

# The reversal of the star formation - density relation in high redshift clusters

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1. Introduction
2. XDCP0044: a massive  $z=1.6$  galaxy cluster
3. The Spiderweb proto-cluster
4. Planck high- $z$  candidates.

# Galaxy cluster core : red ellipticals



- ✓ Morphology-density relation, Dressler (1980)
- ✓ Massive galaxies dominated by old stellar populations

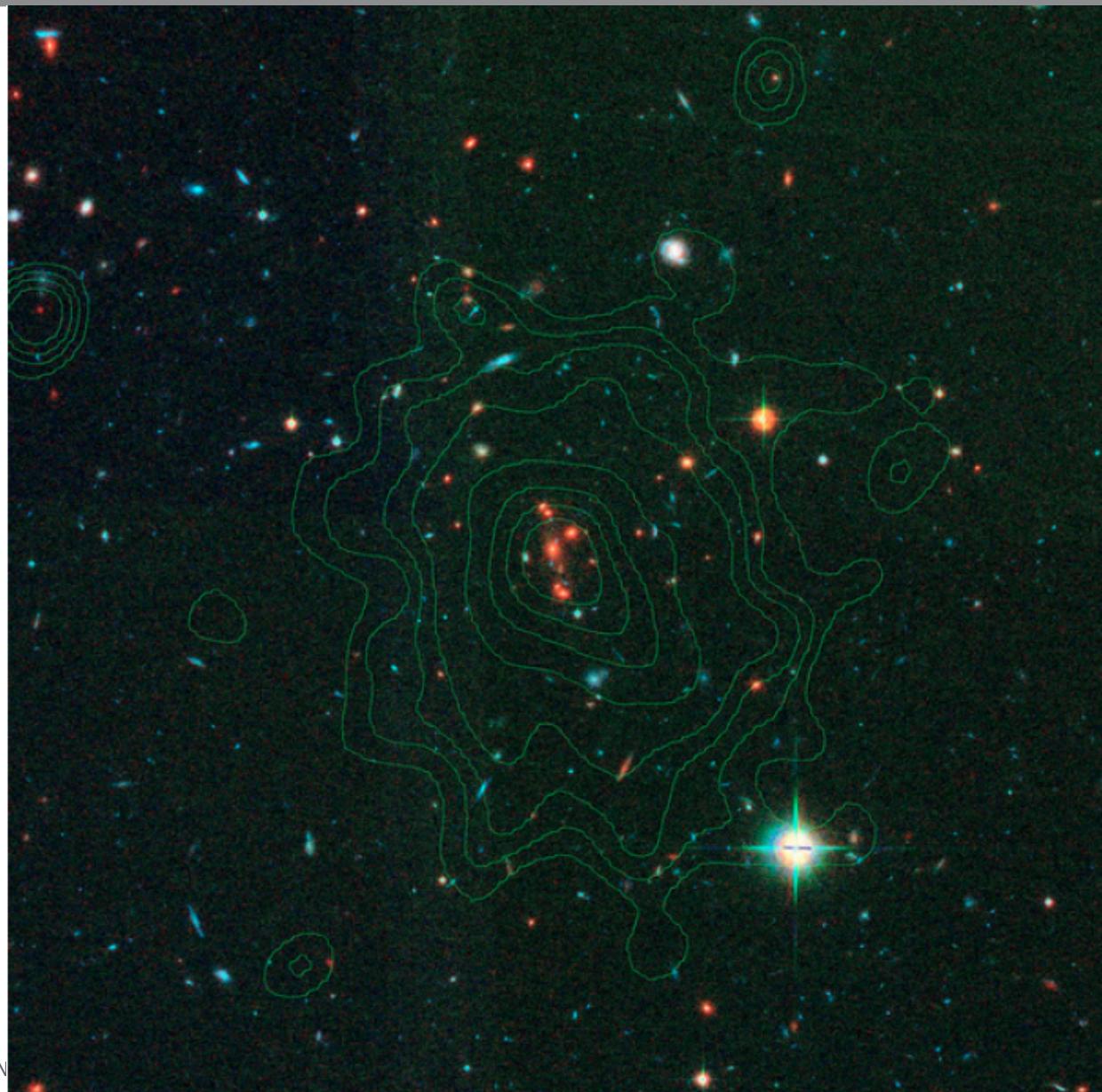


Abell 2218

# Red sequence in place at z~1.4



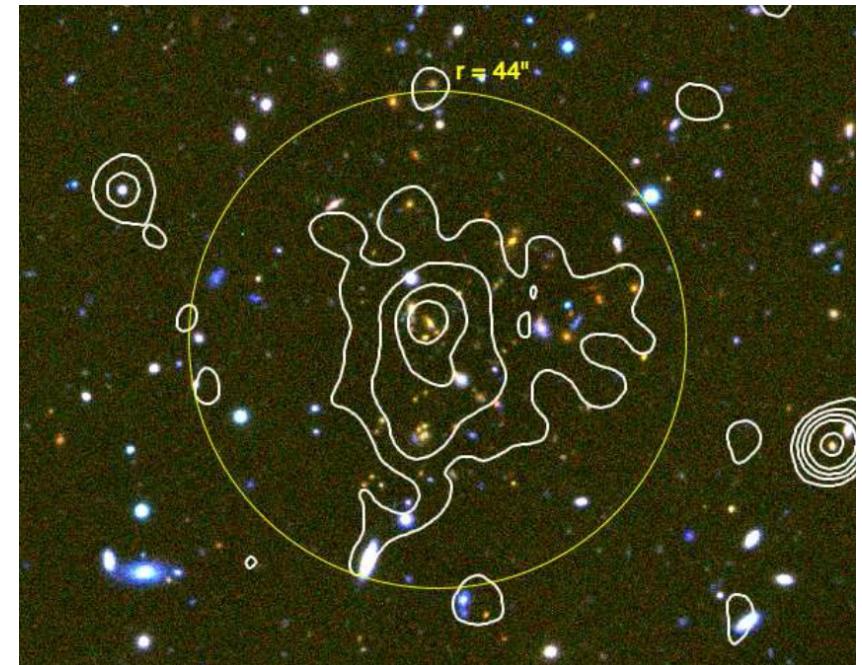
- XMM2235 (Mullis+04)
- Massive :  $7 \times 10^{14} M_{\odot}$
- Reversal beyond  $z=1.5$  ?
- Star formation only in cluster outskirts  
**Santos+2013**



# XDCP J0044.0-2033 @ z=1.58



- The most massive, distant cluster known ( Santos + 2011) in the XMM distant cluster survey (XDCP)
  - $S_{0.5-2.0\text{keV}} = 1.6 \cdot 10^{-14} \text{ ergs}^{-1}\text{cm}^{-2}$
  - Over-density in deep I and H-band imaging at ESO/NTT
- Deepest Chandra observation of a distant cluster: 380ks (PI Tozzi)
- 13 spec. cluster members
  - ✓ 9 with [OII]
  - ✓ More coming from VLT/FORS2
  - + HAWK-I + VLT/KMOS IFU spec. +
  - + WFC3 slitless spectroscopy

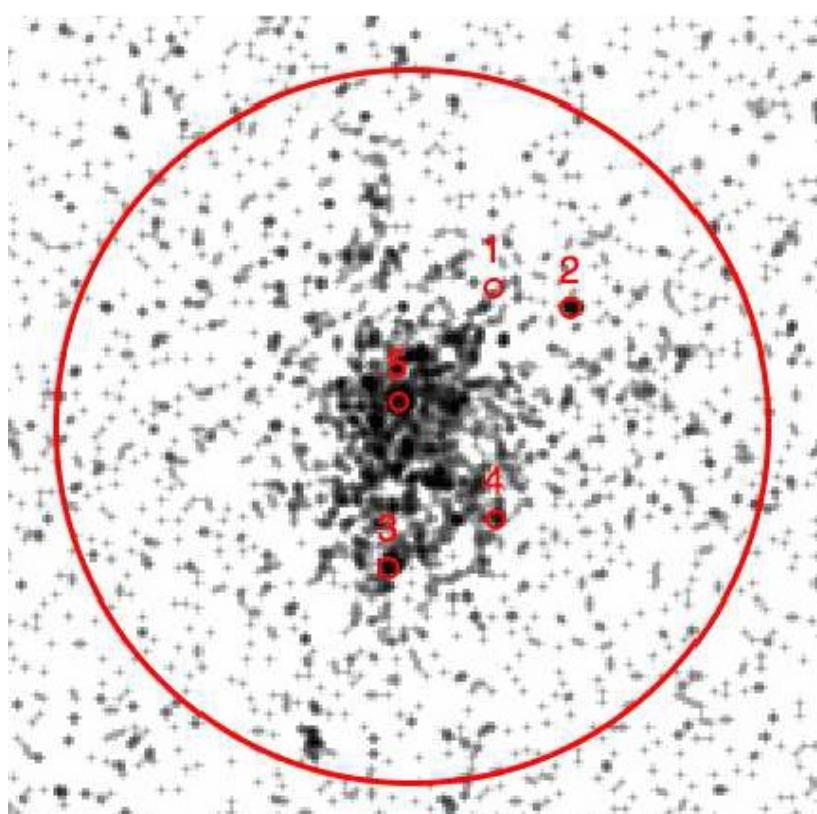


# XDCP0044: *Chandra* image



- Minor contamination by AGNs.

