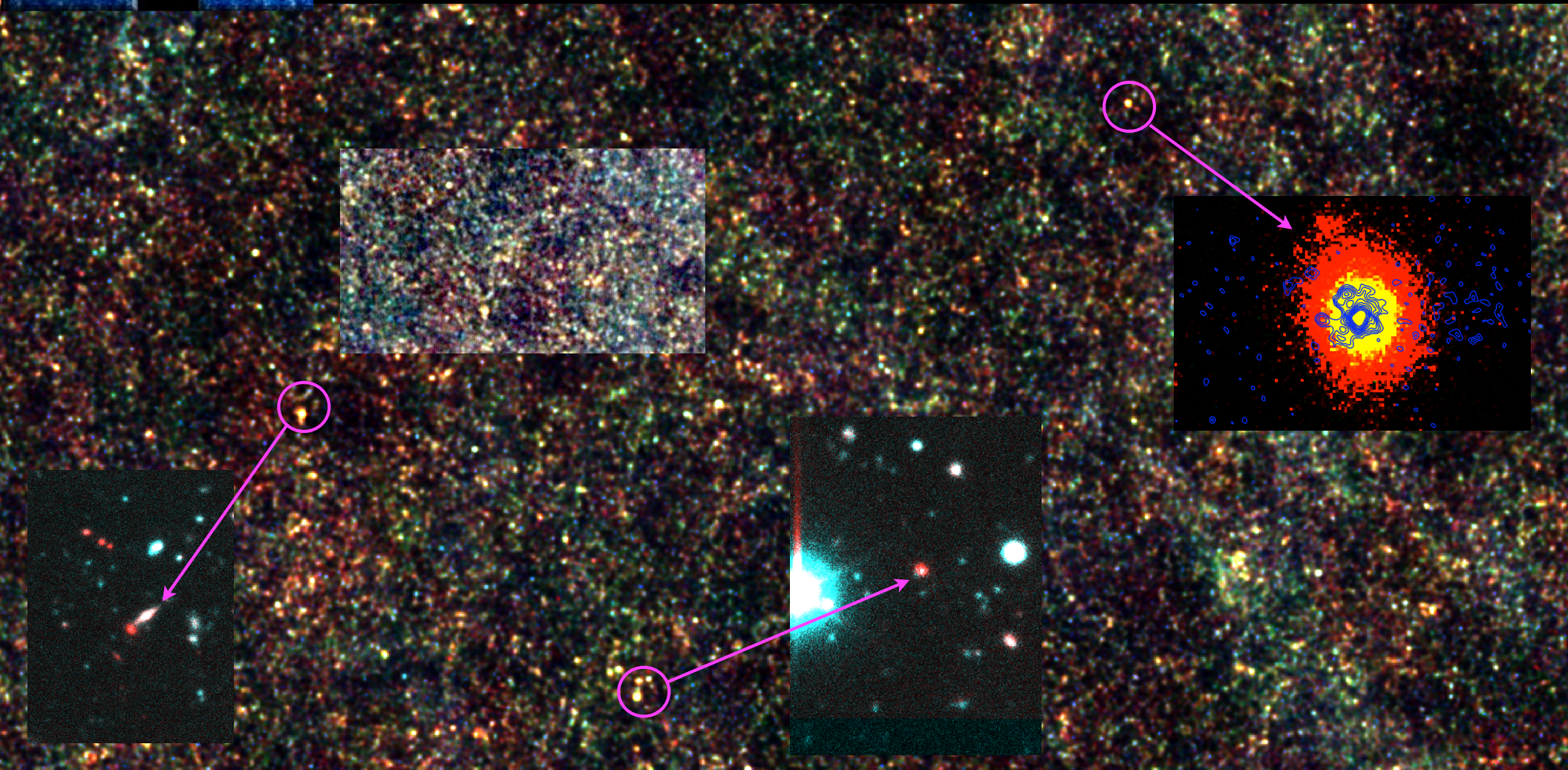




# The high-redshift sub-millimeter galaxy population of Herschel-ATLAS

*Asantha Cooray*



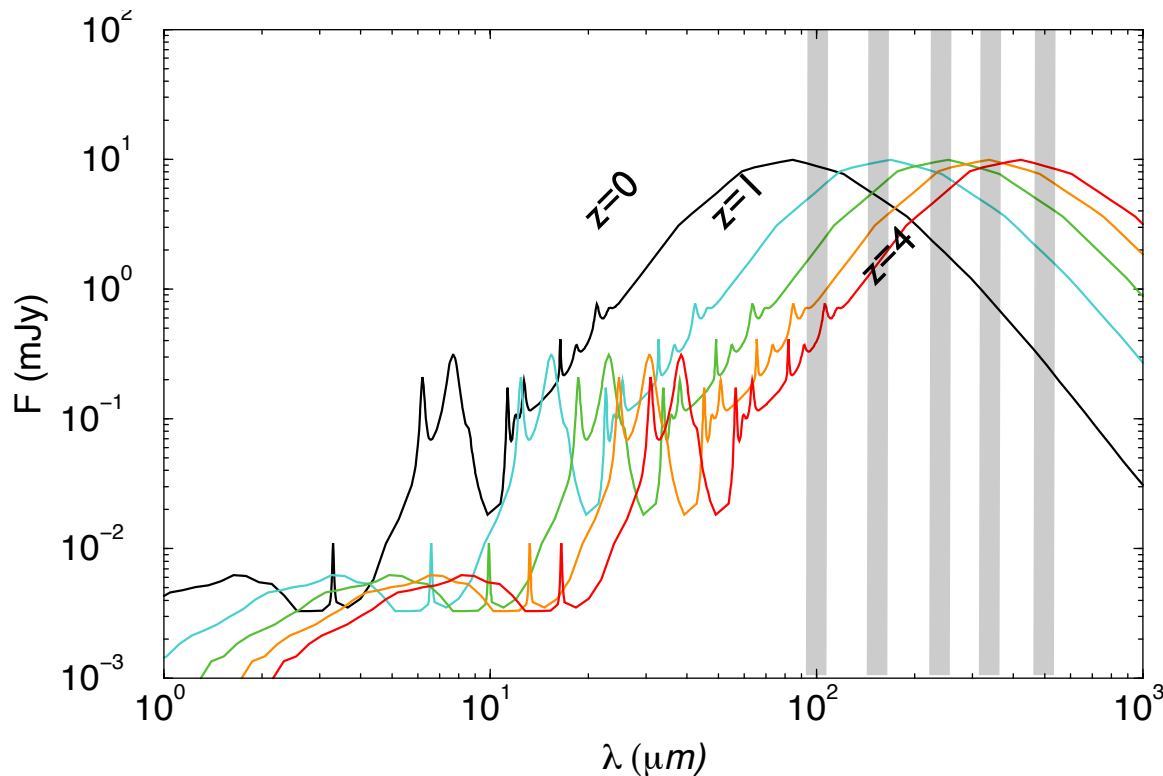


# Herschel-ATLAS



PACS & SPIRE parallel mode. 550 sq. degrees total.  
14 sq. degrees in SDP (GAMA 9-hour field).

~6800 sources down to 32, 36, 45 mJy ( $5\sigma$ ) at 250, 350, 500  $\mu\text{m}$



Naive expectation based on  
sub-mm SED

$S_{250} > S_{350} > S_{500}$ :  $z < 2$

$S_{250} < \sim S_{350} > S_{500}$ :  $z \sim 2$  to 3

$S_{250} < S_{350} < S_{500}$ :  $z > 4$

Exceptions: AGNs, Galactic  
sources, .....

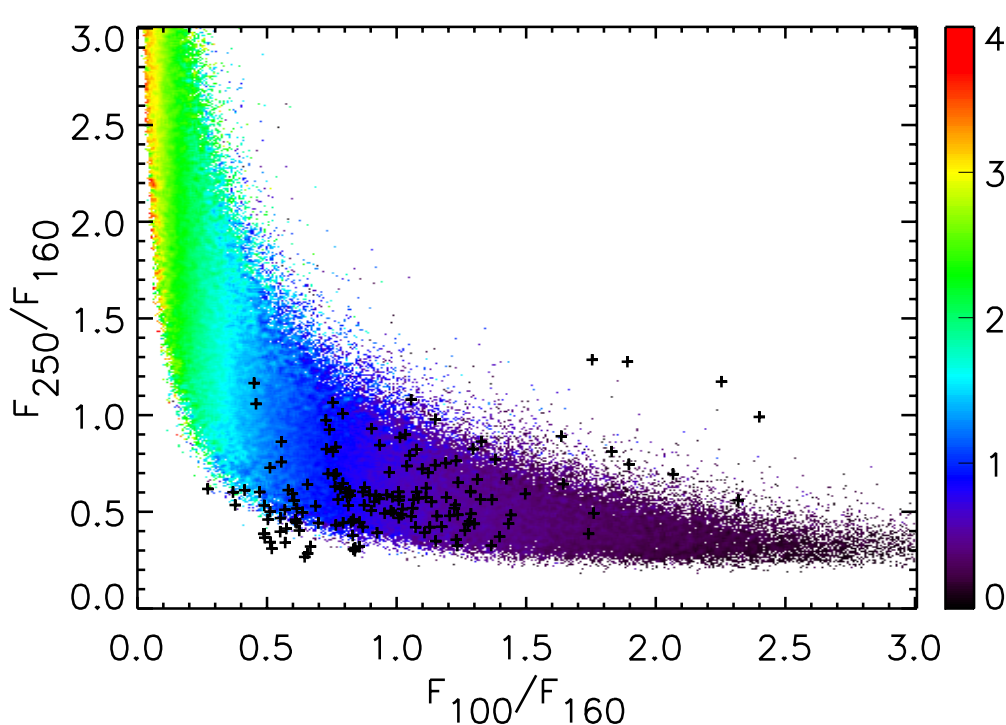
*sub-mm colors as a mechanism to select  $z > 2$  galaxies*



