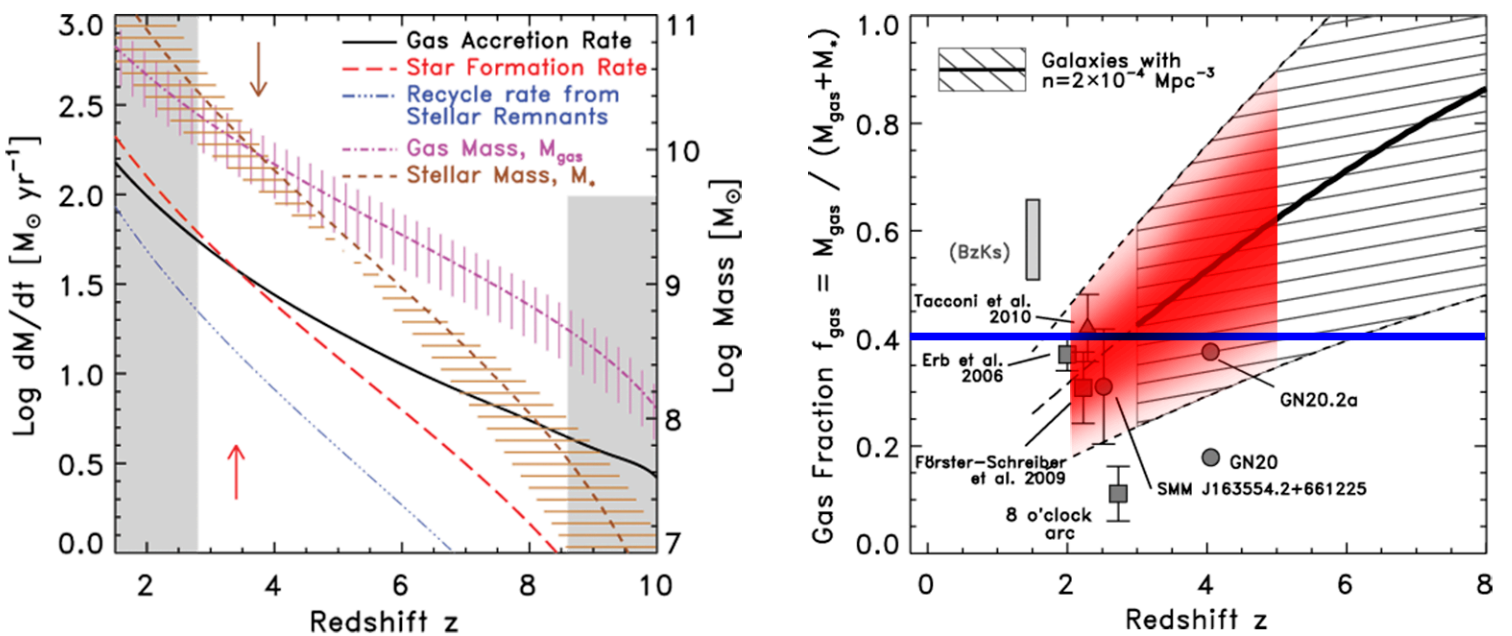
Pant, N., Motiño, S., Ferguson, H., Guo, Y., Koo, D., Kocevski, D., Mobasher, B., Brammer, G., Kassin, S., Koekemoer, A., Giavalisco, M., Papovich, C., Ravindranath, S.

Preliminary results from an ALMA program

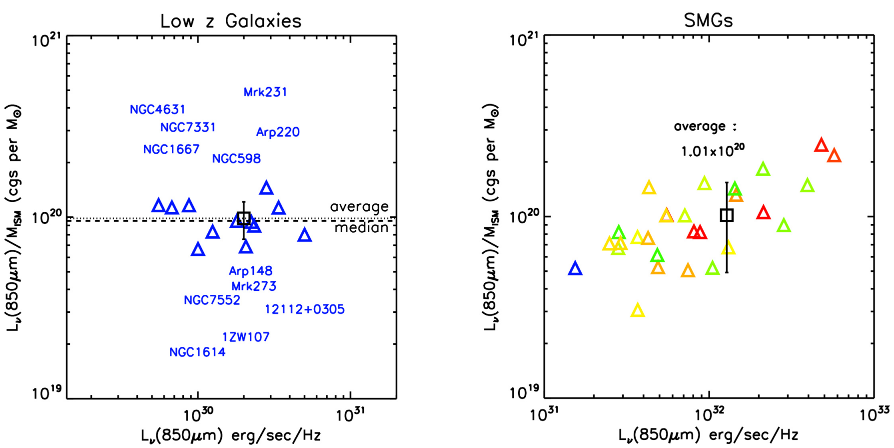
Measure the cold-gas mass fraction of 70 galaxies that today have a stellar mass log(M_*) =11.2, but observed as lower-mass progenitors from z=2 to 5.



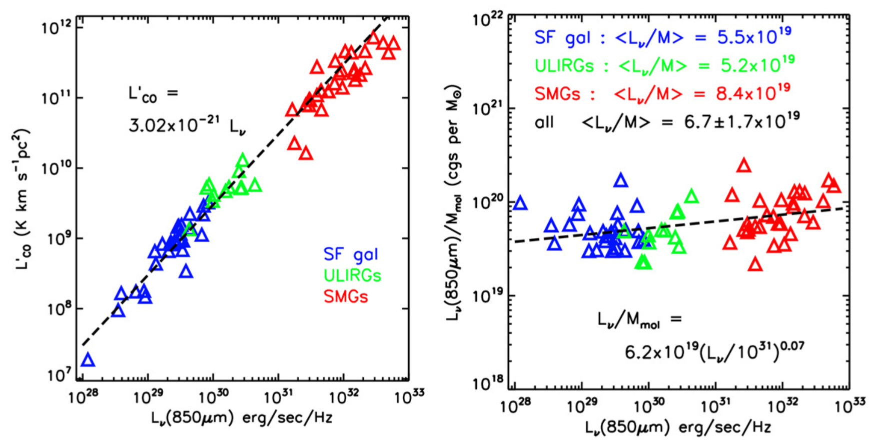
adopted from Papovich+ 2011

Gas mass measurements:

Atomic hydrogen	–	HI 21cm line	Difficult/impossible at high-z
Molecular hydrogen	–	CO rotational lines	Time consuming/X-factor
Ionized hydrogen	–	Recombination lines	Usually small mass component
Molecular+Atomic ISM	–	Dust continuum emission	Metallicity/gas-to-dust ratio



Scoville+ 2014



Scoville+ 2015

Assumptions behind using submm continuum as a proxy for ISM mass

- Most of the dust mass is contained in a cold component

  Dust and heating sources distributed in a similar manner as in low-z galaxies with T_{dust} ~ 15-25K

- The Raleigh-Jeans part of the dust SED is optically thin

  Need to observe at longer wavelengths for highest redshifts

- Gas-to-dust mass ratio and dust opacity coefficient constant

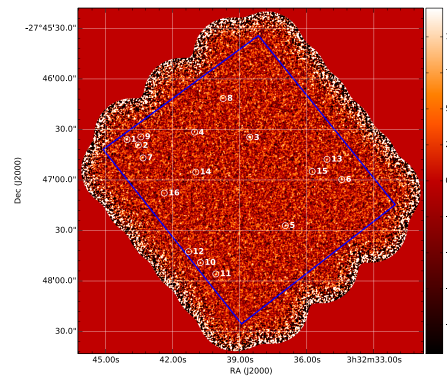
  Metallicity must be in the range 0.2 – ~1 Solar

  - M_{gas} linearly dependent on observed flux
  - M_{gas} linearly dependent on dust temperature

Sample selection techniques

Basically three approaches with ALMA:

UDF



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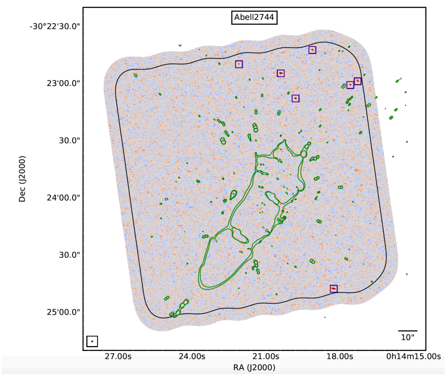
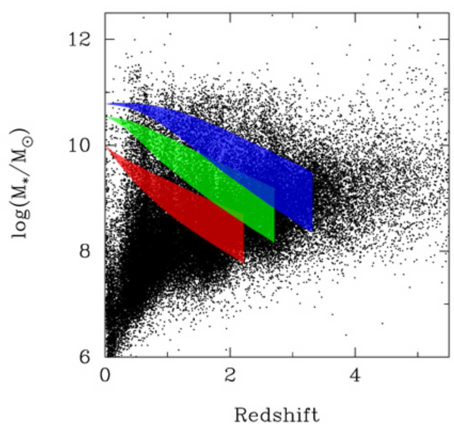


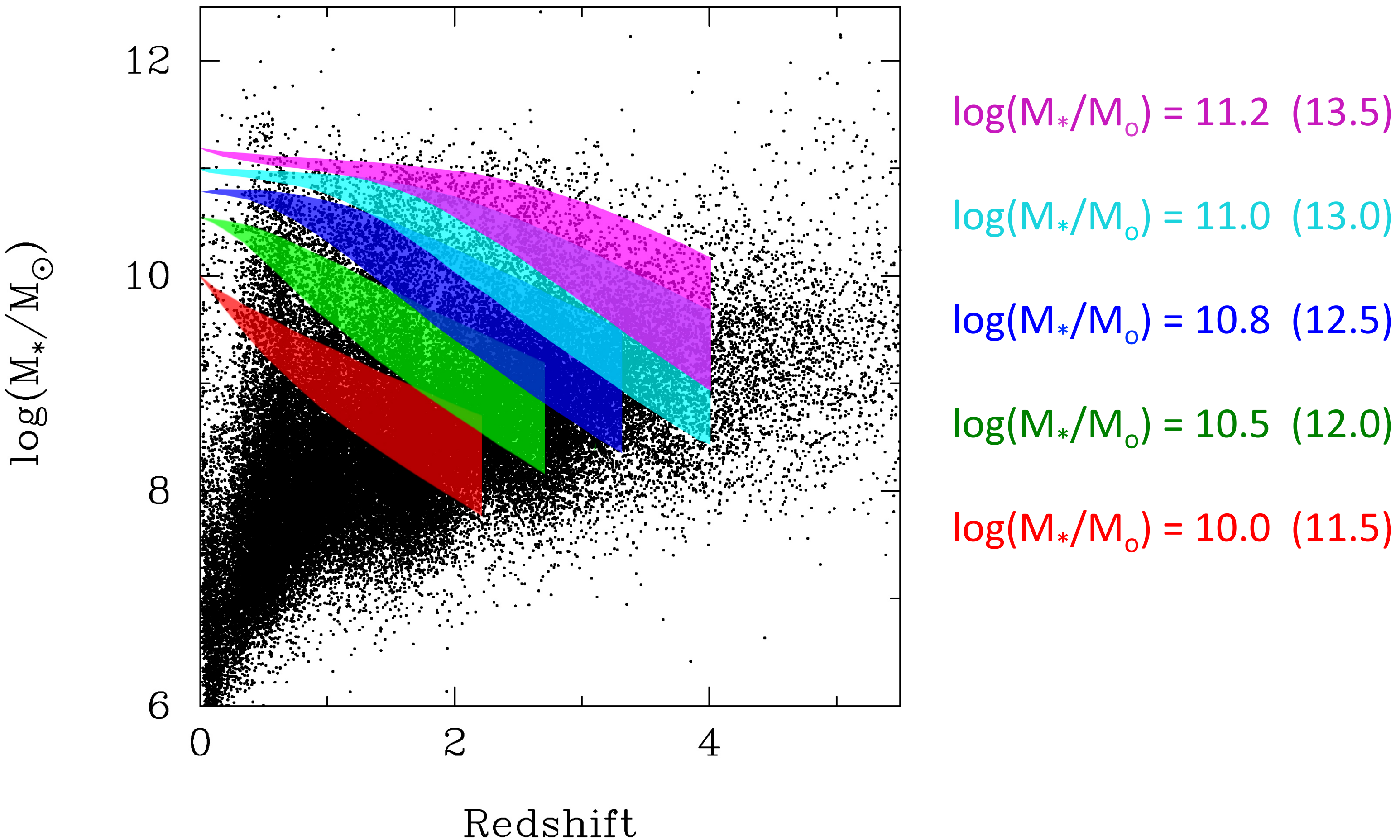
Blind surveys – UDF, Frontier Fields
(Dunlop+ 2016; González-López+ 2016)

FIR selected survey – COSMOS
(Scoville+ 2016, 2017; Schinnerer+ 2016)

Stellar mass selected survey – CANDELS/GOODS-S
(Wiklind+ 2017)



Selecting galaxies using abundance matching (Behroozi+ 2013; Moster+ 2013)