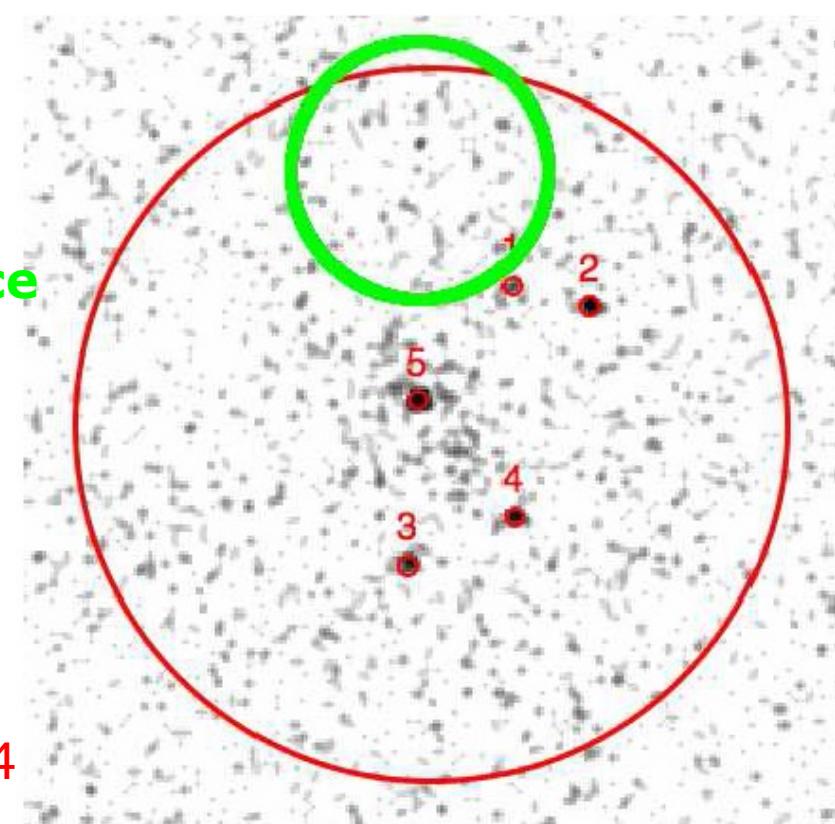
**0.5-2 keV**



$$R_{\text{ext}} = 44'' \\ = 375 \text{kpc}$$

NVSS source

**2-7 keV**



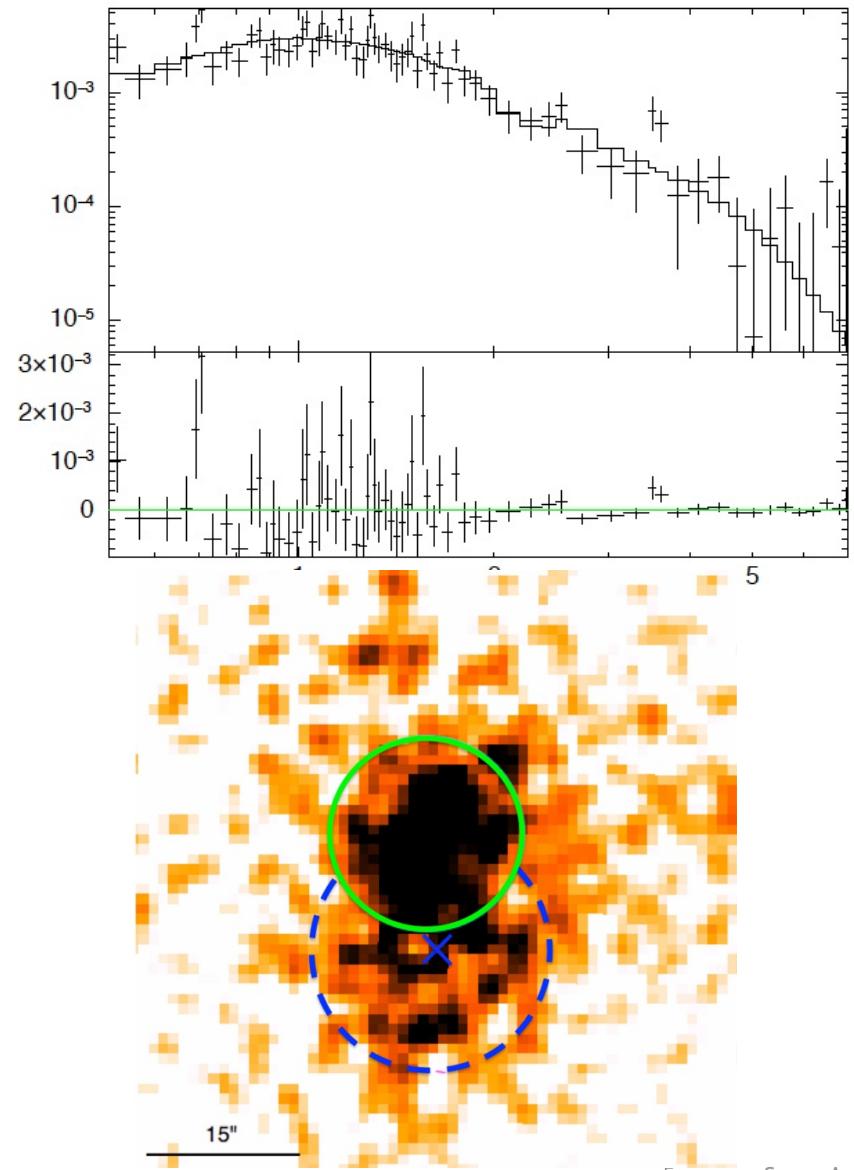
Tozzi+2014

# XDCP0044 : a massive cluster



- 1500 counts
- $kT=6.7 \text{ keV}$
- $Z_{\text{Fe}}=0.41^{+0.29}_{-0.27} Z_{\odot}$
- Clear elongation north-south
- North and south clumps have marginally different temperatures (recent merger, young dynamical status?)
- No evidence of cool core
- Complex dynamical state

Tozzi+2014



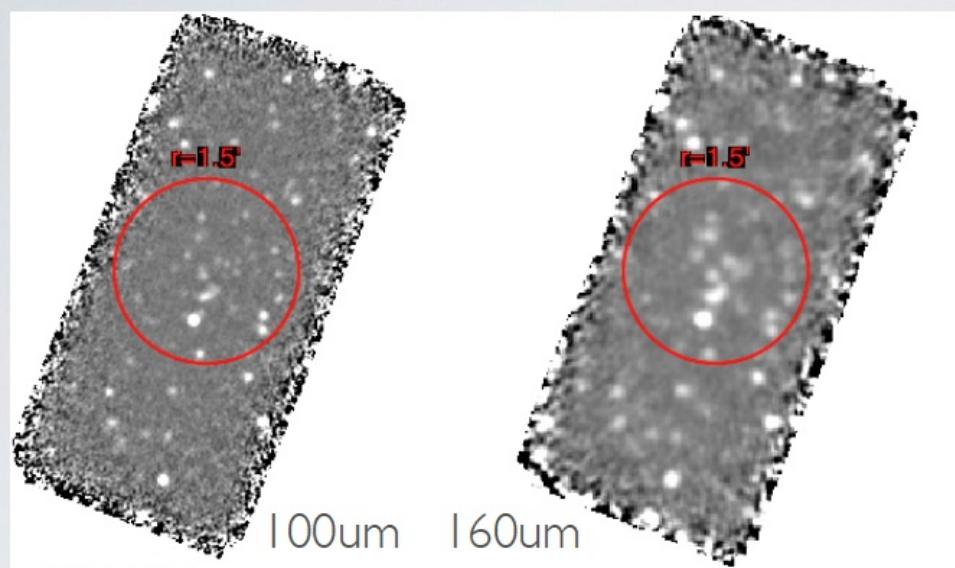
# First physical characterization of a cluster at z~1.6 (Tozzi+2014)



- First robust x-ray analysis at  $z > 1.5$ : only cluster whose diffuse X-ray emission provides constraint at these redshifts on the ICM temperature and mass – *under assumption of hydrostatic equilibrium*.
- $M_{2500} = 1.35 \cdot 10^{14} M_\odot$
- $M_{(r < 375 \text{ kpc})} = 2.4 \cdot 10^{14} M_\odot$ ,  $f_{\text{ICM}} = 7\%$
- $M_{500} = 3.5 \cdot 10^{14} M_\odot$  ( $R_{500} = 576 \text{ kpc}$ ): consistent with empirical relations between X-ray observable & mass.
- $M_{200} \text{ (extrapolated)} = 4.7 \cdot 10^{14} M_\odot$  ( $R_{200} = 870 \text{ kpc}$ , virial radius)
- Typical cluster at  $z \approx 1.6$  when compared to expectations for a  $\Lambda$ CDM universe based on Tinker+08 mass function.
- Most massive cluster identified at  $z > 1.5$