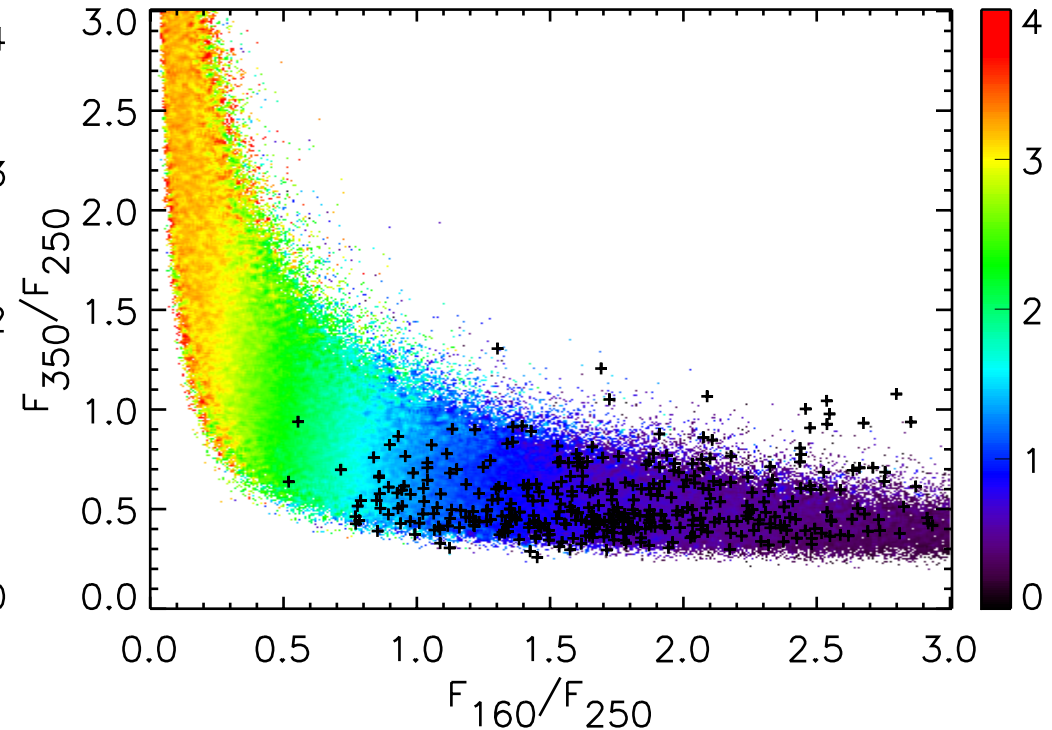
# Herschel-ATLAS



Color-color diagrams for sources detected at  $> 5\sigma$  in central band and  $> 3\sigma$  in other two bands.



158 sources (selected PACS 160)  
SPIRE 250 & PACS 100



402 sources (selected SPIRE 250)  
SPIRE 350/PACS 160

Background colors: isothermal SED models with  $f_\nu = \epsilon_\nu B_\nu \propto \nu^{3+\beta} / [\exp\left(\frac{h\nu}{kT_d}\right) - 1]$ .  
 $10^6$  models:  $10\text{K} < T < 60\text{K}$ ,  $0 < \beta < 2$

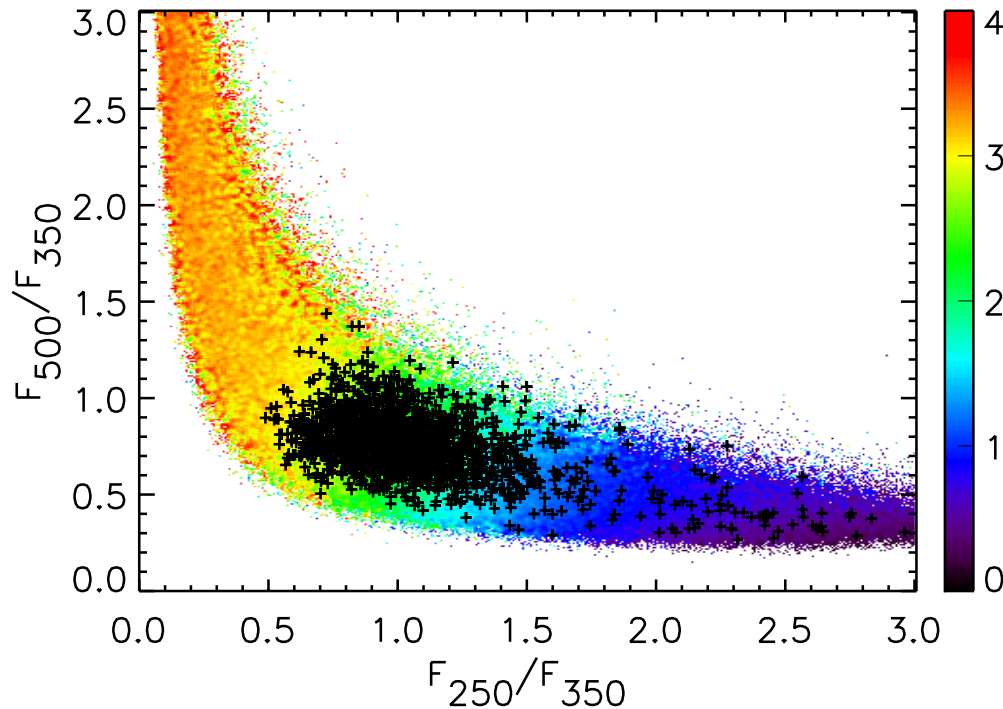


# Herschel-ATLAS

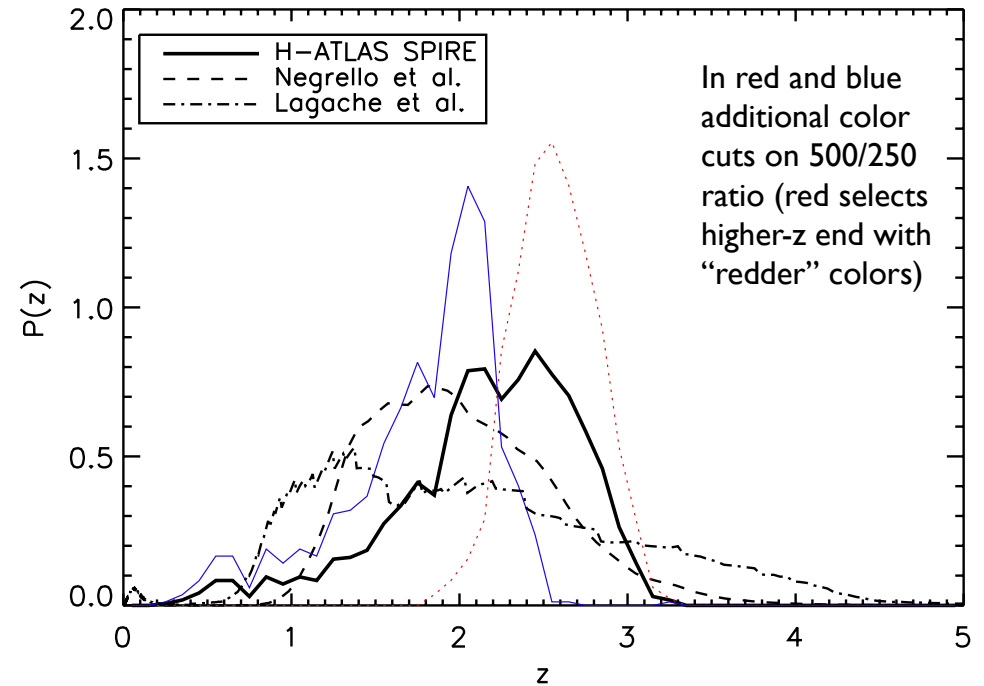


350 $\mu$ m selected galaxies  $> 5\sigma$  are at mostly at  $z = 2.2 \pm 0.6$

(Amblard et al. A&A special issue)



1686 sources  
(selected SPIRE 350  $> 35$  mJy)  
SPIRE 250 & 500 ( $> 3\sigma$ )



The “statistical” redshift distribution implied by SPIRE colors for the 1686 sources

*[equivalent to fitting each SED with a single-temp model and marginalizing over  $T, \beta$ ]*  
(Hughes et al 2002; Aretxaga et al. 2007)



