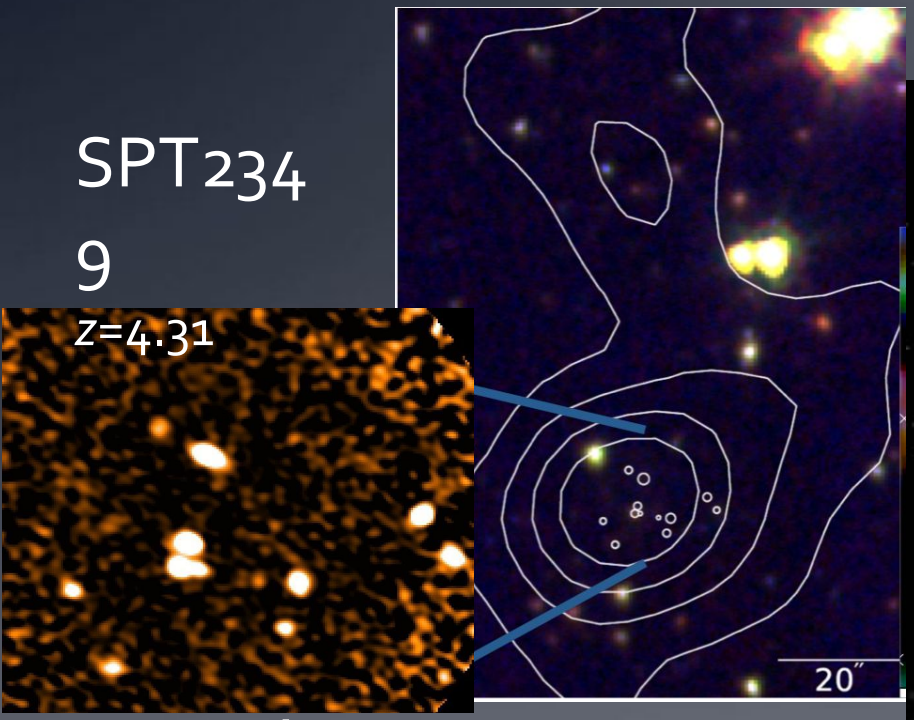
Using Gemini to study Galaxy Protoclusters at z=4-7 from the South Pole Telescope survey

Gemini Users Meeting

SPT234
9
z=4.31



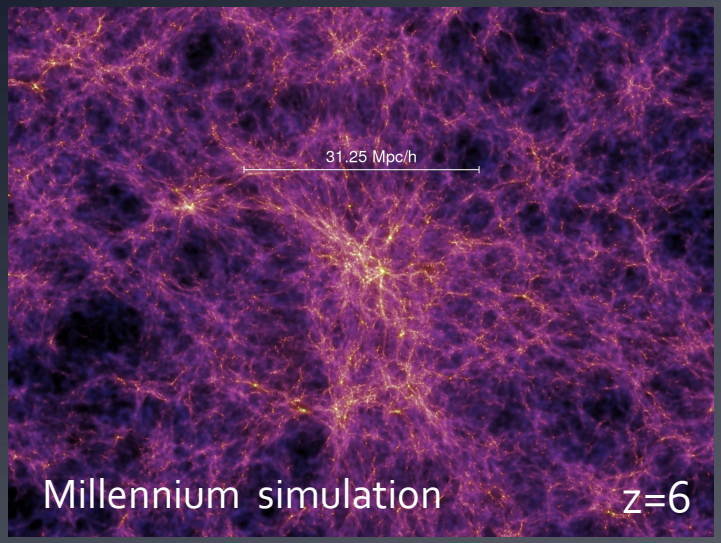
Scott Chapman
(NRC,UBC,Dalhousie)
SPT collaboration

Hill R., Wang, G., K. Rotermund,
Weiss, A., Hayward, C., de Breuck, C.,
Vieira, J. Marrone, D. , Spilker, J., D. Scott

Detecting rich galaxy **clusters**

Robust methods to detect massive galaxy clusters at $z < 1.5$:

- Sunyaev Zel'dovich effect
- Cluster red sequence
- X-ray hot ICM

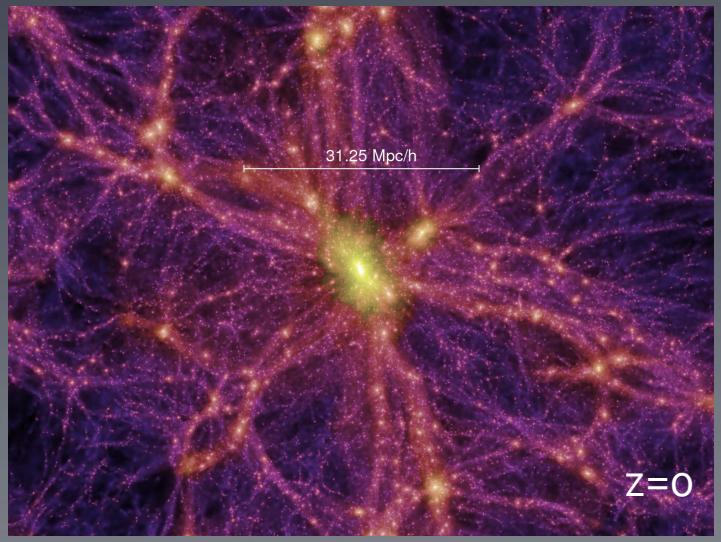


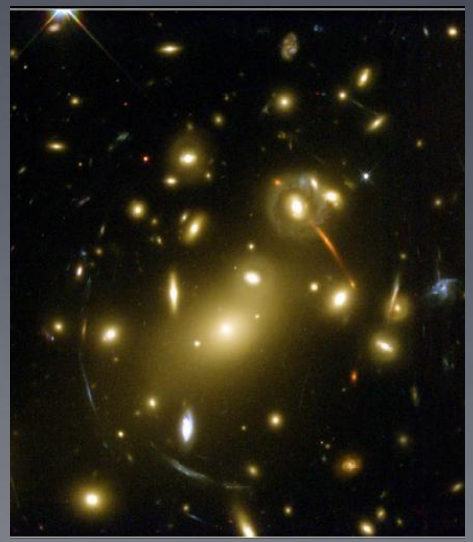
Progenitors of clusters – *Protoclusters* – are traced in simulations

… and *probed observationally*, ***sort of***

(how do we know an overdensity is a protocluster)

Massive Clusters detected out to z<2



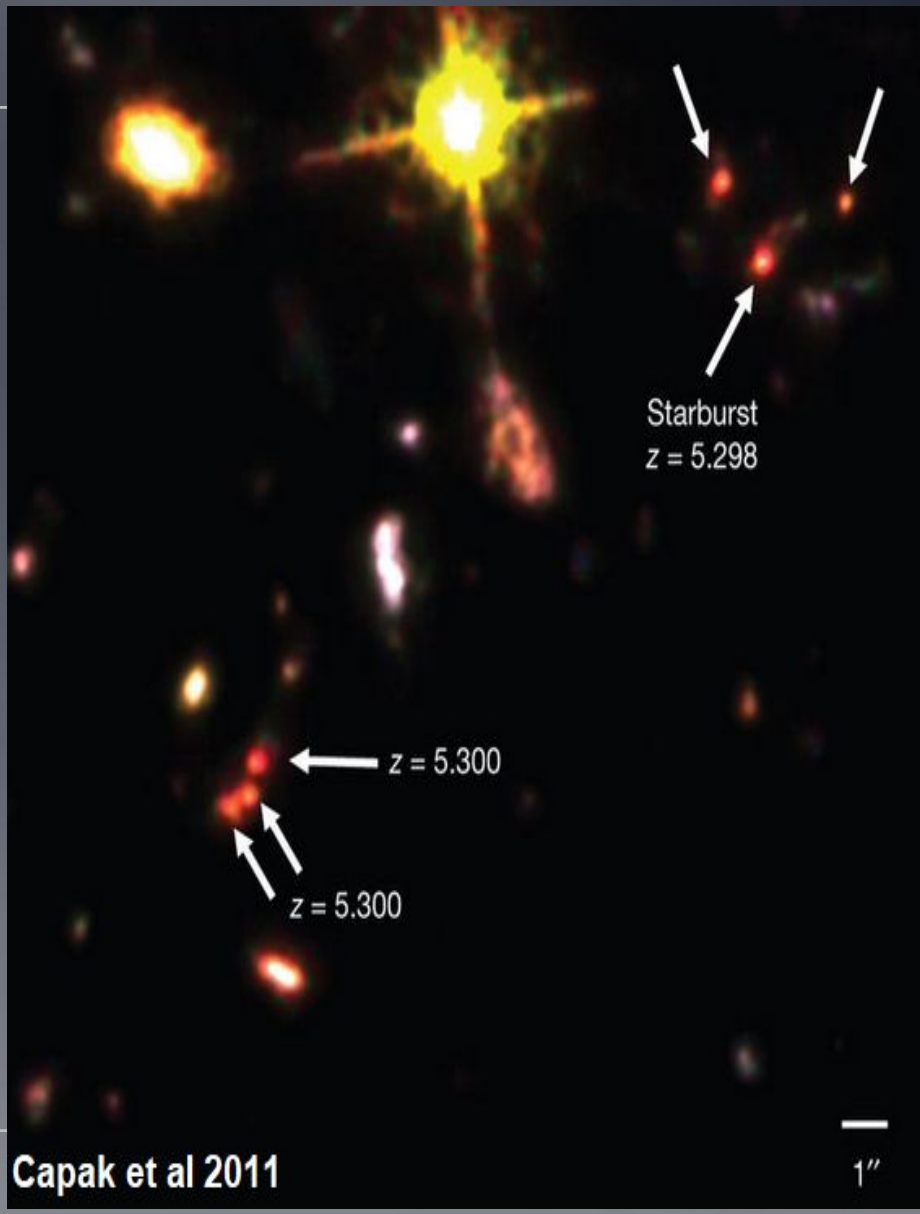


Detecting protoclusters

Not obvious what a protocluster is …

But detecting z > 2 overdensities can be accomplished observationally:

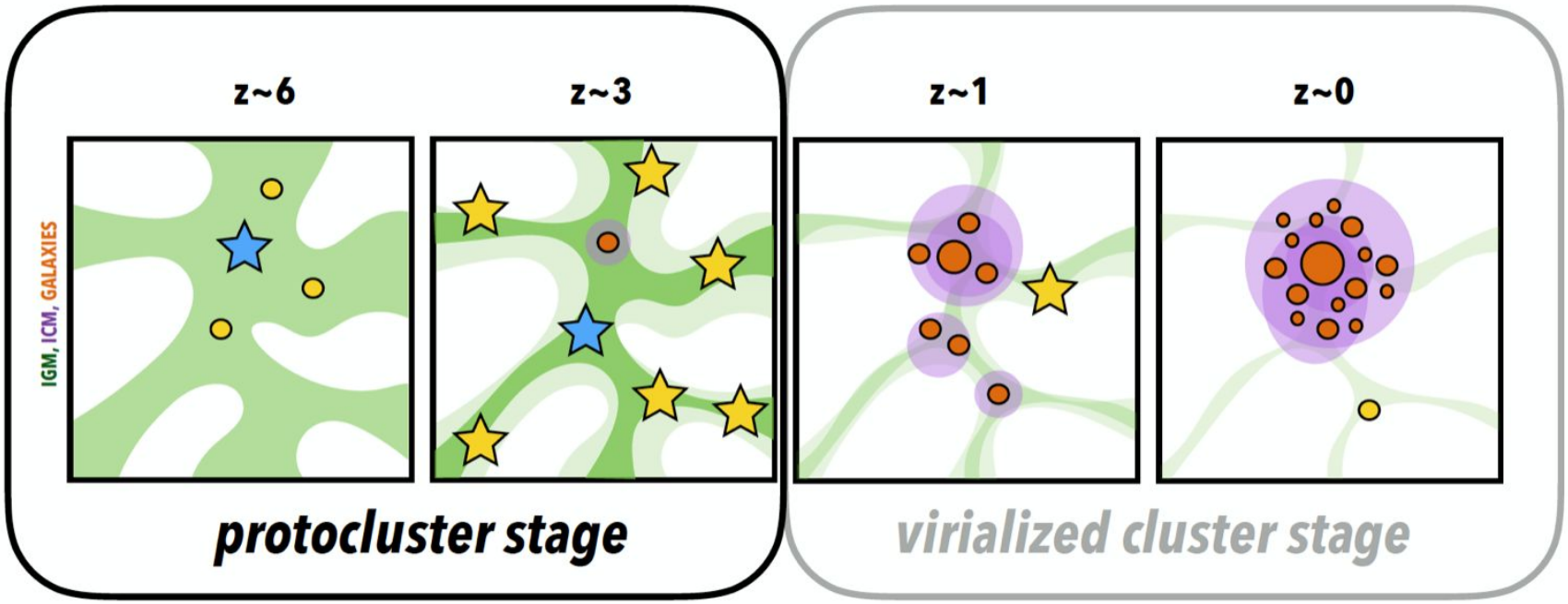
- Blind spectroscopic Lyman break galaxy surveys
- Targeted LBG and Narrow band searches for galaxies around quasars/radio galaxies
- Searches around known high-redshift submm-galaxies (SMGs)



Protoclusters traced by luminous galaxies?

1. Can ULIRGs be useful tools in studying the assembly history of protoclusters (galaxy cluster progenitors)?

2. Do ULIRGs (at z>2) preferentially live in overdensities?

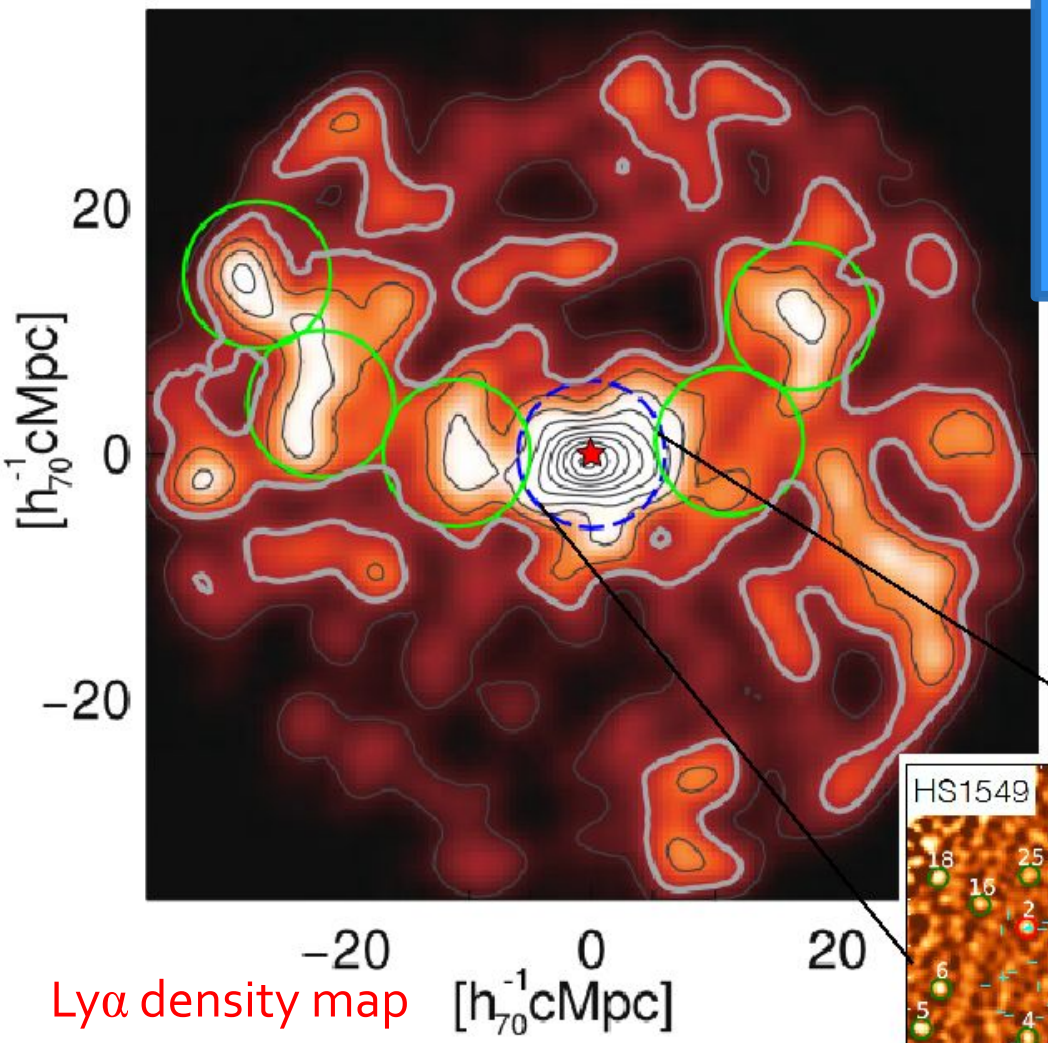


Courtesy of Caitlin Casey 2017;

Examples of Protoclusters identified from SMGs over ~10' fields:
HDF z=1.99 (Chapman+2009) COSMOS z=2.47 (Casey+2015)

HS1549+19 z=2.9 protocluster (Steidel et al. 2011)

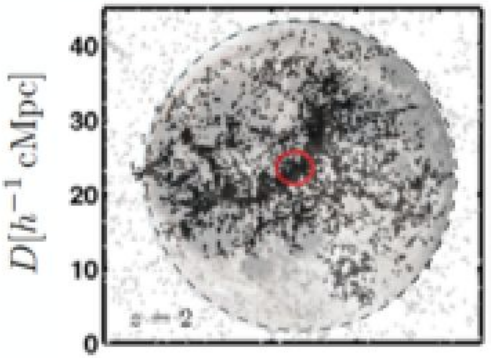
Protoclusters at z>3 are large, ~1 deg² region will collapse down by factor 100x



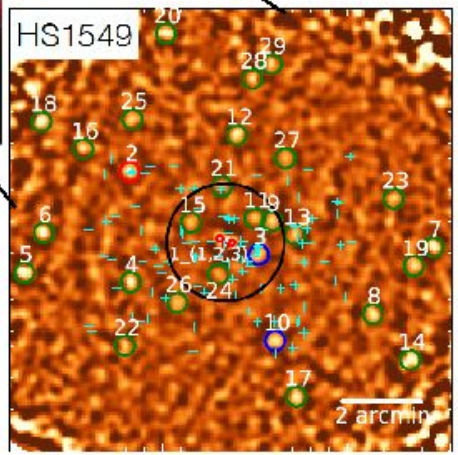
Lyα density map

Matsuda et al. in prep
Kikuta et al. 2019

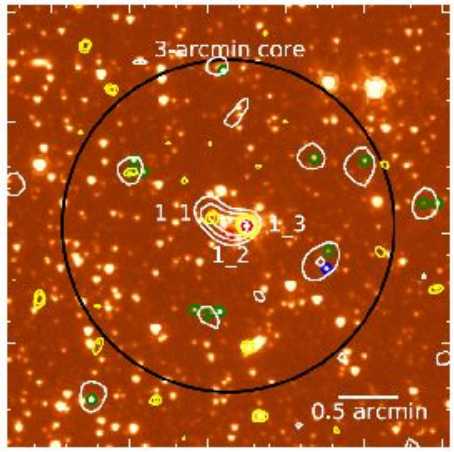
Looks like sims



(Lacaille et al. 2017)