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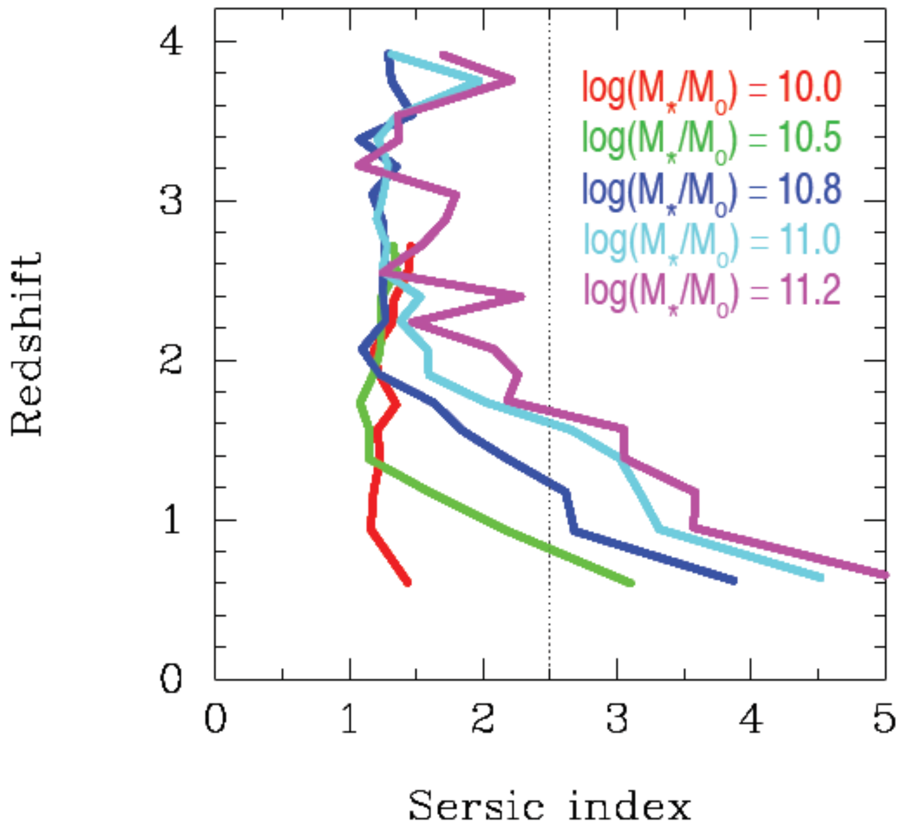
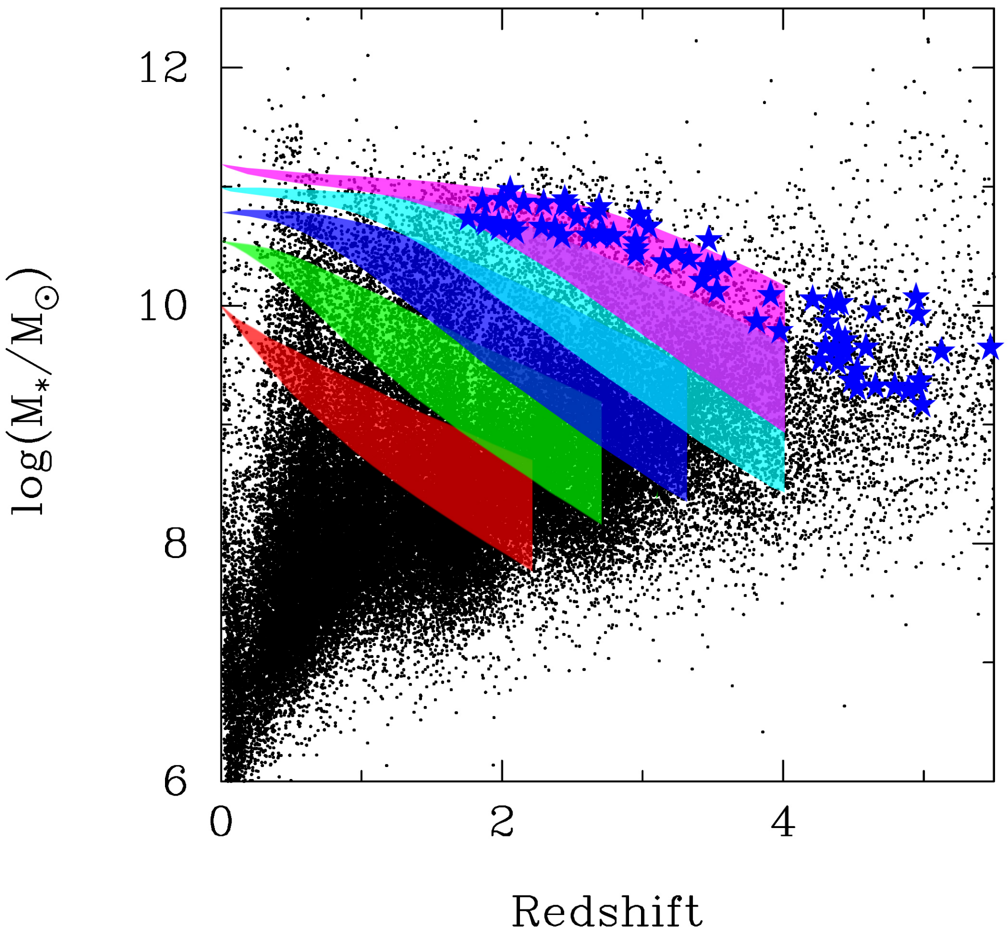




$\log(M_*/M_o)$ = 11.2 (13.5)

$\log(M_*/M_o)$ = 11.0 (13.0)

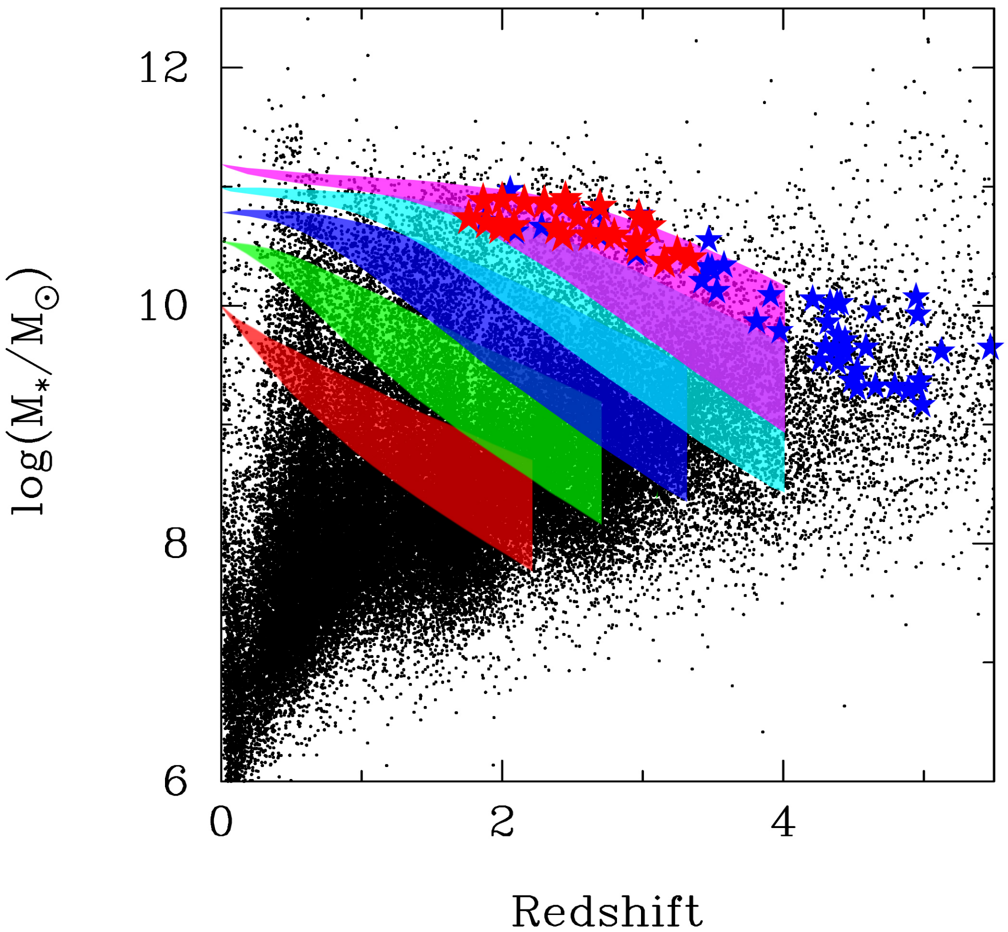
$\log(M_*/M_o)$ = 10.8 (12.5)

$\log(M_*/M_o)$ = 10.5 (12.0)

$\log(M_*/M_o)$ = 10.0 (11.5)

