Multi-wavelength study of Planck high-redshift proto-cluster candidates

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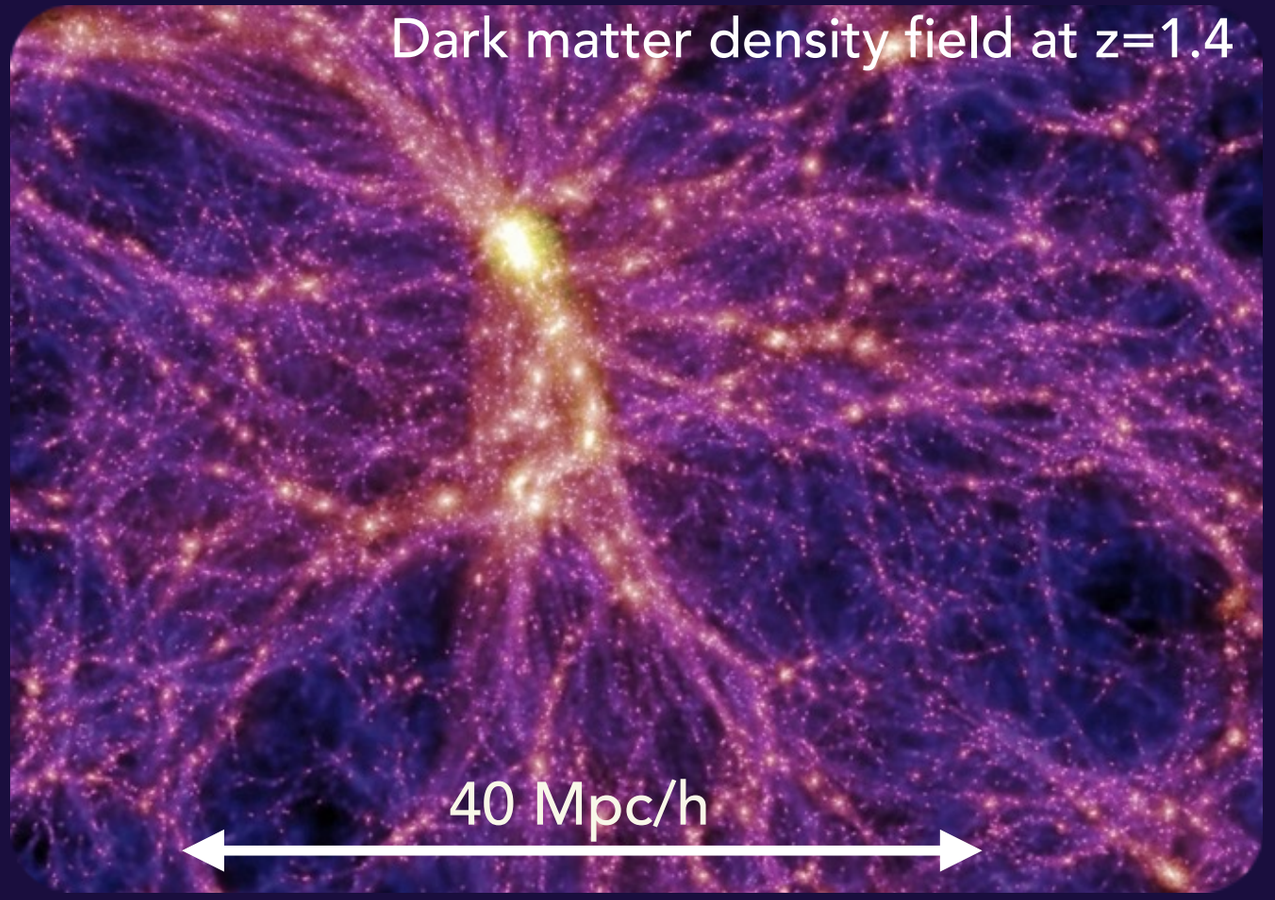
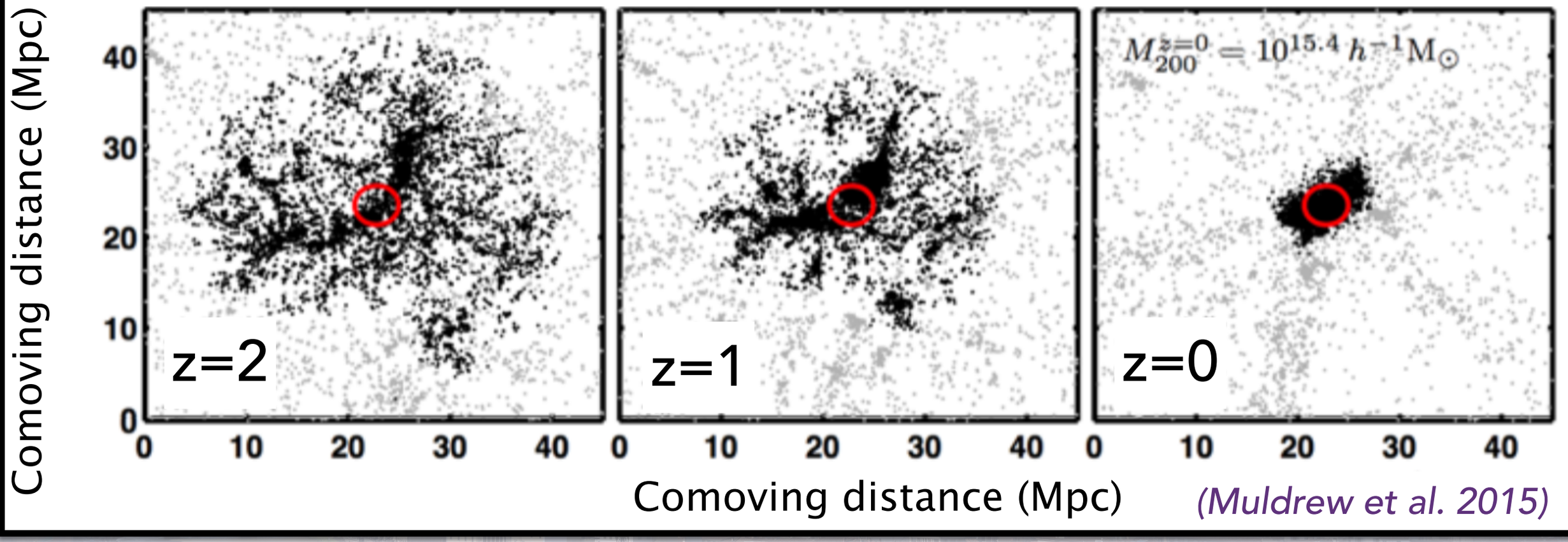


(Millenium Simulation Project; Springer et al. 2005)

What is a proto-cluster ?

- Hundreds of galaxy in **over-densities** that will end up in a cluster at z=0
- Galaxies in **clumps** and **filaments** ➥ complex environmental history
- **Extended** (≲ 40 Mpc ➙ 1.3-1.6 deg @ z=2-4)
- Large fraction of **active** galaxy members
- **Not virialized** (can not be found through standard cluster searching techniques)

Black points: galaxies with $M_{*}>10^{8}M_{\odot}$ that will end up in the cluster at z=0



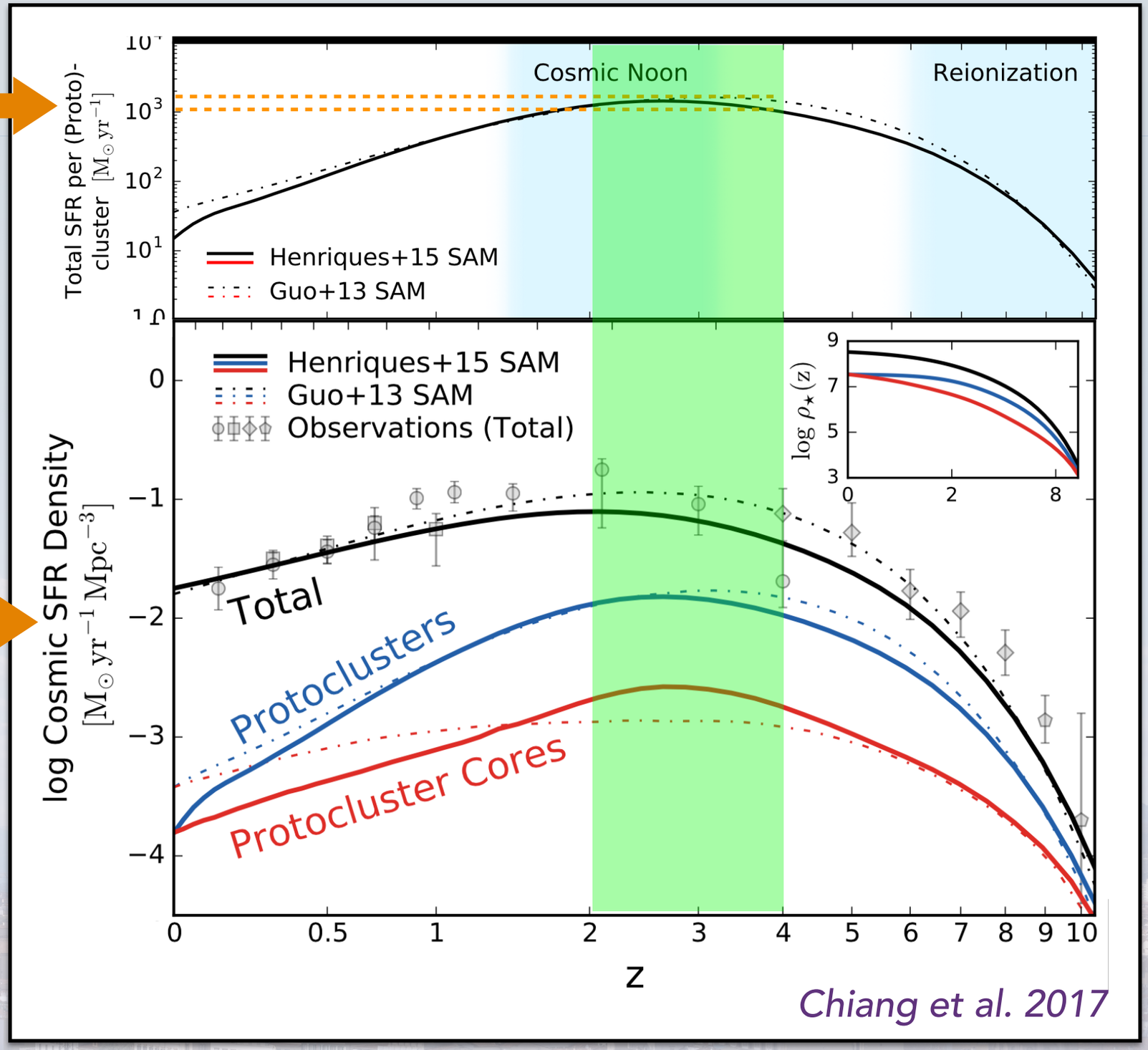
(Muldrew et al. 2015)

(Tanaka et al. 2010; Papovich et al. 2010; Hatch et al. 2011; Toshikawa et al. 2012; Hayashi et al. 2012; Rudnick et al. 2012; Santos et al. 2013; Cucciati et al. 2014; Smail et al. 2015; Casey et al. 2015, 2016, and others)

Proto-clusters experience rapid and intense star-formation activity at z~2-4

Proto-cluster total SFR:
1000-2000 $M_\odot$/yr

Proto-cluster contribution to the Cosmic SFR Density:
20-30%



High-z dusty Star-Forming Galaxies (DSFGs) as proto-cluster signposts

- DSFGs trace dense large-scale structures in the high-z universe (*Blain et al. 2004*).
- Over-densities of DSFGs are signposts of massive structures in formation (*Negrello et al. 2010, Clements et al. 2014, Narayanan et al. 2015*)
- The progenitors of today massive ellipticals are thought to be DSFGs at high redshift (z~2-4) (*Lilly et al. 1999, Swinbank et al. 2008*)

How to find them ?

Sub-mm wide surveys (+ wide beam to collect the extended emission)

Planck all sky survey at multiple sub-mm wavelengths with a 5’ resolution

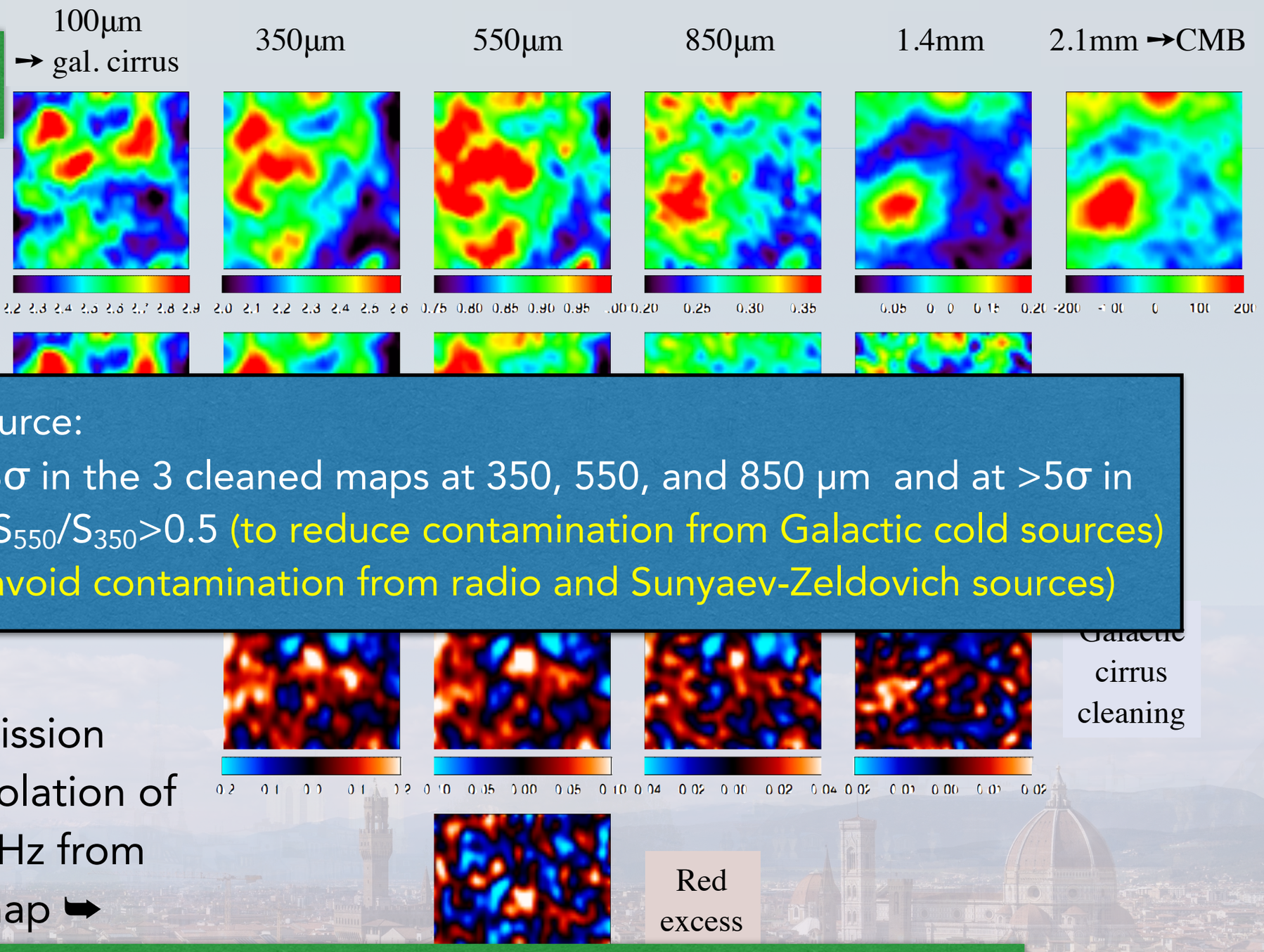
Planck image processing

Components to remove:

A. Cosmic Microwave Background (**CMB**) assuming a black body model

B. **G**
us
ar
m
100μm)

C. **Foreground** source emission removal through interpolation of signal at 353 and 857GHz from the 545 GHz cleaned map ➥ 545 GHz red

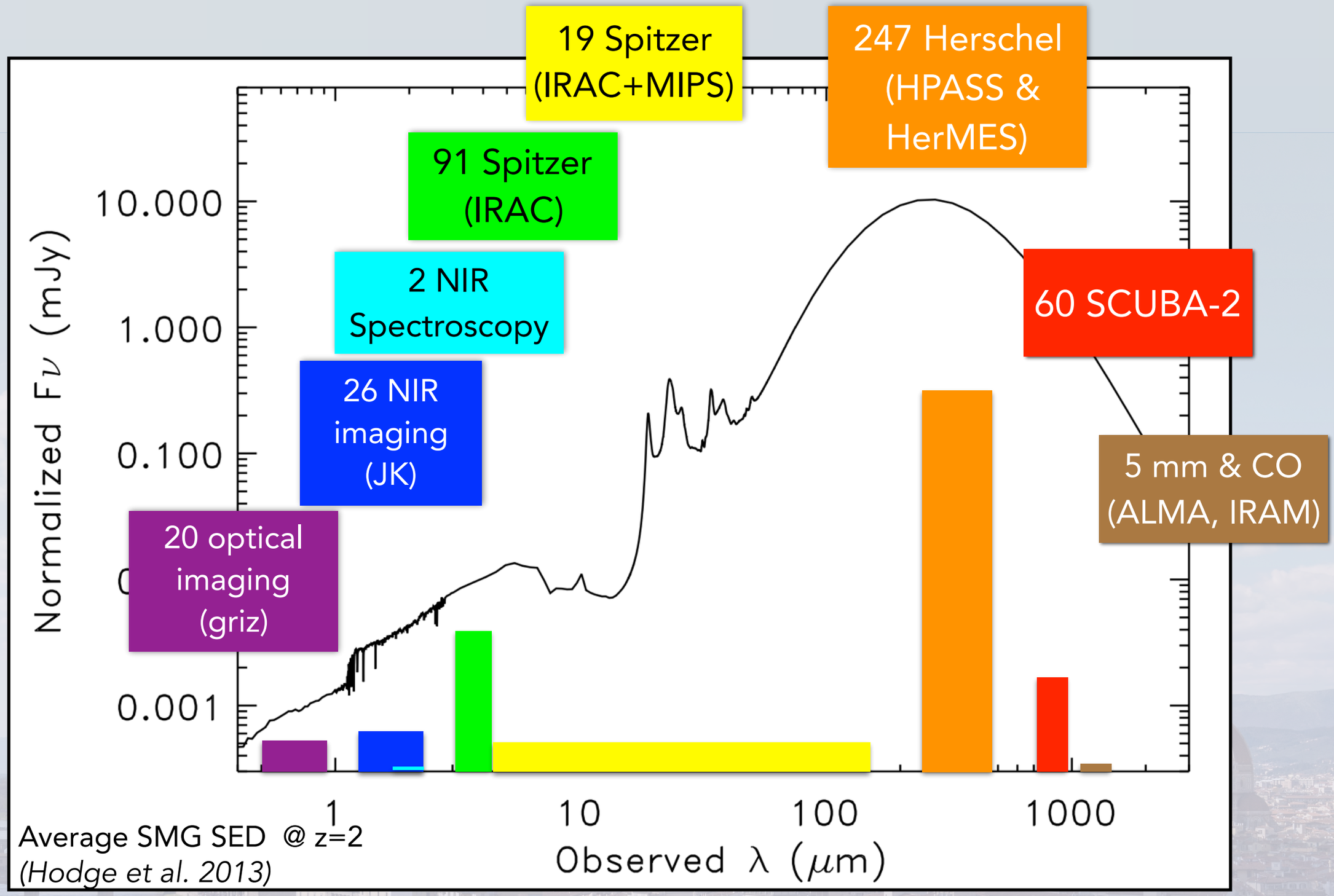


Planck high-z (PHz) source:
source detected at >3σ in the 3 cleaned maps at 350, 550, and 850 μm and at >5σ in the RX map and with $S_{550}/S_{350}>0.5$ (to reduce contamination from Galactic cold sources) and $S_{850}/S_{550}<0.9$ (to avoid contamination from radio and Sunyaev-Zeldovich sources)