Tozzi+2014

# Herschel ultra-deep maps

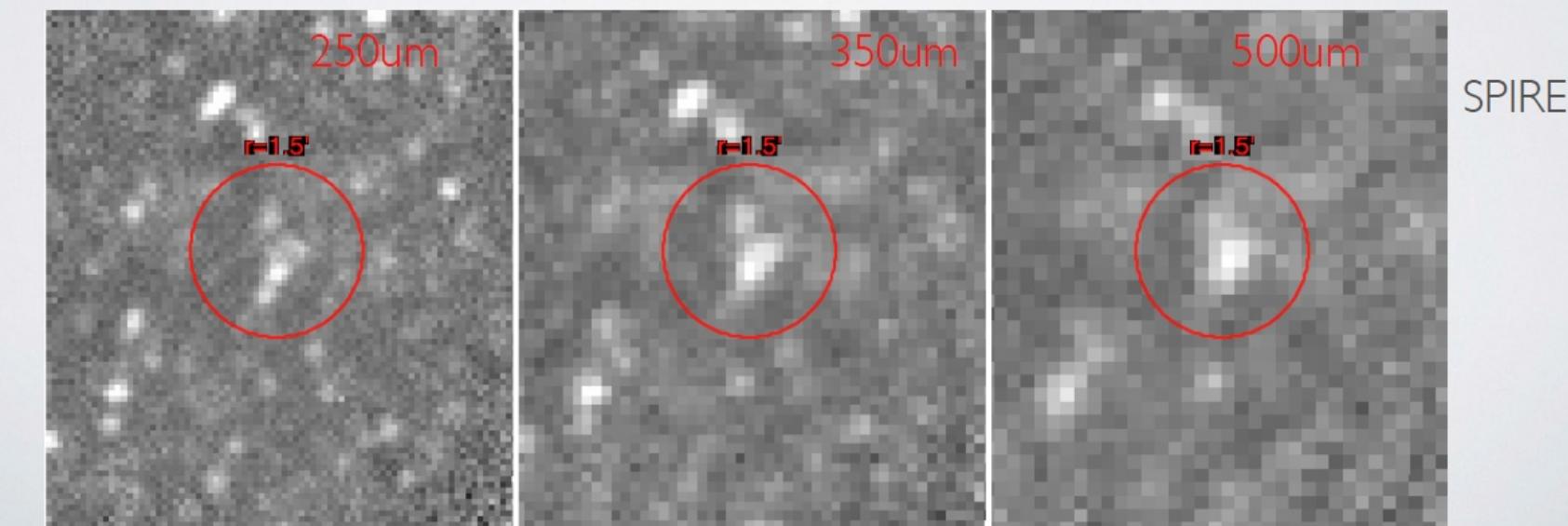


Herschel DDT, PI Santos

PACS, 10 hr

3- $\sigma$ : 1.65 mJy @ 100  $\mu$ m

3- $\sigma$ : 4.5 mJy @ 160  $\mu$ m



# FIR star formation in XDCP J0044



5 spectroscopic redshift, 9 photometric redshift

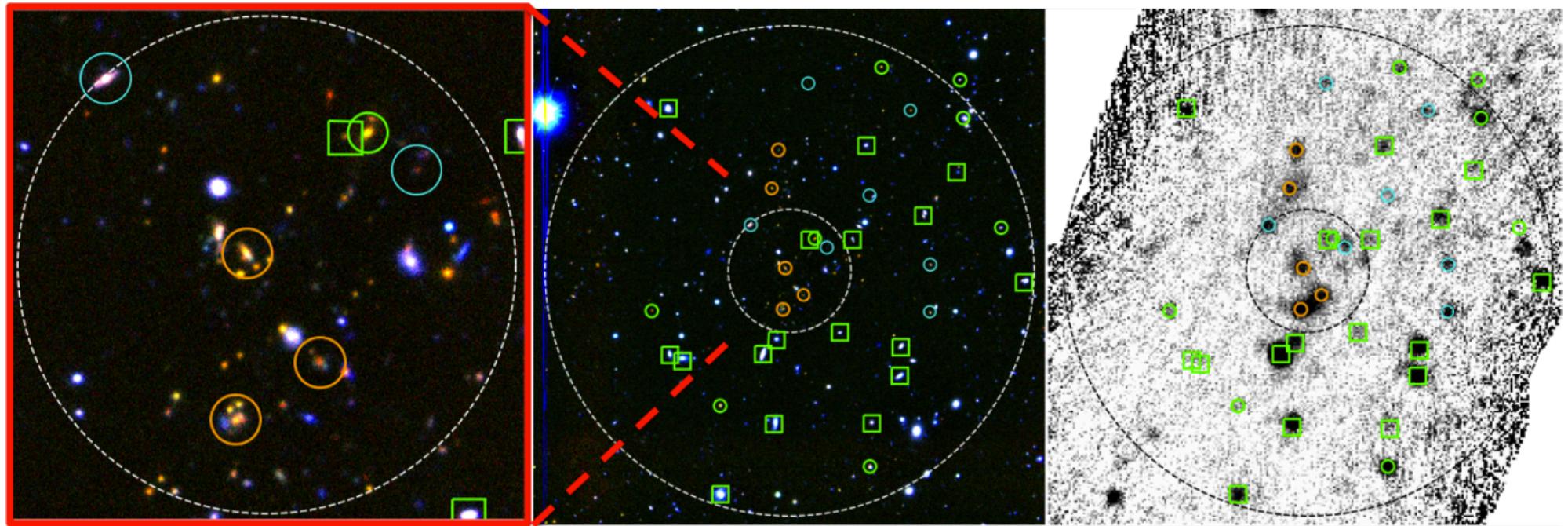
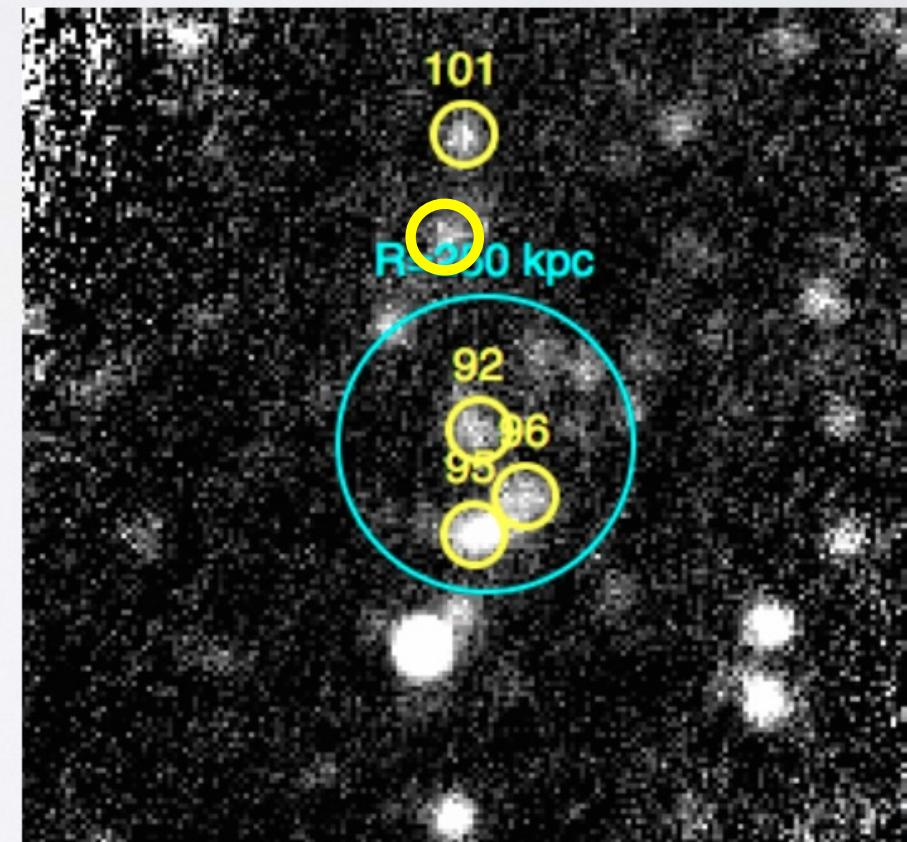
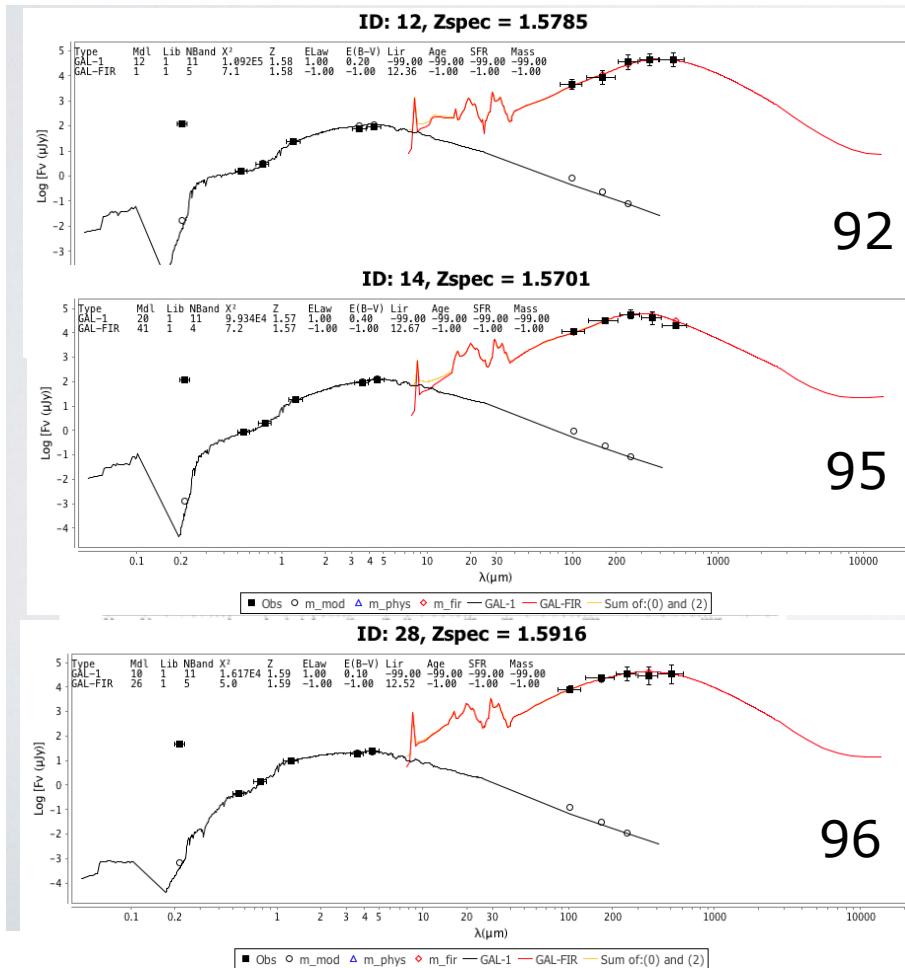


Figure 1. KsJI color composite of the central  $\sim 500$  kpc (left) of the field of XDCP0044 (middle) and corresponding *Herschel*/PACS  $100 \mu\text{m}$  map (right). Dashed circles have radii of  $30''$  and  $2'$  centered on the cluster X-ray center. The 5 spectroscopic members with FIR emission are shown in orange circles, cyan regions indicate the photometric candidates with FIR emission and green regions correspond to spectroscopic (circles) and visual/photo- $z$  (squares) interlopers.

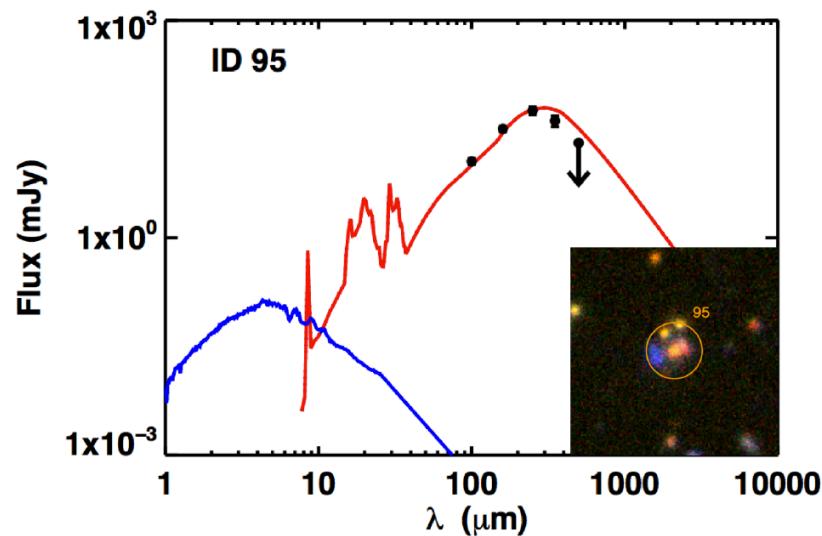
# FIR star formation in XDCP J0044 in cluster core



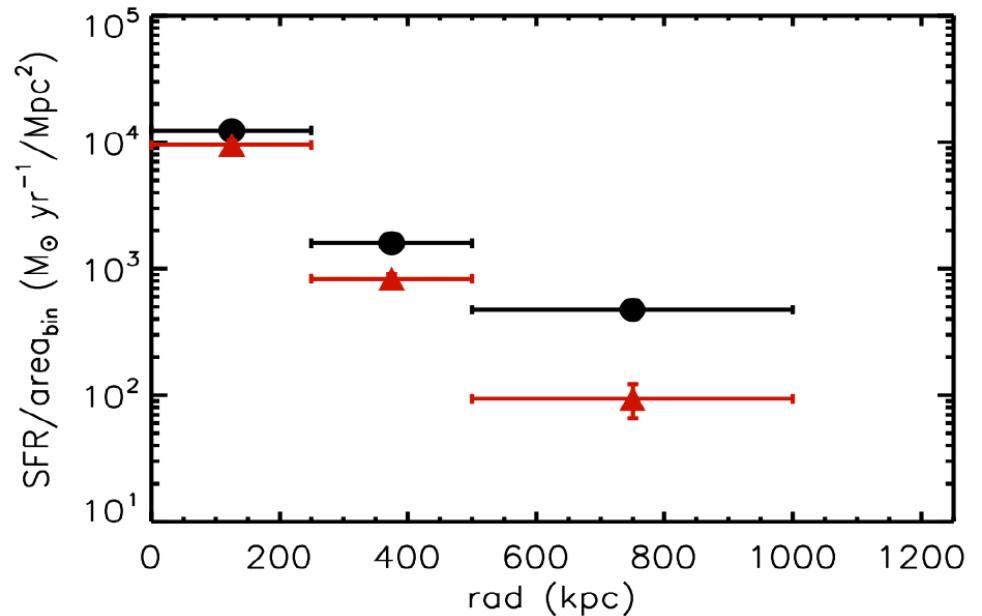
- 5 members detected ( $>3\sigma$ ) in *Herschel*
- SFR core ( $<250\text{ kpc}$ ) =  $1875 \text{ M}_\odot/\text{yr}$  & SFR( $1\text{Mpc}$ ) =  $2500 \text{ M}_\odot/\text{yr}$



# Higher SF in cluster core than in outskirts



**Figure 2.** Best-fit FIR SED (red line) of cluster member ID 95, with KsJI inset ( $15'' \times 15''$ ). Datapoints are shown in black.