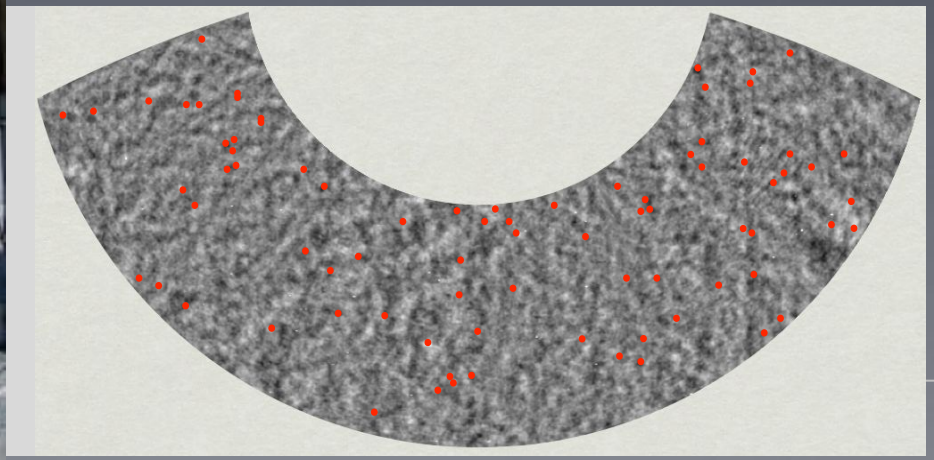


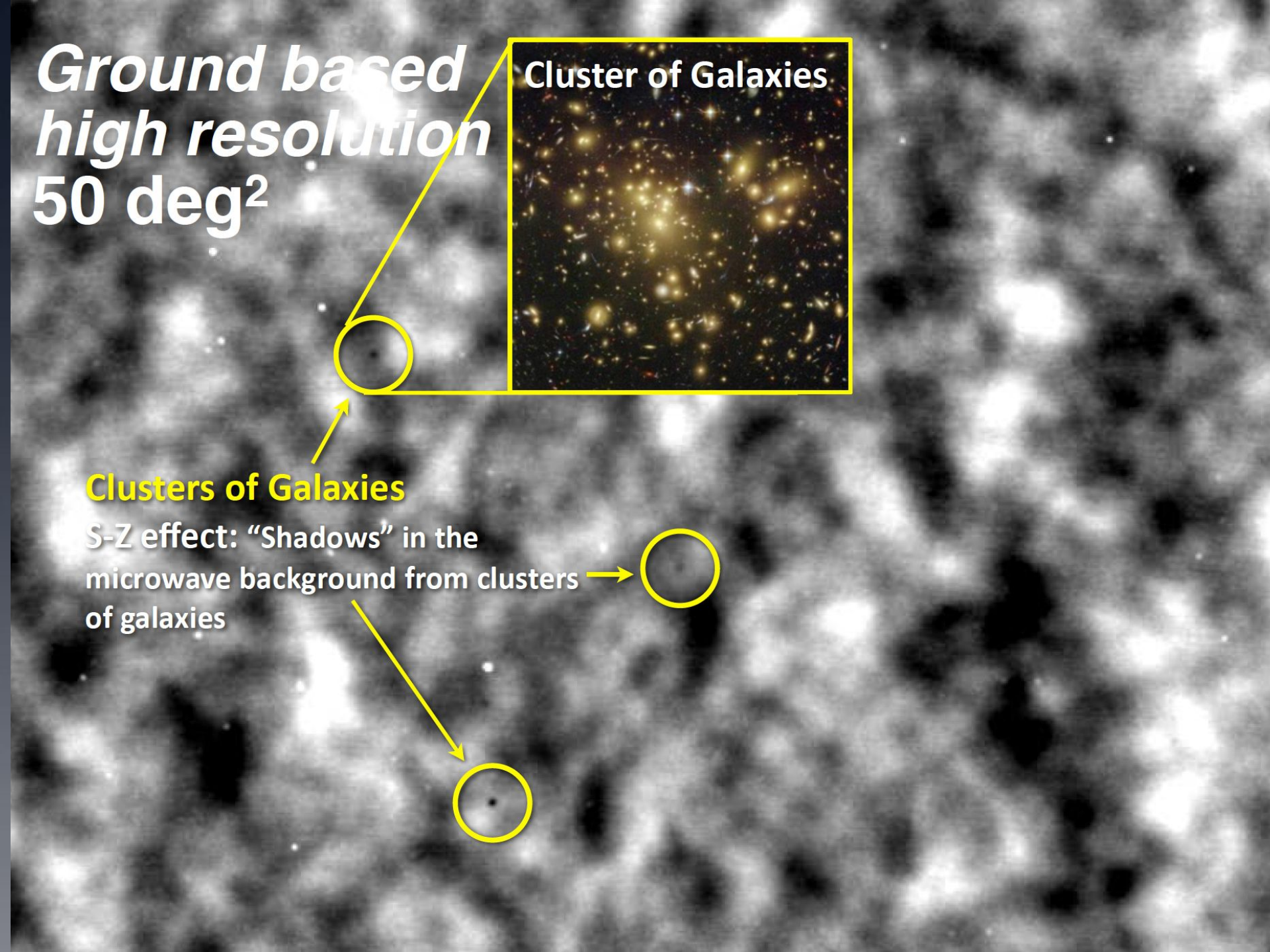
SCUBA-2 maps



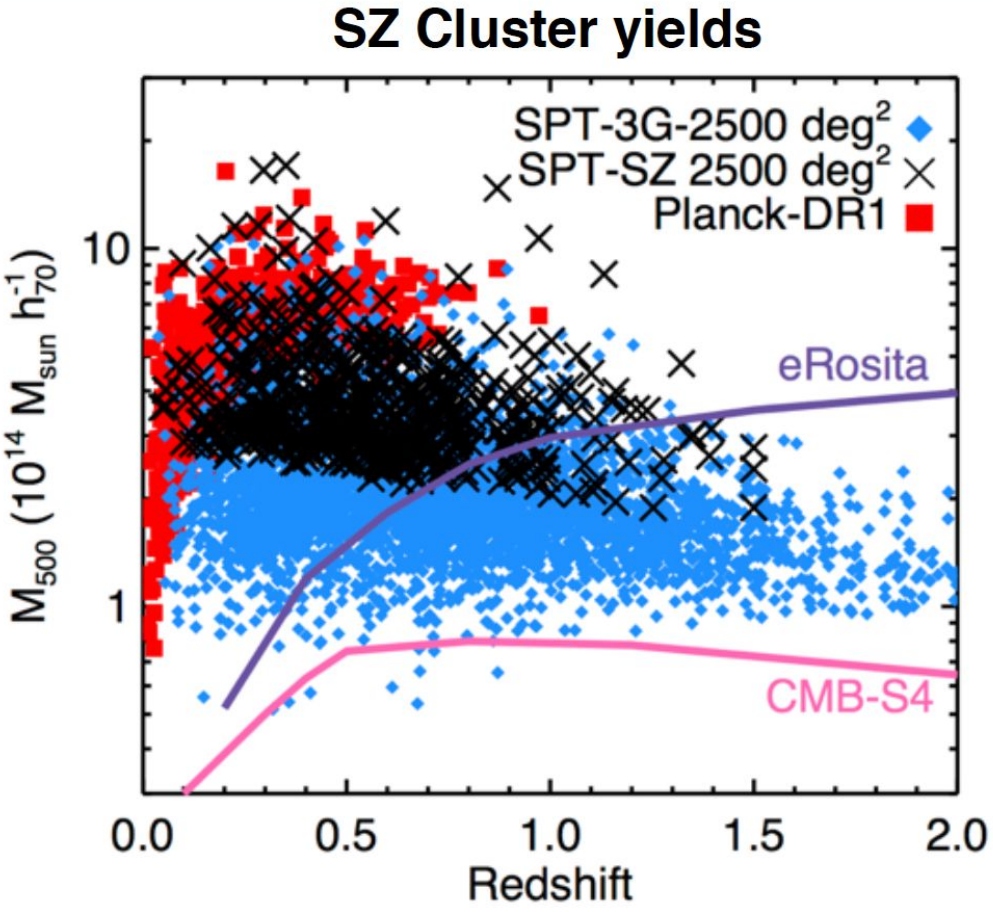
SMA/NOEMA resolved core

SPT-SZ 2500 deg² @ 3mm, 2mm, 1.4mm




Ground based
high resolution
50 deg²
Cluster of Galaxies
Clusters of Galaxies
S-Z effect: "Shadows" in the
microwave background from clusters
of galaxies

Expectations for SZ Cluster Surveys



Stage 2: $N_{\rm clust} \sim 1{,}000$

Stage 3: $N_{\rm clust} \sim 10{,}000$

CMB-S4: $N_{\rm clust} \sim 100{,}000$

CMB lensing will directly calibrate cluster mass SZ scaling:

CMB-S4: $\sigma(M) \sim 0.1\%$

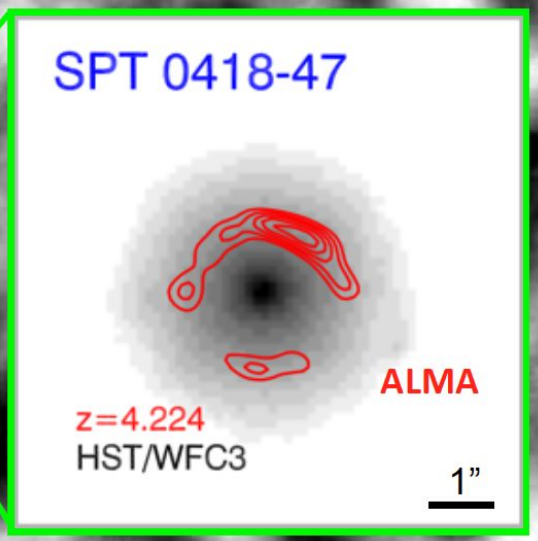
for an extremely powerful probe of structure formation and dark energy.