2151 sources with red sub-mm colors ➥ z~2-4

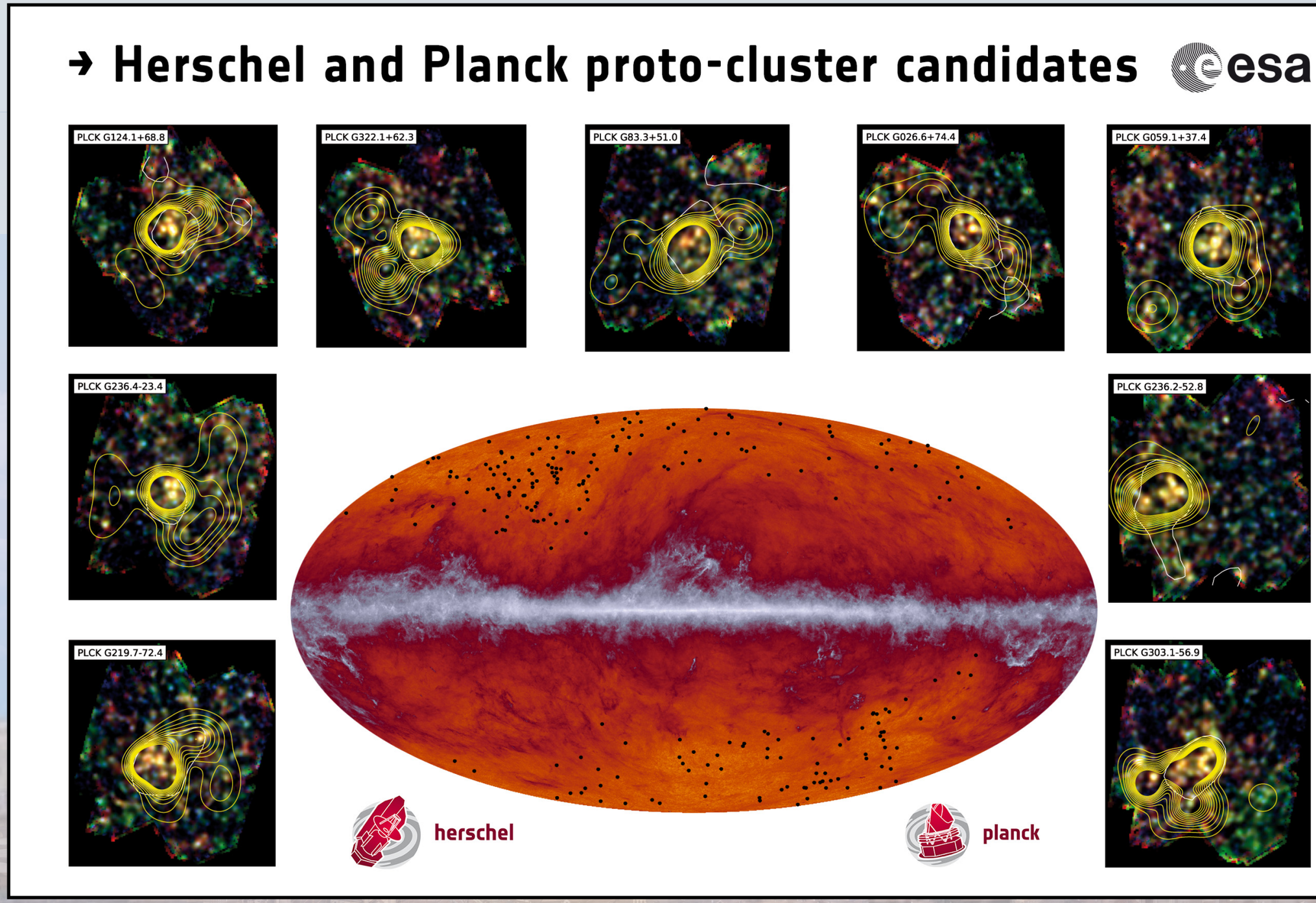
(Planck coll. 2016. Int. results XXXIX)

PHz multi-wavelength follow-up observations



(Oliver et al.2012; Cañameras et al. 2015; Planck collaboration 2015. Int. results XXVII; Flores-Cacho et al. 2016, MacKenzie et al. 2016; Kneissl et al., in prep.; Martinache et al., in prep.; Polletta et al., in prep.)

PHz: over-densities of red dusty star-forming galaxies (DSFGs)



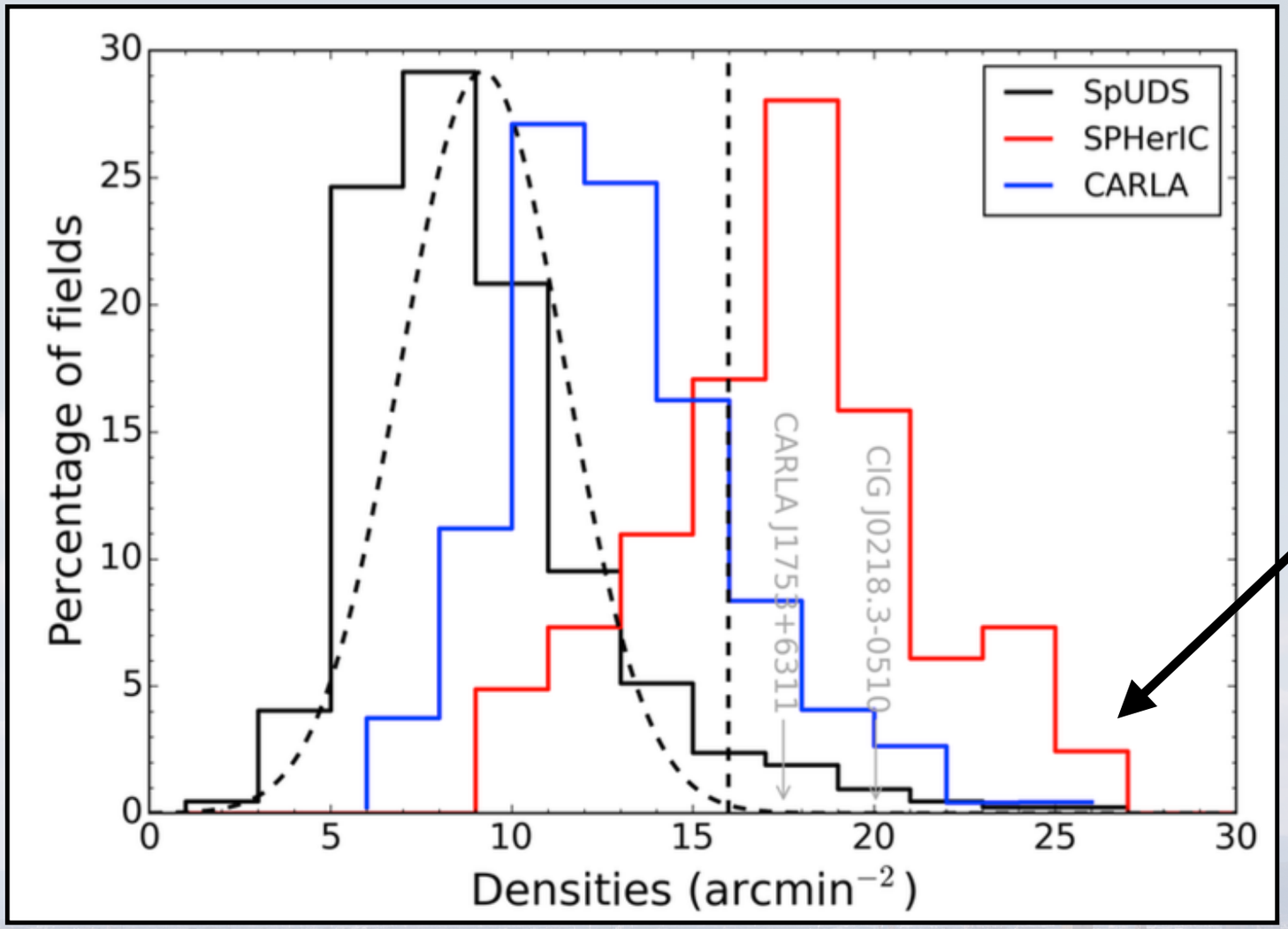
Herschel RGB images (~20′x20′)
White contours: Planck 545 GHz image
Yellow contours: overdensity significance

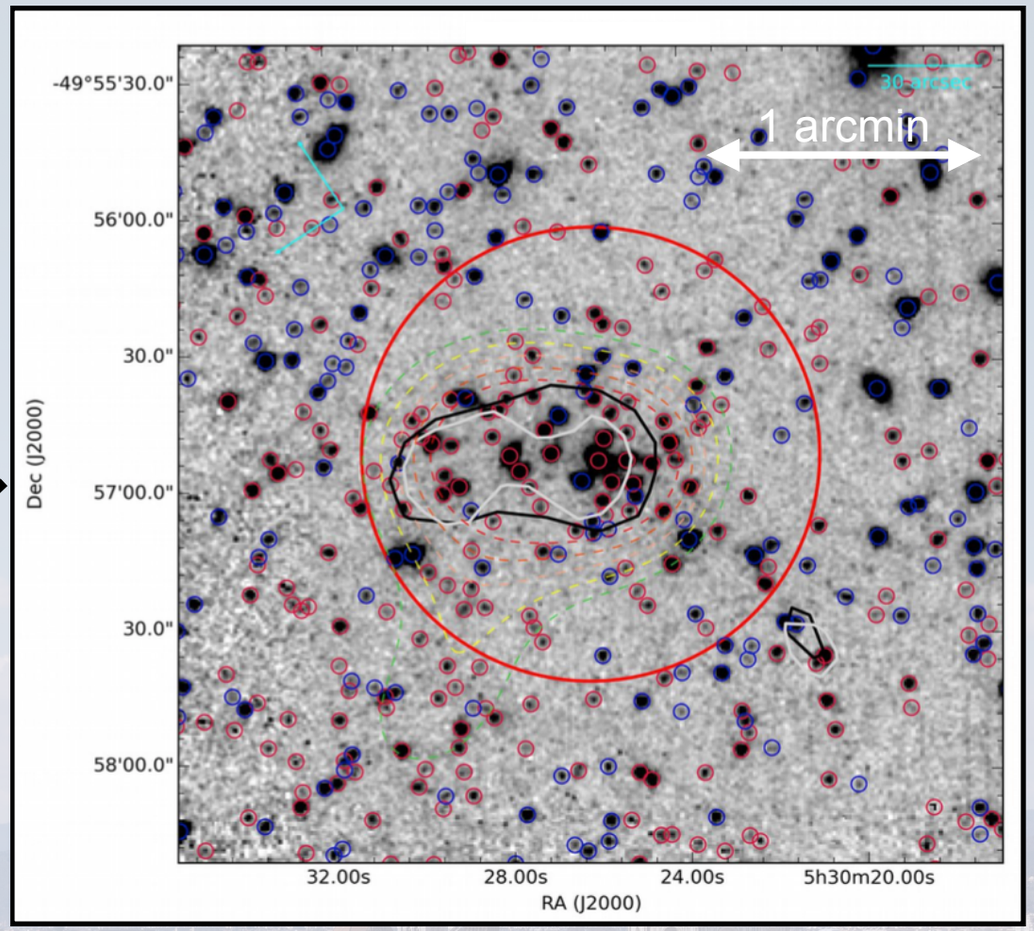
Planck collaboration 2015. Int. results XXVII

PHz: over-densities of red IRAC sources

(Martinache et al., in prep.)

PHz G256.8:
Σ_{IRAC}=26 arcmin^2



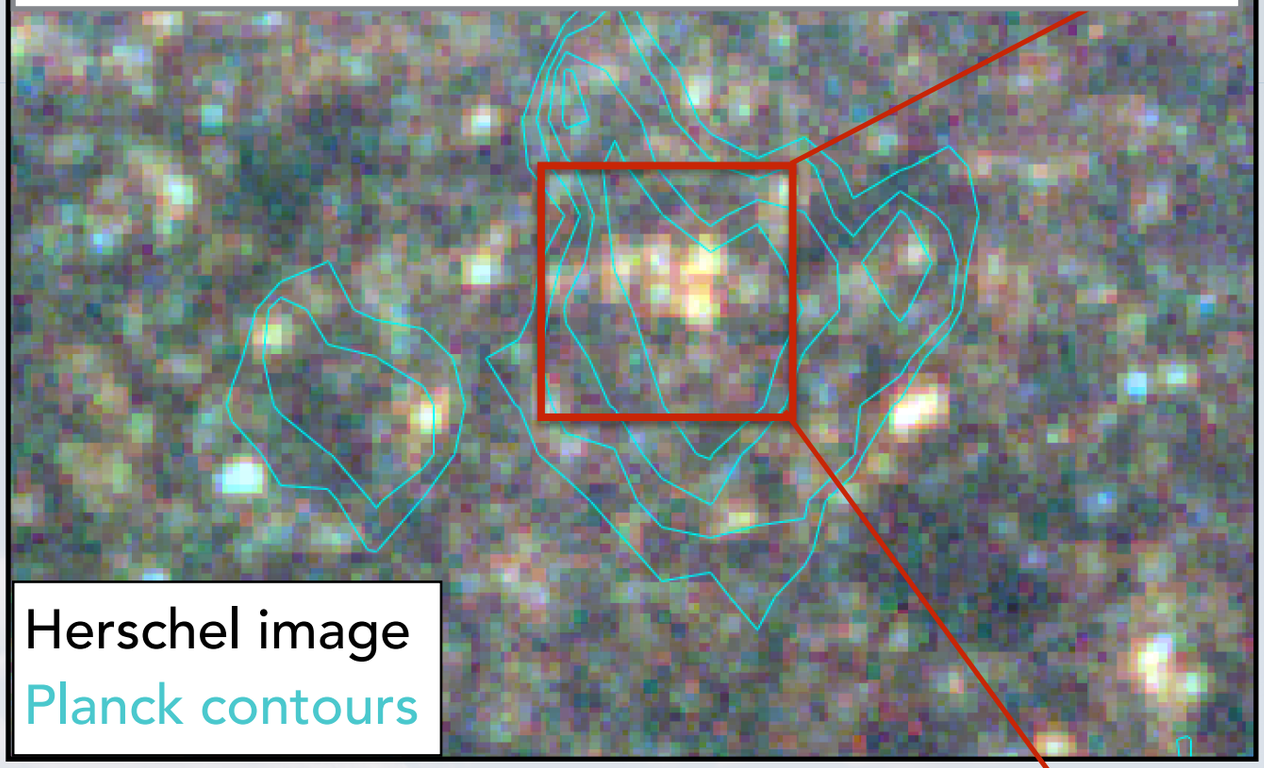


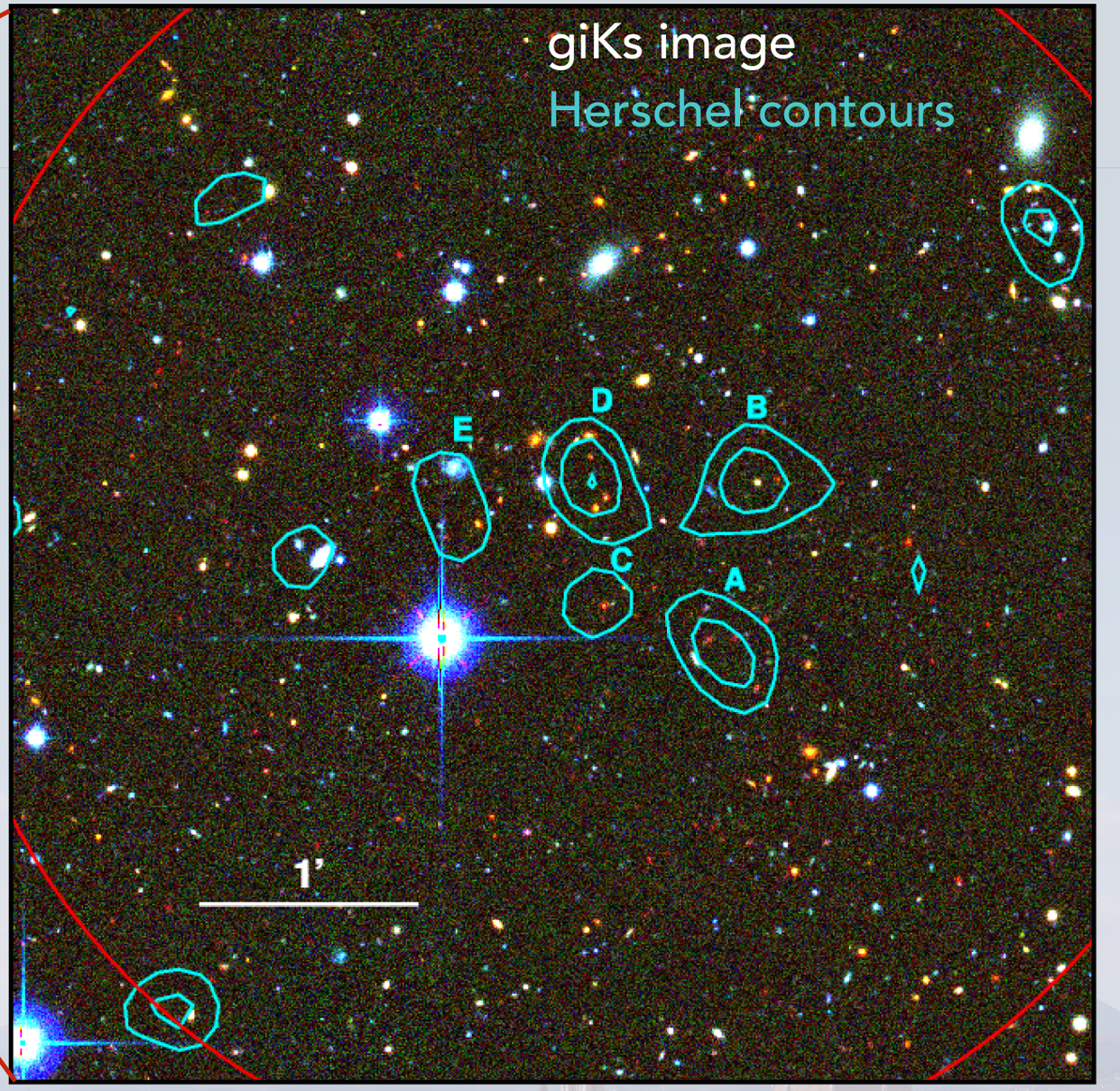
CARLA: Clusters Around Radio-Loud AGN; Wylezalek et al. 2013)
SpUDS: Spitzer UKIDSS Ultra Deep Survey (PI: J. Dunlop)
SPHerIC: Spitzer Planck Herschel Infrared Cluster survey