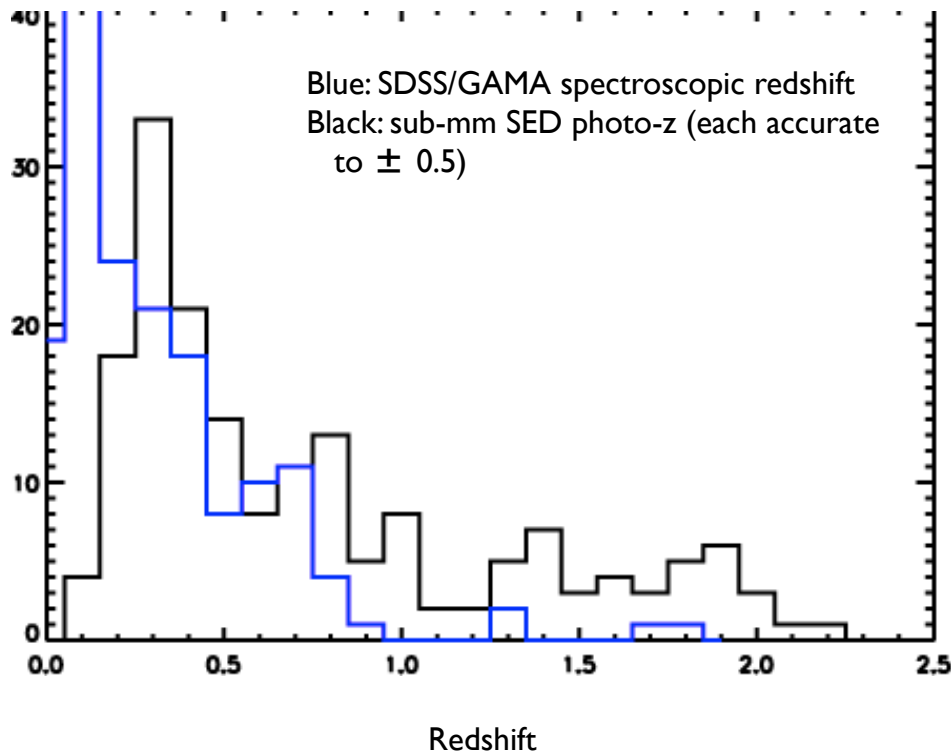
# Herschel-ATLAS



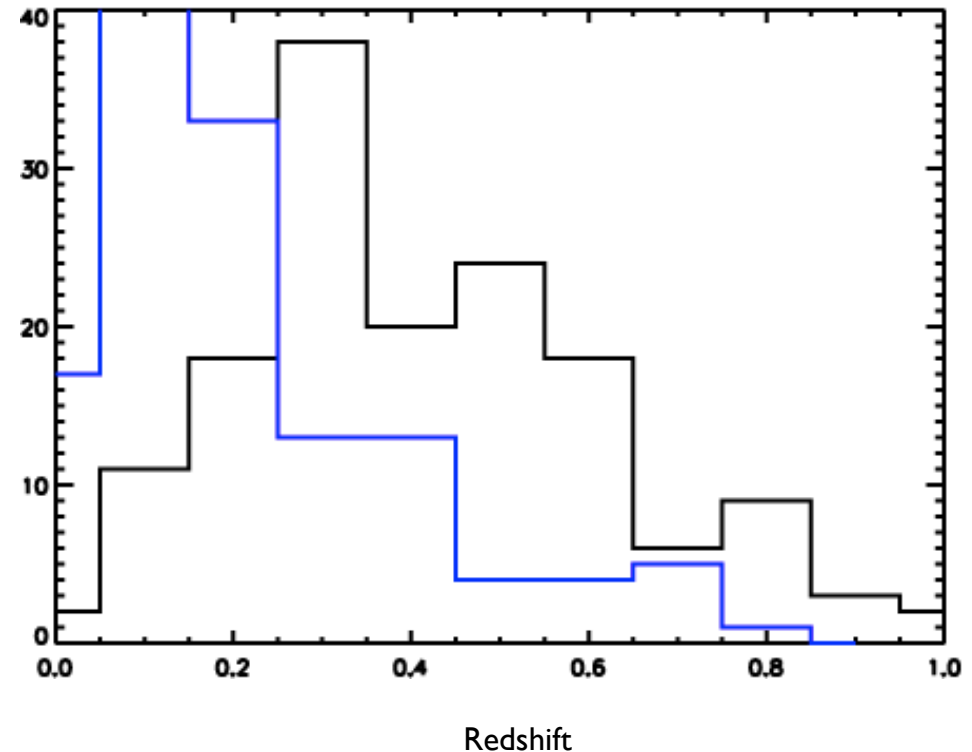
350 $\mu$ m selected galaxies  $> 5\sigma$  are at mostly at  $z = 2.2 \pm 0.6$

(Amblard et al. A&A special issue)

How confident are we on this statement? check sub-mm photo-z method on galaxies reliably ( $> 0.9$ ) identified with SDSS at  $z < 1.0$



SPIRE 350 selected: sub-mm SED biases somewhat redshifts higher (there may also be issues with IDs).  
*Need a mechanism to establish redshifts of our sources!*



PACS 160 selected

$\langle z \rangle = 2.2 \pm 0.6$  is consistent with previous SMG determinations!



# Herschel-ATLAS



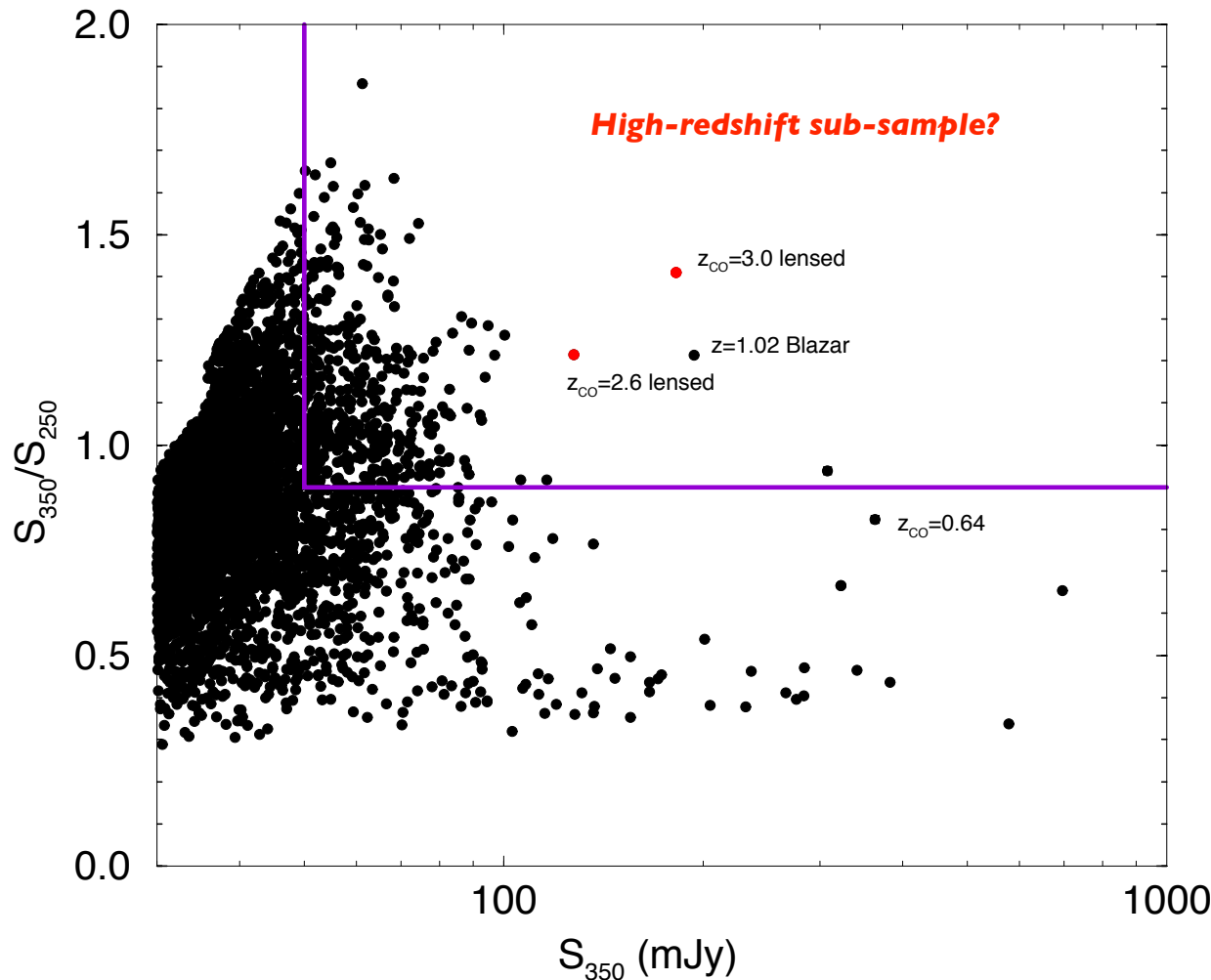
350 $\mu$ m selected galaxies  $> 5\sigma$  are at mostly at  $z = 2.2 \pm 0.6$

(Amblard et al. A&A special issue)

Others? close to 2200 sources are identified through SDSS/GAMA to be at  $z < 1$  (Smith et al. in prep)

~50 to 60 Galactic debris disks, rare Bok globules

(Thompson et al. A&A special issue)



Color-flux diagram:  
a mechanism to identify  
lensed and peculiar  
sources

(Negrello et al. 2010; in preparation)