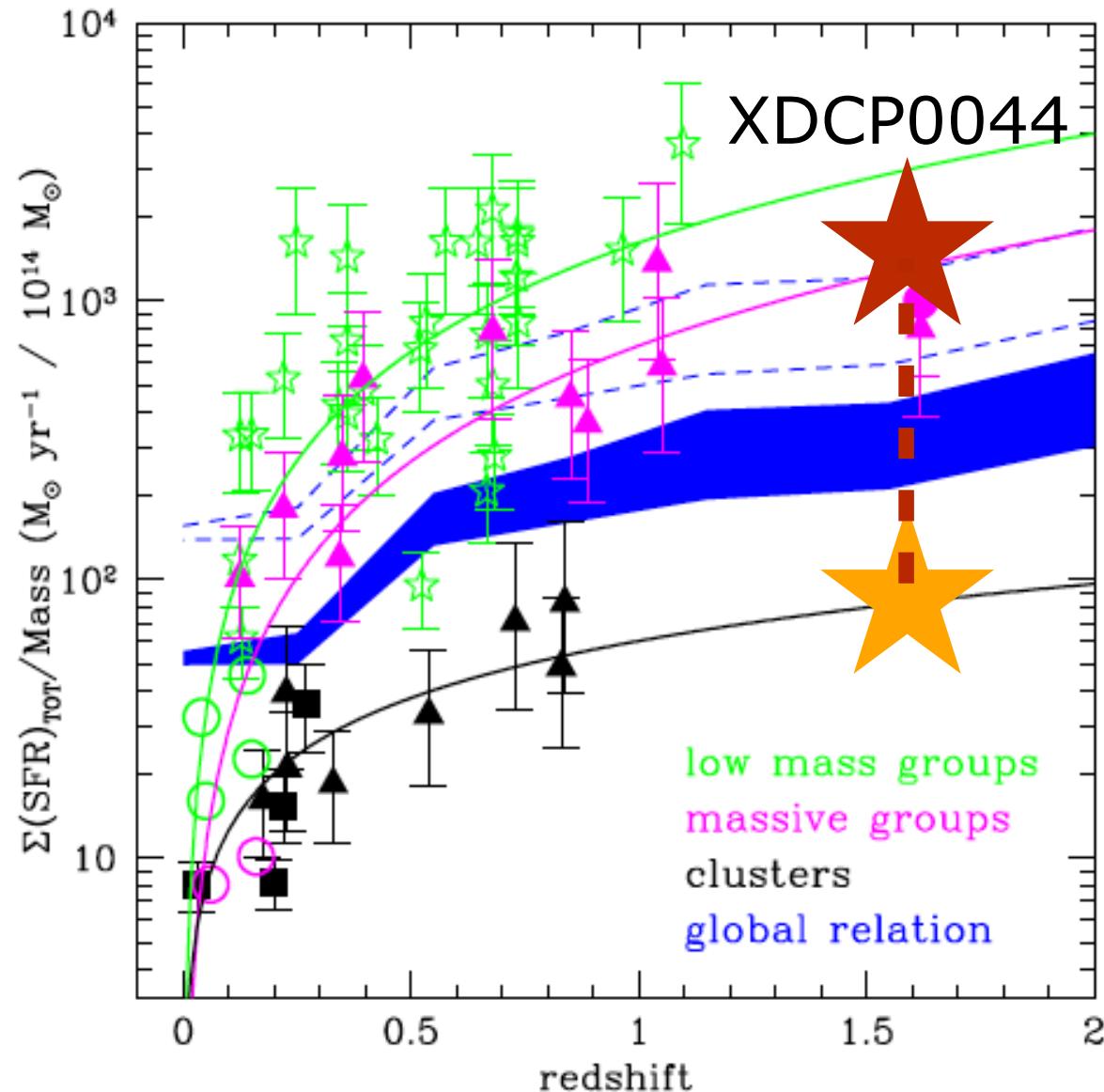


# XDCP J0044 galaxy properties

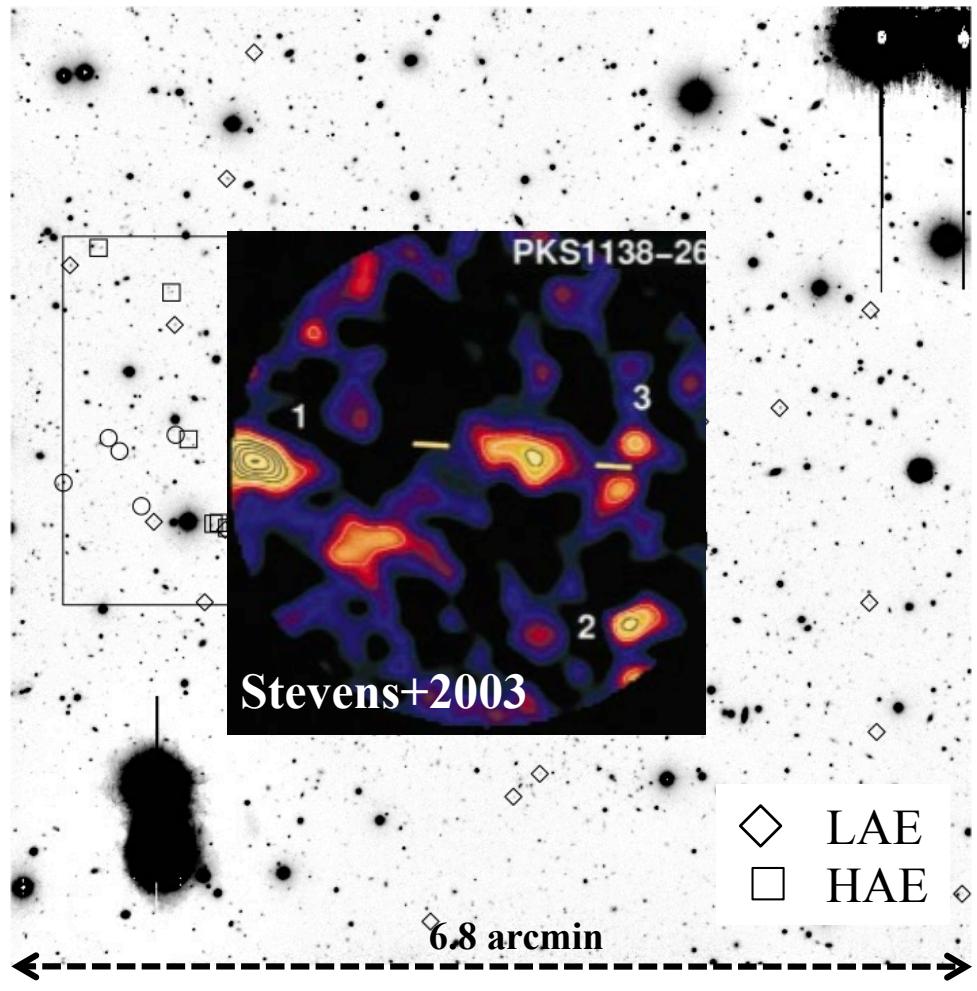
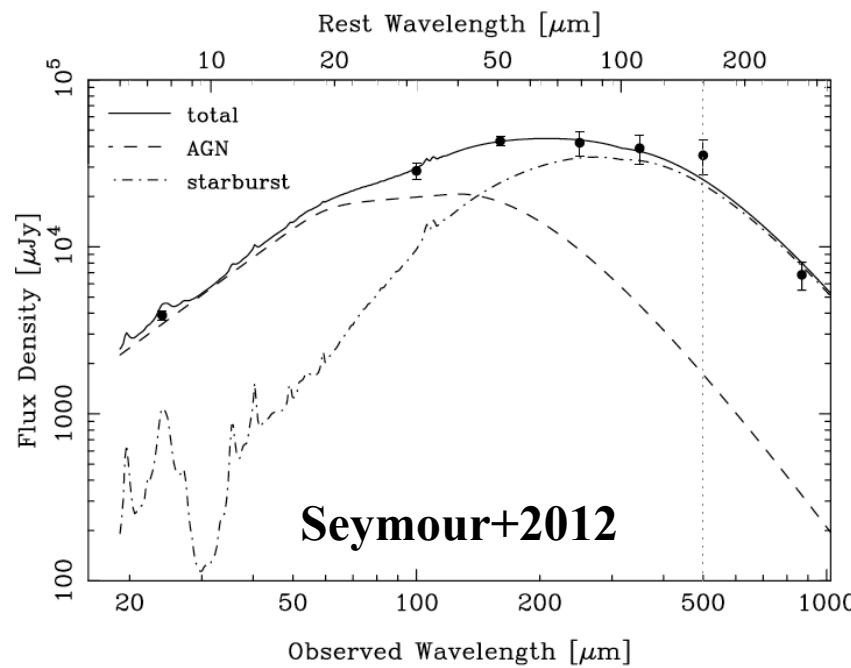
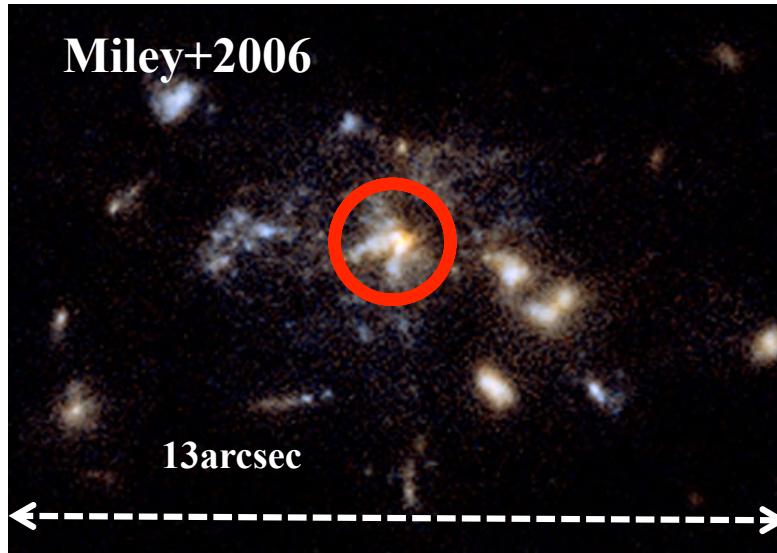


- ✓ Strong star formation in cluster core (<250kpc):  $\approx 1875 M_{\odot}/\text{yr}$
- ✓ Total SFR ( $z_{\text{spec}}$ )  $\approx 2500 M_{\odot}/\text{yr}$
- ✓ Total SFR ( $z_{\text{spec}}+z_{\text{phot}}$ )  $\approx 4500 M_{\odot}/\text{yr}$  (1 Mpc)
- ✓ Reversal of star formation density in a massive cluster
  
- ✓ WFC3 spectroscopy proposal accepted !
- ✓ Fassbender+2014: bright end of red sequence not completely in place yet.