70 targets

20 at z~2
20 at z~3
20 at z~4
10 at z~5



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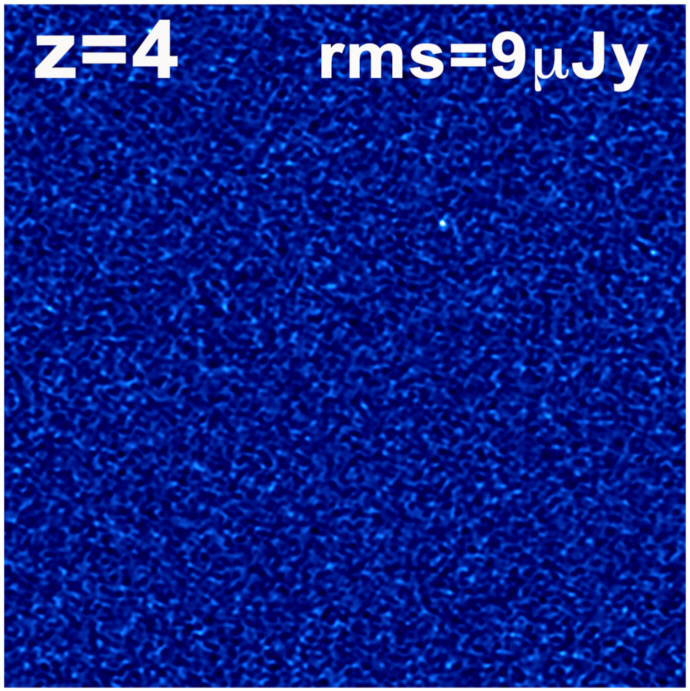
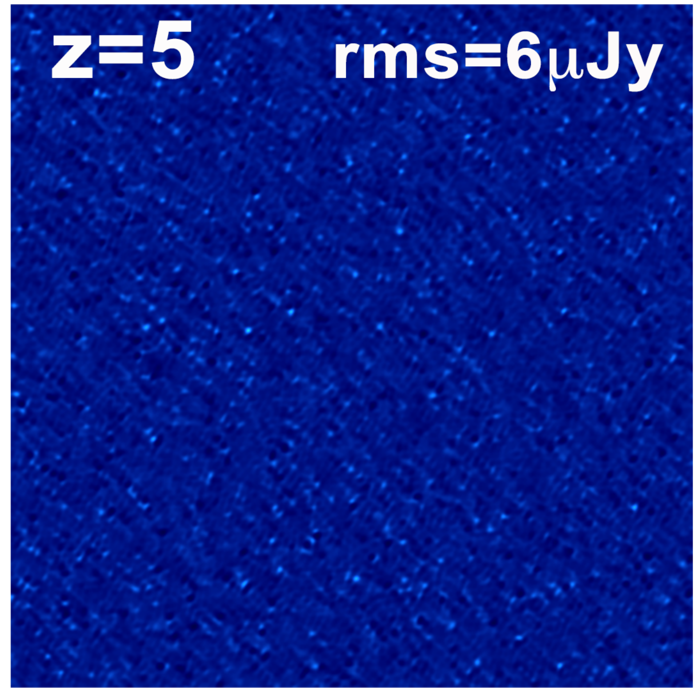
$\log(M_*/M_o)$ = 10.0 (11.5)

70 targets

20 at z~2	15/20 detected
20 at z~3	10/20 detected
20 at z~4	0/20 detected
10 at z~5	0/10 detected

Stacked images (20 for z=4 sample ; 10 for z=5 sample)