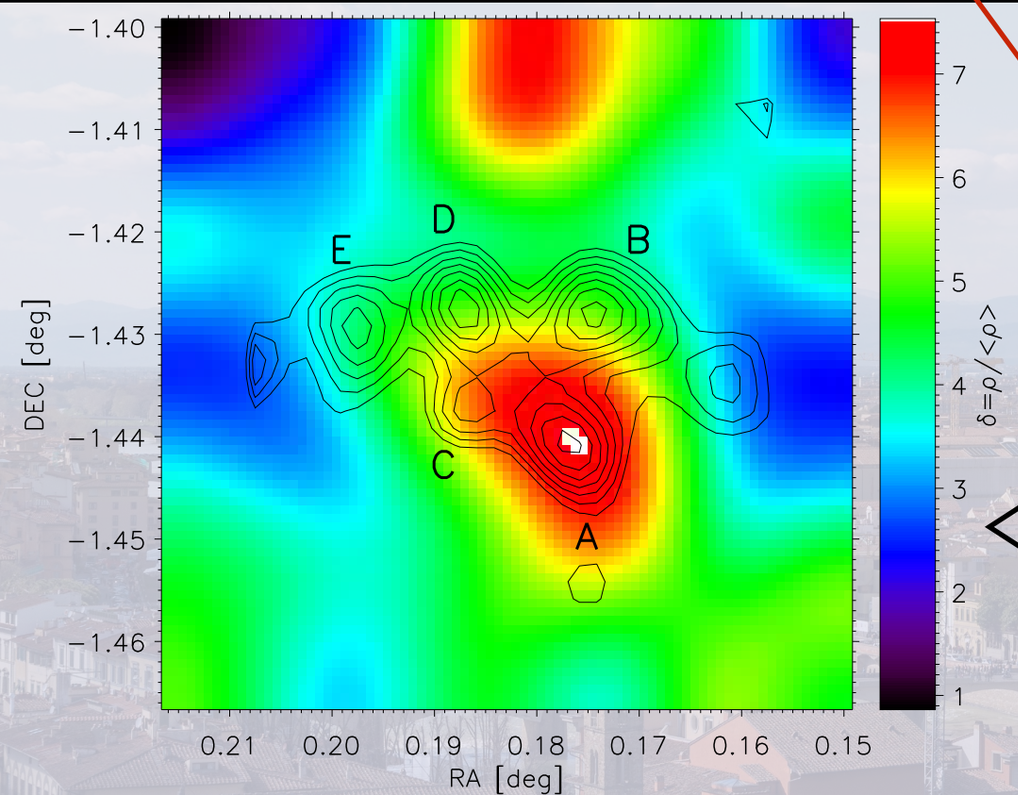
Image: IRAC 4.5μm
IRAC red sources w/ [3.6]-[4.5]>-0.1
250μm 3σ contours, 350μm 3σ contours

PHz G95.50-61.59: over-density of Herschel and red (i-Ks) sources

4 Herschel sources within 1′ →9σ overdensity

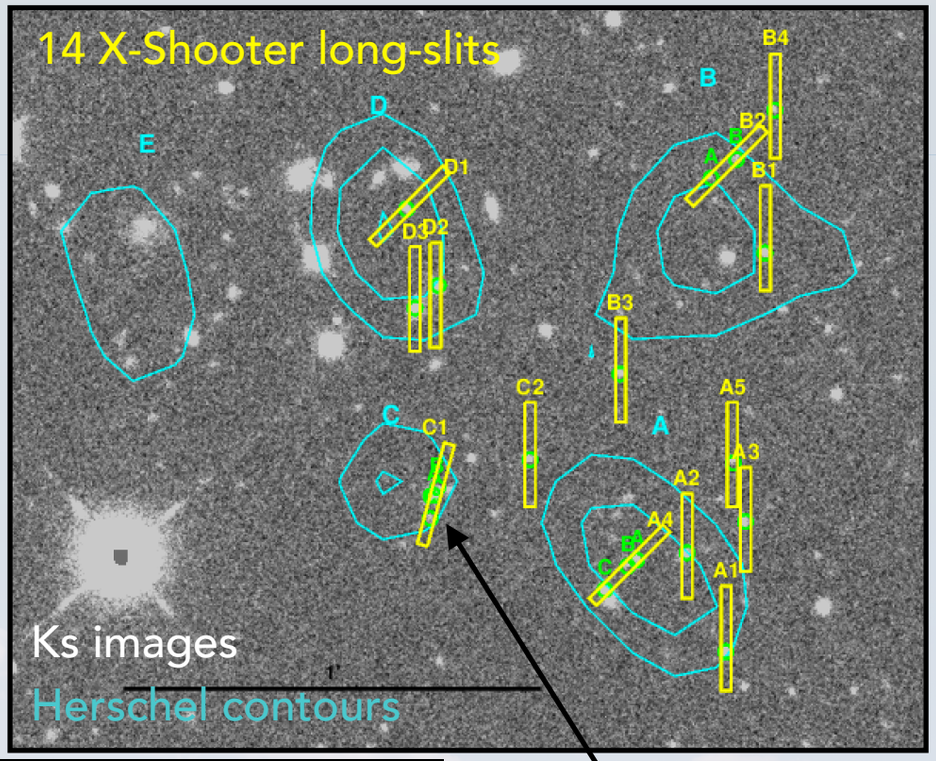


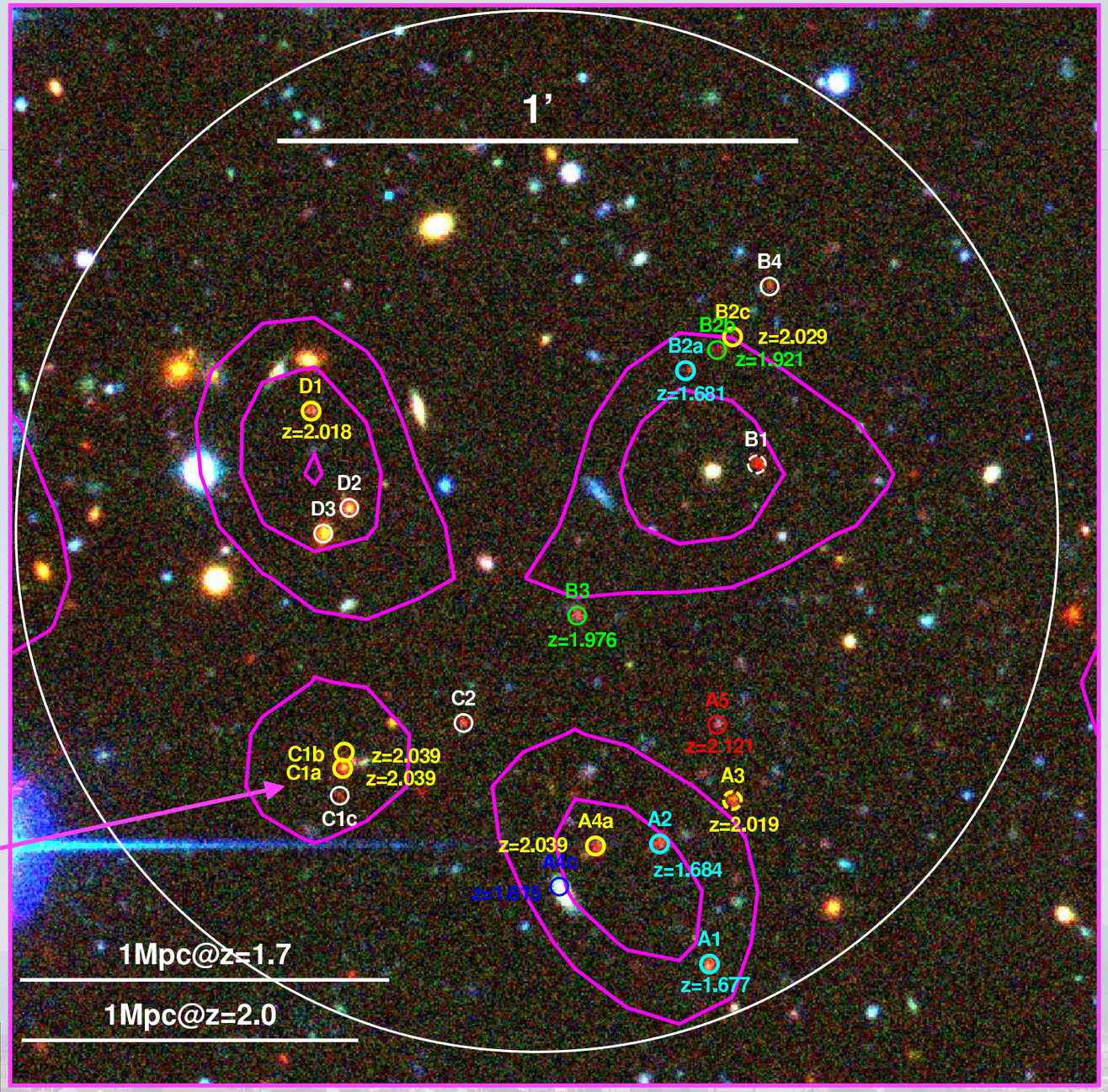




(Flores-Cacho et al. 2016)

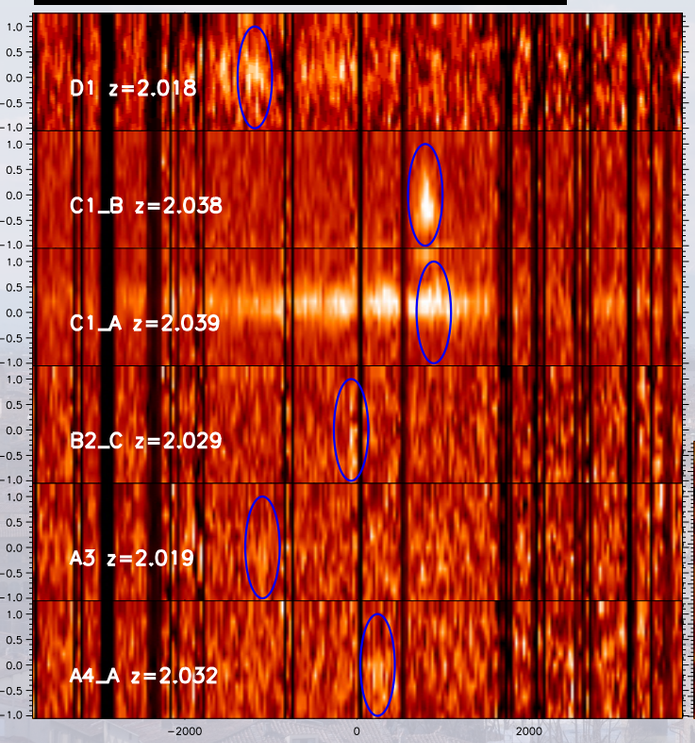
Spectroscopic observations of PHz G95.50-61.59: a double structure at z=1.7 and z=2.0



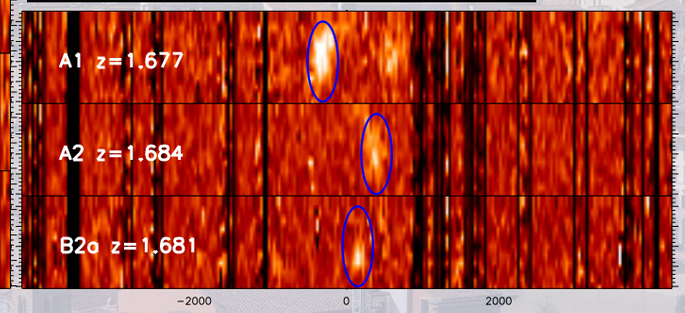


6 sources at z~2.03

1 BLAGN



3 sources at z~1.68

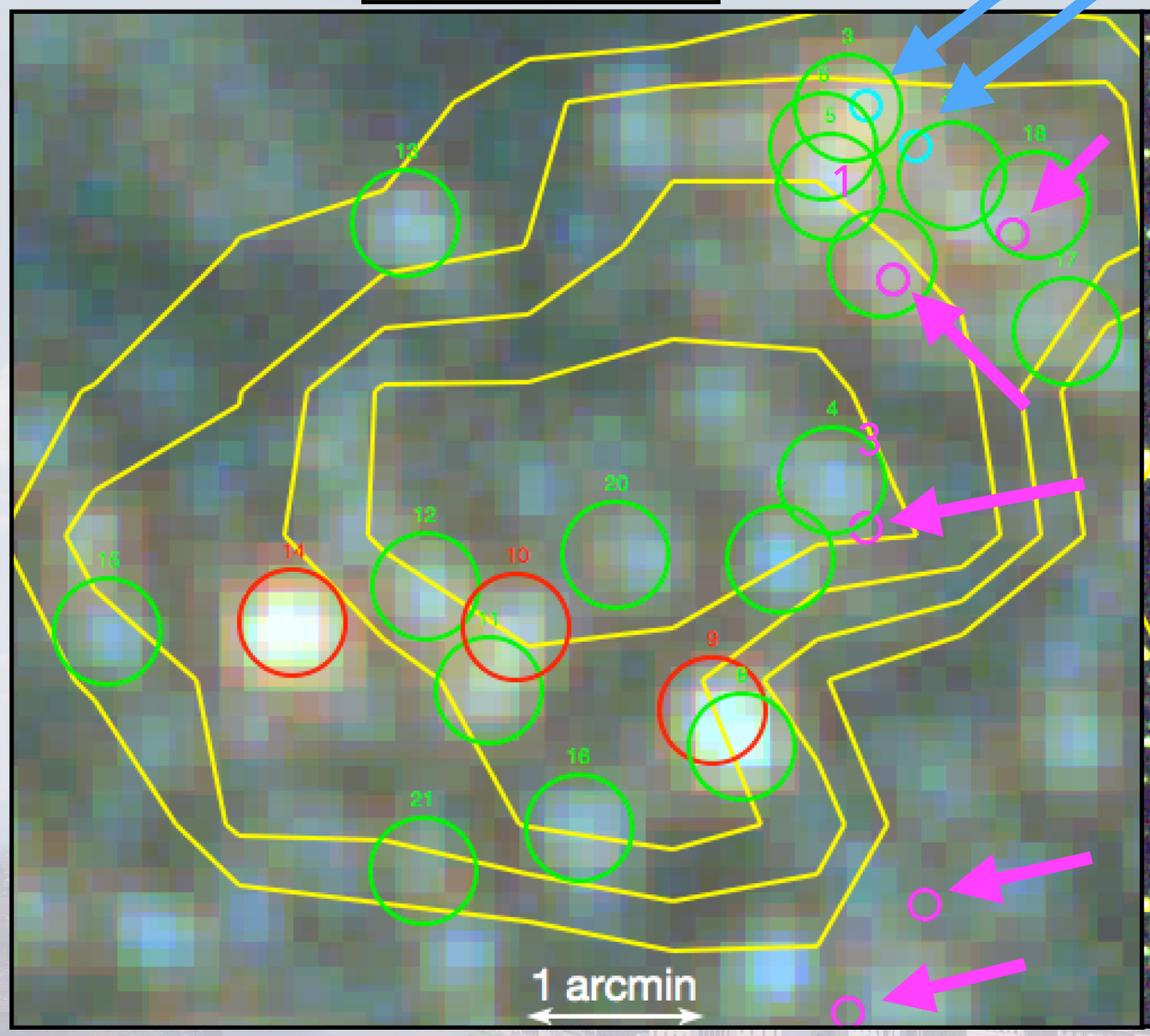


(Flores-Cacho et al. 2016)