# Summary



# Protocluster MRC1138 @ z=2.16



Kurk+2004a



eso1431 — Science Release

SPACE SCOOP

# Construction Secrets of a Galactic Metropolis

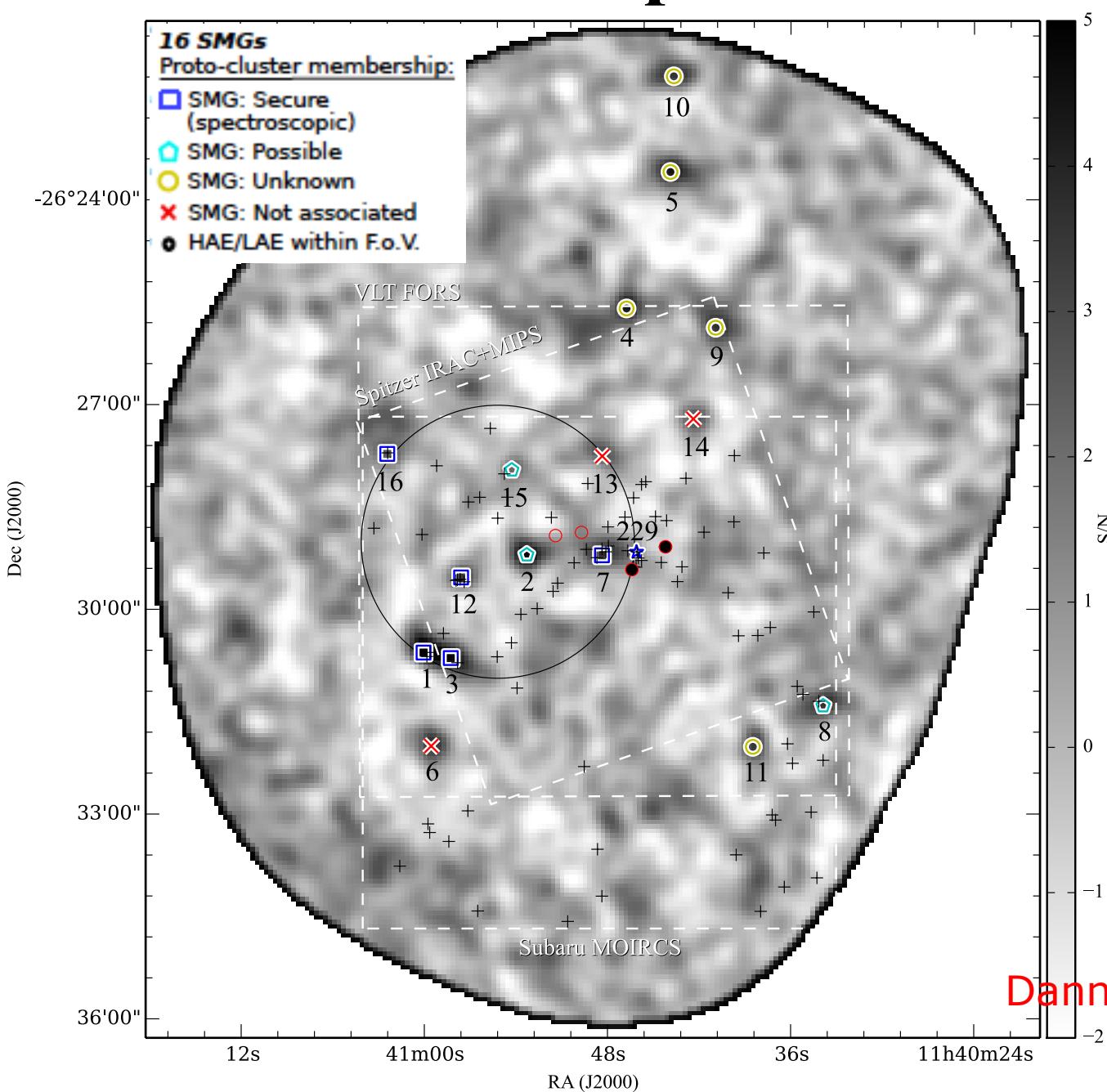
APEX reveals hidden star formation in protocluster

15 October 2014

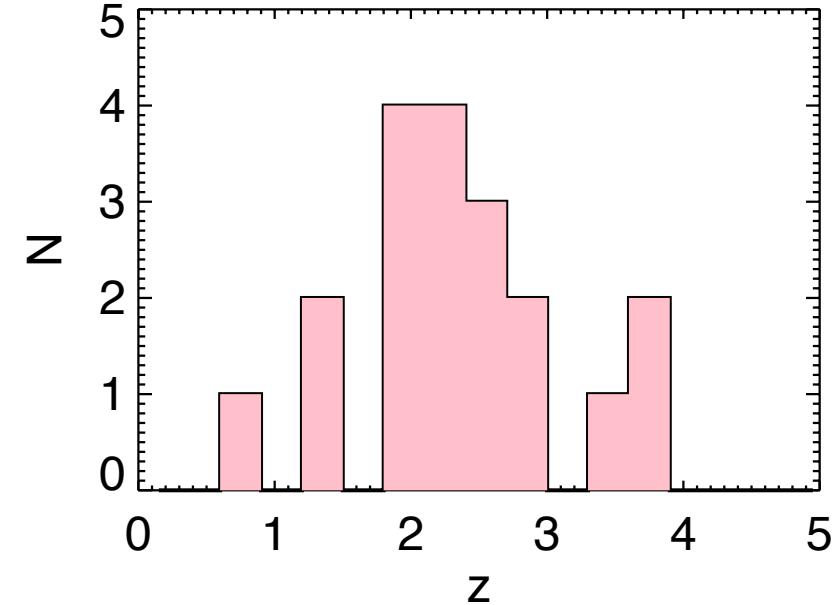
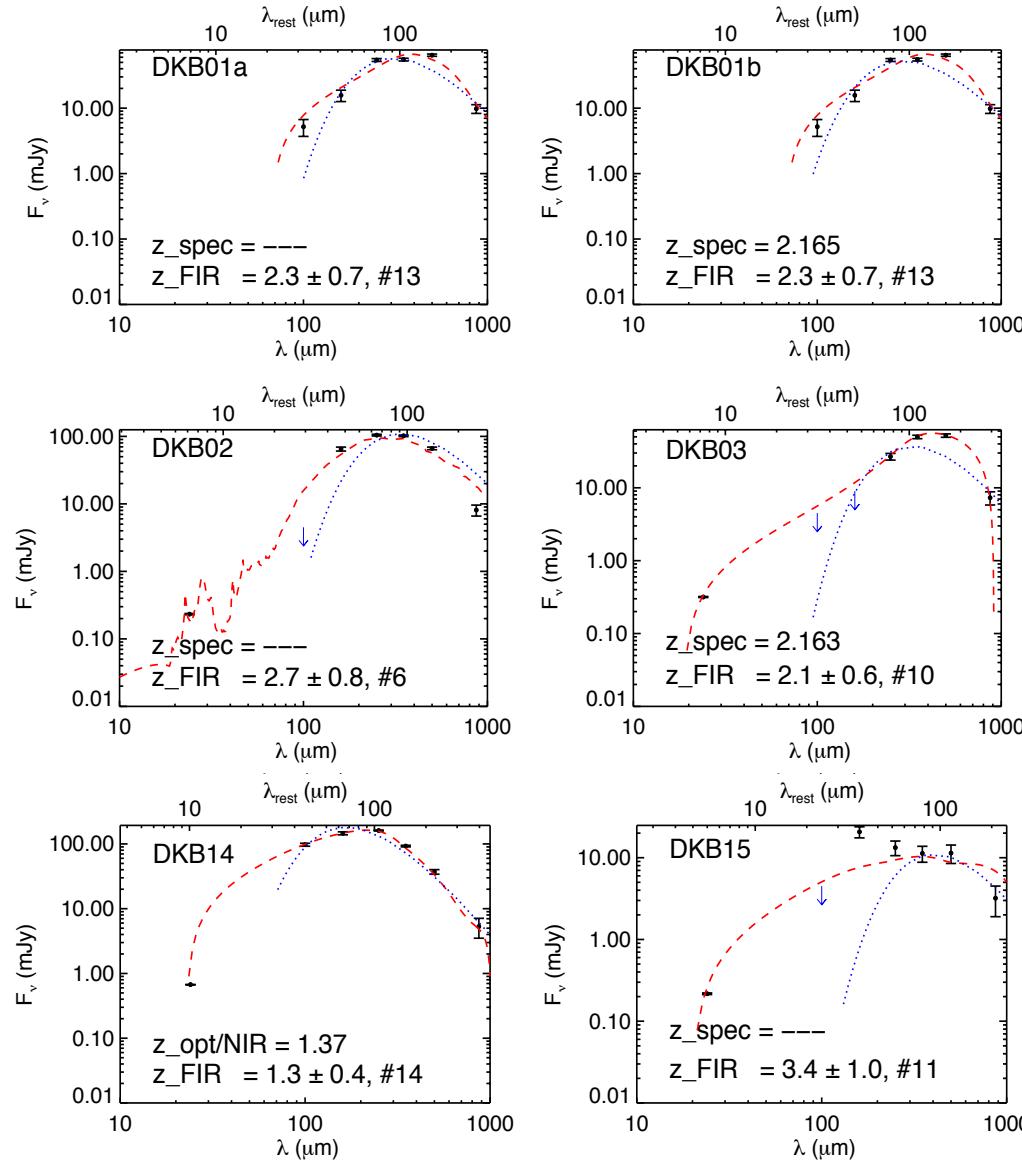


Astronomers have used the APEX telescope to probe a huge galaxy cluster that is forming in the early Universe and revealed that much of the star formation taking place is not only hidden by dust, but also occurring in unexpected places. This is the first time that a full census of the star formation in such an object has been possible.