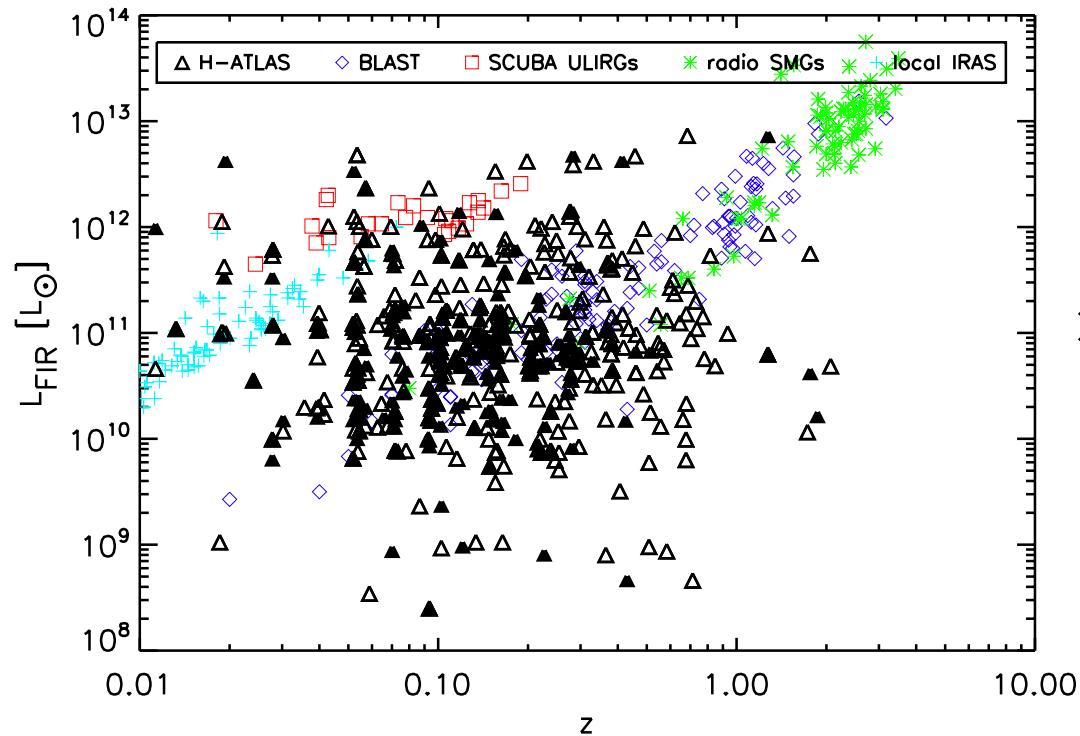


# Herschel-ATLAS



## Properties of the 350 $\mu$ m selected sub-mm galaxies

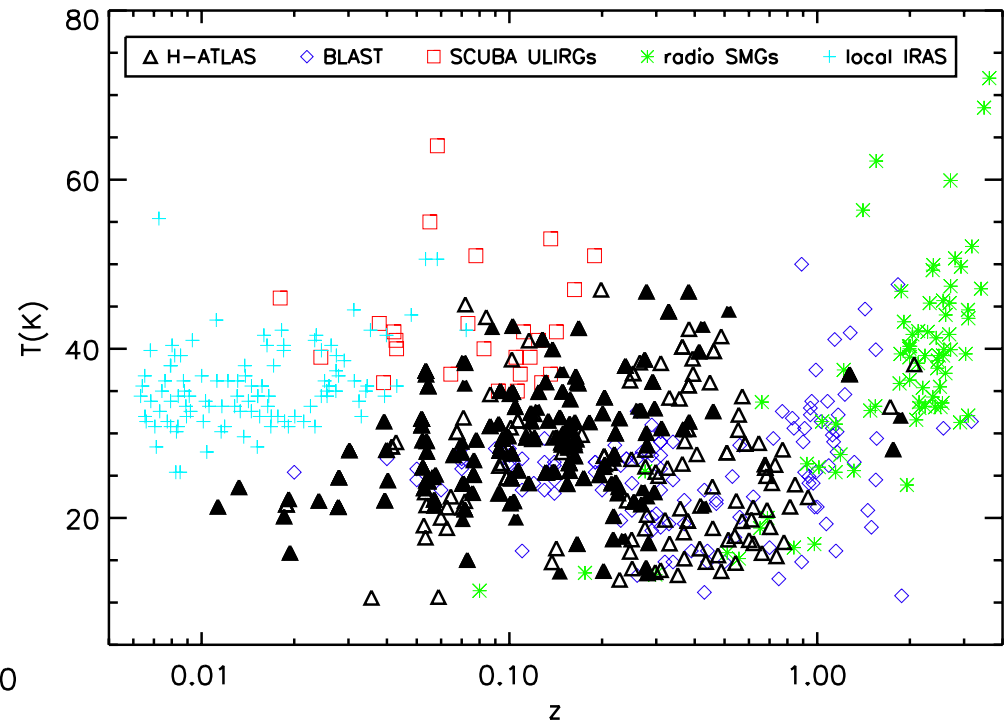
(Amblard et al. A&A special issue)



Average  $\log(L_{FIR}/\tilde{L}_{\odot})$   $10.9 \pm 0.8$

$\beta = 1.5$  assumed, isothermal fits

Filled triangles: SDSS/GAMA spectroscopic redshift  
Open triangles: SDSS/GAMA photometric redshift

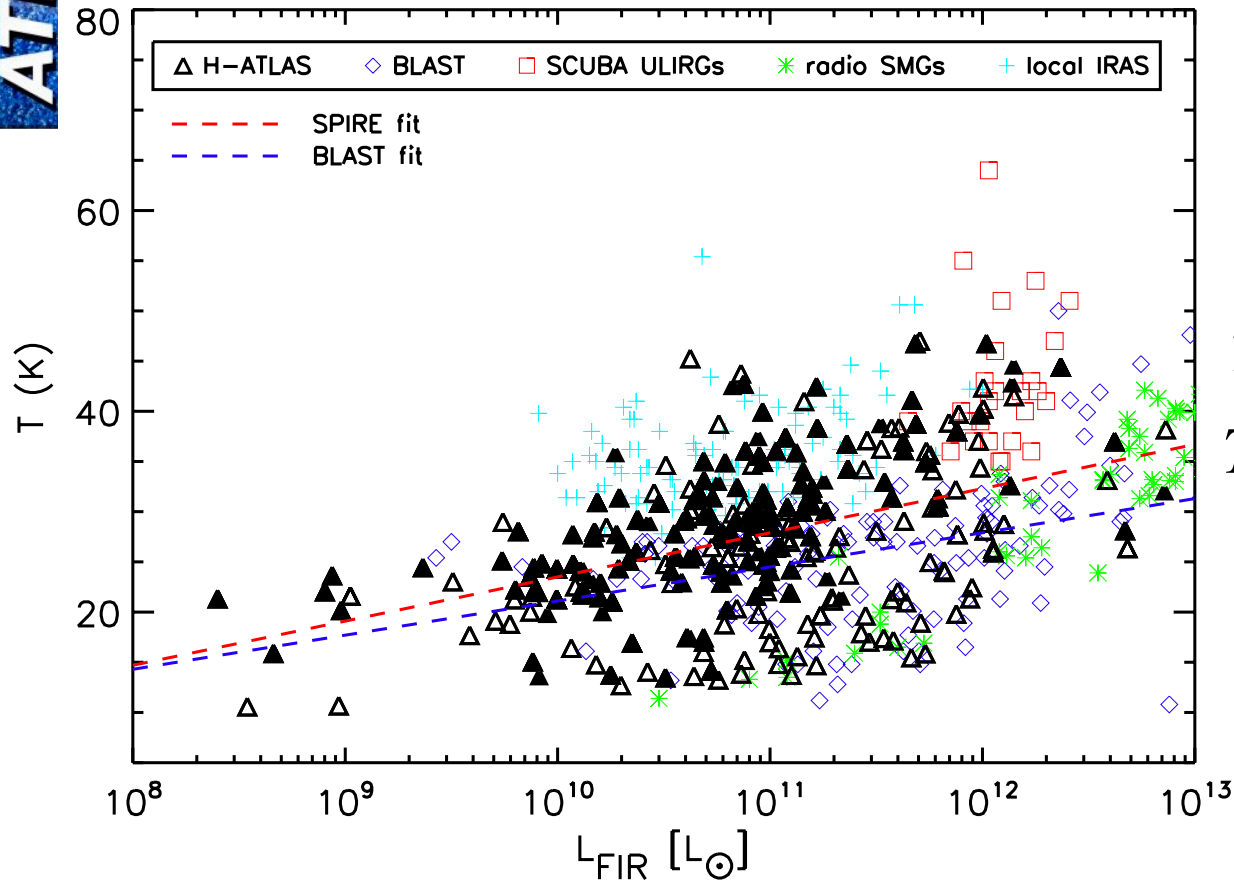


Bridge the gap between  $z \sim 2$  radio SMGs (Chapman et al/Ivison et al.) and  $z \sim 0.1$  ULIRGS with  $T \sim 40$  K

SPIRE or PACS selected and identified with Sloan (reliability  $> 0.9$ ; Smith et al. 10)



# Herschel-ATLAS



$$T_d = T_0 + \alpha \log(L_{FIR}/L_\odot)$$

$$T_0 = -20.5\text{K}$$

$$\bar{\alpha} = 4.4$$

**Table 1.** Average dust temperatures as a function of redshift for the 331 H-ATLAS galaxies (column 2) and for all the data (column 4) presented in Fig. 2 and 3 (including H-ATLAS).

z-range	H-ATLAS	$T_d$	all data	all data $T_d$
	$N_{\text{srcs}}$		$N_{\text{srcs}}$	
All z	331	$28 \pm 8$	658	$30 \pm 9$
$0 < z < 0.1$	106	$27 \pm 8$	235	$32 \pm 9$
$0.1 < z < 0.5$	186	$29 \pm 8$	260	$28 \pm 8$
$0.5 < z < 1$	33	$23 \pm 5$	67	$24 \pm 7$
$z > 1$	6	$32 \pm 8$	96	$37 \pm 10$

Luminosity-temperature relation:  
Evidence for SMGs with cold  
( $T < 20\text{K}$ ) dust? (expected due to  
peak of SED when  $z < 1$  at cold dust  
end of the BB spectrum).