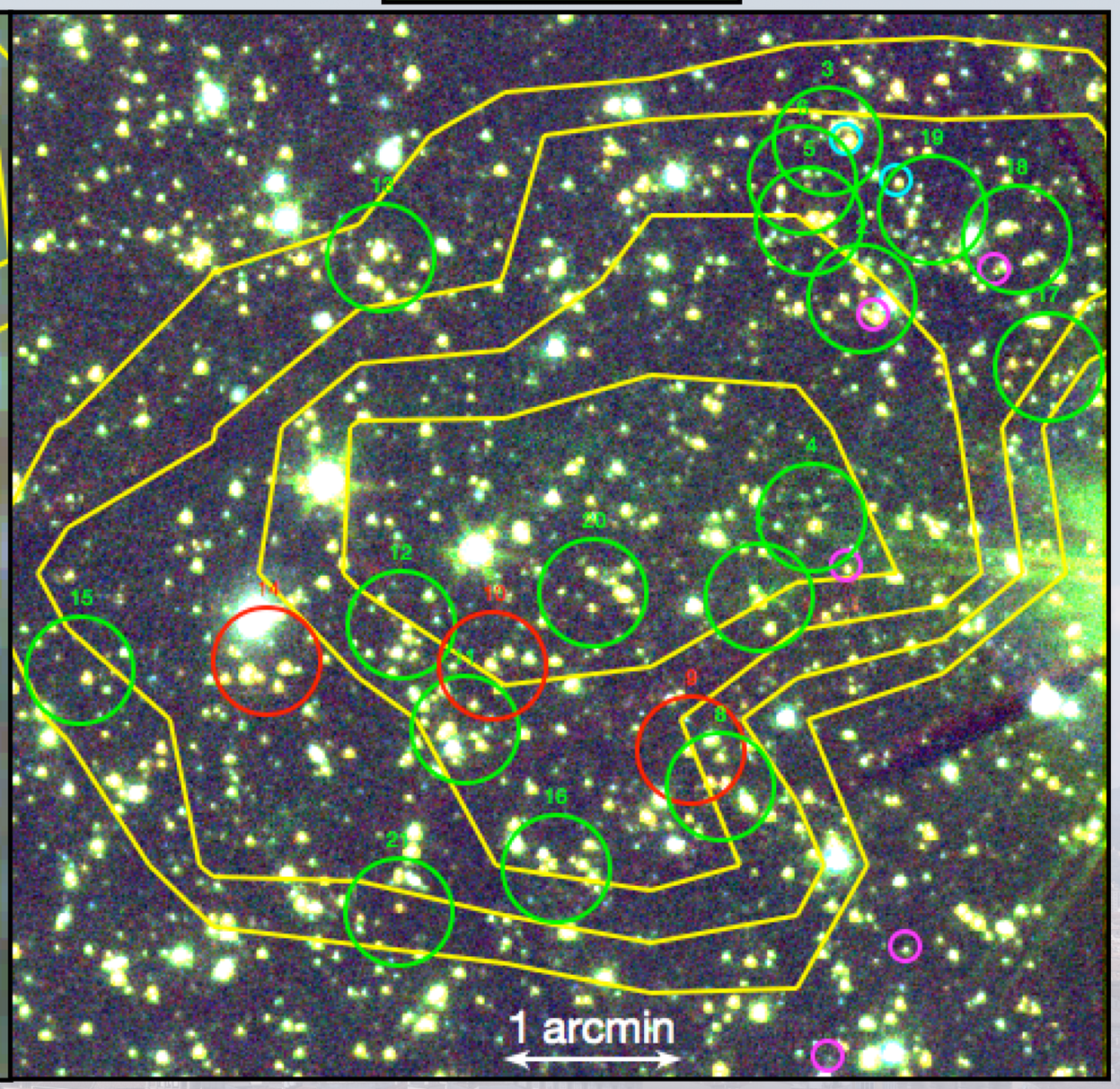
A protocluster candidate at z=2.16
PHz G237.01 in HerMES (Cosmos)

7 sources (2 AGN) at z_{spec} = 2.16 within 5.7′ (~6.2 cMpc)

Herschel image



K+IRAC image



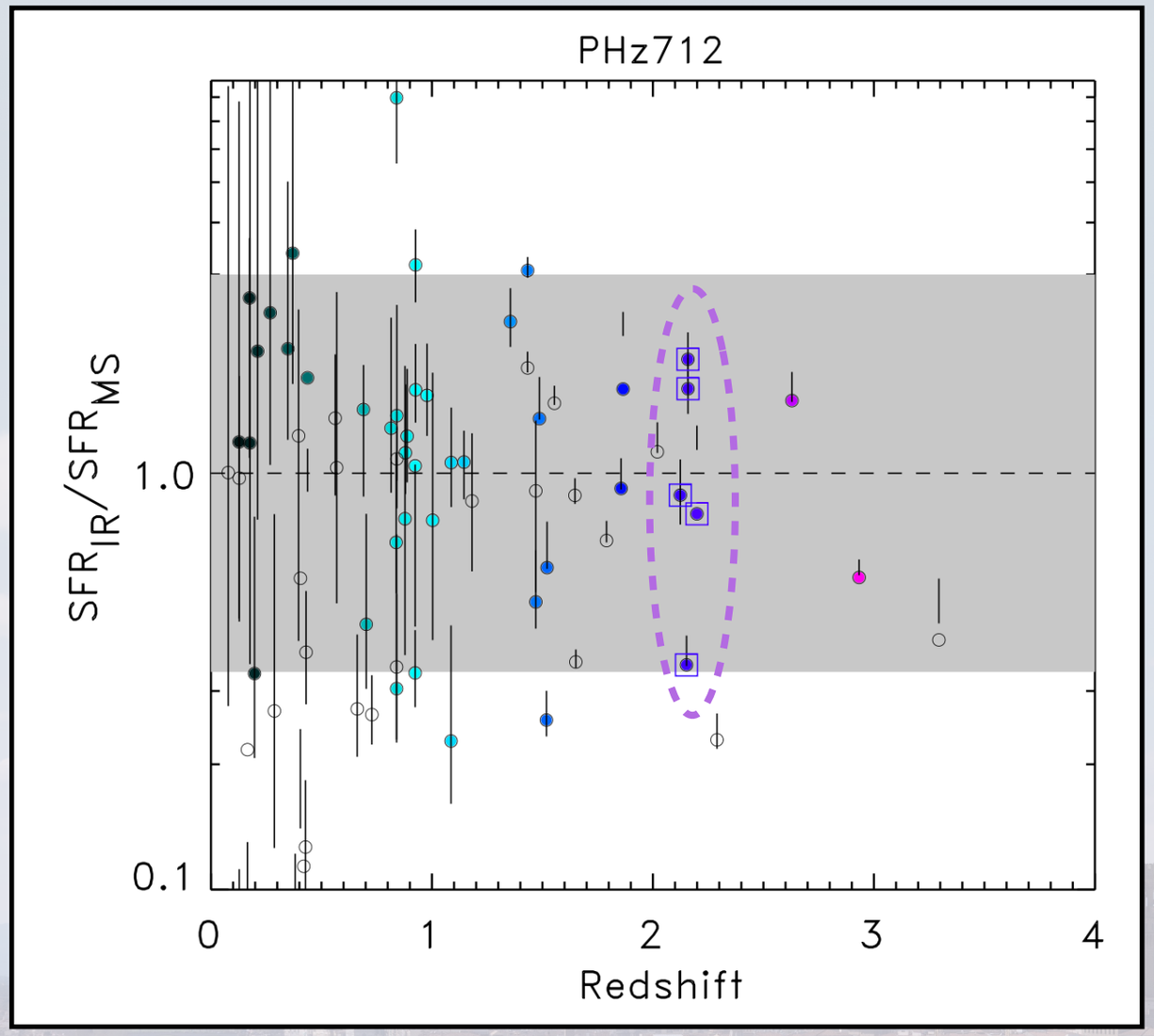
Planck contours (yellow)
Herschel (red or green circles)

z_{spec} from LBT/LUCI and zCosmos (Scodeggio, priv. comm)

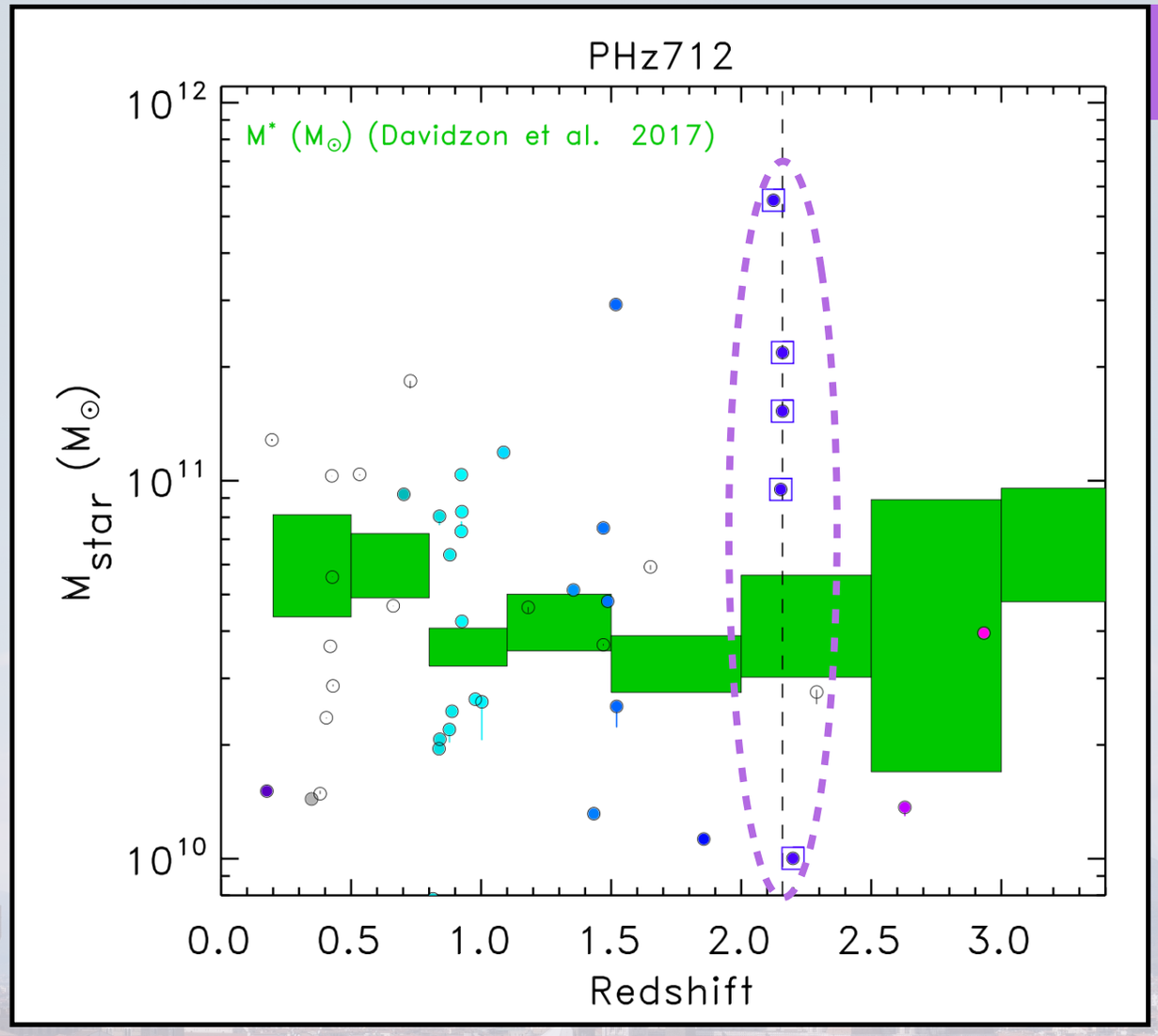
DSFGs in PHz G237.01: SFRs and M_{star}

(Polletta et al., in prep.)

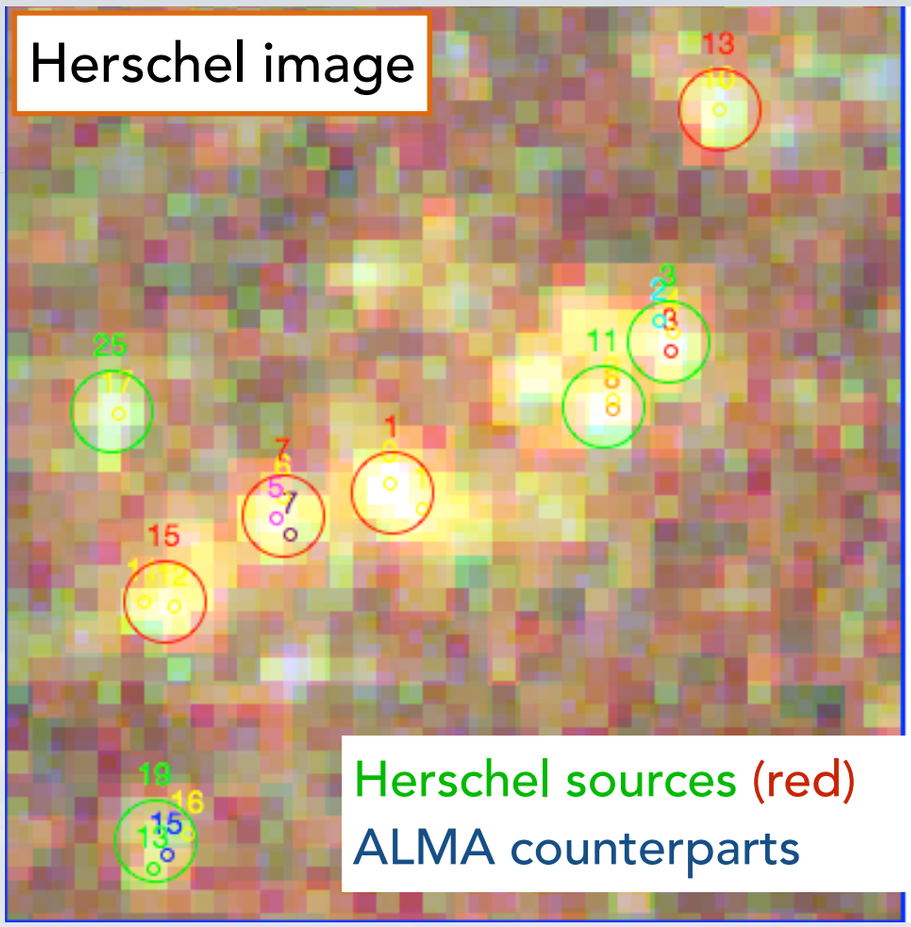
SFR vs M_{star}

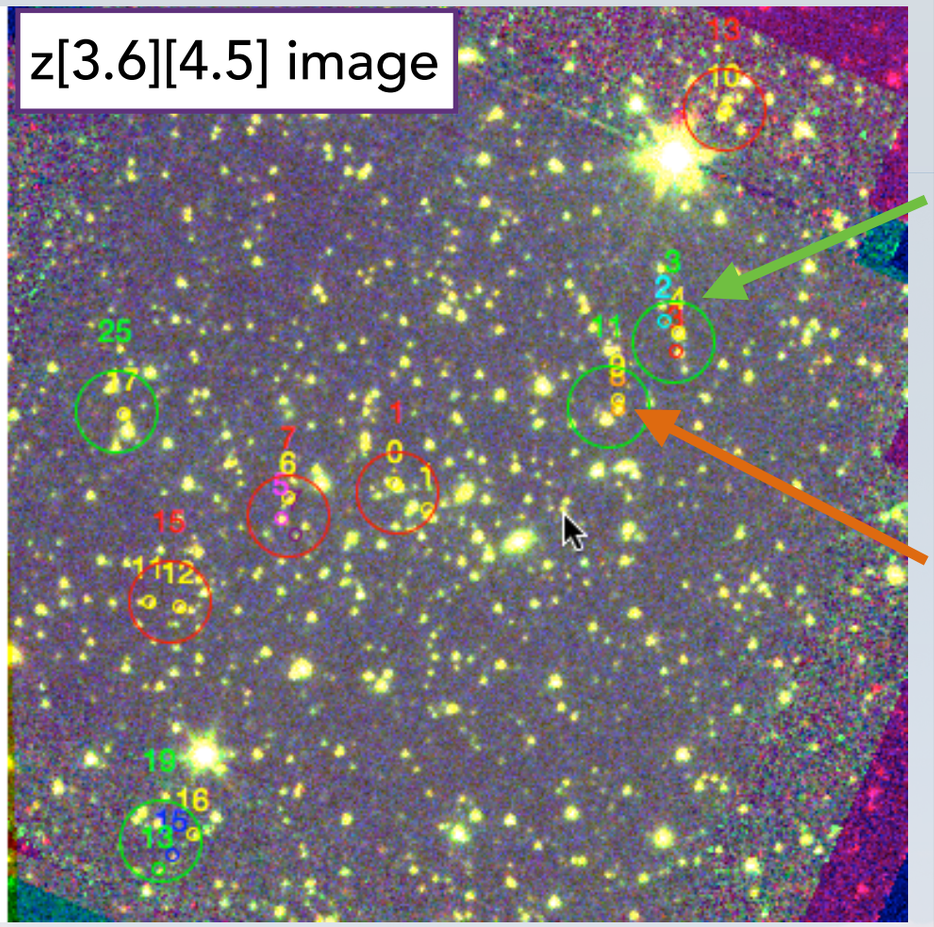


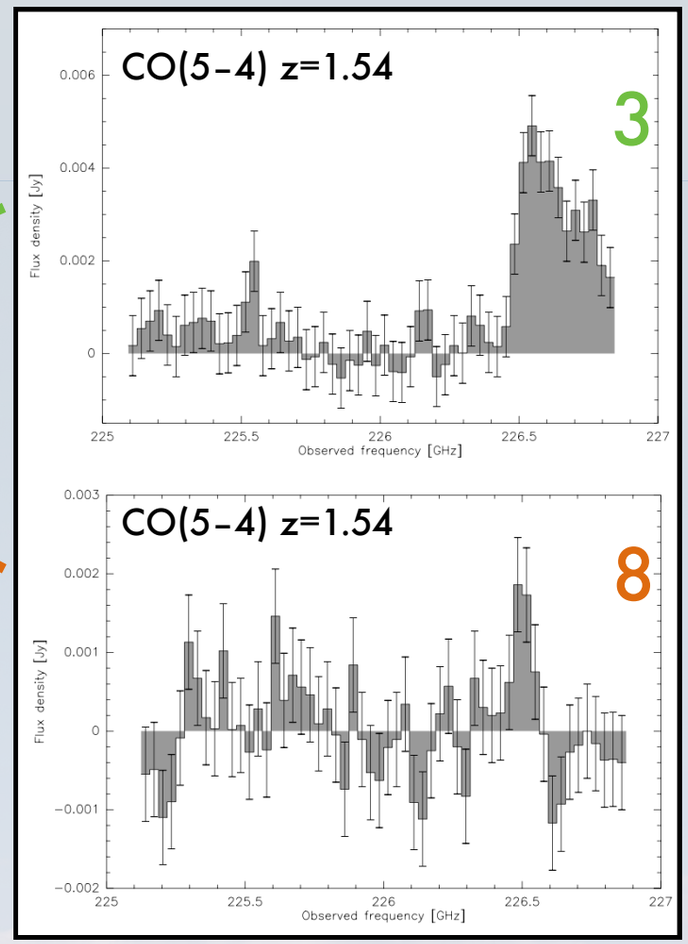
M_{star} vs z



ALMA observations of PHz G73.4-57.5: a structure candidate at z=1.54







- 13 Herschel sources (6 are red*) ➙12σ overdensity
- 18 ALMA (233 GHz) dets. in 8 Herschel sources ➙ from 1 to 4 ALMA per 1 Herschel
- 2 CO line detections ➙ z = 1.54 + 3 z_{phot} ≅ 1.5 ➙ structure w/ 5 members @ z=1.54

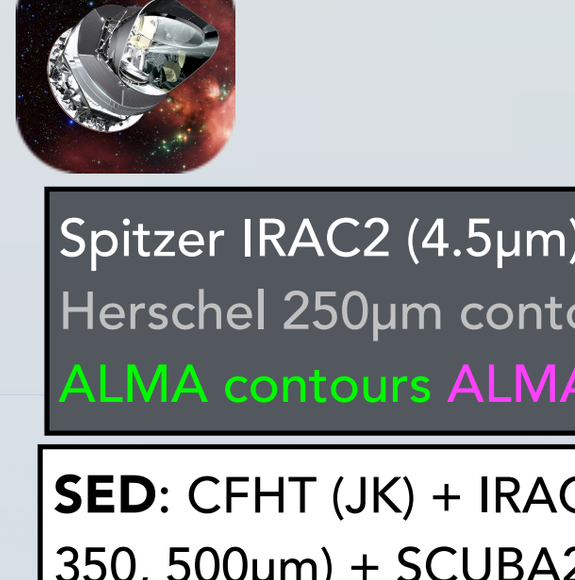
(Kneissl et al., in prep.)