# Proto-Cluster Membership

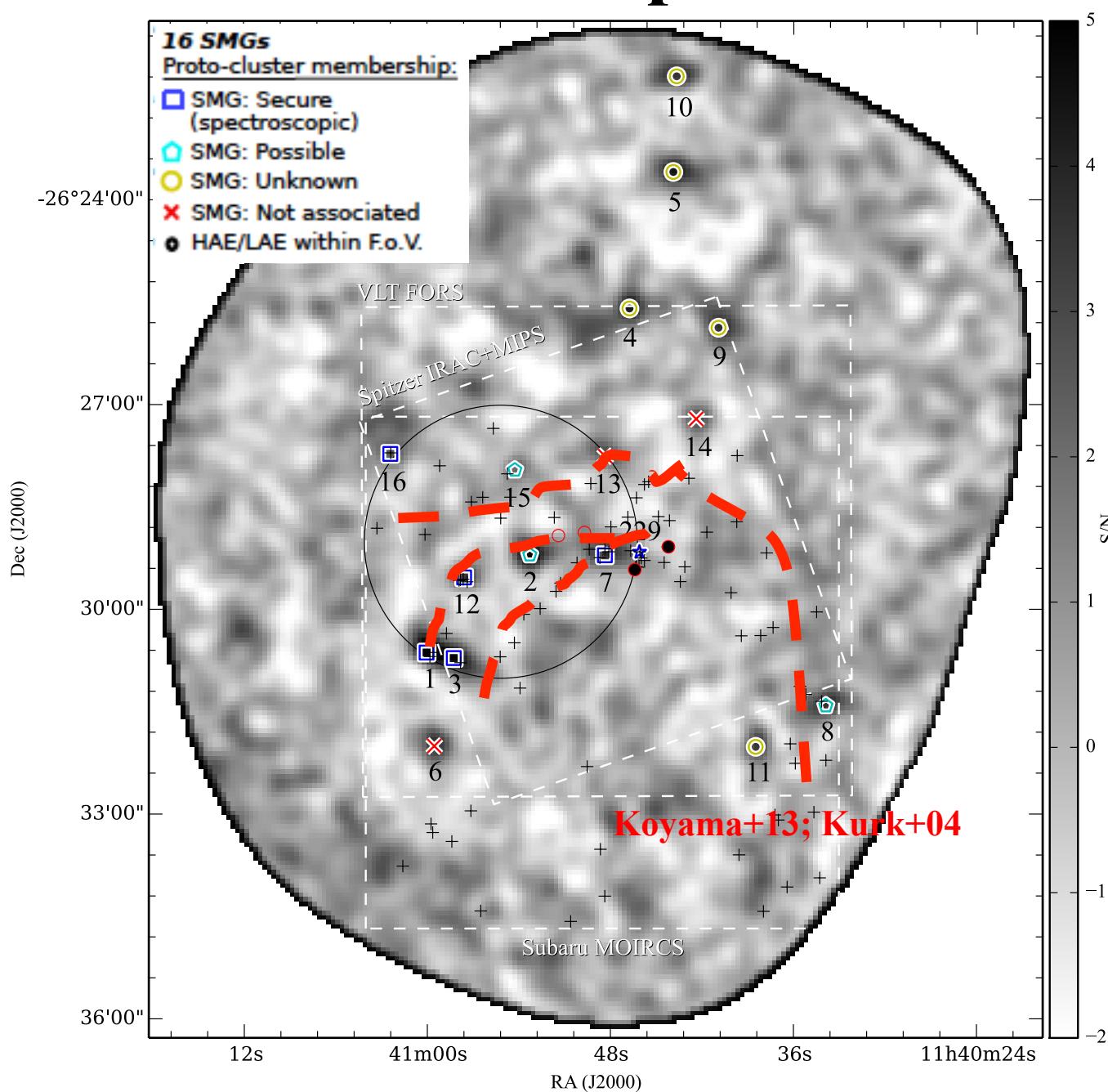


# FIR-photo-z

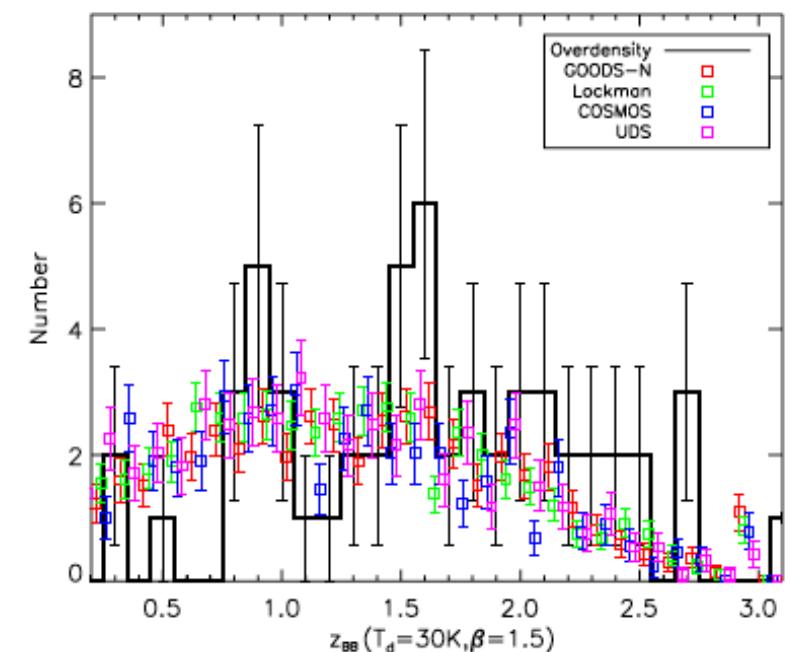
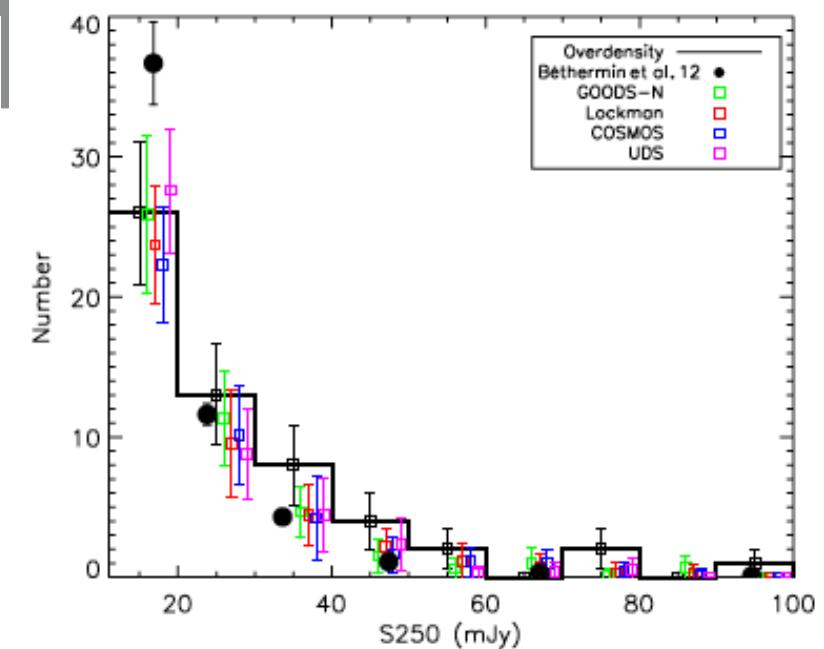
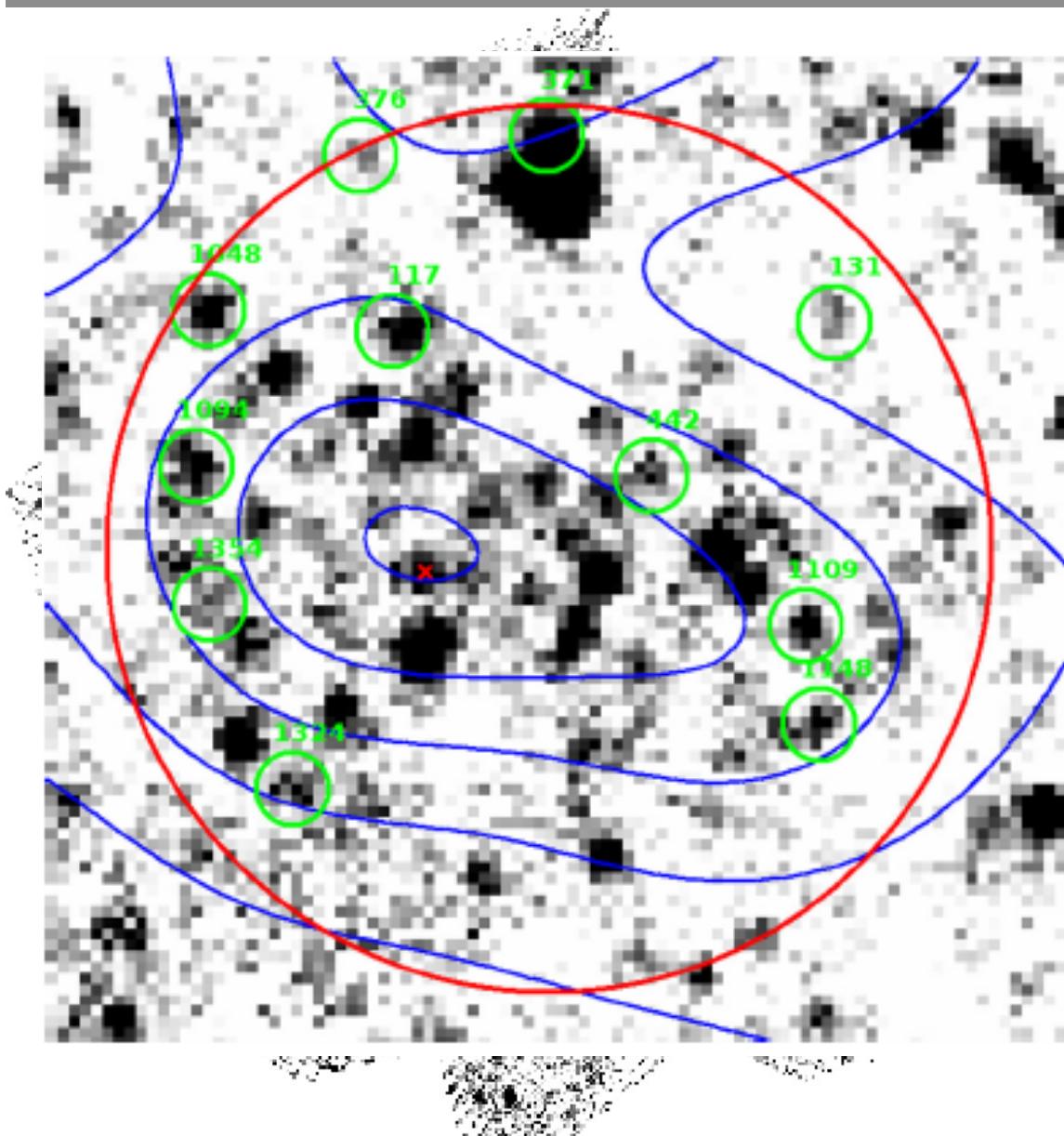


Dannerbauer +14

# Proto-Cluster Membership



# Herschel-SPIRE 250 $\mu$ m Overdensity



Valtchanov et al. (2013)

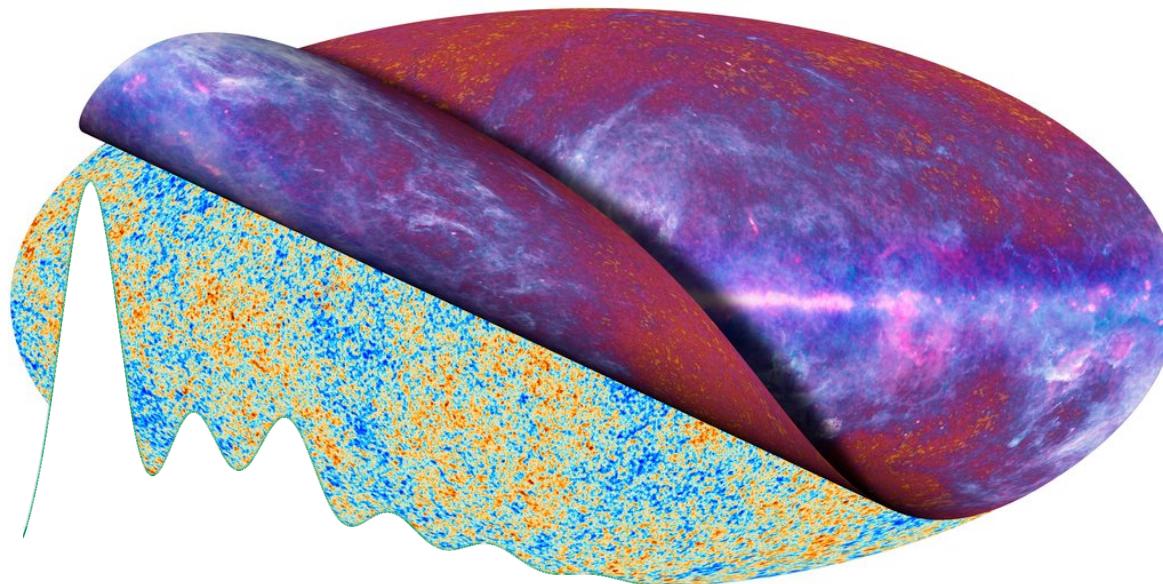
# SFR Spiderweb proto-cluster



- **overdensity of dusty starbursts associated to MRC1138**
- **at least 7 SMGs are members of the proto-cluster within 1 Mpc**
- **HAEs promising approach to trace (part of) the SMG (system)**
- **Deep sub-mm imaging seems to be a good way to search for overdensities/large scale structures**