Ground based high resolution 50 deg^2

Point Sources S870~50-200 mJy

Active galactic nuclei, and the most distant, star-forming galaxies

Gravitationally lensed luminous, dusty galaxies

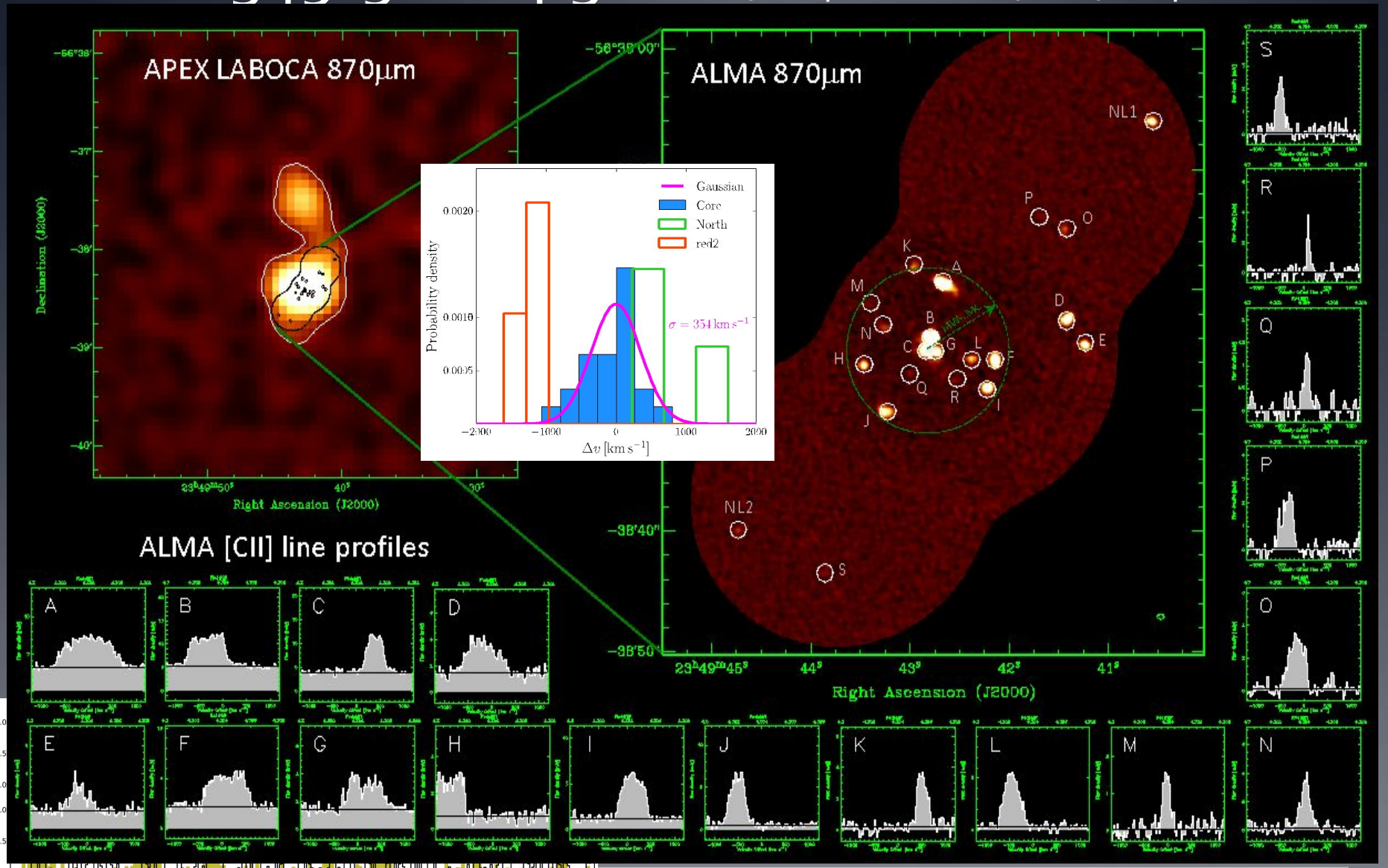


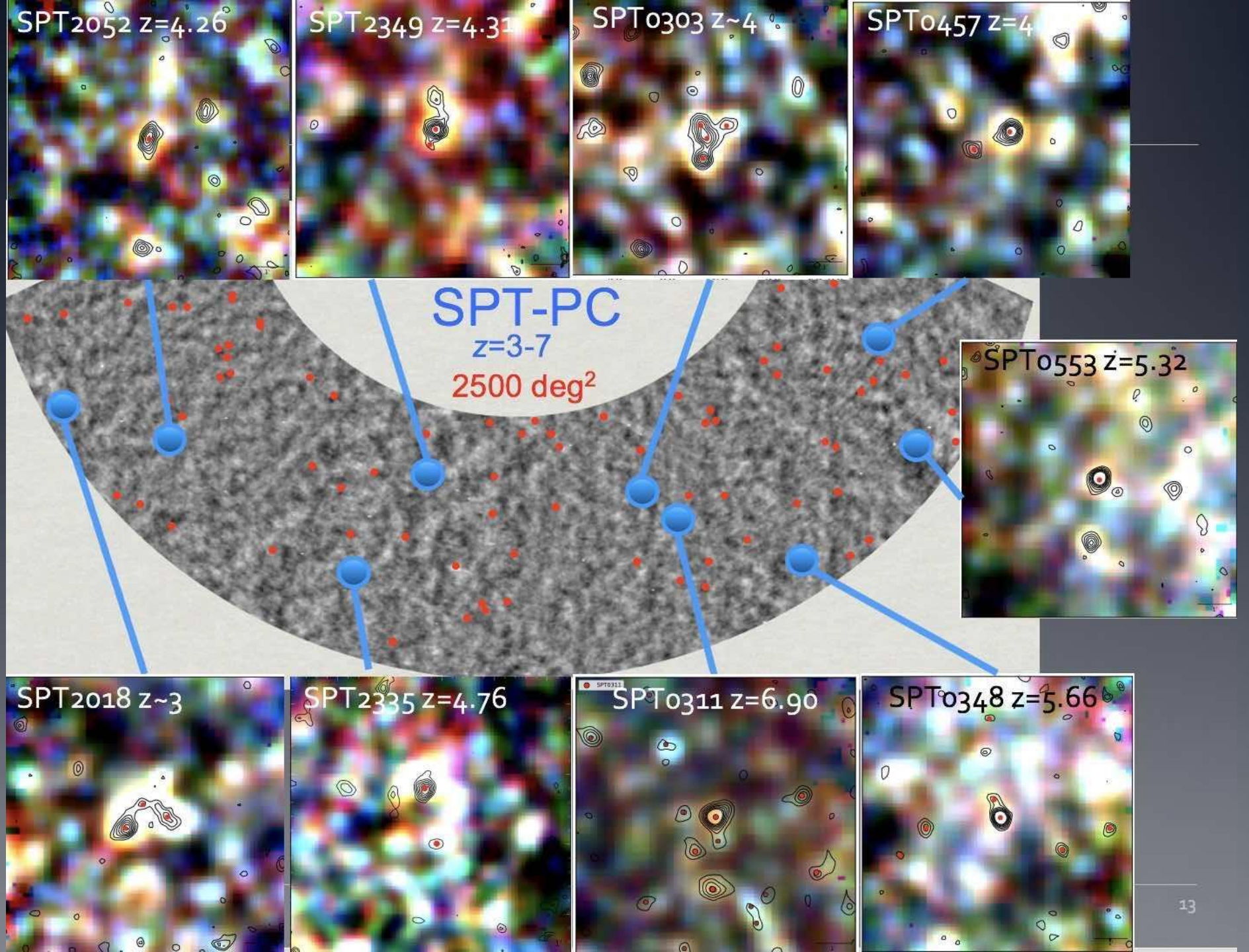
What if instead of
~~a single gravitationally lensed galaxy~~
… an SPT source consisted of many ***unlensed*** galaxies?

S1.4mm > 25mJy sources correspond to SFR > 10,000 M./yr

Extremely active 'proto-cluster' core ~~regions in early Universe?~~

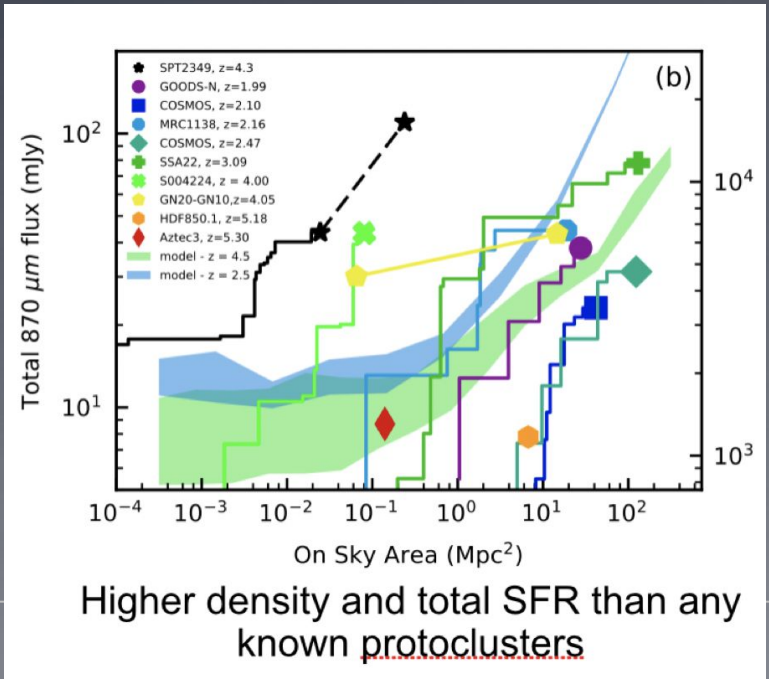
SPT2349-56 z=4.3 (Miller,Chapman+2018; Hill,Chapman+2020)

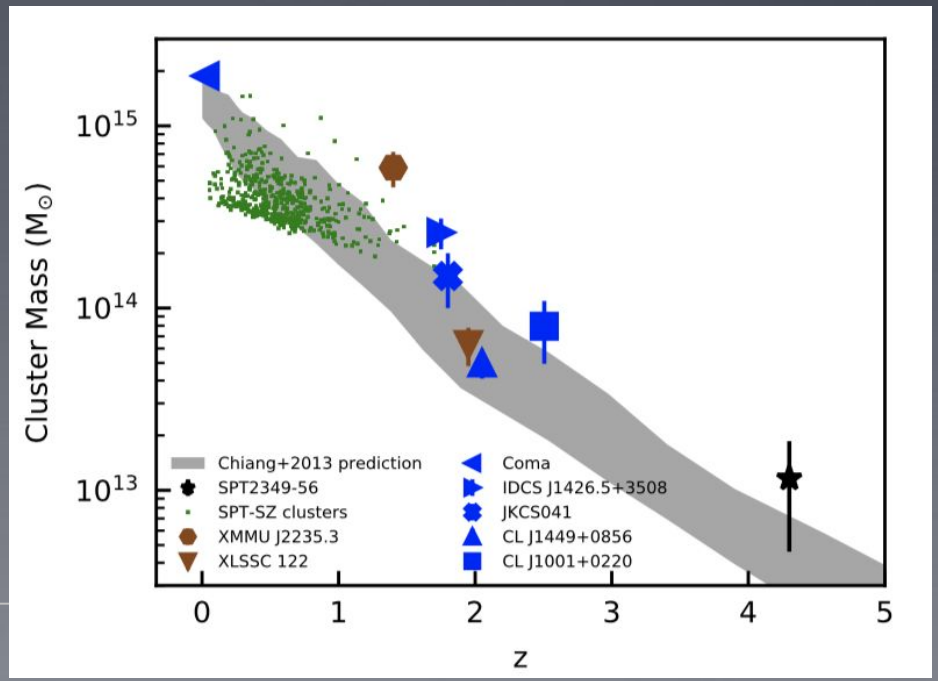



SPT2052 z=4.26
SPT2349 z=4.31
SPT0303 z~4
SPT0457 z=4
SPT-PC
z=3-7
2500 deg²
SPT0553 z=5.32
SPT2018 z~3
SPT2335 z=4.76
SPT0311 z=6.90
SPT0348 z=5.66

SPT2349-56: Key results

- *Most concentrated, and highest total SFR system known*
- *17,000 Msol/yr*
- *Core: 1e6 Msol/yr / Mpc^3*
- Most massive halo (>10^{13} Msol) observed kinematically at z>4
- Progenitor of Coma-like cluster?