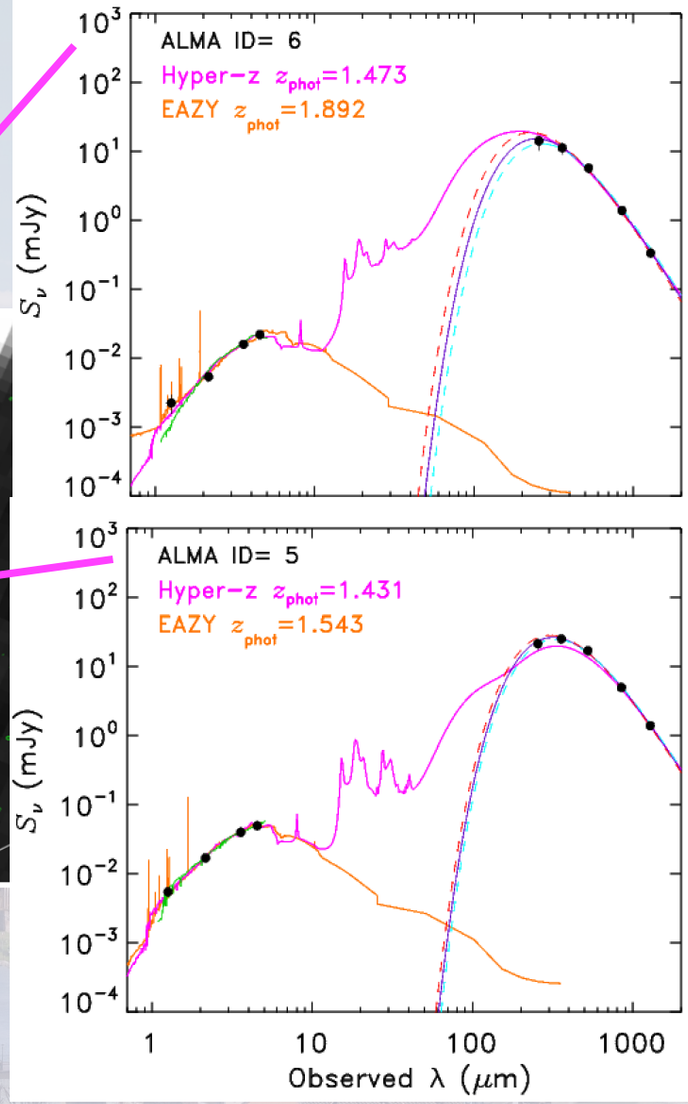
* red (S_{250}/S_{350}<1.4 & S_{500}/S_{350}>0.6 ➙ high-z candidate)

ALMA observations of PHz G73.4-57.5: structure member SEDs

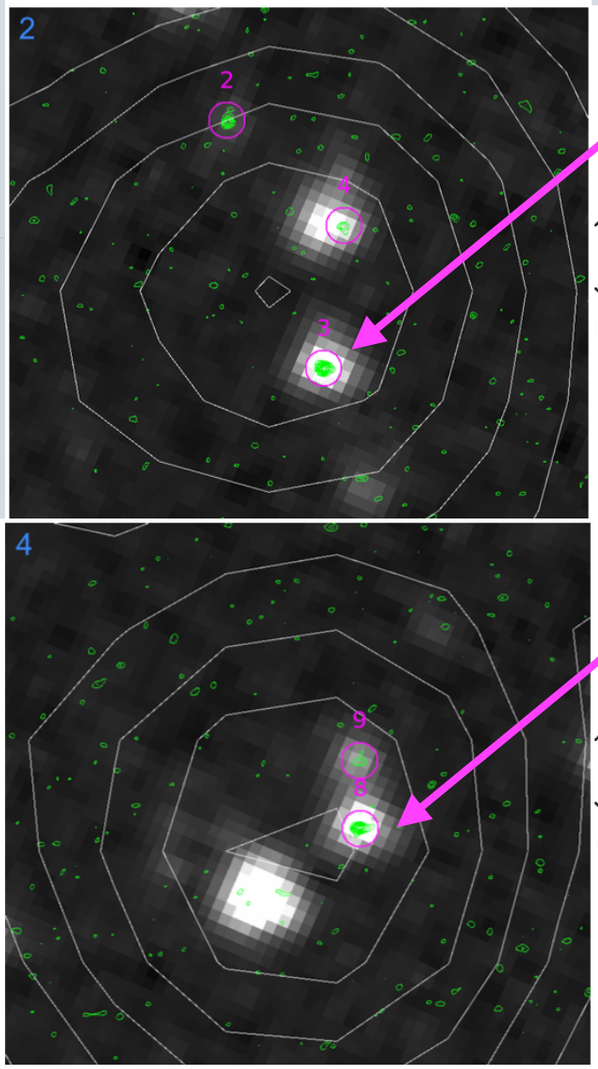
Spitzer IRAC2 (4.5μm) 30”x30” images (2”)
Herschel 250μm contours (18”)
ALMA contours ALMA source (0.5”)

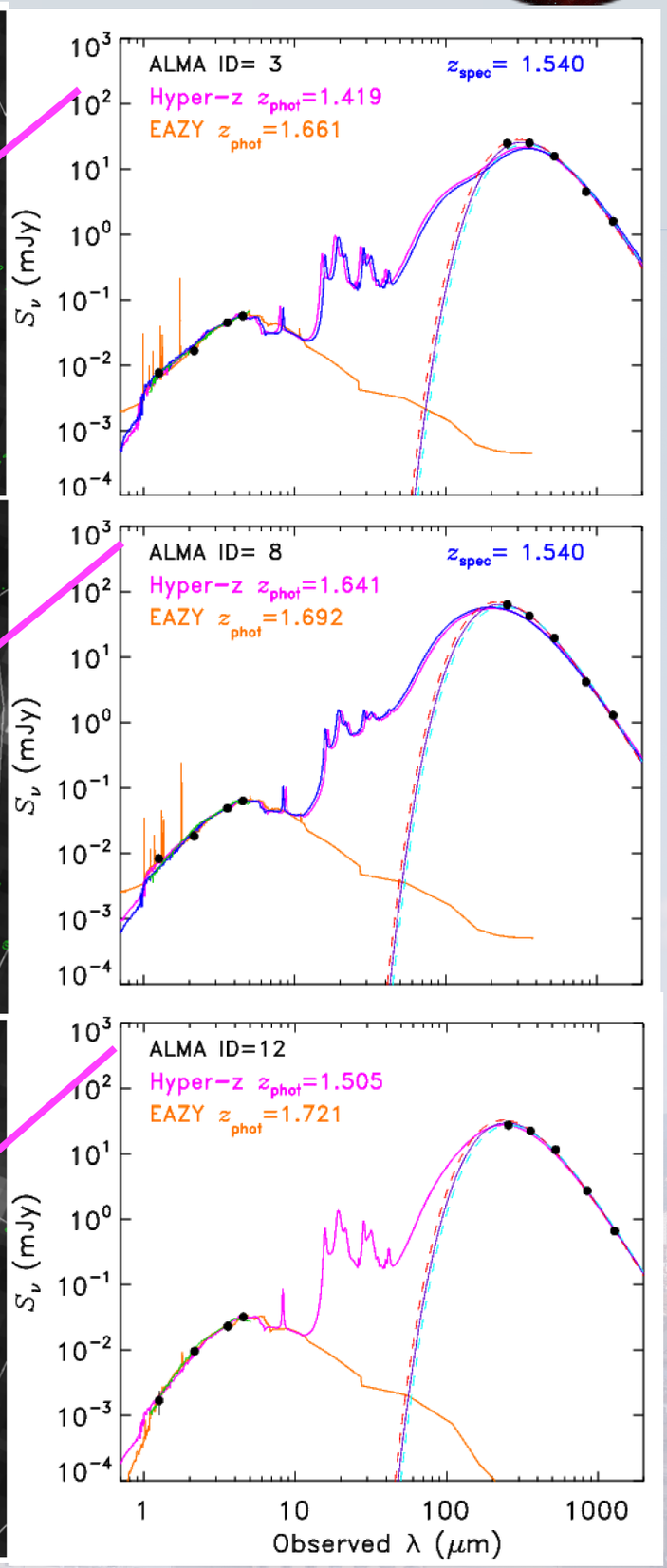
SED: CFHT (JK) + IRAC (3.6, 4.5μm) + SPIRE (250, 350, 500μm) + SCUBA2 (870μm) + ALMA (1.3mm)
Photometric-z (Hyper-z & EAZY)





Hyper-z (Bolzonella et al. 2000) with empirical templates (Polletta et al. 2007; Danielson et al. 2017)
EAZY (Brammer et al. 2008)

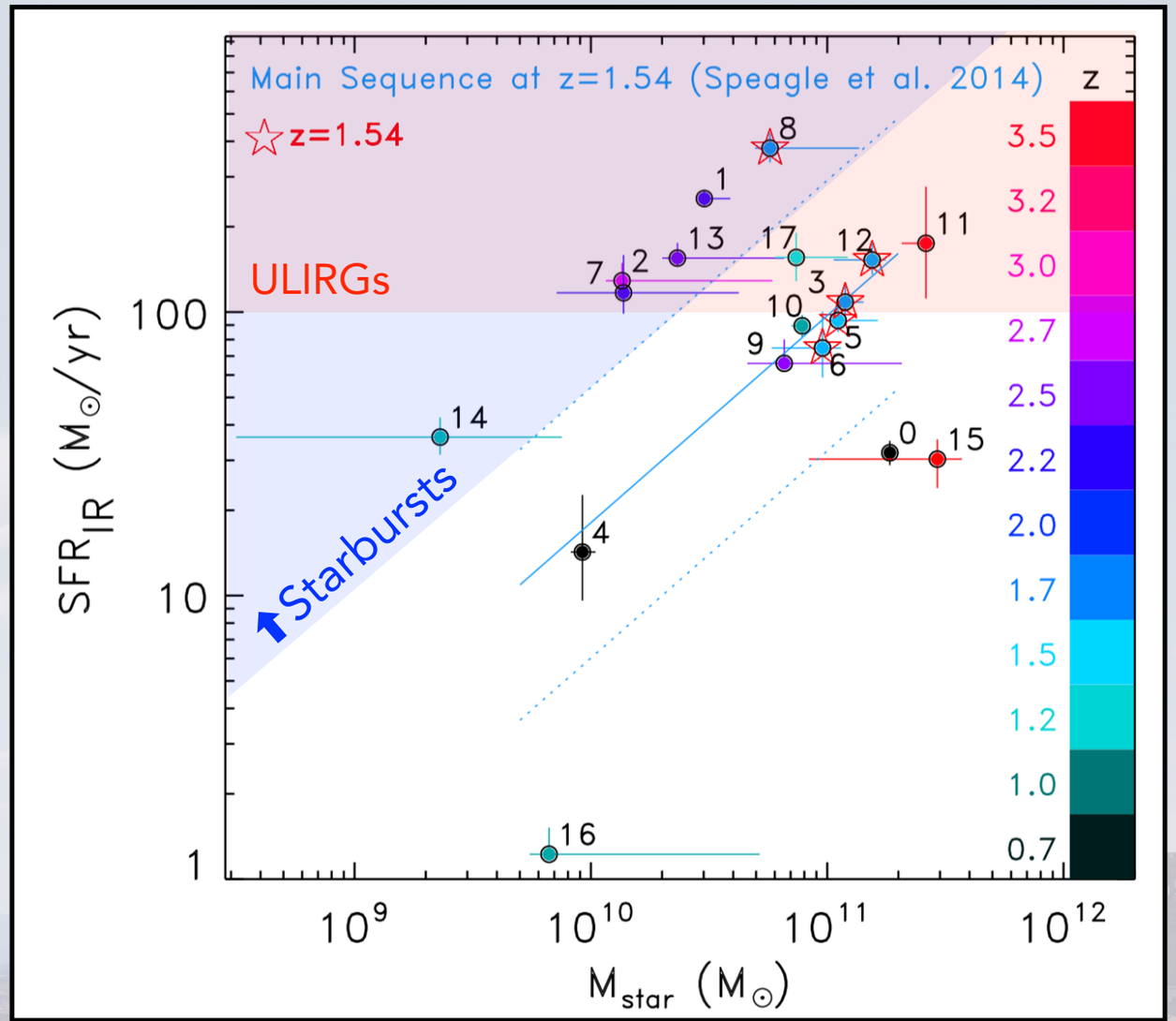




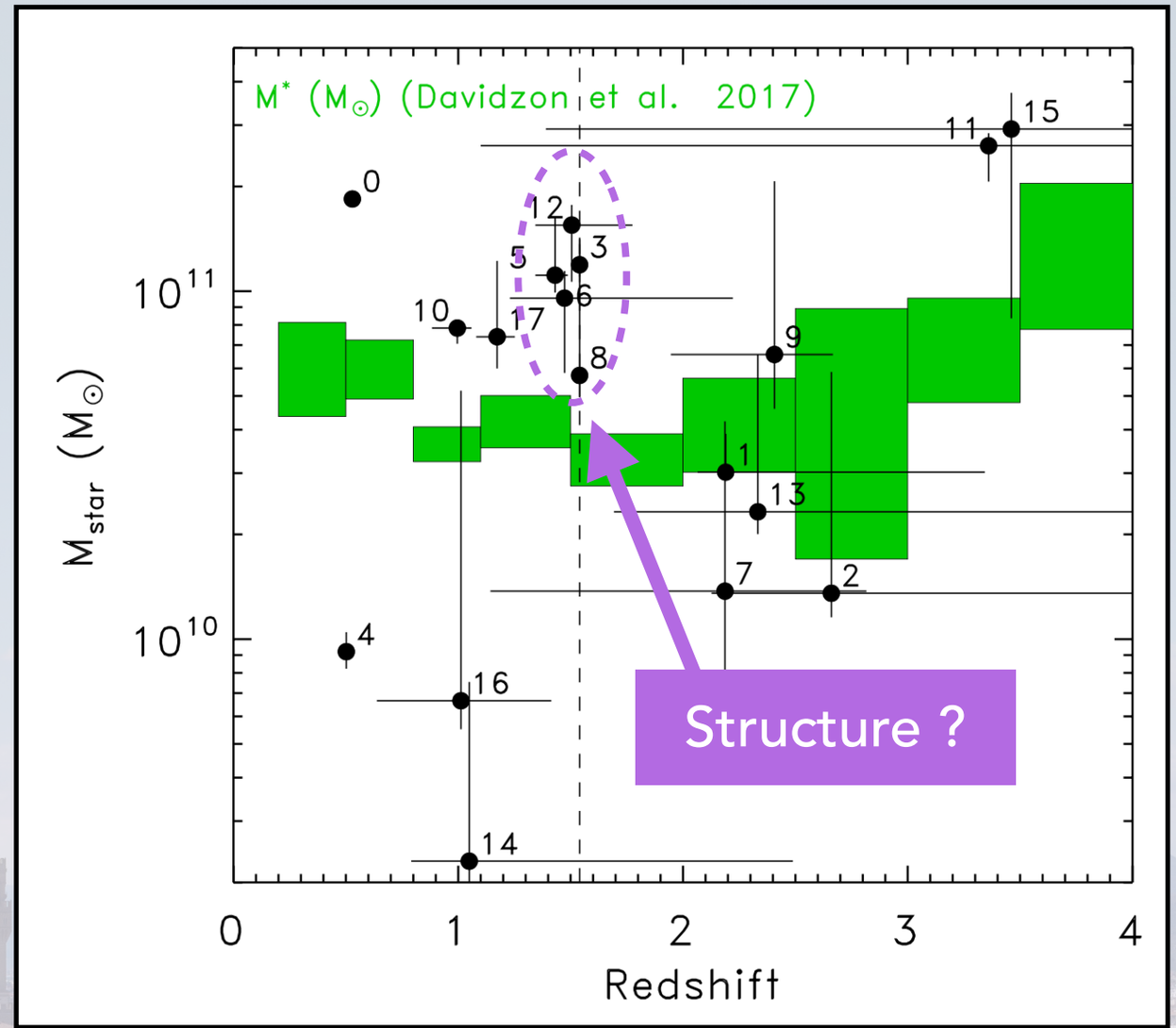
DSFGs in PHz G73.4-57.5: SFRs and M_{star}

(Kneissl et al., in prep.)

SFR vs M_{star}



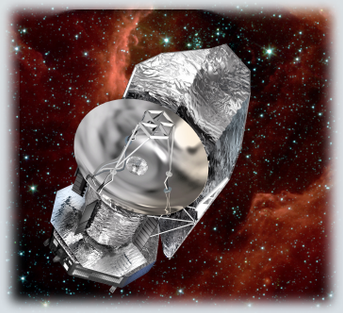
M_{star} vs z



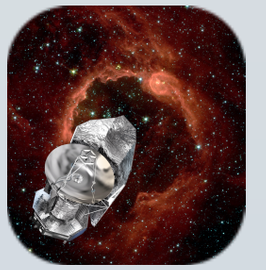
50% of ALMA sources are ULIRGs

☆ 5 DSFGs at z~1.5 (2 z_{CO} + 3 z_{phot}):

$M_{star} > M^*_{star}$ & on main-sequence ➞ close to quench ?