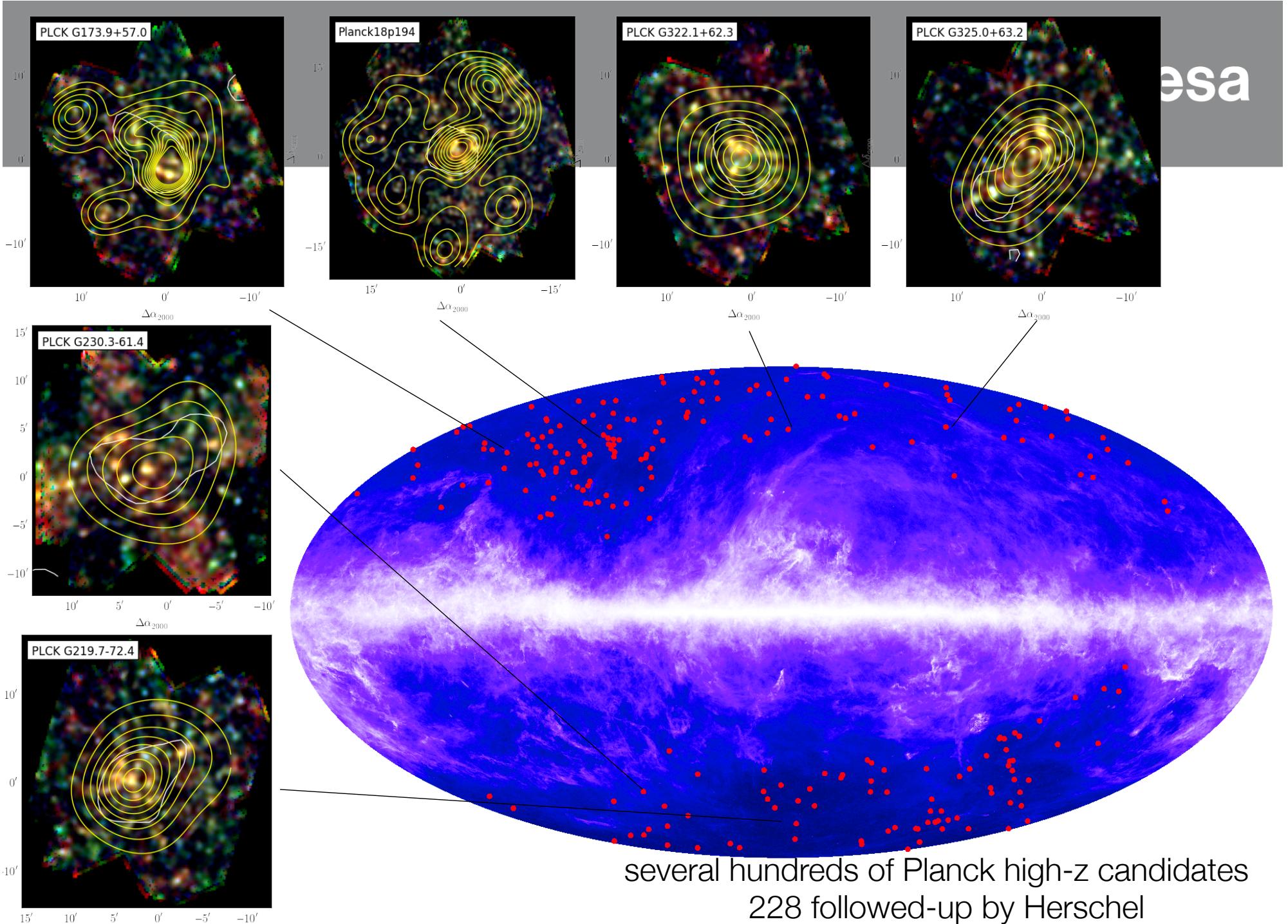
**See poster Dannerbauer et al.**

# Planck & Herschel unveil enigmatic high-z candidates



Planck cold sources follow-up

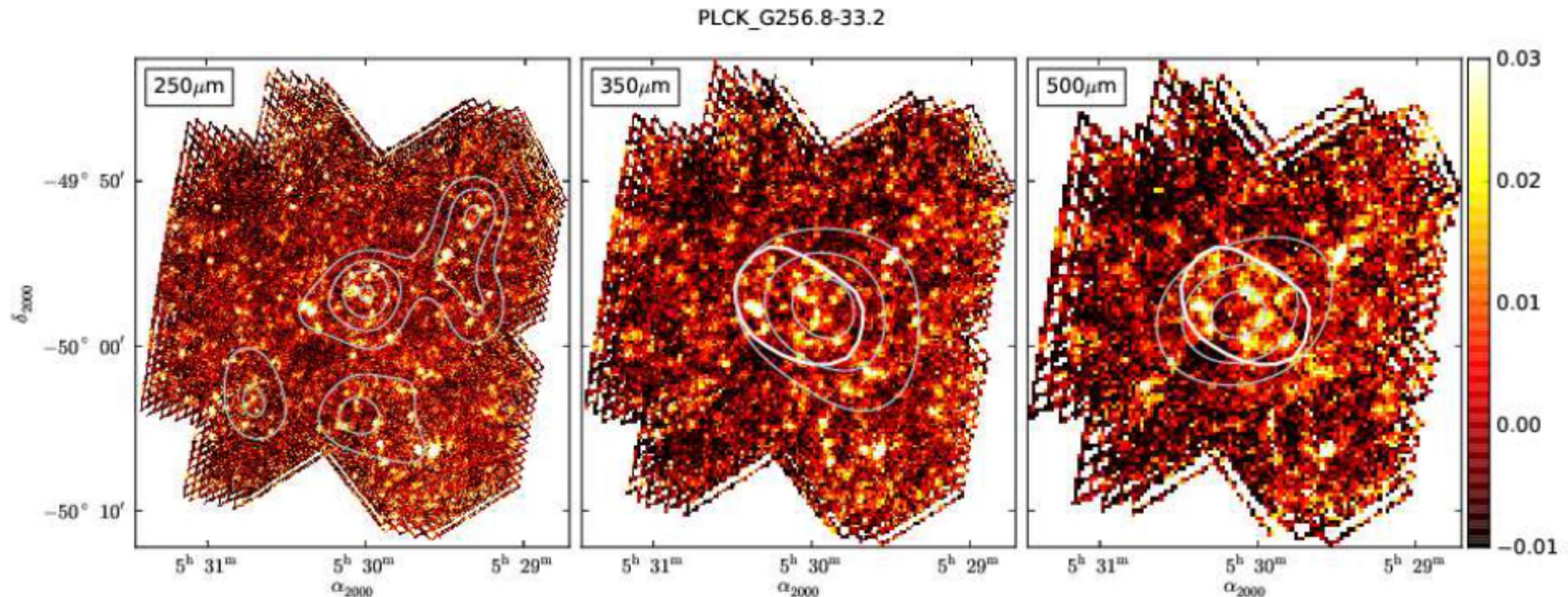
Hervé Dole  
on behalf of the Planck collaboration



# Planck proto-clusters

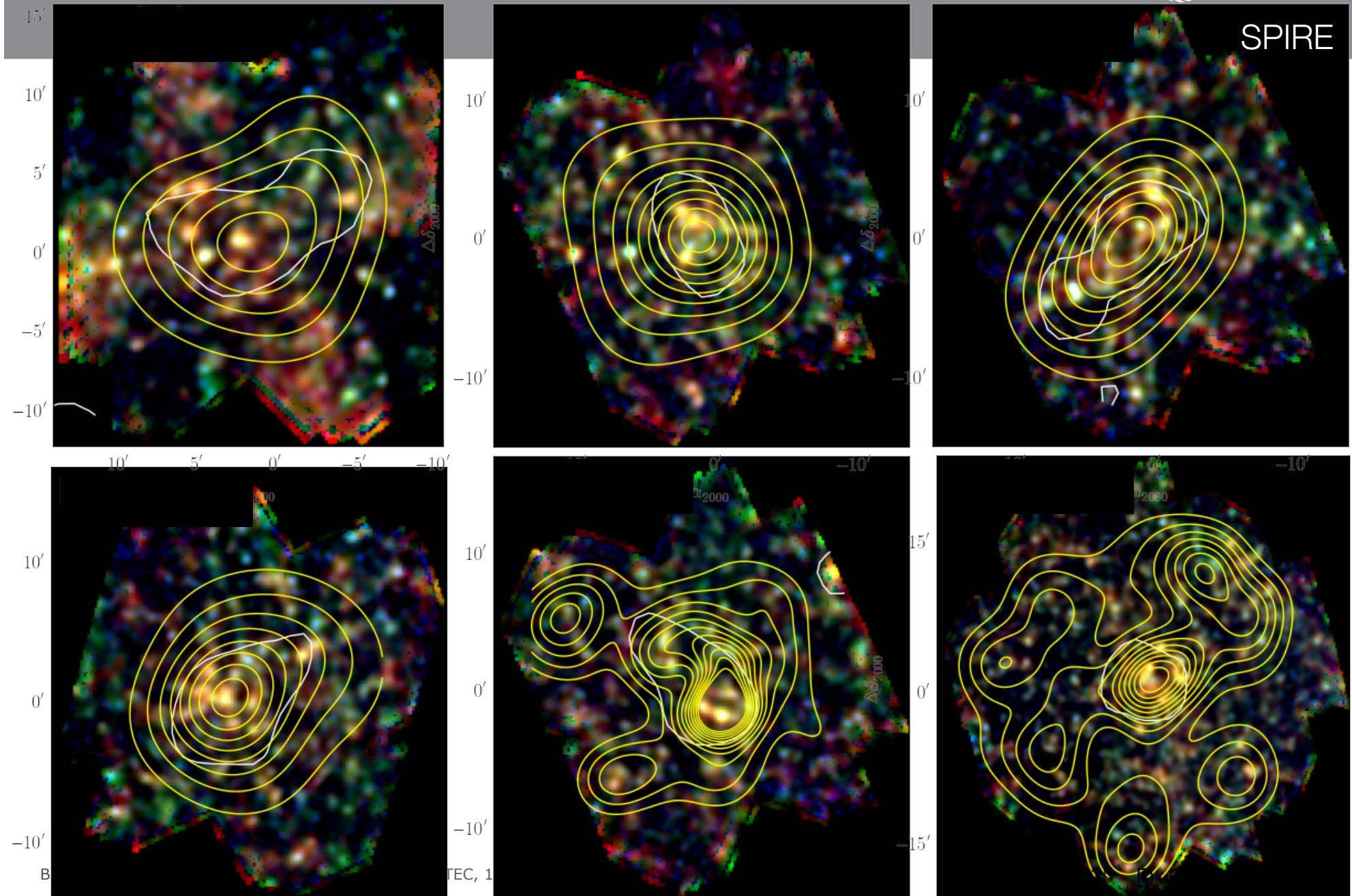


- *Planck cold sources as proto-clusters candidates: High-z infrared galaxies overdensity confirmed by Herschel/SPIRE*