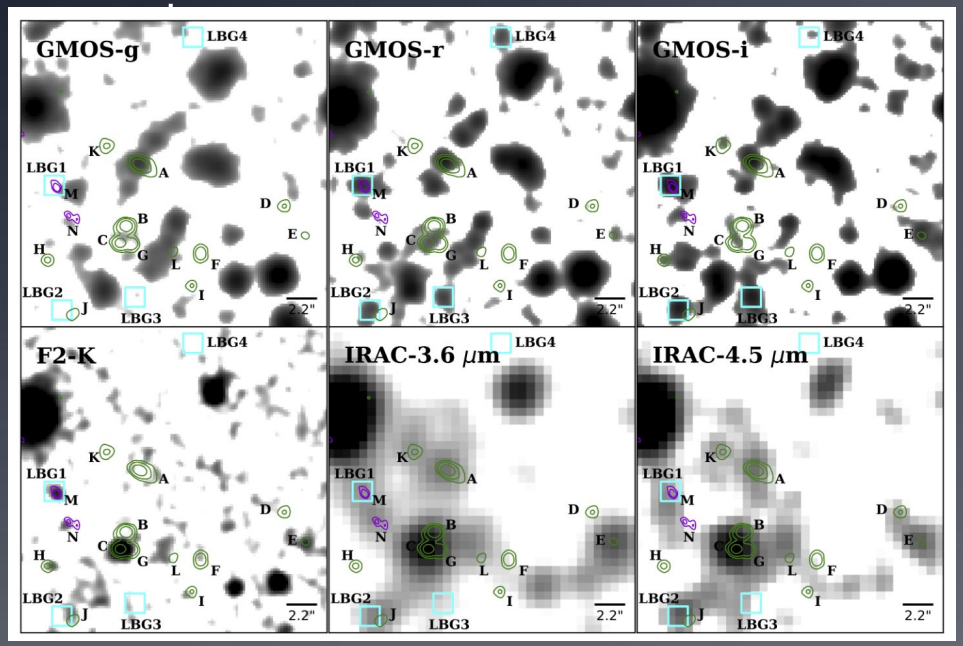




SPT2349-56: Gemini characterizing properties

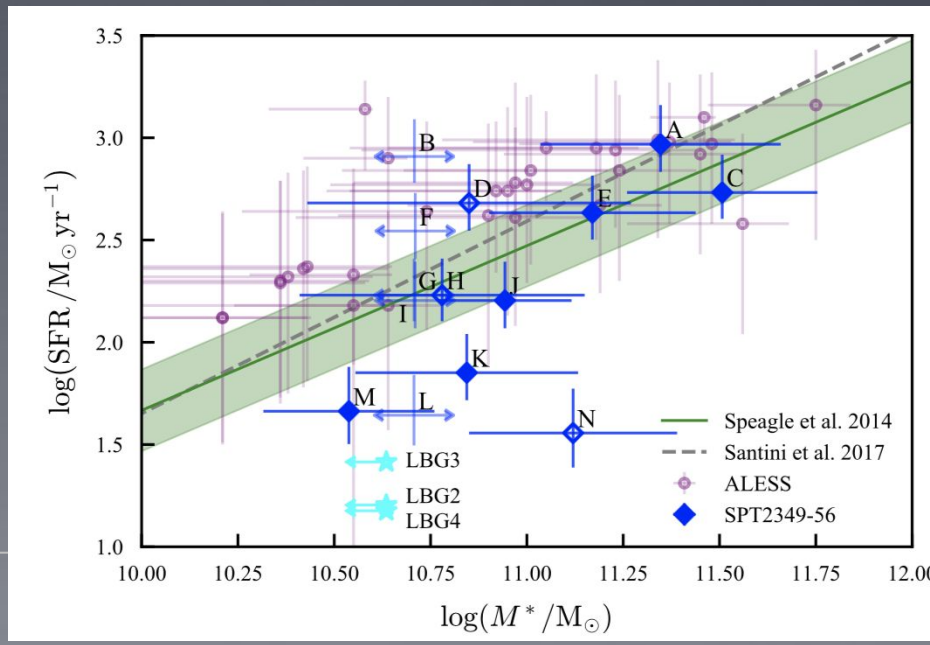
Rotermund, Chapman + 2021 Hill + 2022

- M* from Gemini-IRAC and SED fitting: Comparable to field ***Main Seq.***



Individual galaxies in PC aren't particularly unusual relative to z=4 field

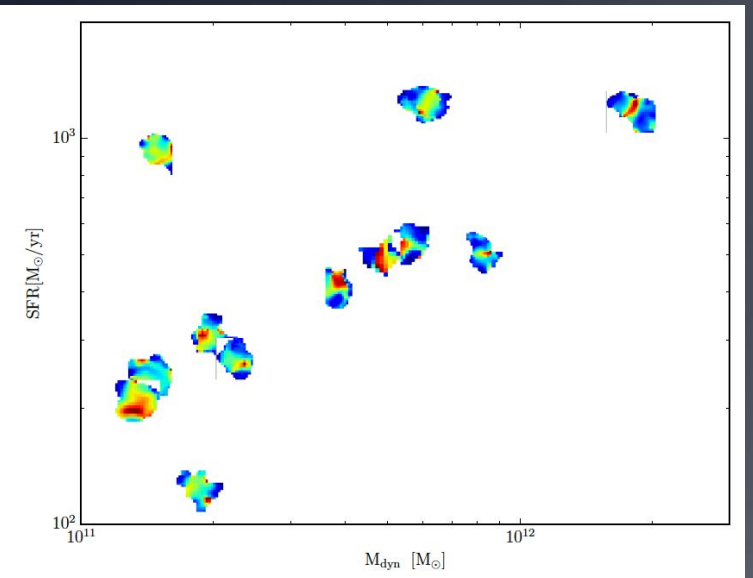
Some quenched galaxies!