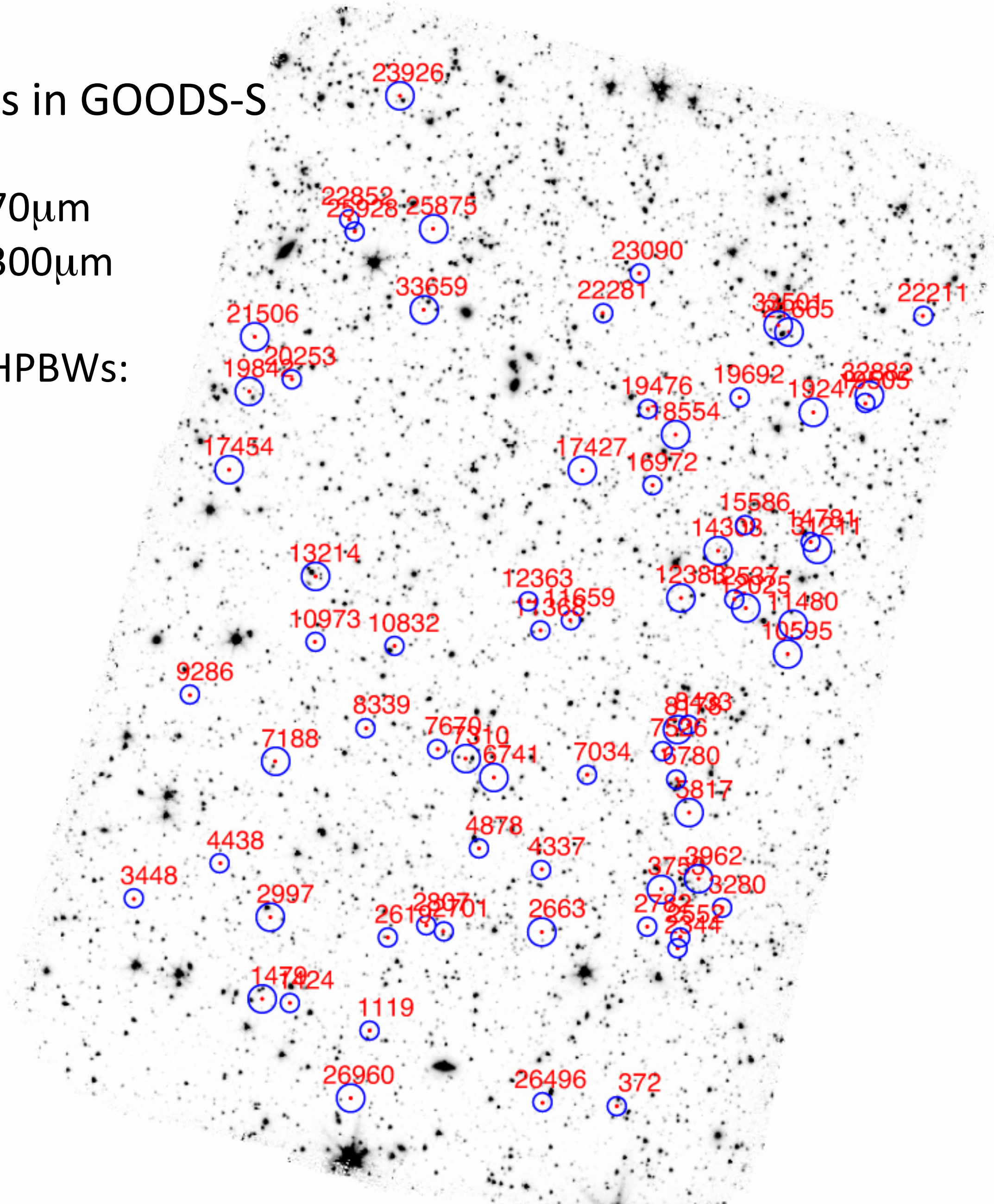


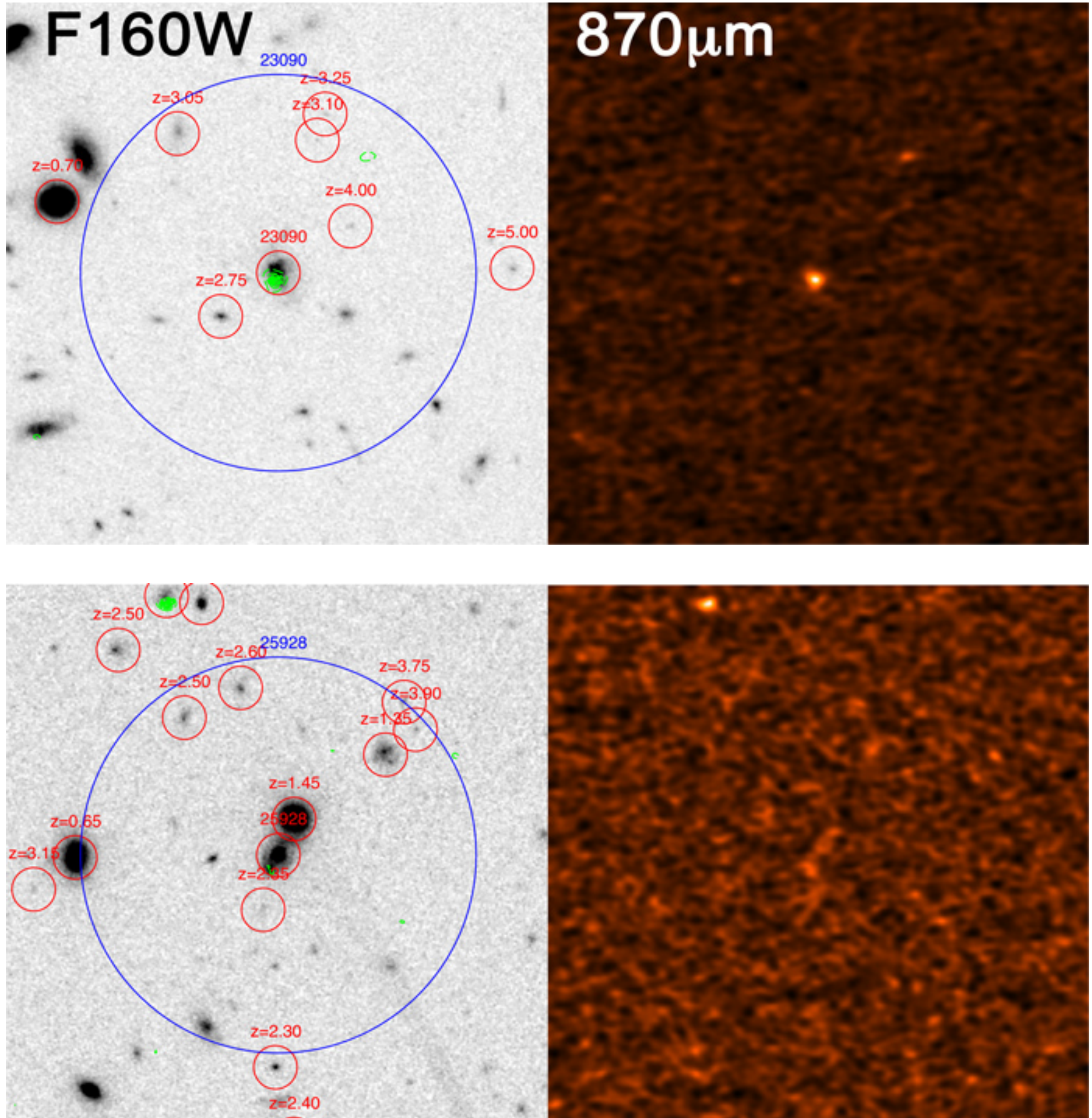


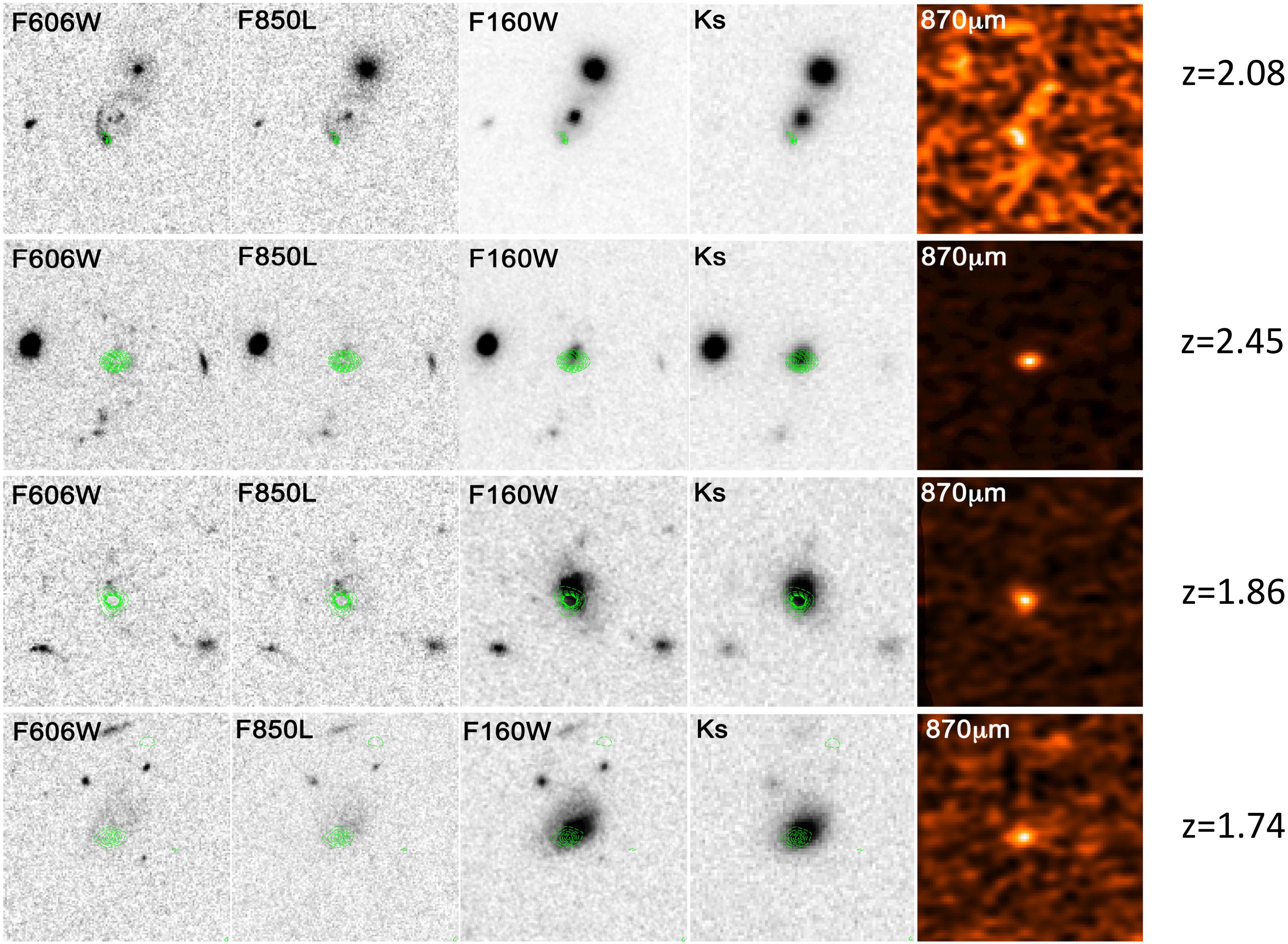
70 ALMA targets in GOODS-S

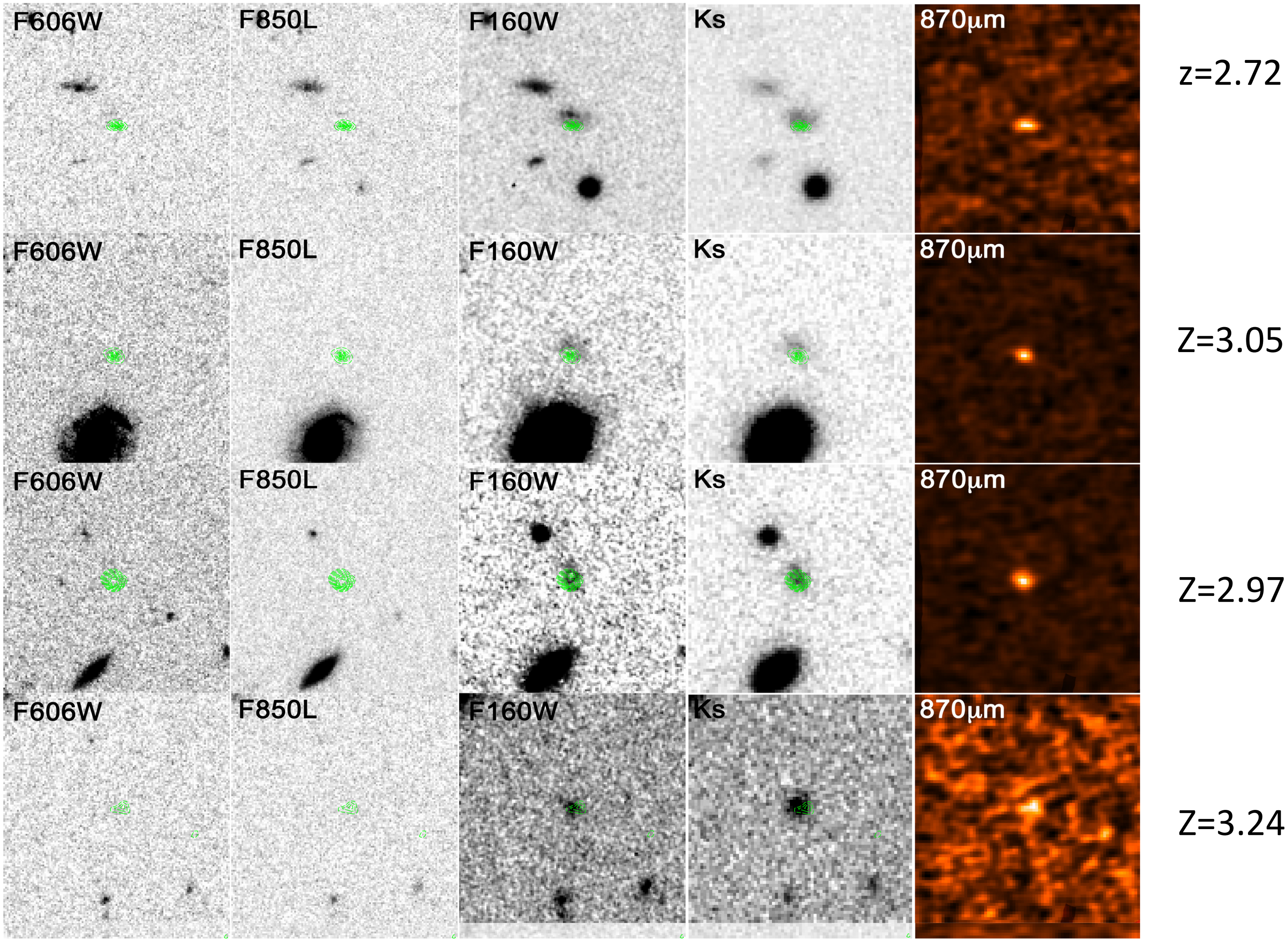
HPBW = 19” for 870μm
HPBW = 27” for 1300μm