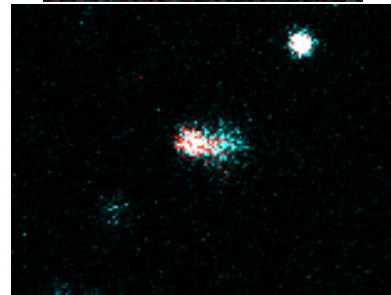
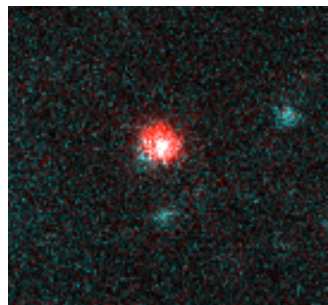
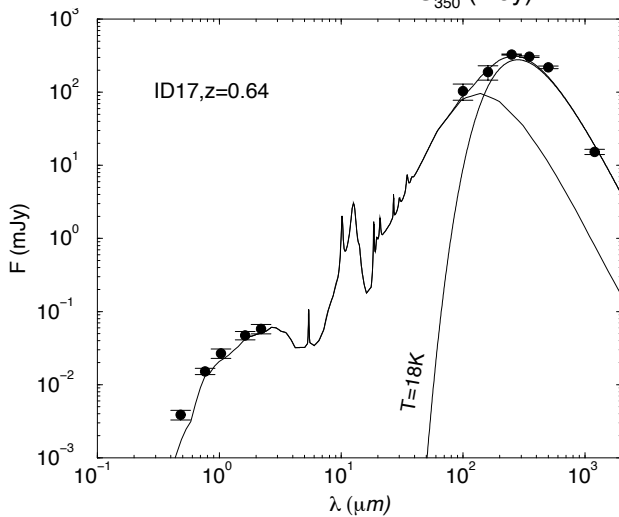
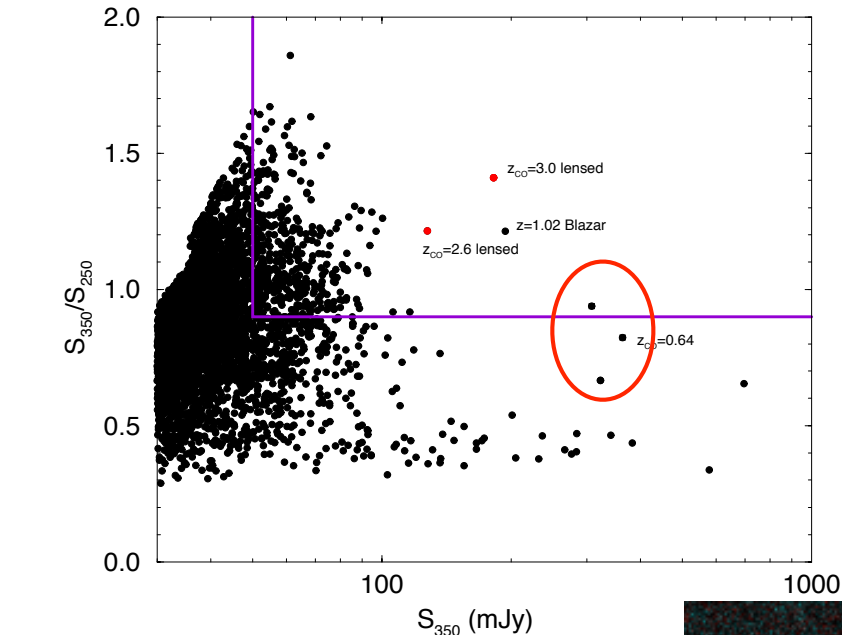




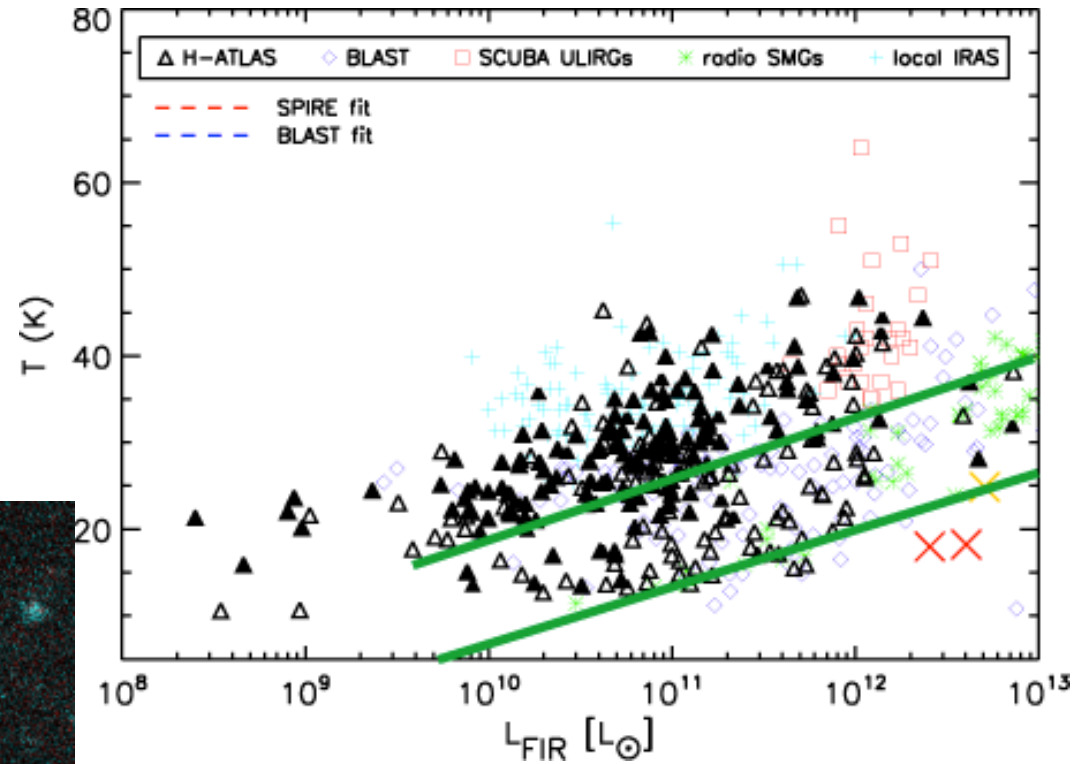
# Herschel-ATLAS



Luminous  $z < 1$  sub-mm galaxies with  $T < 20\text{K}$  cold dust



(Keck u,g,i; g>24 mag)



fall below the existing SMG L-T tracks.  
SPIRE should find additional rare and bright cold dust galaxies.

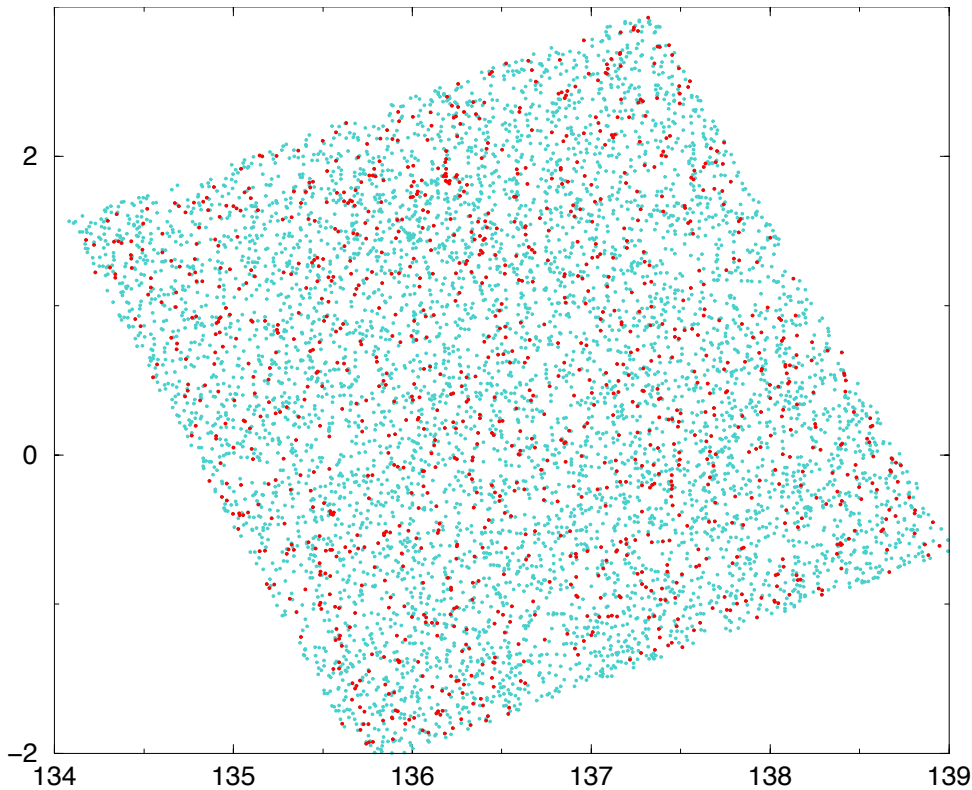
*Many questions: why cold? what are these sources? What stage of merging?*