Dole +2014

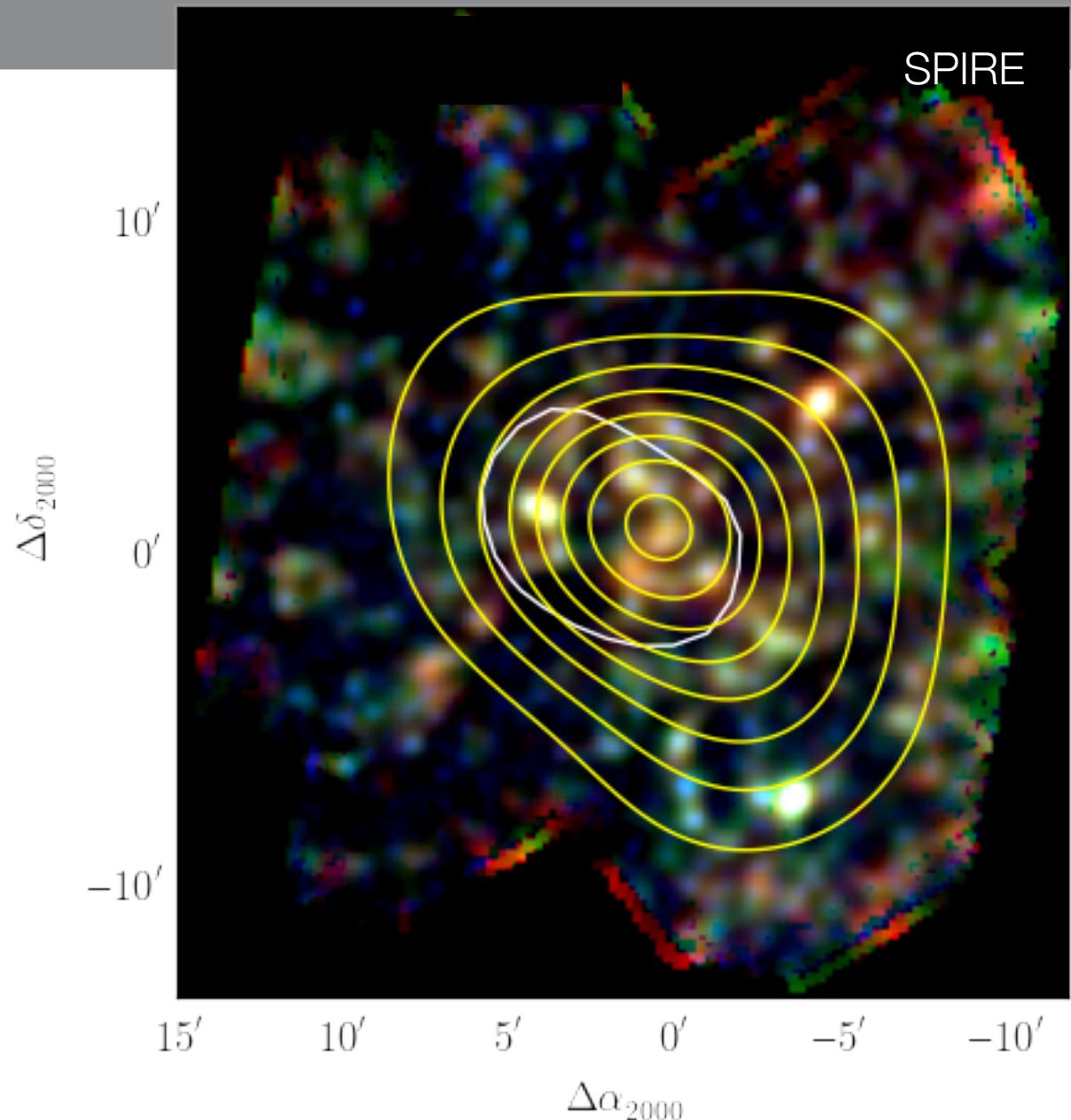
# a remarkable dataset (30' x30' images)



# The case of one field: Spitzer and VLT



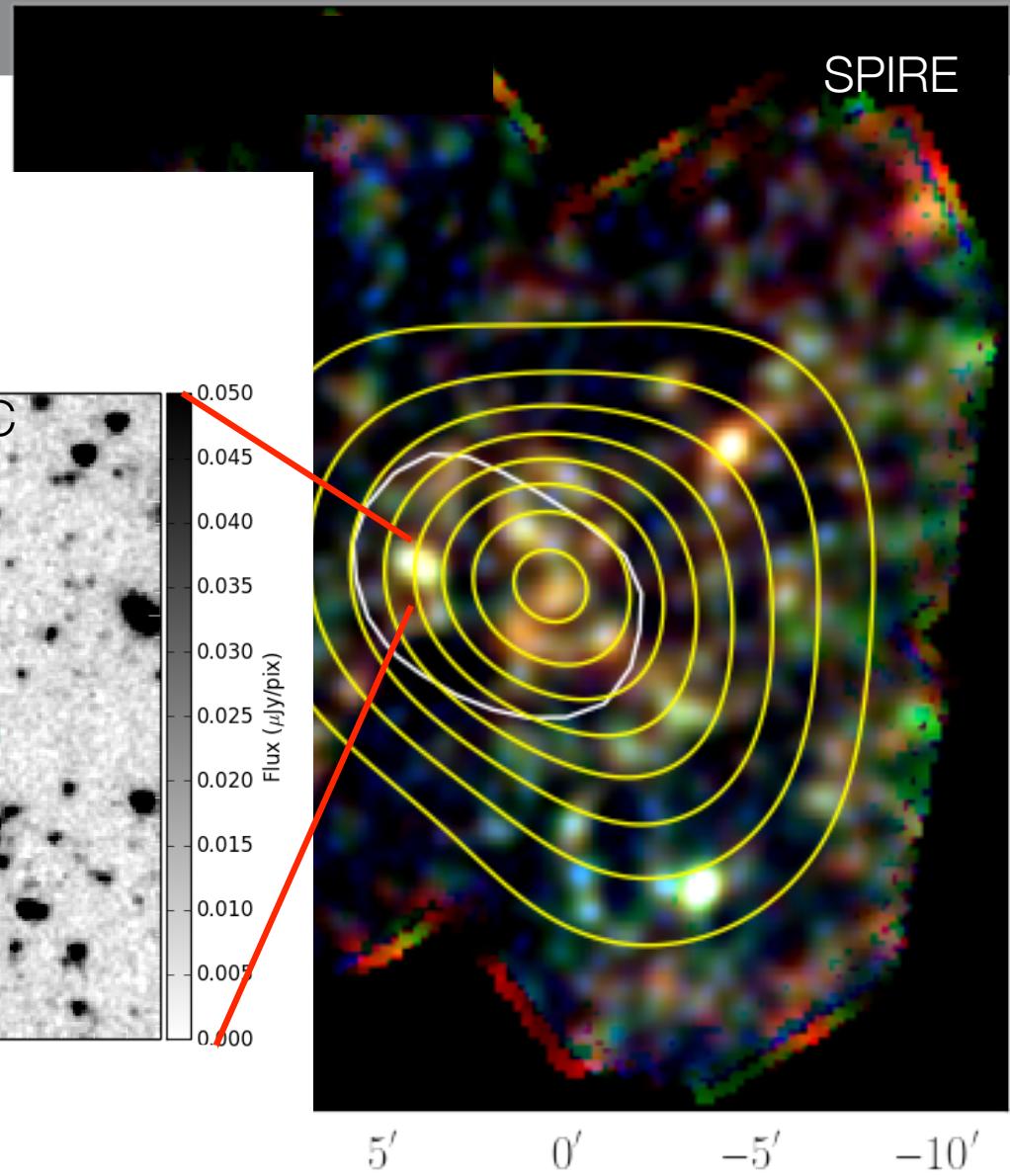
Herschel-SPIRE  
3-color image:  
blue = 250um  
green = 350um  
red = 500um



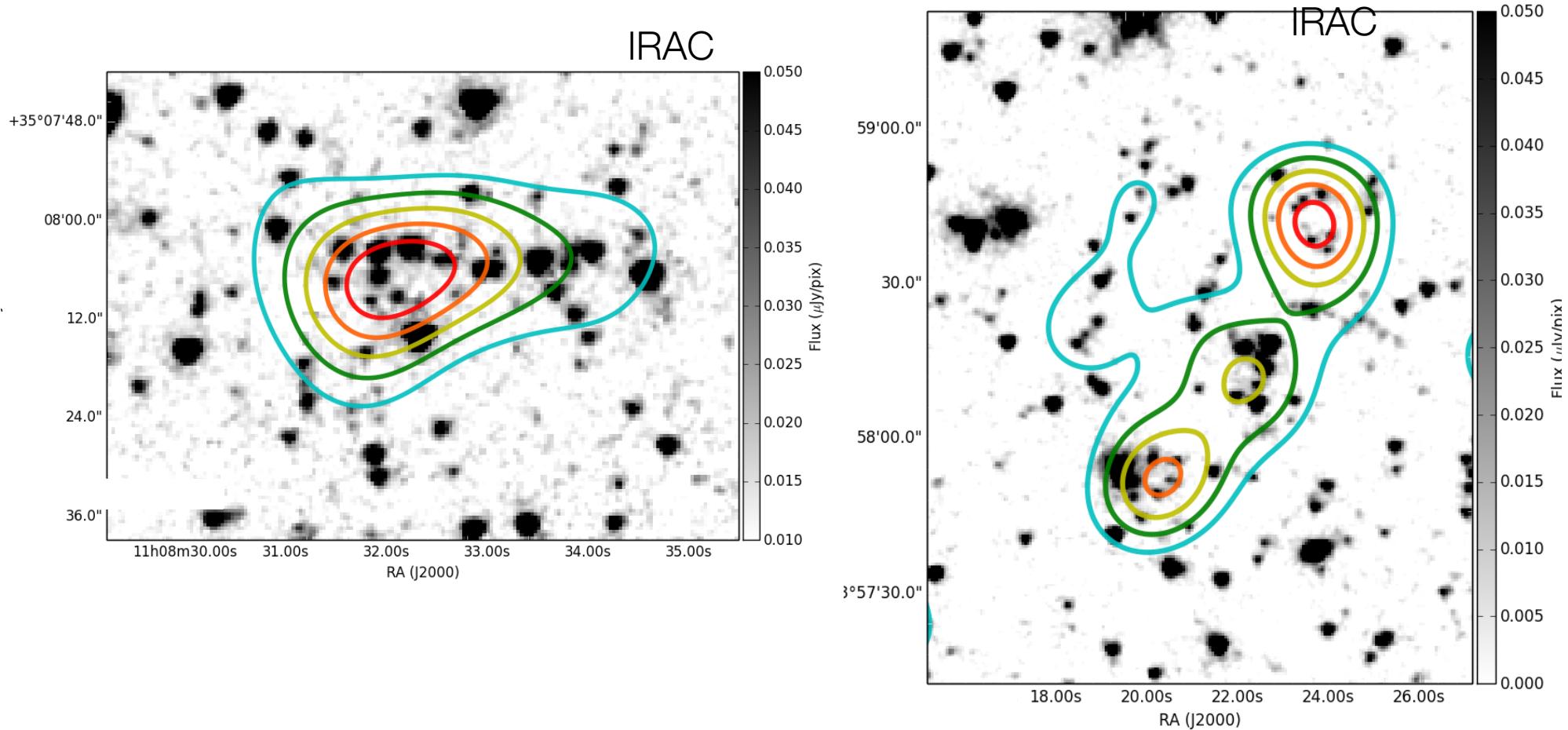
# The case of one field: Spitzer and VLT



Herschel-SPIRE  
3 color image.



many more examples etc etc.



# Reversal of star formation – density Conclusion



- Evidence of reversal of star formation-density relation at  $z>1.5$  in a high- $z$  massive cluster (XDCP J0044), still in the process of assembling the Brightest Central Galaxy.
- MRC1138, a precursor of massive cluster caught in a phase of active star formation, but with no sign of intracluster medium.
- Overdensities of high- $z$  FIR galaxies discovered by Planck/Herschel-SPIRE are extremely promising to unveil a population of protocluster of intensively star forming galaxies, precursors of today's massive clusters

**TBW**



**END**