Total area within HPBWs:
8.0 □’

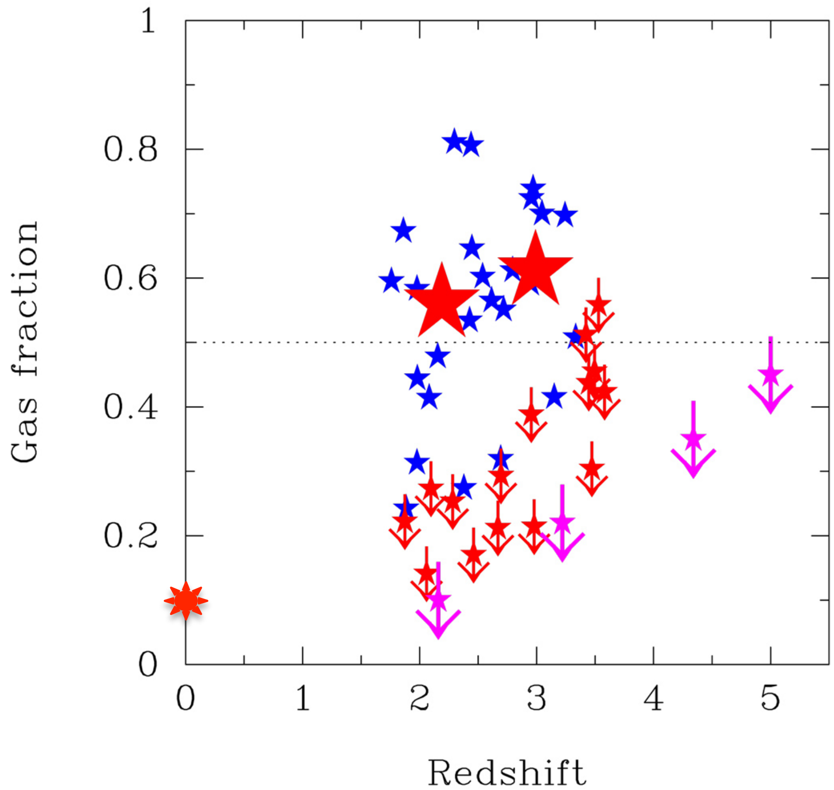



F160W
870μm
23090
z=3.25
z=3.05
z=3.10
z=0.70
z=4.00
23090
z=5.00
z=2.75
z=2.50
25928
z=2.60
z=3.75
z=2.50
z=1.45
z=0.65
z=2.30
z=2.40


F606W
F850L
F160W
Ks
870μm
z=2.08
F606W
F850L
F160W
Ks
870μm
z=2.45
F606W
F850L
F160W
Ks
870μm
z=1.86
F606W
F850L
F160W
Ks
870μm
z=1.74


F606W
F850L
F160W
Ks
870μm
z=2.72
Z=3.05
Z=2.97
Z=3.24

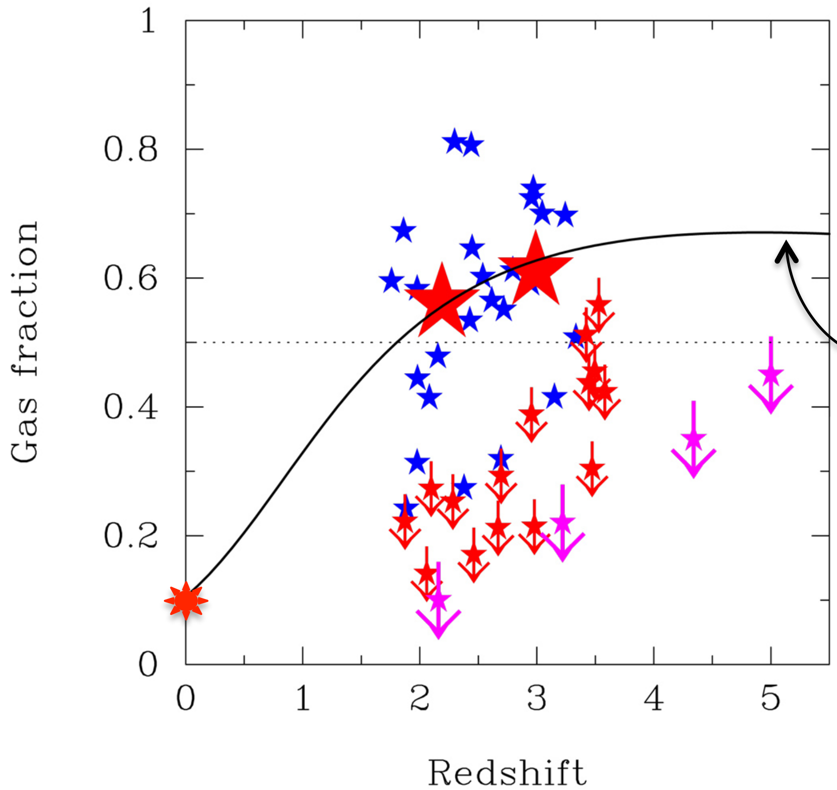
Gas fraction as a function of redshift



Total gas fraction

$$f_{gas} = \frac{M_{gas}}{M_{gas} + M_*}$$

Gas fraction as a function of redshift



Total gas fraction

$$f_{gas} = \frac{M_{gas}}{M_{gas} + M_*}$$

Prediction for MS galaxies (Sargent+ 2014)