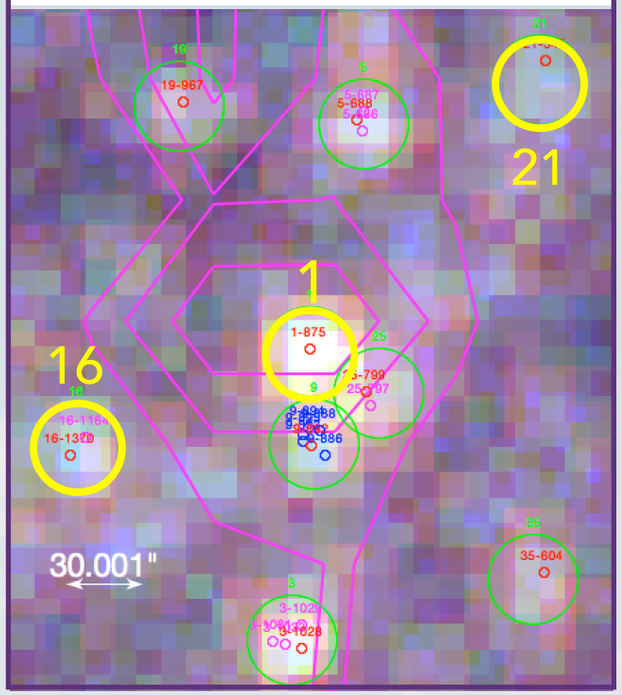
IRAM/NOEMA observations of PHz G59.1+37.4: a proto-structure @ z=2.36?



(Martinache et al., in prep.)

Herschel 500 350 250

Planck contours



IRAC 3.6μm

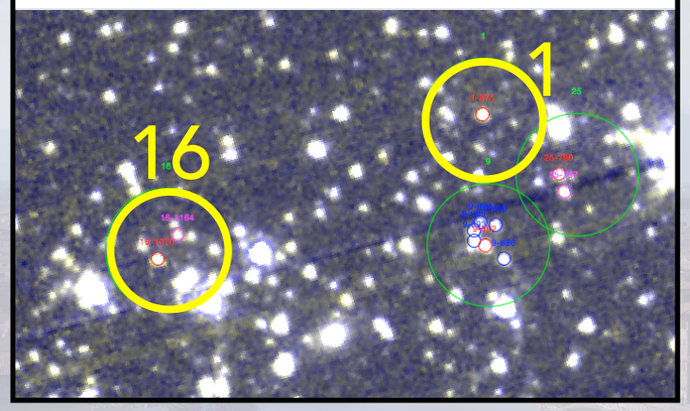
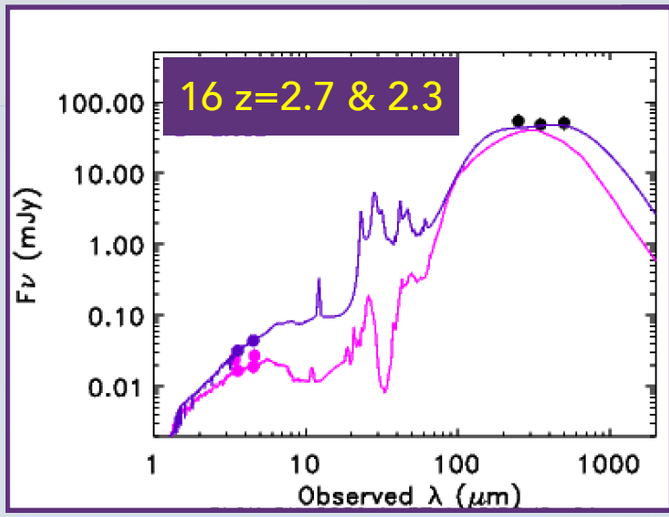
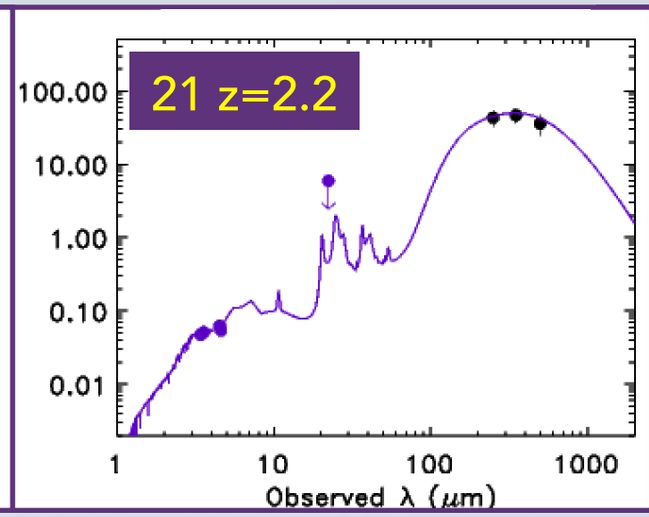
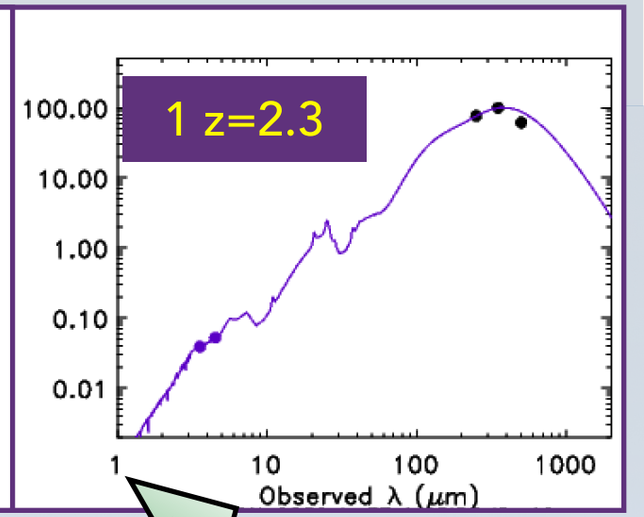
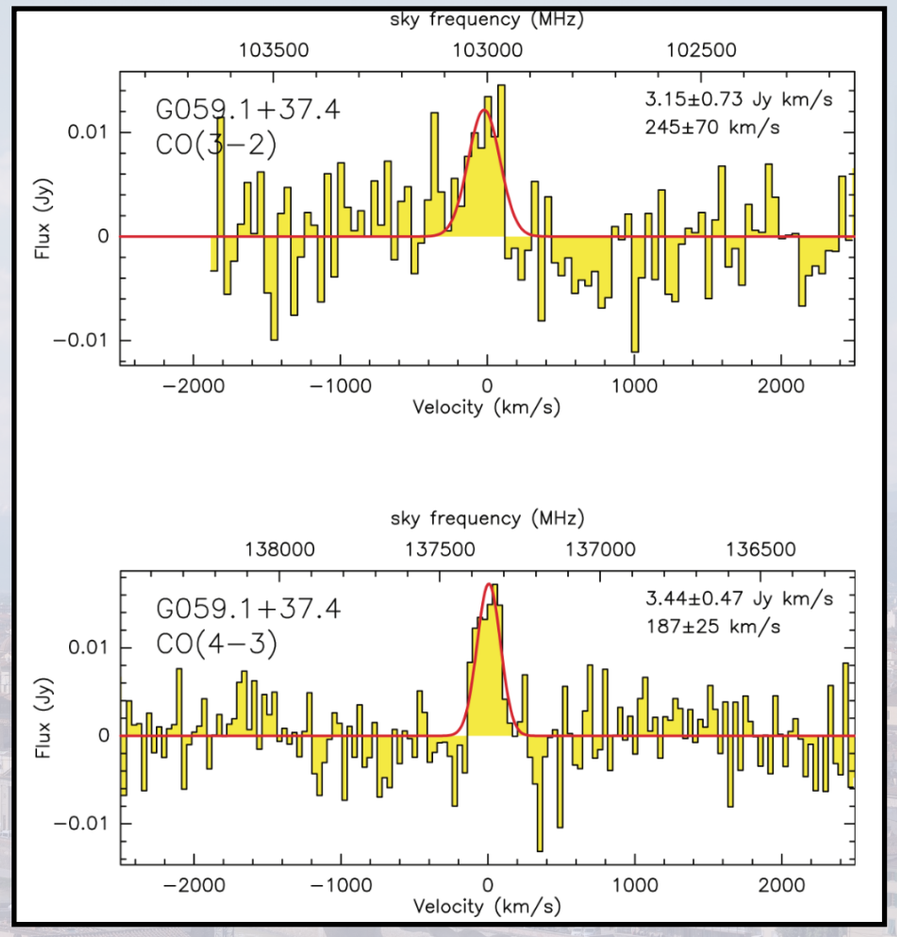


Photo-z and SED fitting with Hyper-z (Bolzonella et al. 2000) and empirical templates (Polletta et al. 2007; Berta et al. 2013)





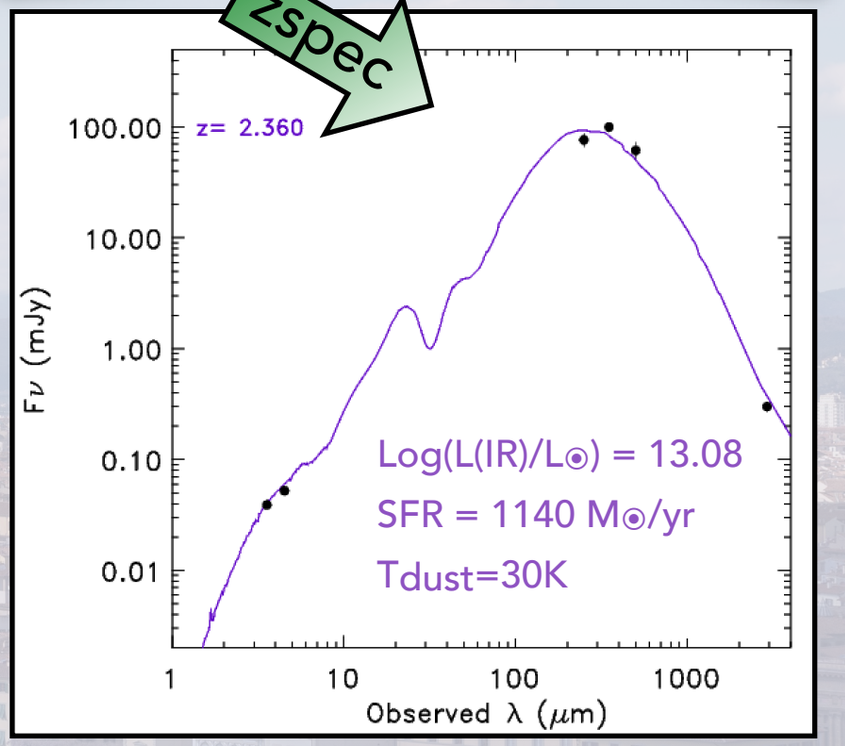




zphot

EMIR (CO) z_{spec} = 2.36

zspec



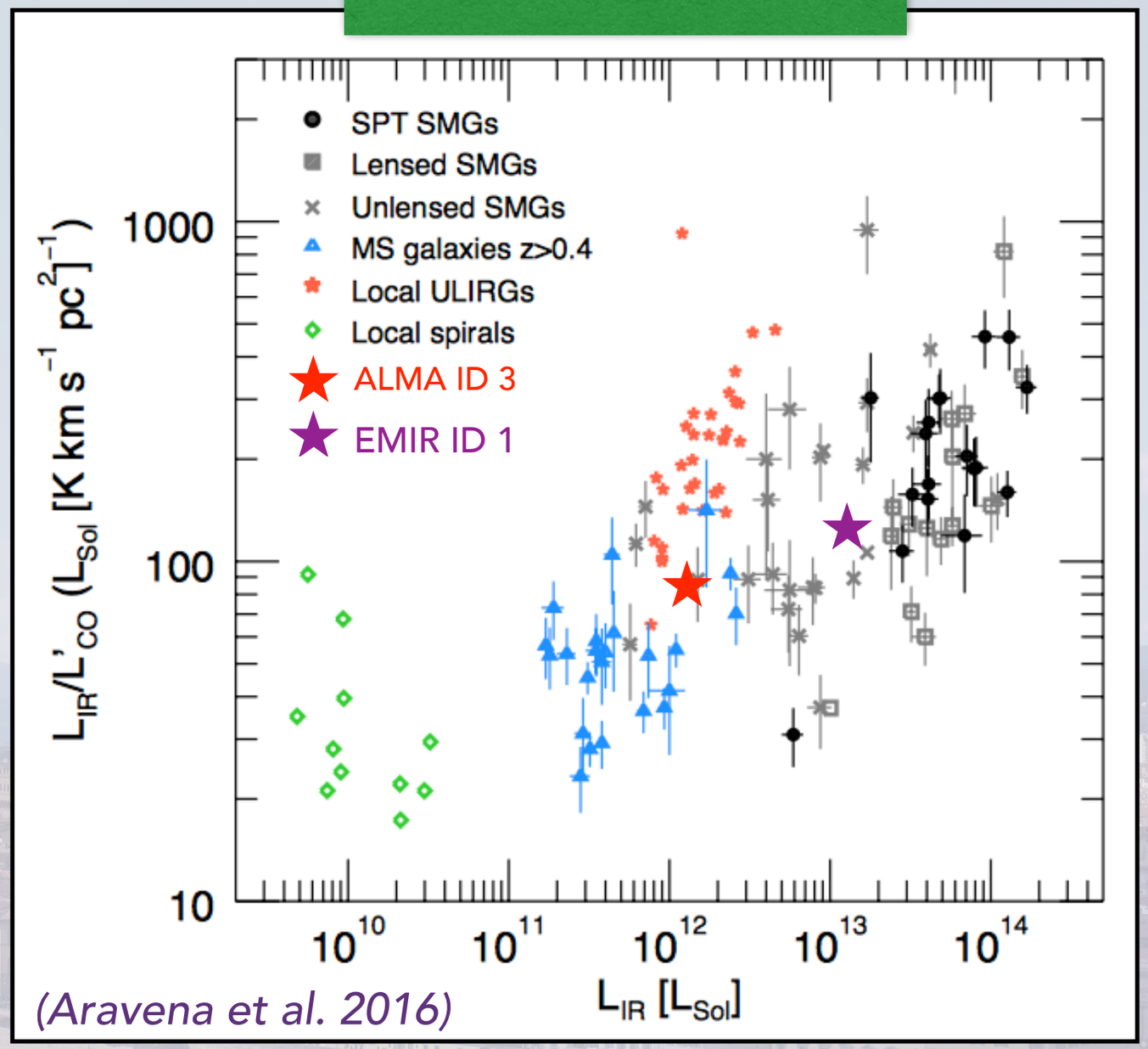
Simultaneous bursts are favoured by molecular gas observations

DSFGs in PHz sources are similar to SMGs from survey fields

⚠ limited statistics and large uncertainties (CO SLED, **α** (CO-H_2), M_{star})

PHz	G73.4 (ALMA)	G59.1 (NOEMA)
z_{CO}	1.54	2.36
L_{IR} [$L_\odot$]	1.1×10^{12}	1.2×10^{13}
SFR [$M_\odot yr^{-1}$]	108	1140
M_{gas} [$M_\odot$]	1.1×10^{10}	7.8×10^{10}
M_{star} [$M_\odot$]	1.0×10^{11}	3.5×10^{11}
f_{gas}	0.10	0.18
τ_{depl} [Myr]	104	70

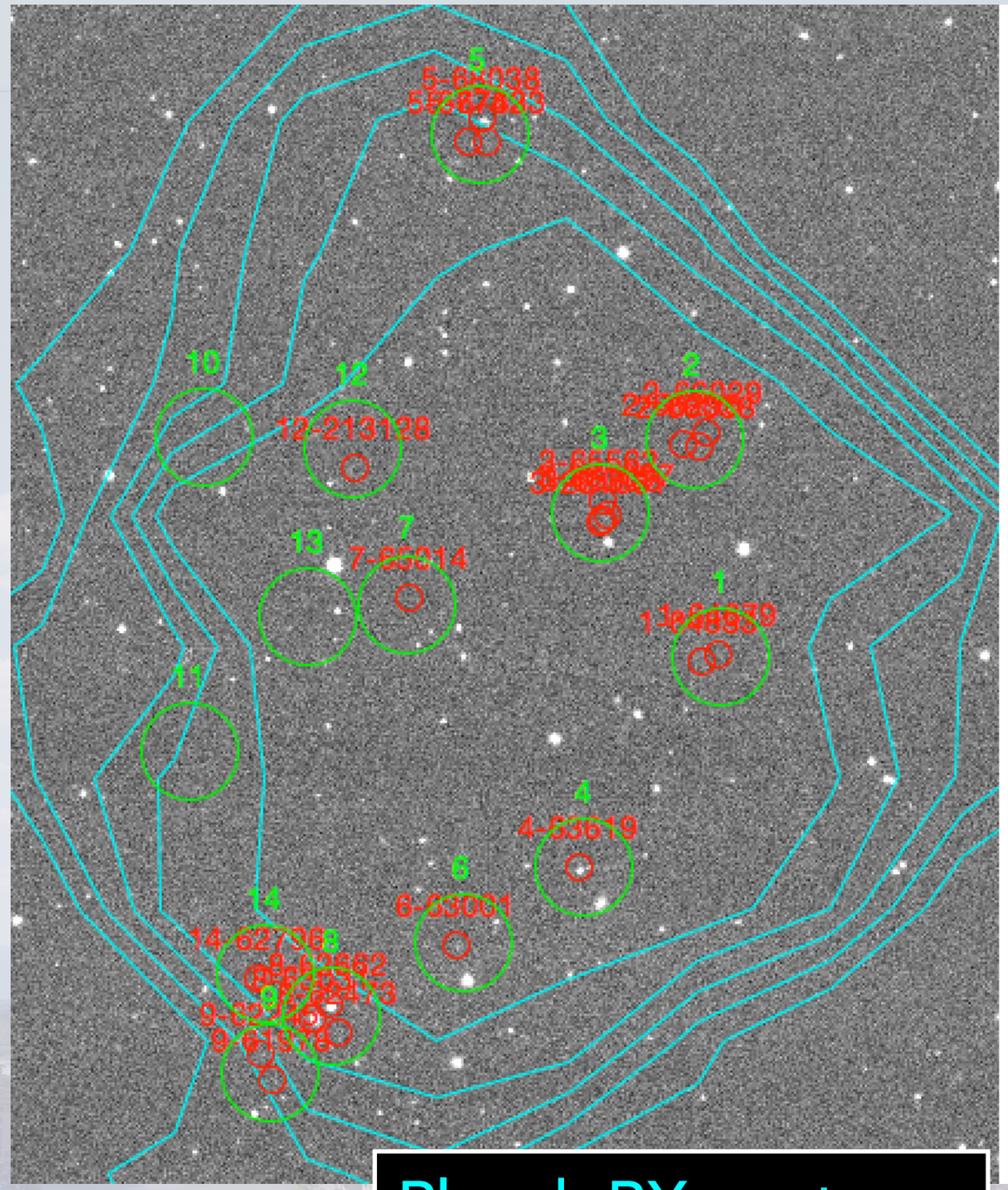
Star Formation Efficiency



(Aravena et al. 2016)