# Herschel-ATLAS

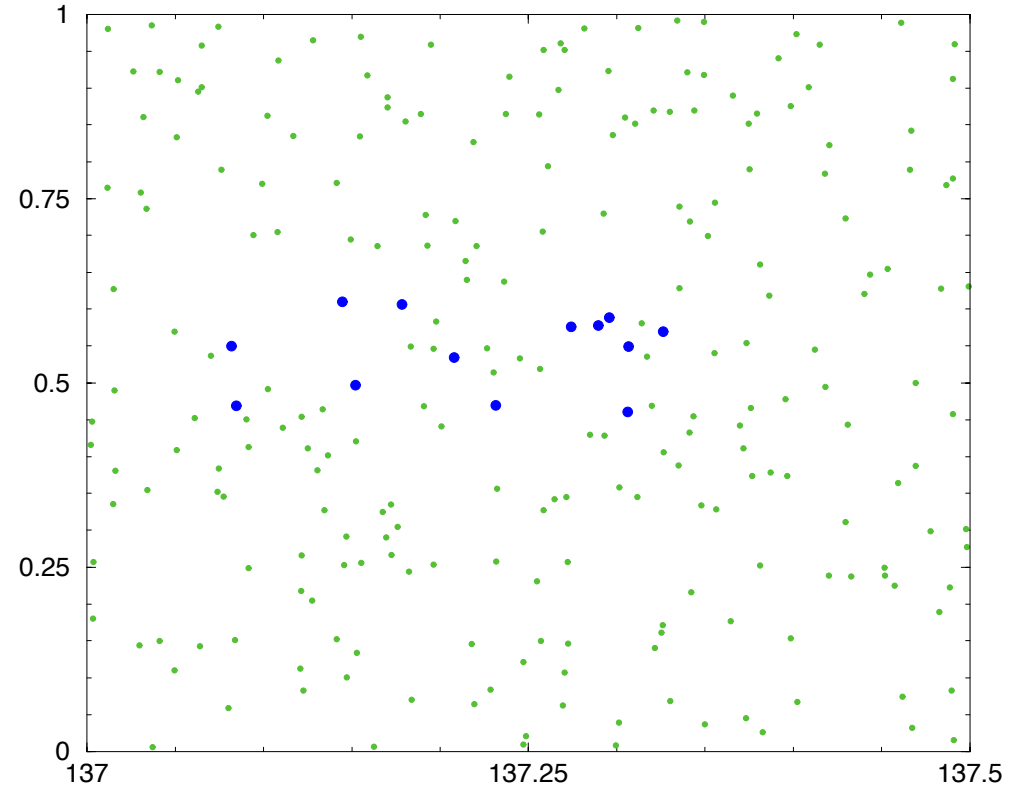


## Spatial distribution of $350\mu\text{m}$ selected sub-mm galaxies



Some evidence for strong clustering with correlation length  $\sim 10$  Mpc for “red” ( $350/250 > 0.75$ ) sources

(Maddox et al A&A special issue)



At  $z > 2$  find proto-clusters! (bright SMGs are unlikely to be in virialized clusters by large numbers, but should trace large overdensities before collapse when galaxies are still undergoing massive starformation)

(de Zotti et al. in preparation)



# Herschel-ATLAS

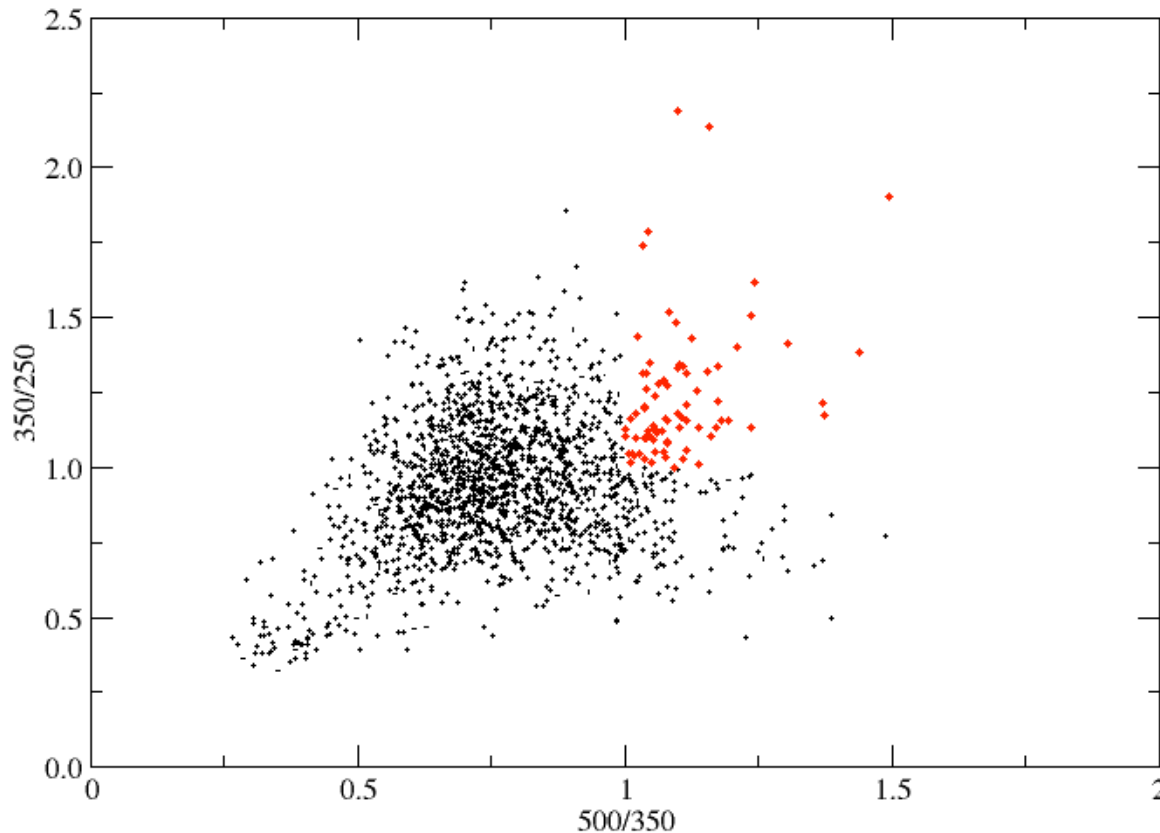


$z > 4$  sources?

We find 281 sources with  $S_{500} > S_{350}$

55 of these sources are detected above  $5\sigma$  ( $>45$  mJy), while others are detected at  $> 3\sigma$

49 detected above  $5\sigma$  in all 3 bands. One of these is a blazar at  $z \sim 1.02$ , in Fermi all-sky catalog.



**Are all the 281 sources at  $z > 4$ ?**

Unclear, again we need significant follow-up data, especially at near-IR. Also CO-line redshifts?

Assuming all 281 sources are  $z > 4$ , a rough lower limit on the surface density of  $z > 4$  sources down to  $S_{500} > 20$  mJy is  $\sim 20/\text{deg}^2$  ( $\sim 50\%$  uncertainty)