Gas fraction as a function of redshift

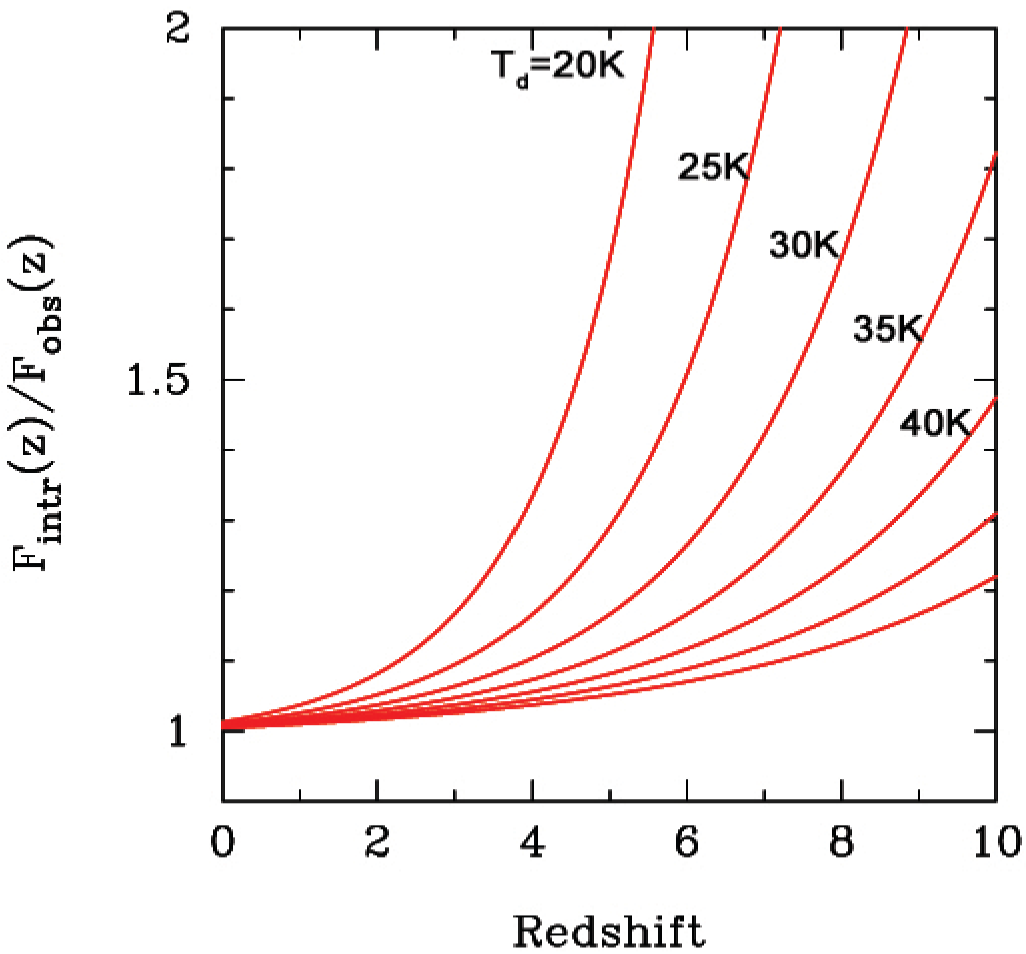
The CMBR temperature affects the observed flux in two ways:

1. The effective dust temperature increases

2. The observed flux decreases

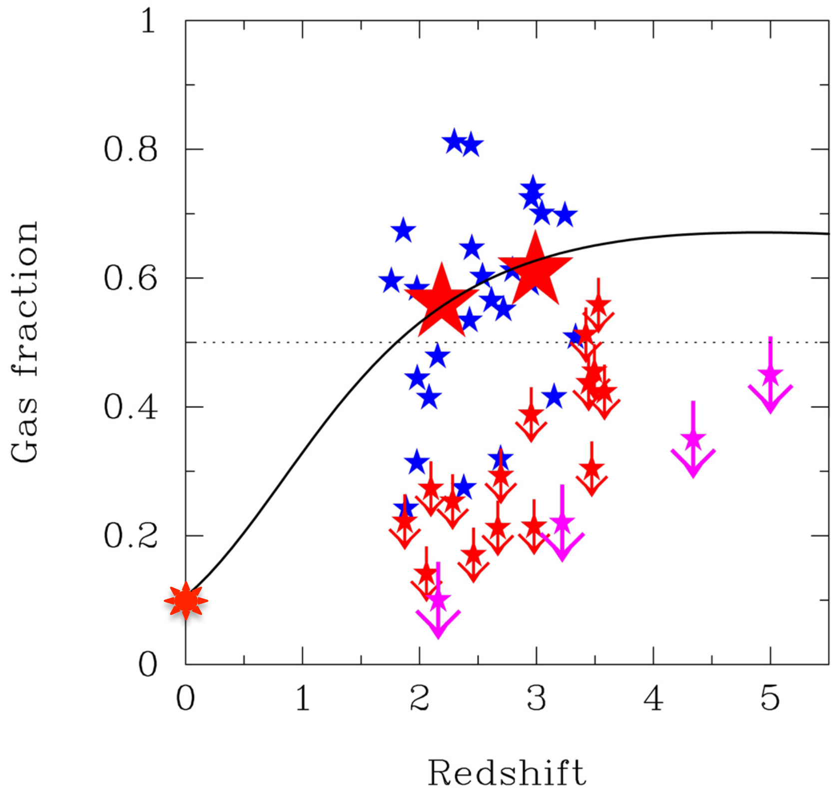
Once the dust thermalize with the CMBR, no emission can be seen.

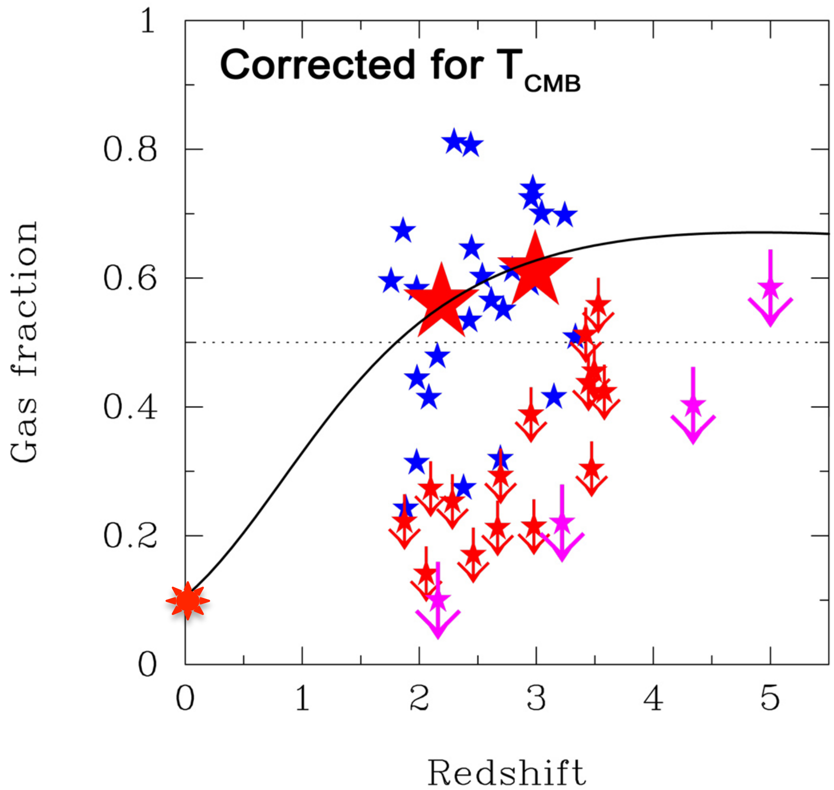
The effect becomes strong for z≥4 and for colder dust temperatures.