PHz G56.85 in Bootes (HerMES)

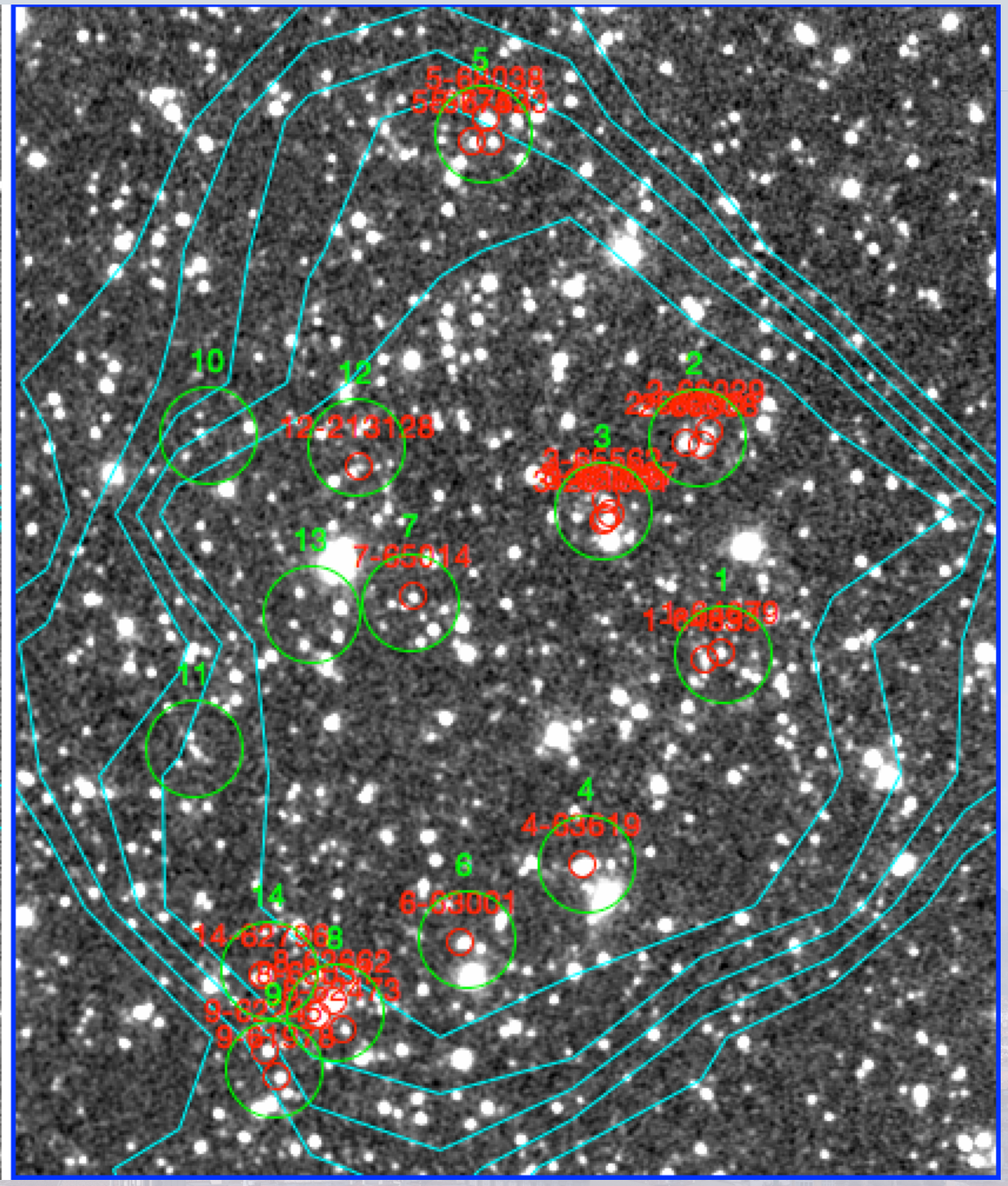
Herschel counterparts



Ks

Planck RX contours

Herschel sources



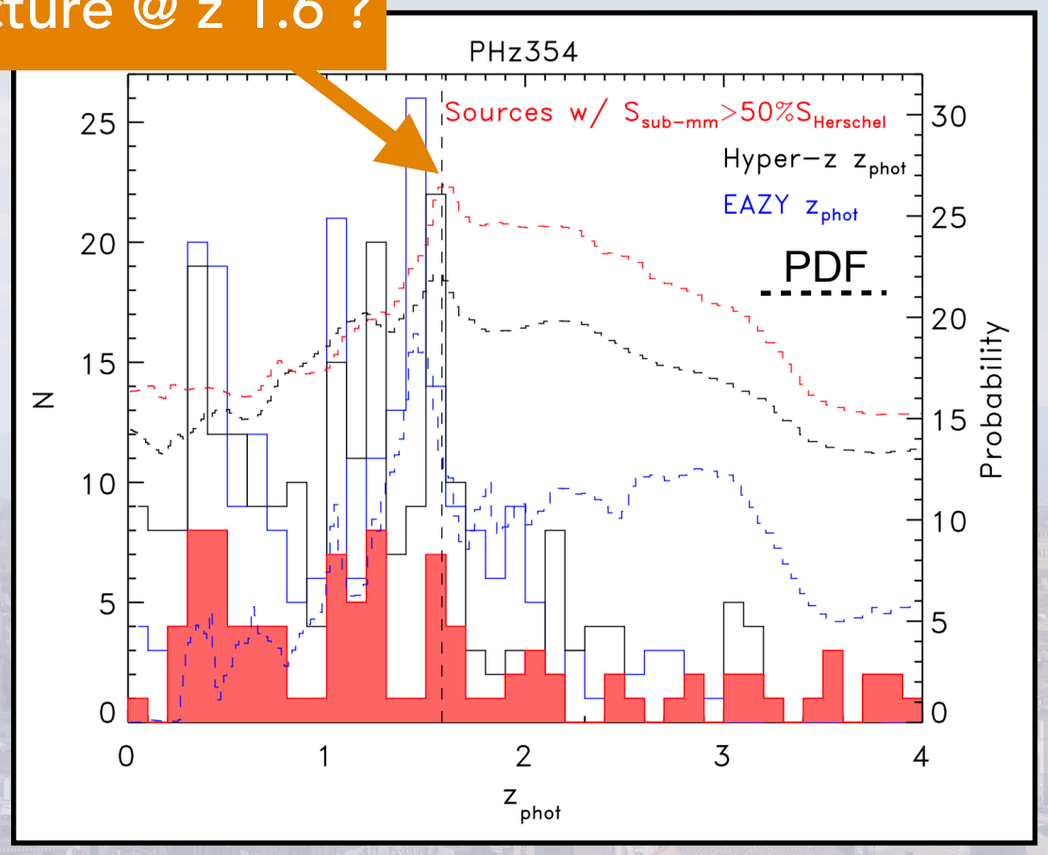
IRAC 3.6μm

Proto-cluster identification and study using photometric redshifts

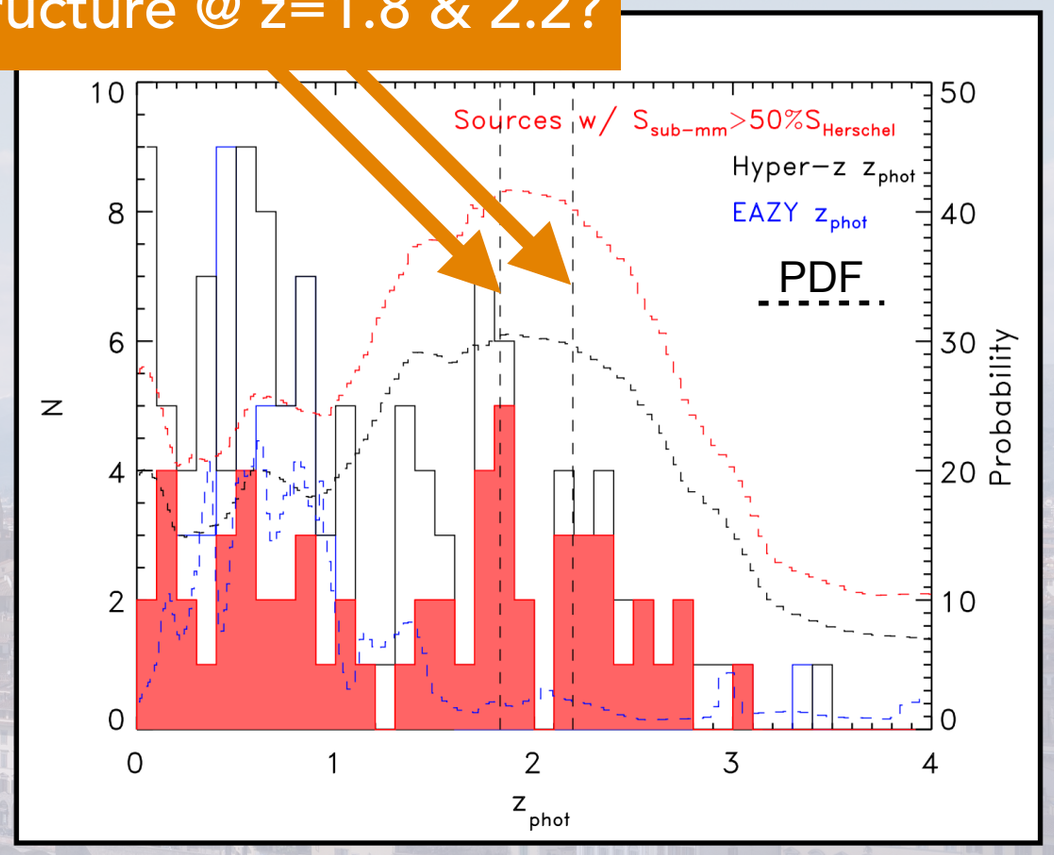
1) 11 PHz with optical-NIR-MIR-Herschel data from HerMES
2) SED fitting with Hyper-z (Bolzonella et al. 2000) including Herschel data as upper limits
3) z_{phot} from EAZY (Brammer et al. 2008) using optical-NIR SED
4) z_{phot} validation on spectroscopic samples and combining results from the two codes
5) selection of likely "Herschel counterparts" when expected sub-mm fluxes >50% of the Herschel flux
6) structure candidates at redshift peaks in the z_{phot} distribution of the "Herschel counterparts"
7) stellar mass estimates from Hyper-z, L(IR) from expected sub-mm fluxes, SFR from L(IR)

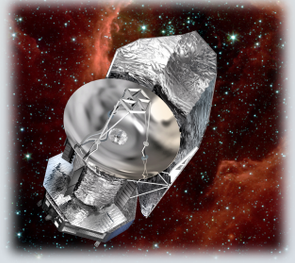
Photometric z distribution and Probability distribution function

Structure @ z 1.6 ?



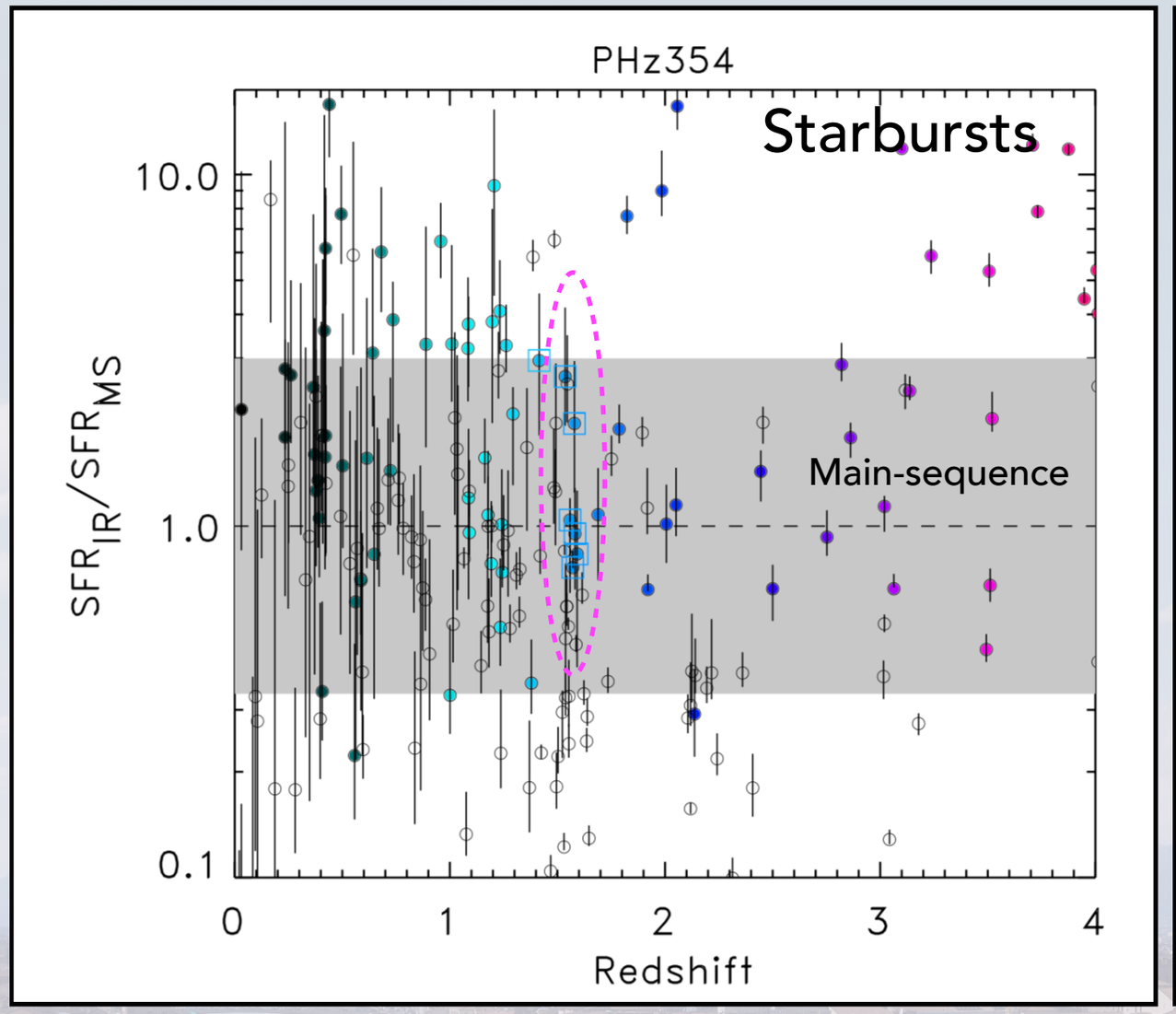
Structure @ z=1.8 & 2.2?

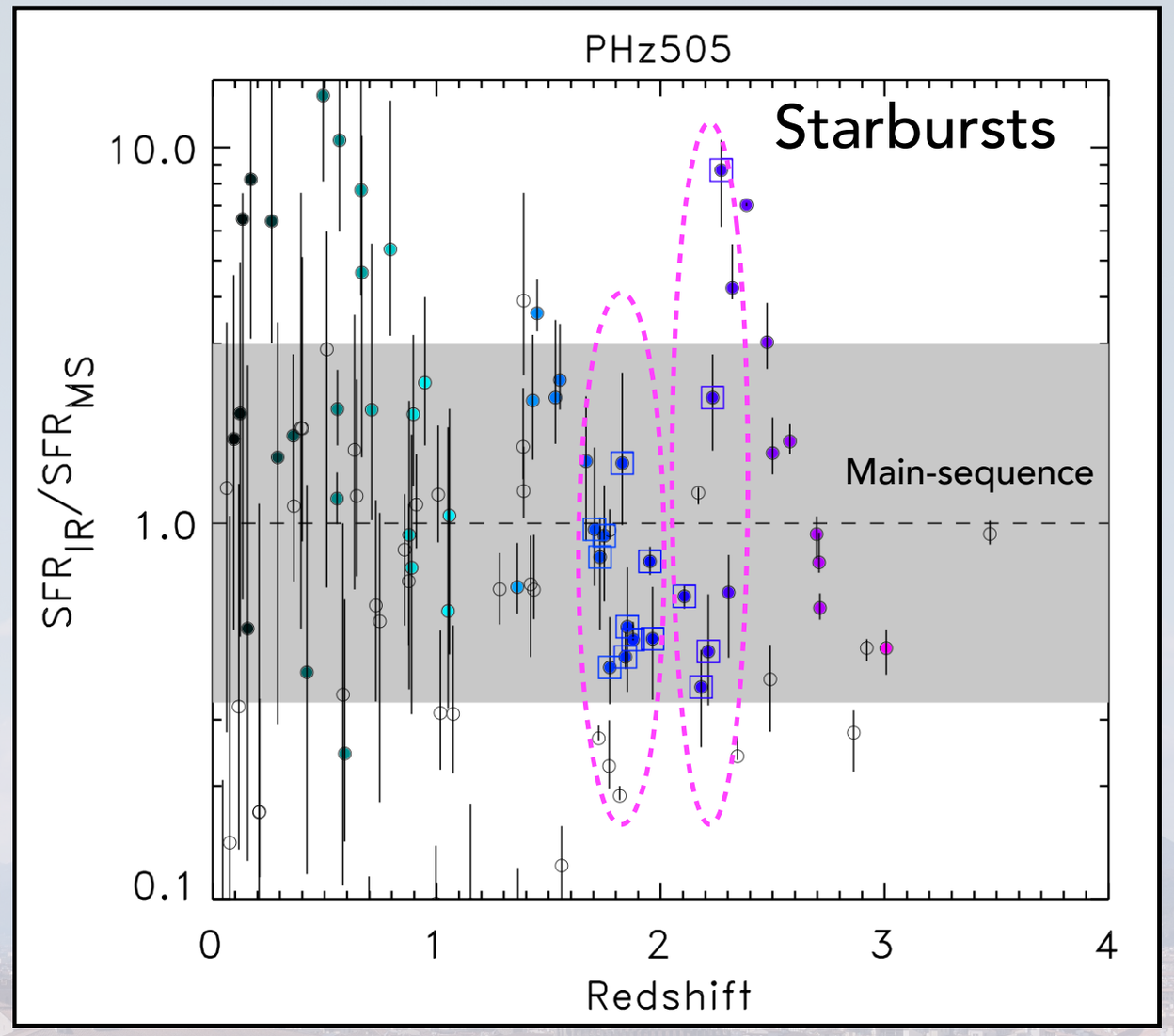




How active are the DSFGs in the ‘proto-structures’ ?