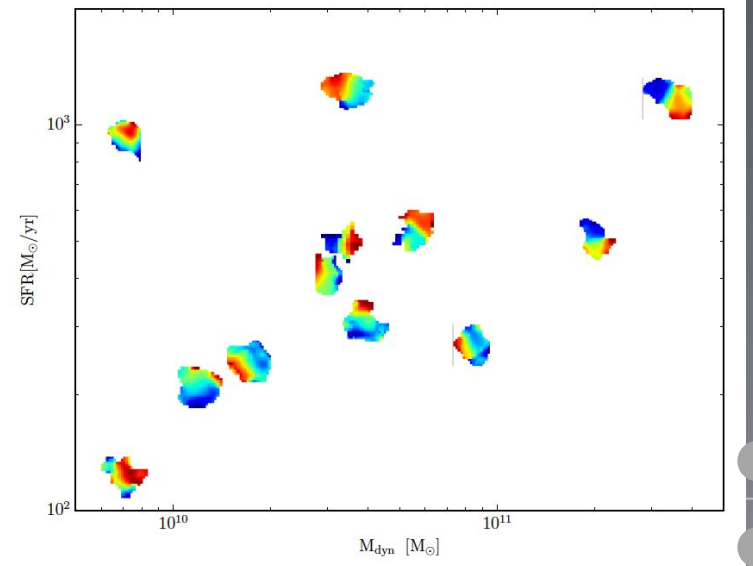


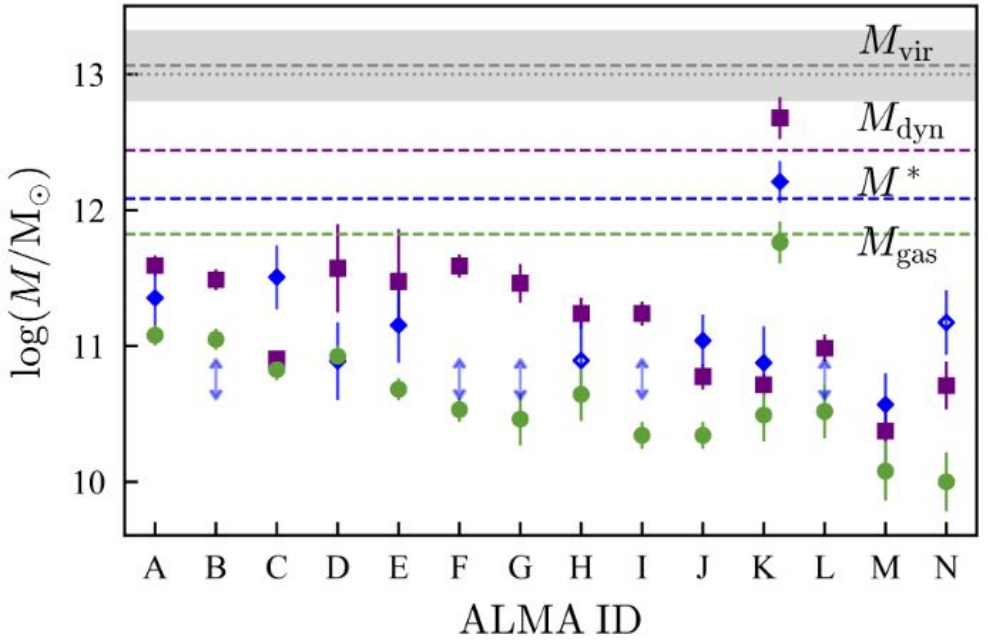
SPT2349-56

Rotermund Dalhousie PhD thesis

Mass budget ~66% Dark Matter







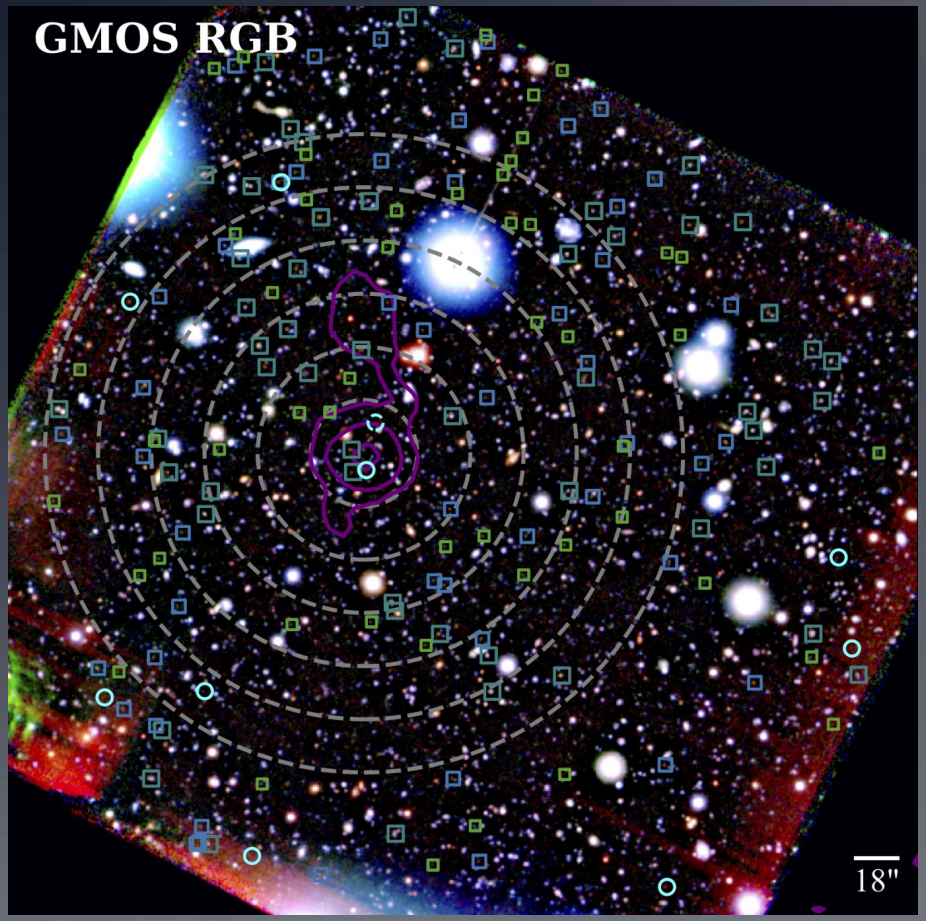
Mass estimates in 2 ways

- Dispersion
- rotation

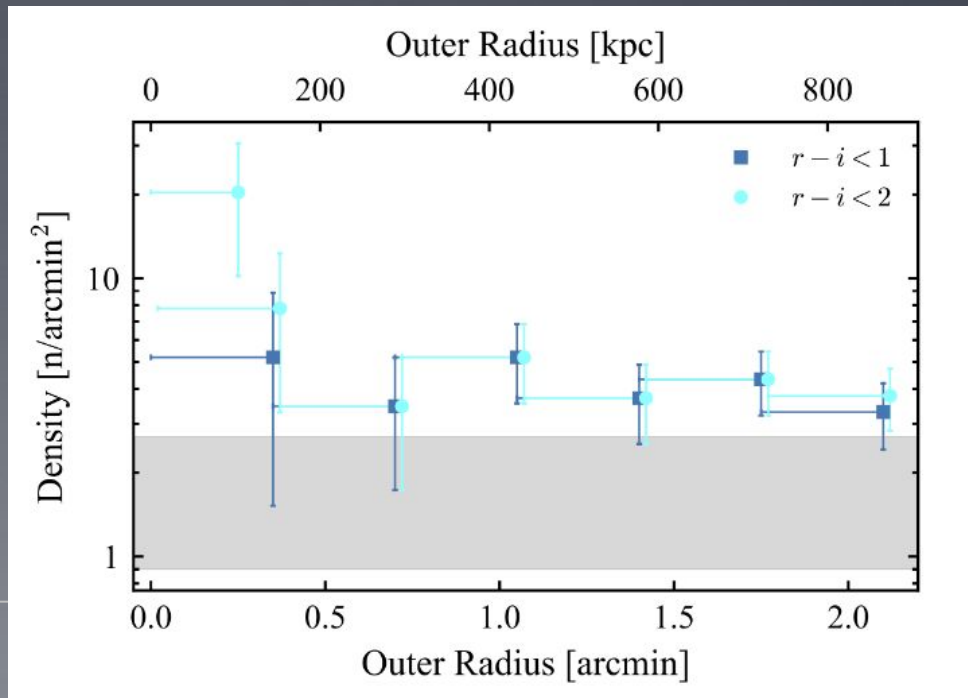
Gemini g,r,I,K. IRAC 3.6,4.5 enables crucial M* measurements

SPT2349-56

Rotermund et al 2021

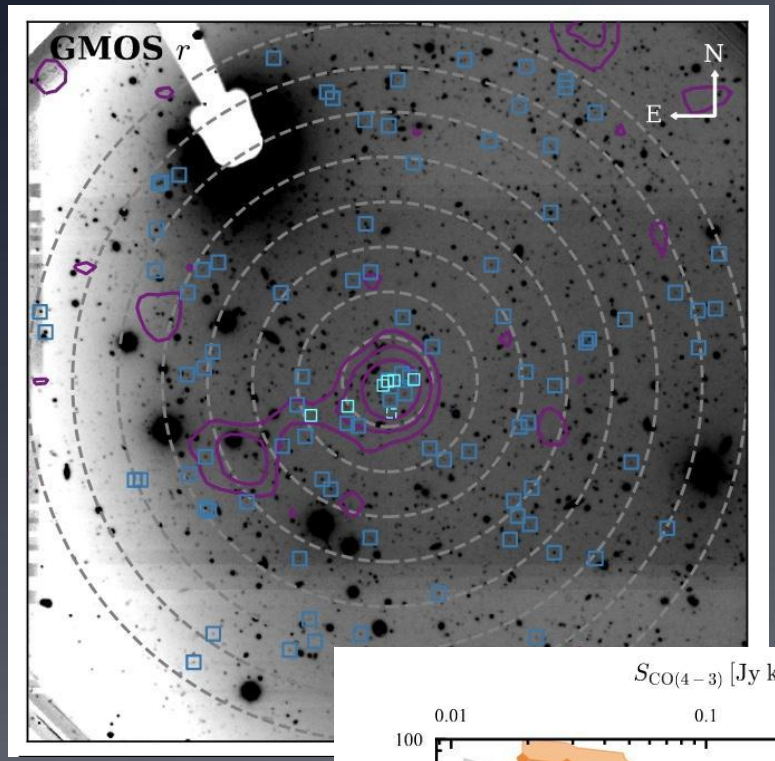


- *Wider field shows rest-UV Lyman-break galaxy overdensity*
- *5 confirmed with GMOS spectroscopy at z~4.31*
- But easier to uncover in wide-field mm-wave surveys (SPT, CCATp, etc)