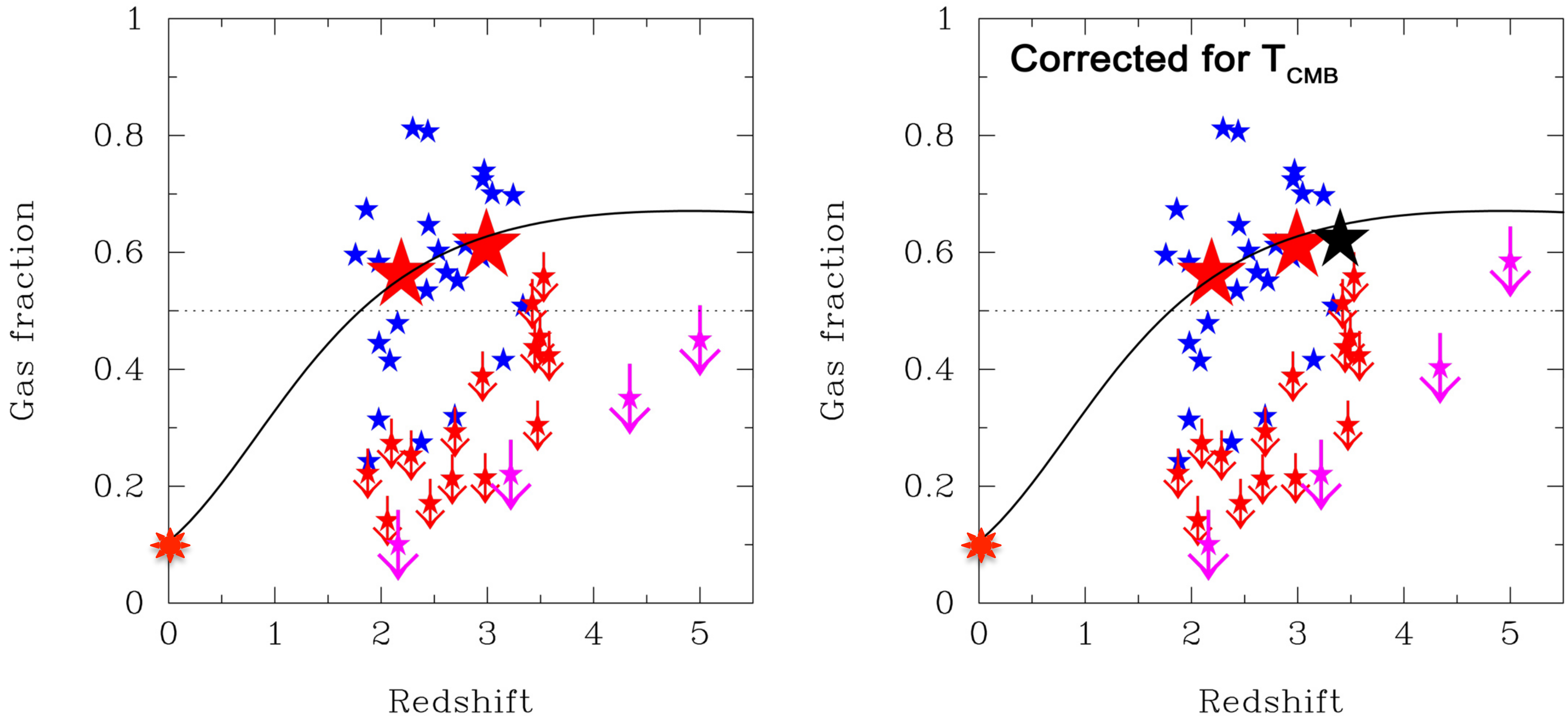
Adopted from da Cunha+ 2013

Gas fraction as a function of redshift



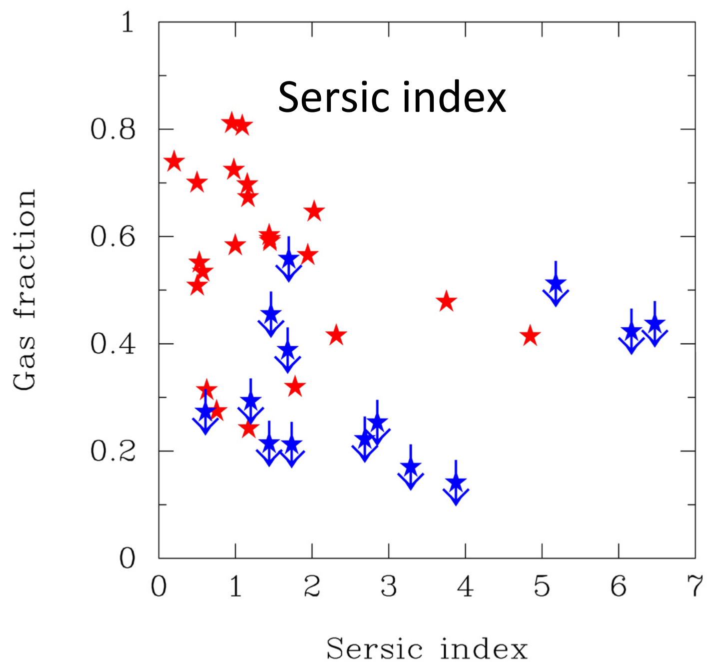


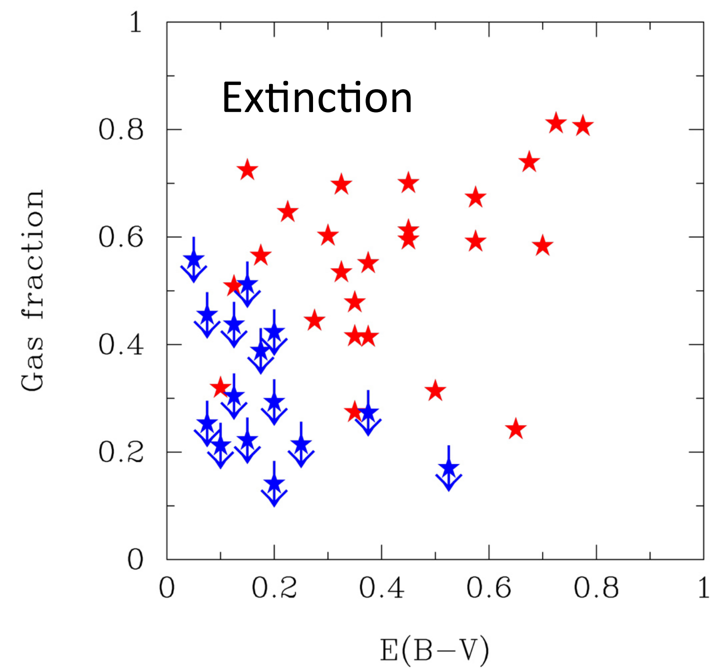
Gas fraction as a function of redshift



Schinnerer+ 2016
Targeting massive star forming galaxies at z=3-4

Only z=2 and z=3 samples





Detections
- Low Sersic index
- High extinction

Non-detections
- High Sersic index
- Low extinction

Sersic index from van der Wel+ 2012

Average properties of the sample

Sample		$\bar{z}$	$\log \frac{M_*}{M_\odot}$	SFR	sSFR	Sersic	R_e	f_{gas}
				$M_\odot\,\mathrm{yr}^{-1}$	Gyr^{-1}		arcsec	
z = 2	Detection	2.2	10.76	119	1.95	1.6	0.52	0.56
	Nondetection	2.2	10.78	87	1.90	2.7	0.29	<0.10
z = 3	Detection	3.0	10.59	35	0.93	1.0	0.31	0.61
	Nondetection	3.2	10.49	22	1.23	3.0	0.19	<0.22
z = 4	Nondetection	4.3	9.80	26	3.58	2.5	0.42	<0.35
z = 5	Nondetection	5.0	9.61	28	7.17	2.5	0.29	<0.45

Summary

- Detection rate
  - 'Binary' detection of dust emission for z=2-3 (either or)
  - No detections at z>4

- The median gas mass fraction
  - f_{gas} =0.5 at z=2
  - f_{gas} =0.6 at z=3

- This follows the predicted trend based on a 2-mode SF model (but with a large dispersion)

- The gas mass fraction at z=4 and z=5 is less than predicted
  - Metallicity effects?
  - Dust properties?