Starburstiness: SFR/SFR_{MS}

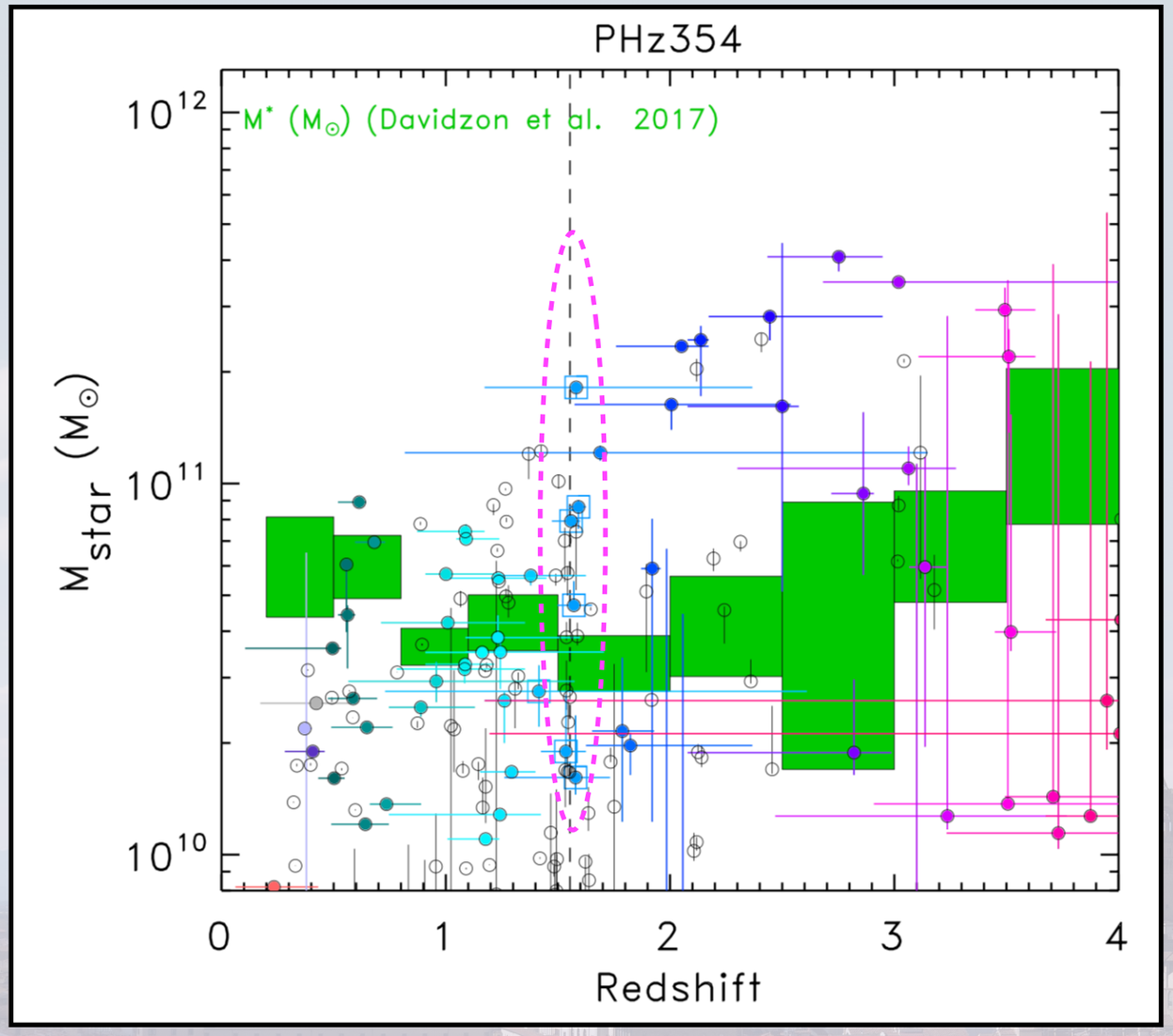


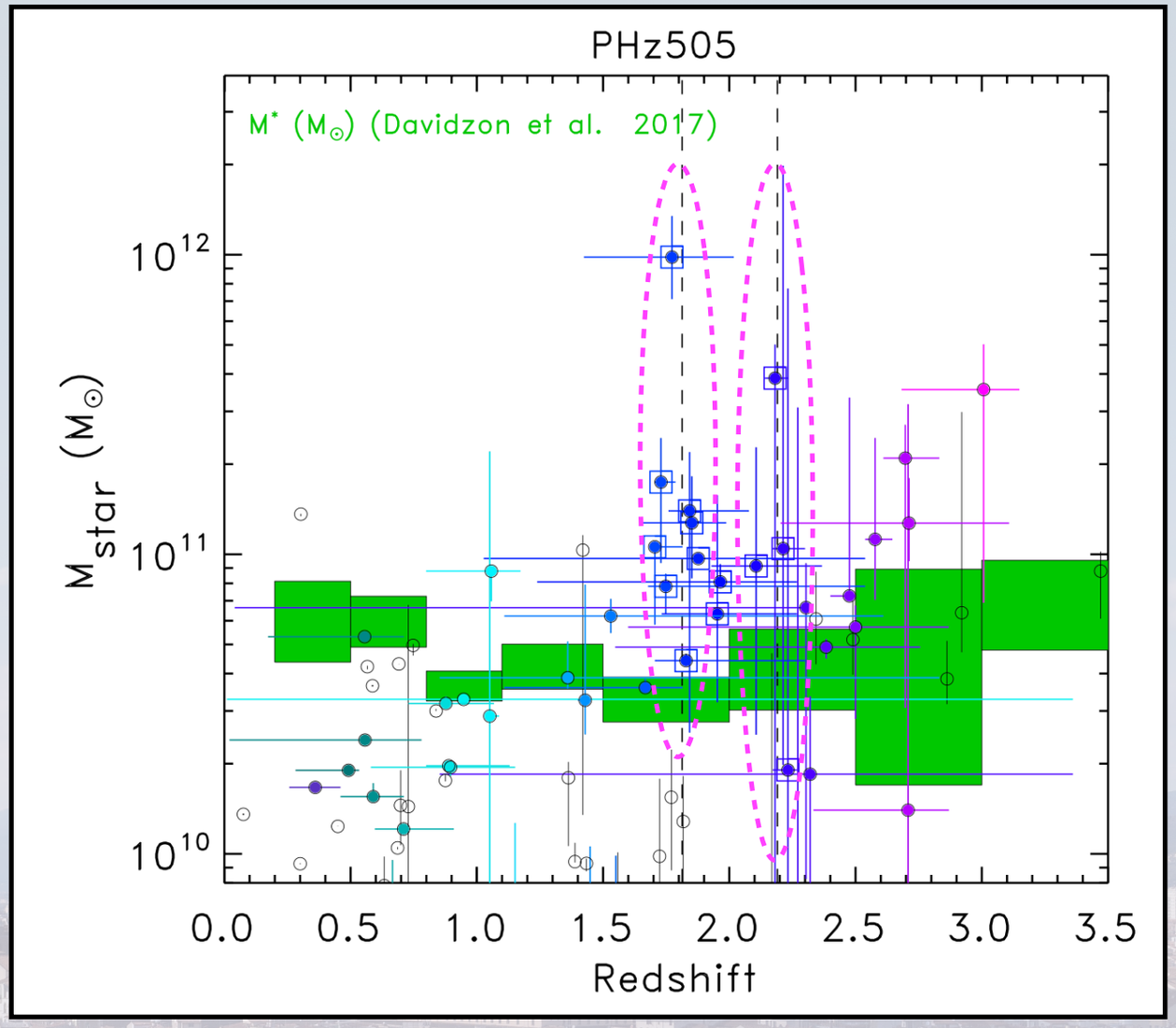


DSFG structure member candidates

How massive are the DSFGs in the ‘proto-structures’ ?

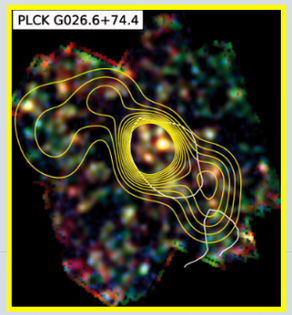
Mstar vs M* in MF

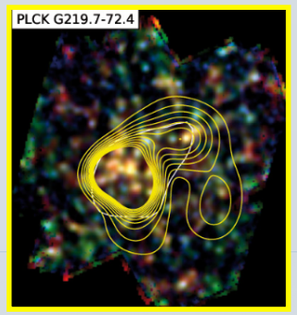




DSFG structure member candidates

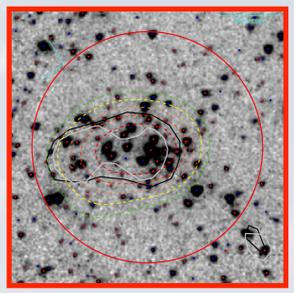
What have we learned about the PHz sources ?

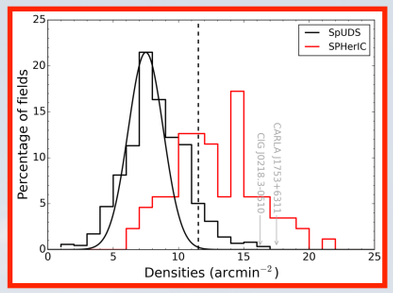




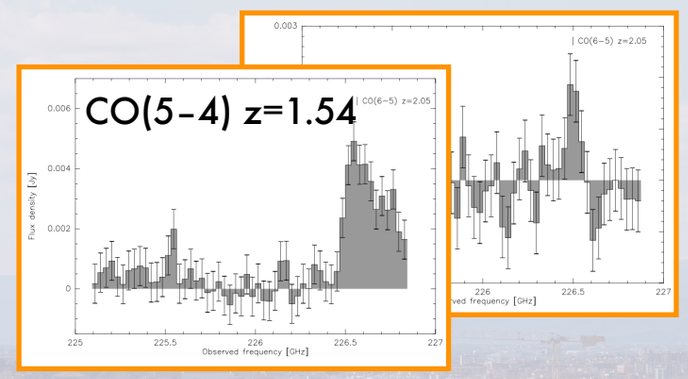
- ~90% are over-densities of red DSFGs (Planck coll. 2015. Int. results XXVII)

- ~6% are bright lensed objects at z~2-4 (Cañameras et al. 2015)

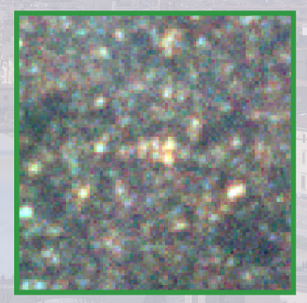


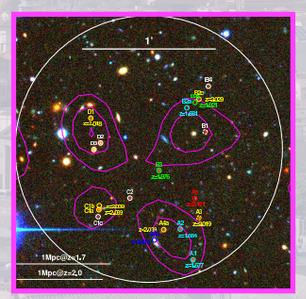


- associated with over-densities of red IRAC sources (Martinache et al., in prep.)



- CO emission at z=1.5-2.75 (Kneissl et al., in prep.; Martinache et al., in prep.)

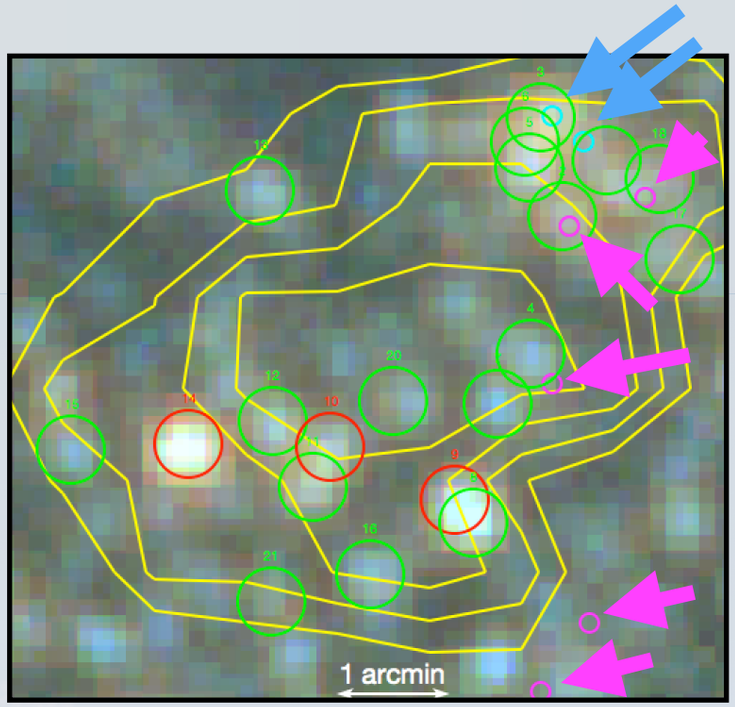




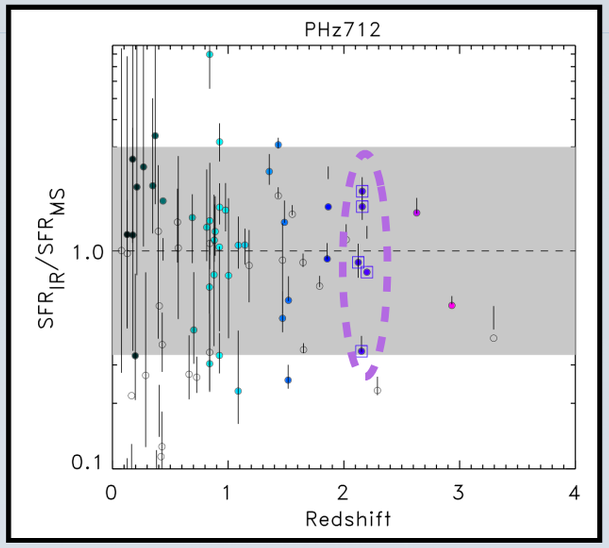
- multiple clumps of galaxies at the same redshift: aligned structures ? (Flores-Cacho et al. 2016)

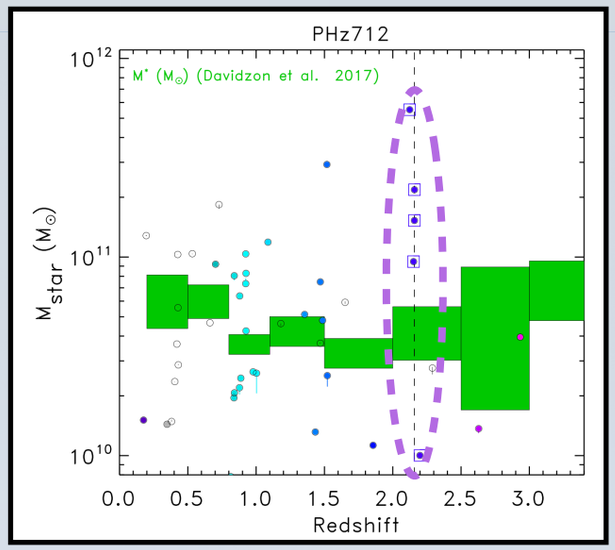
… and about their galaxy members ?

2-7 DSFGs at $z_{spec} \simeq 1.5$-2.75 with $\Delta z \sim 0.4$ (z_{phot}=1.6-3.4)

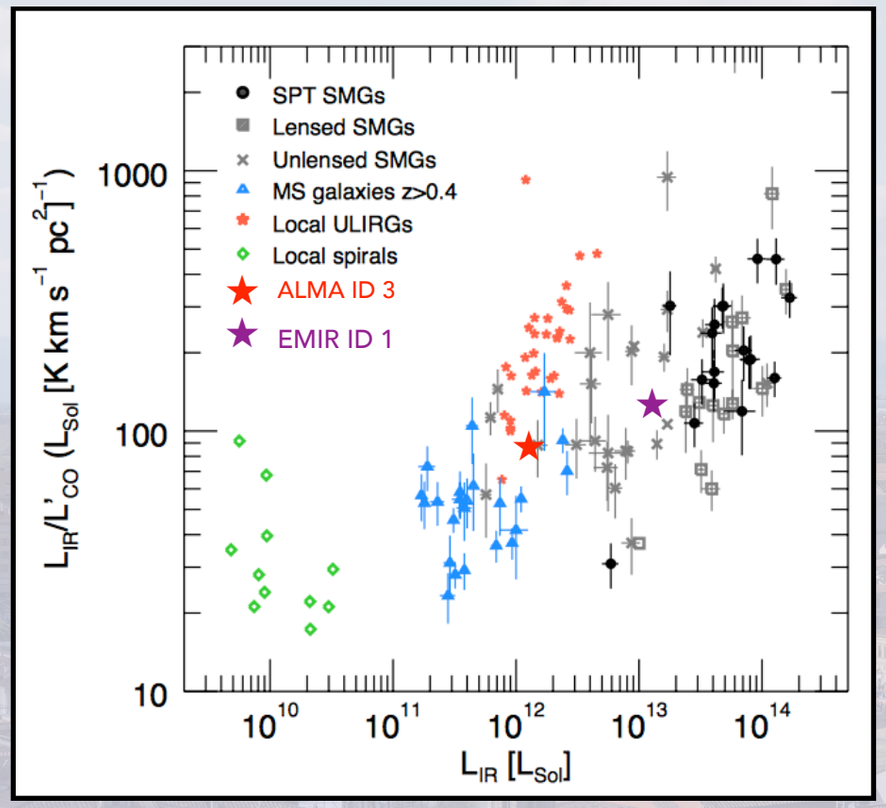


SFR and M_{star} consistent with the main sequence relation (➙ massive SFGs)





similar to field SMGs (z~2, in overdense regions, massive, rapidly star-forming)



gas fractions and depletion time consistent with short bursts (➙ accelerated growth)

PHz	G73.4 (ALMA)	G59.1 (NOEMA)
z_{CO}	1.54	2.36
SFR [$M_\odot yr^{-1}$]	108	1140
M_{gas} [$M_\odot$]	1.1×10^{10}	7.8×10^{10}
M_{star} [$M_\odot$]	1.0×10^{11}	3.5×10^{11}
f_{gas}	0.10	0.18
τ_{depl} [Myr]	104	70