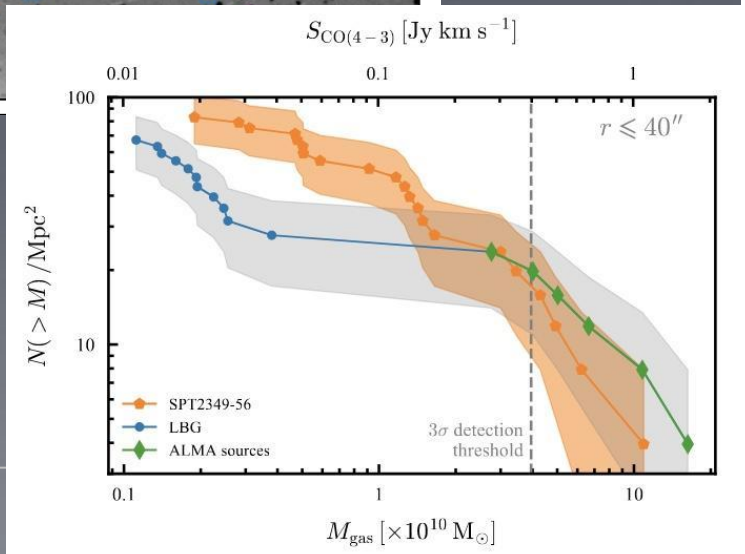


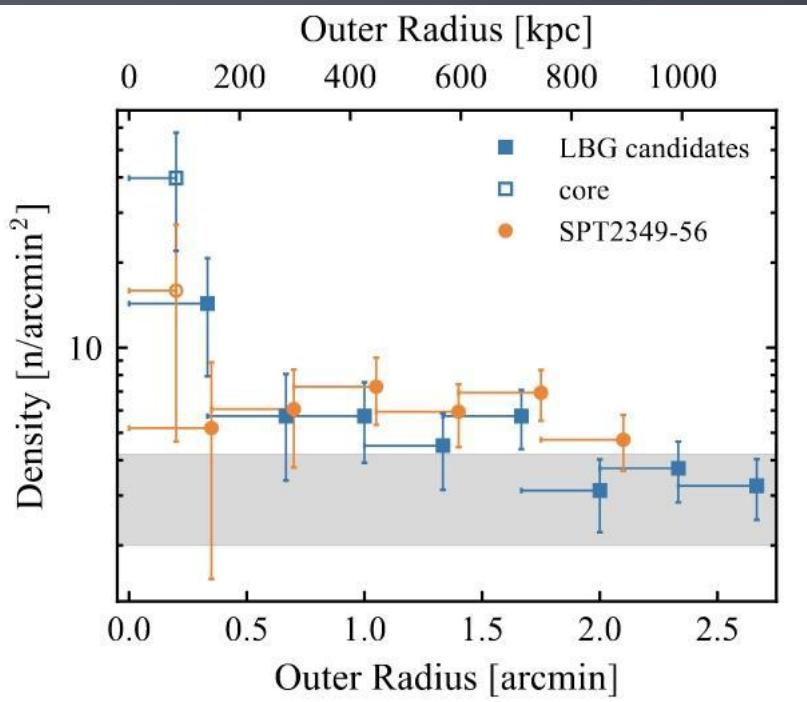
SPT0457-56

Rotermund et al 2022



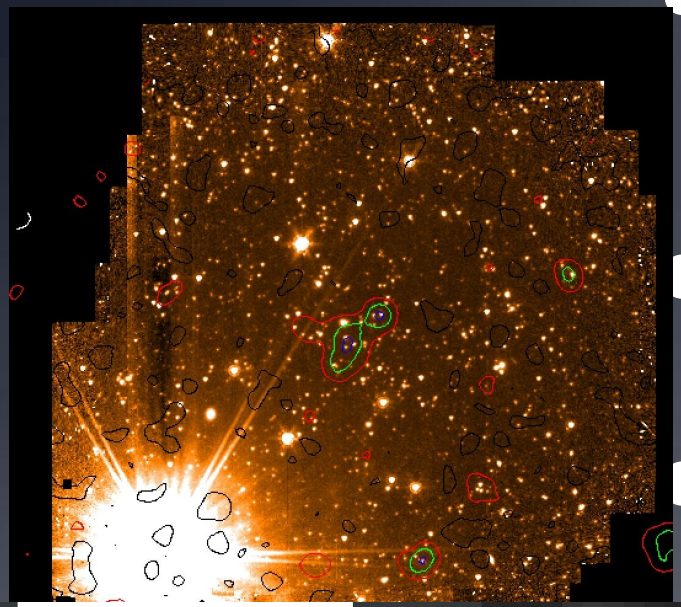
- *Wider field shows **stronger** rest-UV Lyman-break galaxy overdensity*
- *GMOS spectroscopy program ongoing*
- Still easier to uncover in wide-field mm-wave surveys (S



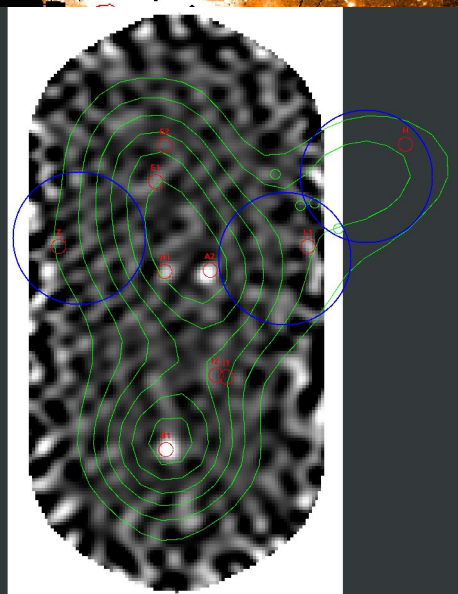


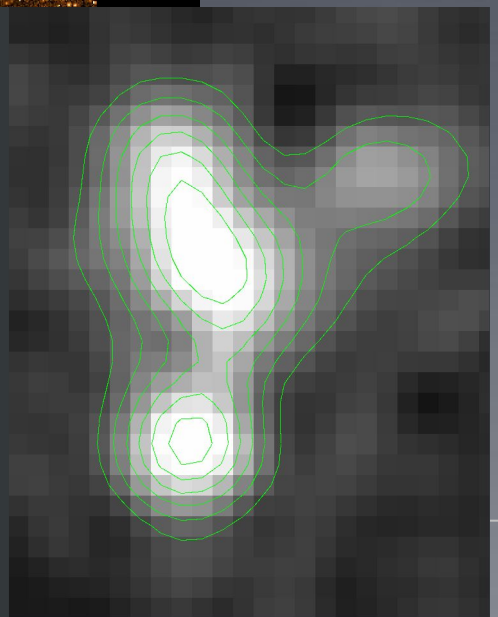
SPT0303-59

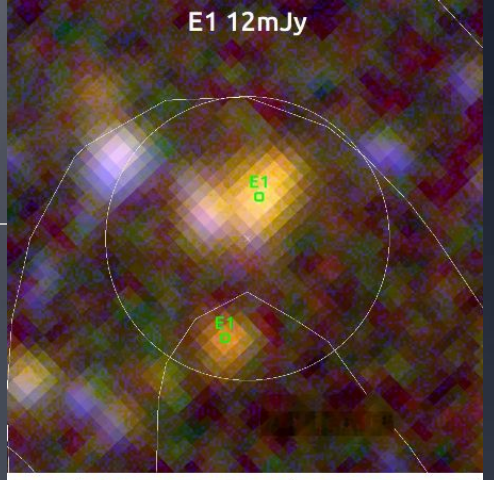
Salzenauer et al 2022

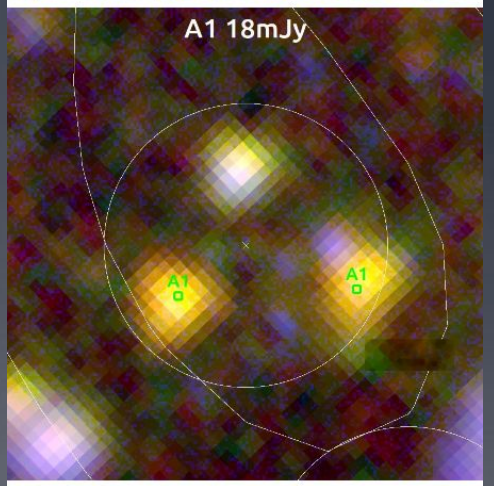


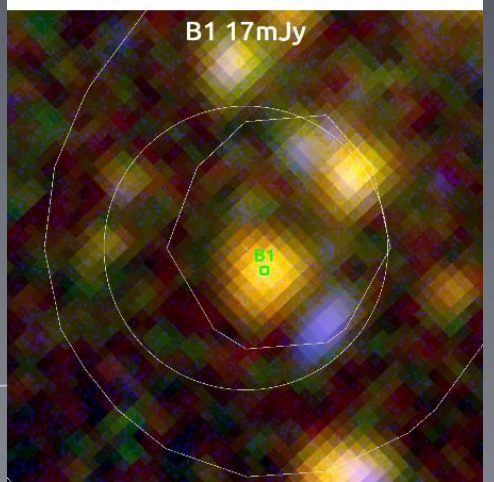
- ~~*Wider field shows rest-UV Lyman-break galaxy overdensity*~~
- Gemini + IRAC reveal IDs for ALMA sources
- GMOS program ongoing