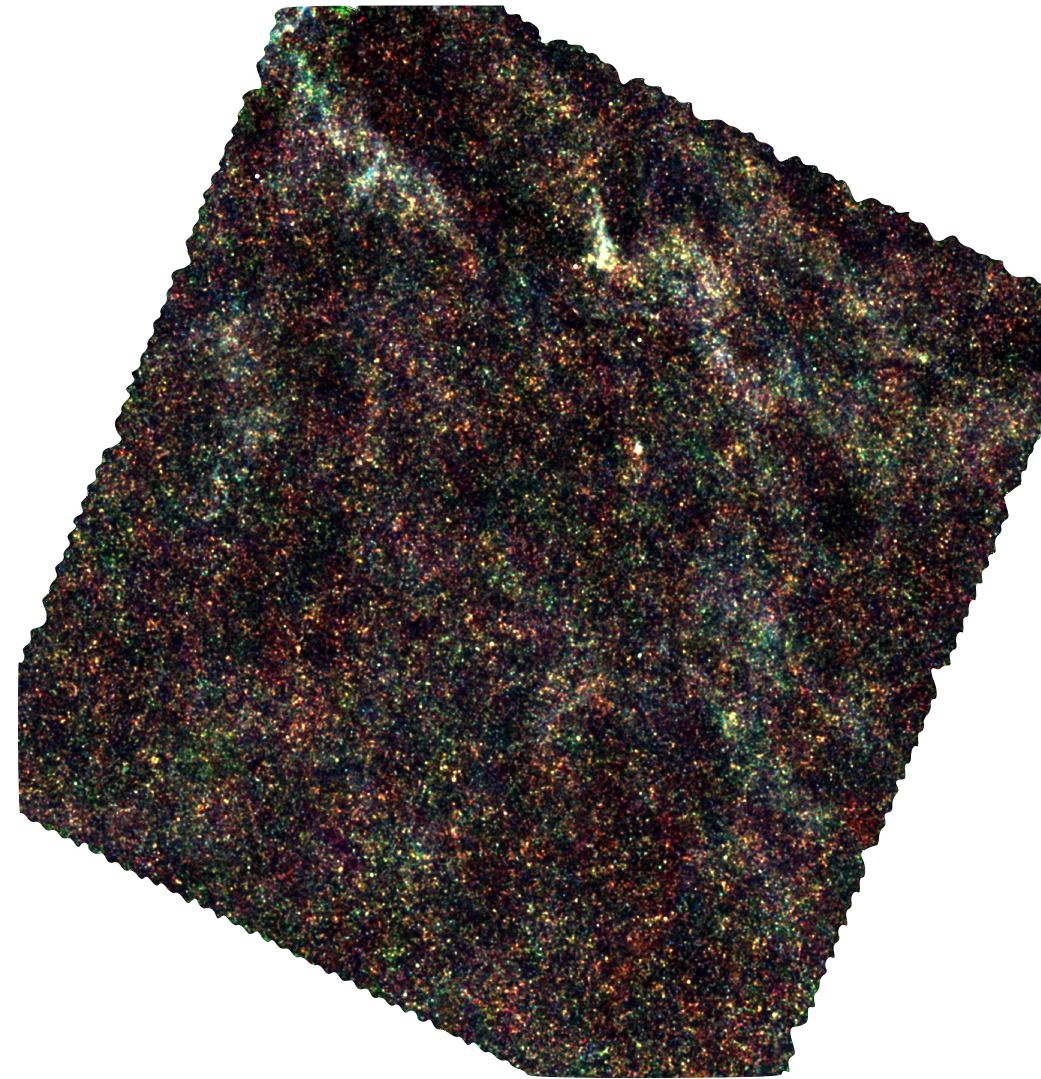
The surface density of 350  $\mu\text{m}$  selected sources ( $z \sim 2$  to 3)  $S_{350} > 35$  mJy is  $\sim 100/\text{deg}^2$



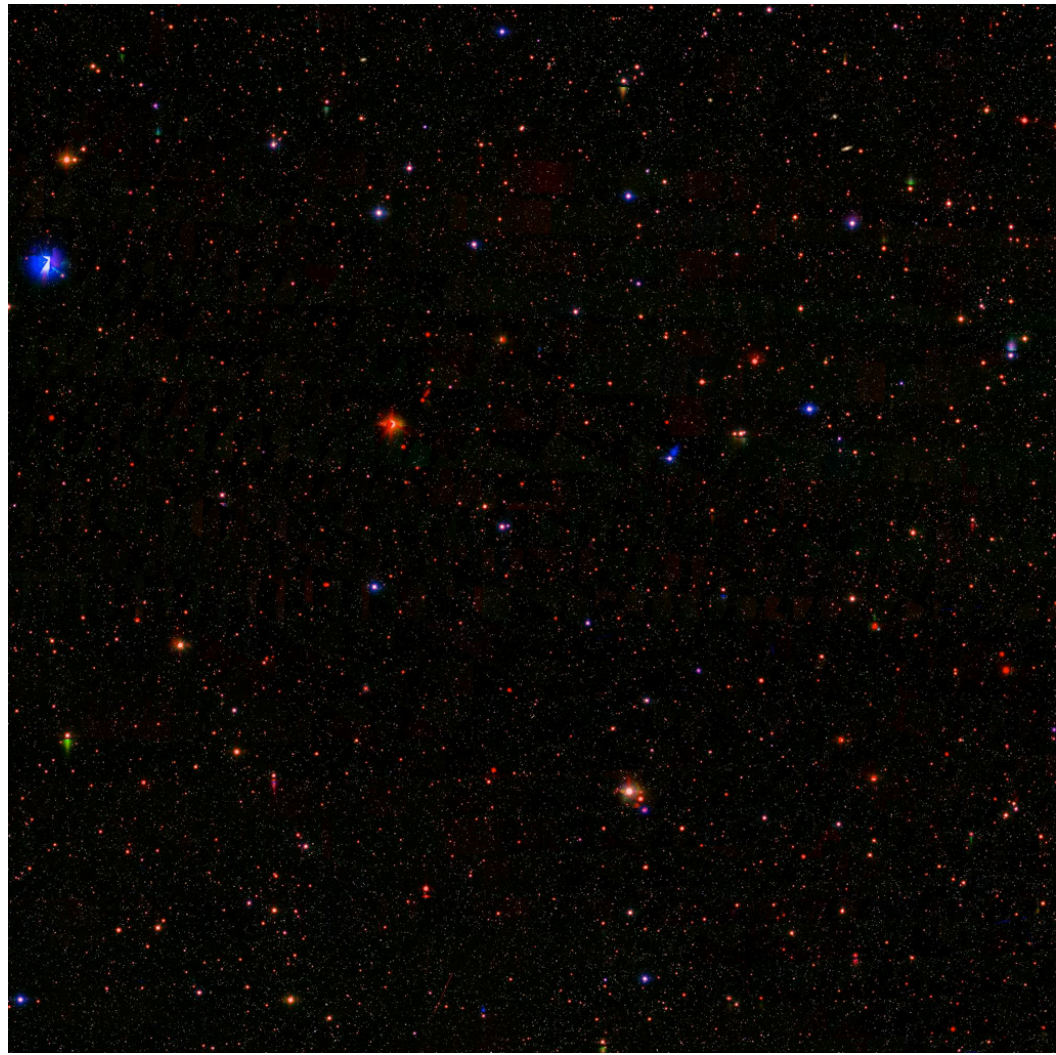
# Herschel-ATLAS



Cross-correlation with optical (GAMA redshifts)



SPIRE 3 color



SDSS 5 color

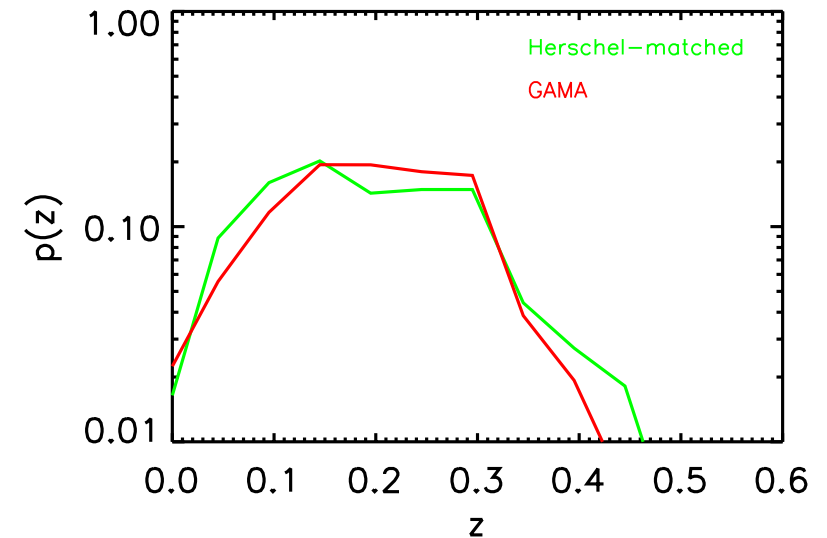
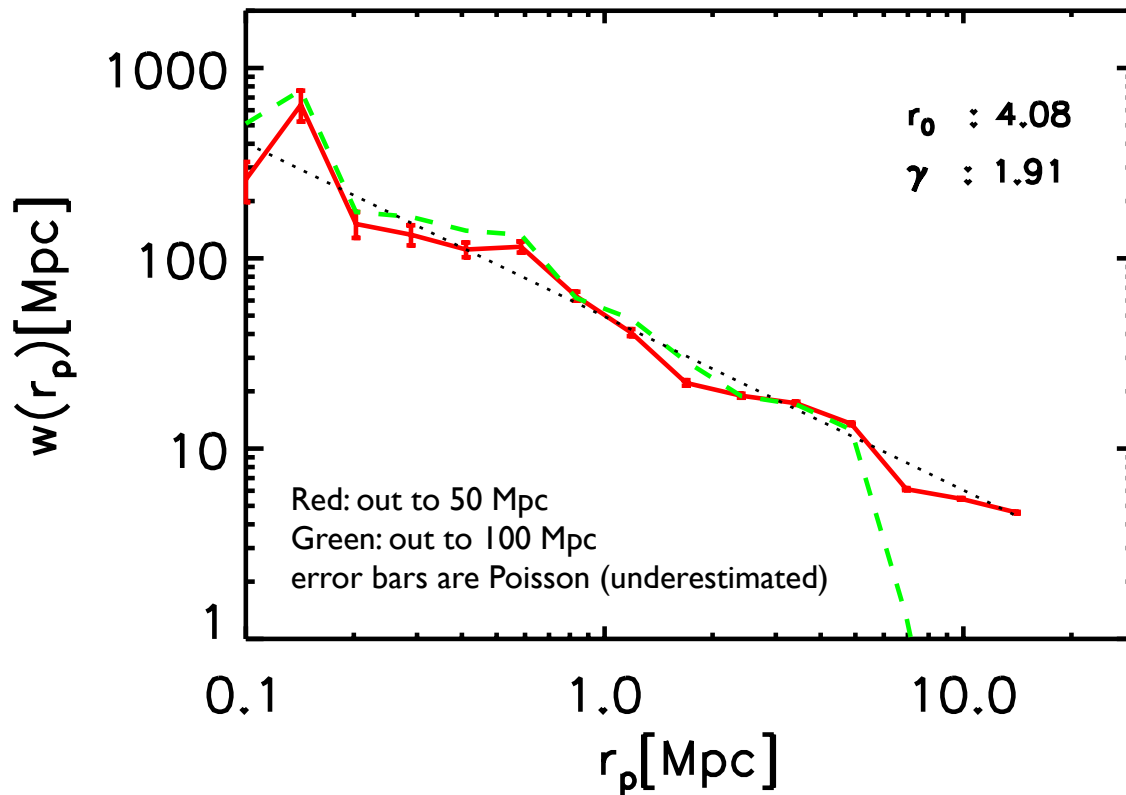


# Herschel-ATLAS



Cross-correlation with optical (GAMA redshifts)

ATLAS–GAMA cross–correlation

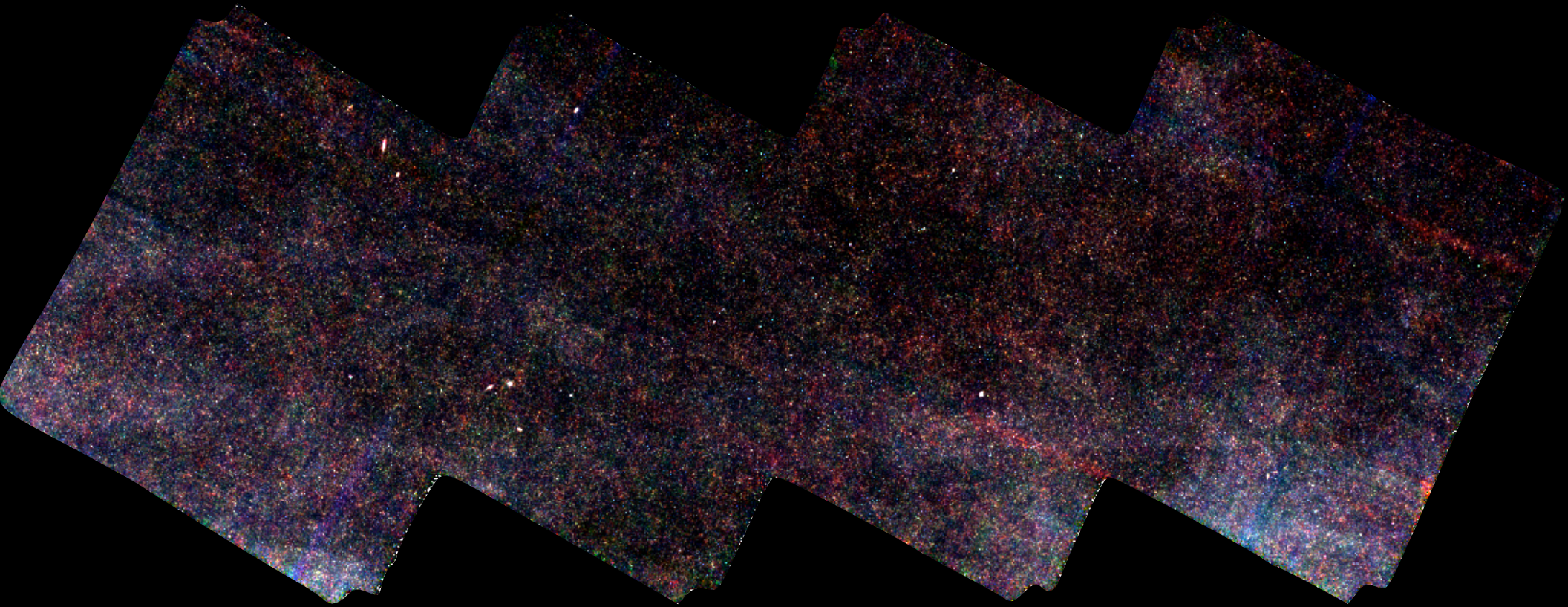


This probes the clustering scale of the low-redshift tail of the sub-mm galaxy distribution ( $\sim 4$ Mpc correlation length)

Using  
 $\sim 900$  SPIRE sources with spectroscopy  
 $\sim 7000$  GAMA redshifts



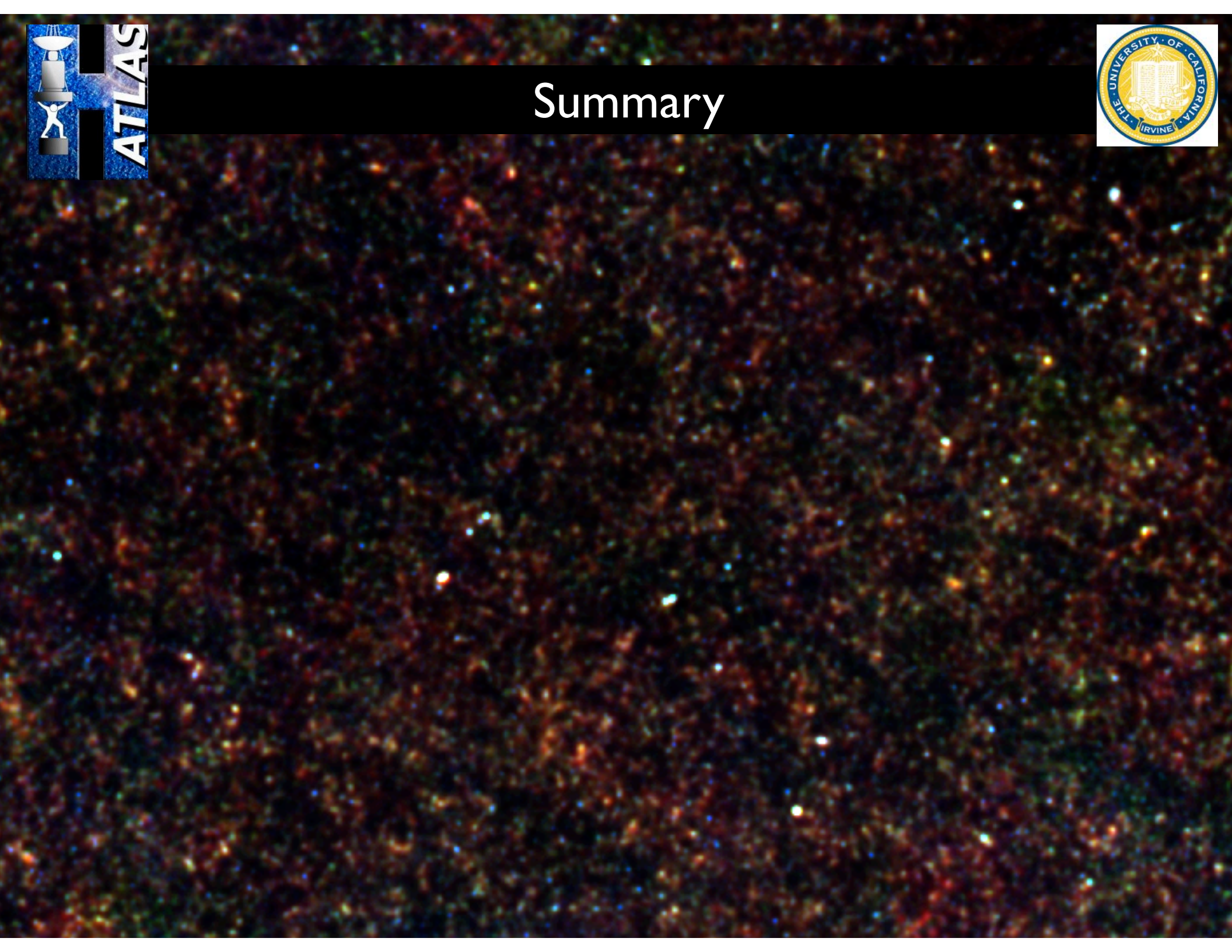
# What's next for H-ATLAS?



GAMA-15 field, 45+ sq. degrees



# Summary





## Summary



We think “red” 350  $\mu$  m selected population is at  $z \sim 2$ .  
We should also have  $\sim 20/\text{deg}^2$   $z \sim 4$  sources (500 micron peakers) - or they must have very cold dust.

We are finding rare, luminous ( $> 10^{12} L_{\text{sun}}$ ) sub-mm galaxies with cold ( $T < 20\text{K}$ ) dust.

We think we can find  $z \sim 2$  protoclusters of sub-mm galaxies tracing overdensities of a few at 10-20Mpc scales. (*hierarchical picture suggests one such an overdensity per ten sq. degrees*).

*There is a clear need for large followup studies.*