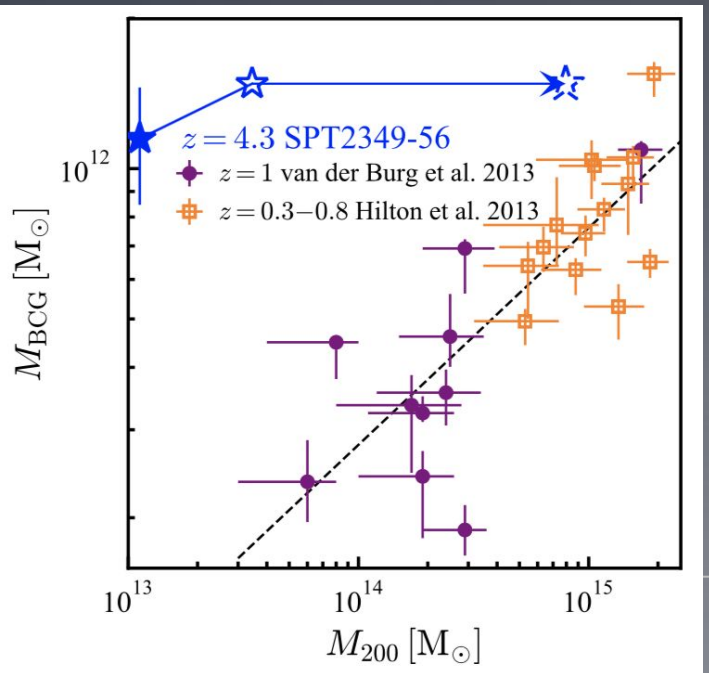




Gemini enables witnessing cluster BCG formation

C. Hayward; Flatiron Institute

Simulation



~20 galaxies merging:
BCG in place after ~500Myr

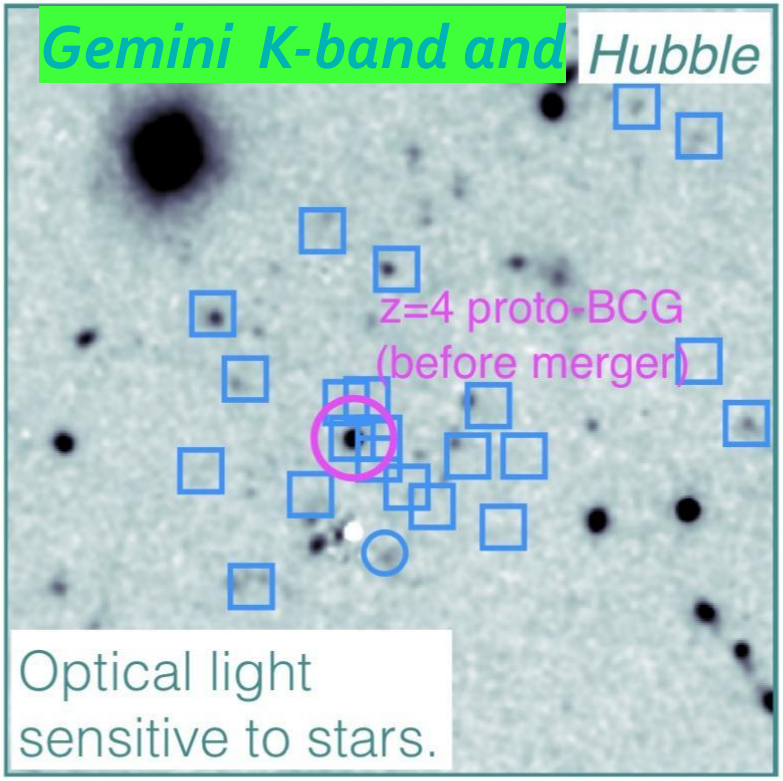
M^* increases >2x
in this event

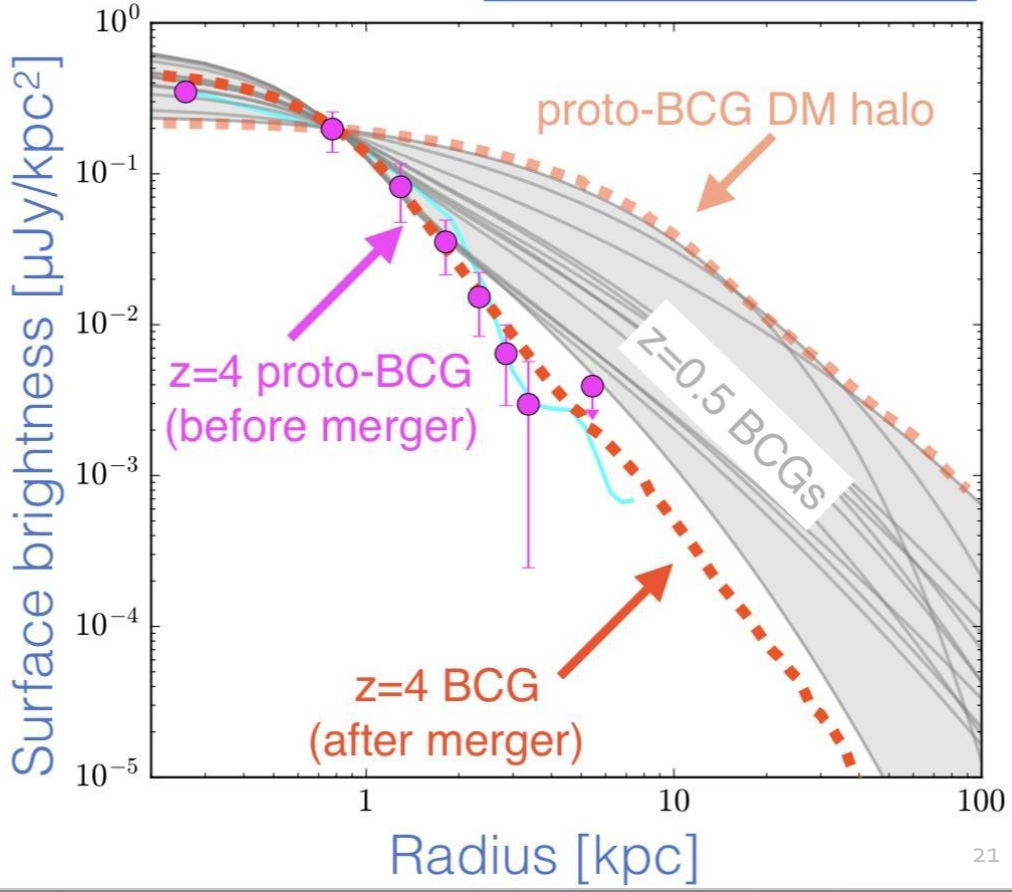
@ z=0: M^* > few x 10^{12} $M_\odot$

Rotermund+2021

The stellar content of SPT2349-56

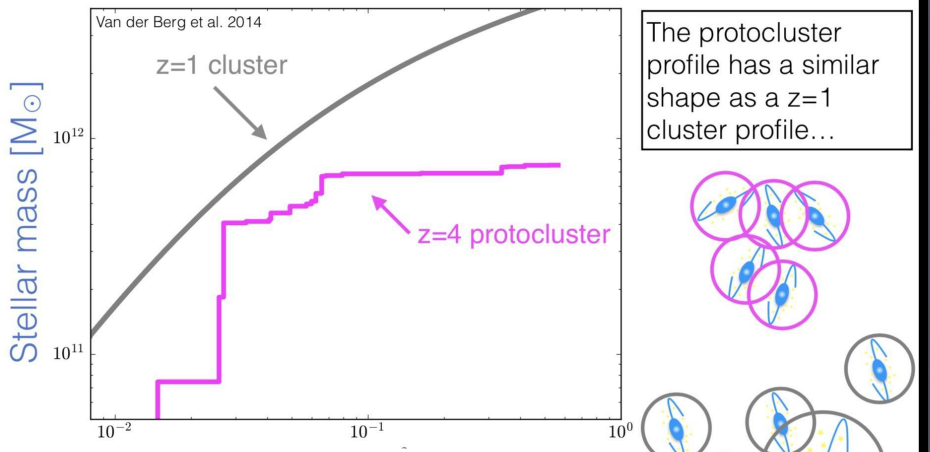
The BCG remains compact after the merger, but forms an extended DM halo.





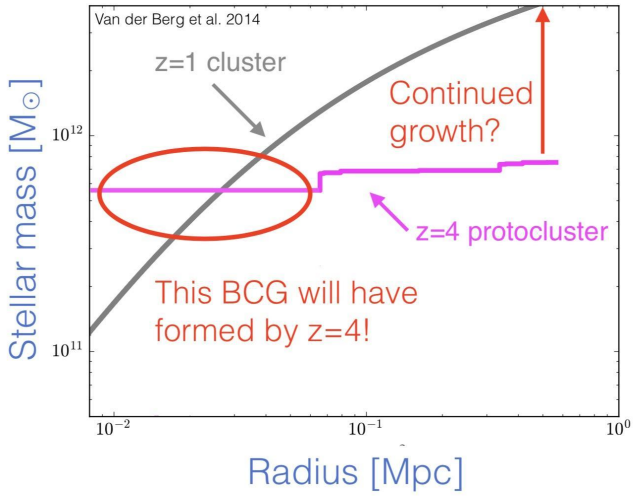
Hill+2022

The stellar content of SPT2349-56

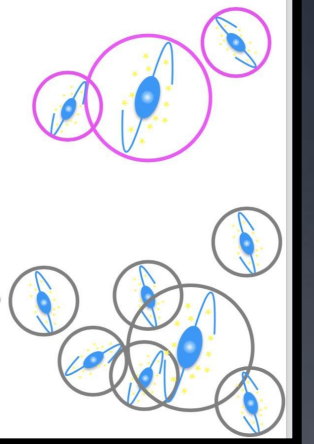


The protocluster profile has a similar shape as a z=1 cluster profile…

The stellar content of SPT2349-56



…until the core galaxies merge in 300 Myrs.



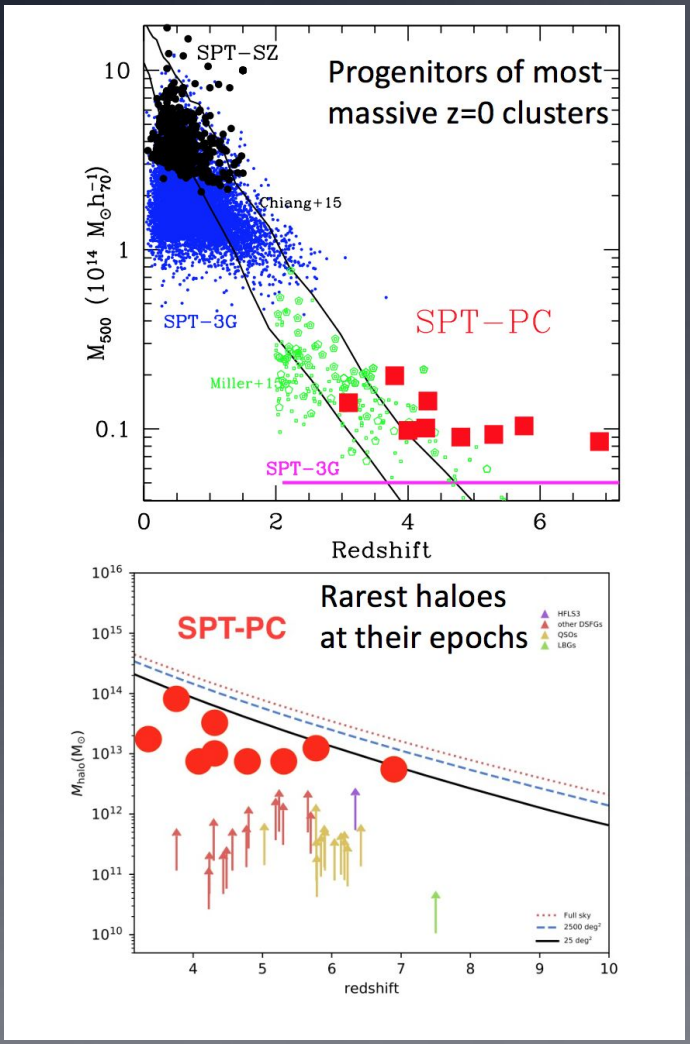
Downsizing in action!

SPT-3G (much deeper 1000deg^2):

Explore/Define protocluster survey

- Up to 5x deeper than SPT-SZ
- But faintest sources will be more prone to blending of line-of-sight galaxies (recall K-correction)
- Offers possibility of search for more extended proto-cluster structures
- Will require ***a lot*** (*more selective?*) of followup with APEX/ALMA

Summary



- Discovery of these PCs is only possible due to the synergy between large area surveys and sensitive interferometers in the submm

- SPT-PCs are unique systems to study the earliest phase of massive galaxy and cluster formation. They allow to study the evolution of the most massive DM halos out to z=7!

- Bright Central Galaxies form earlier than expected from most simulations and current observational wisdom (z>4 vs z~1-2)

High-z PCs will allow to study the evolution of the Forming galaxies in cluster environments

… investigate differences in the evolution between cluster and field galaxies.

extra