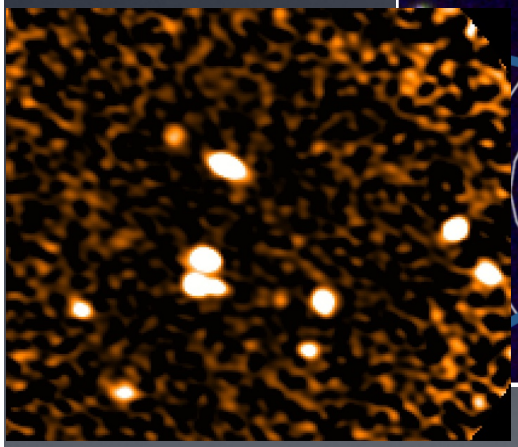
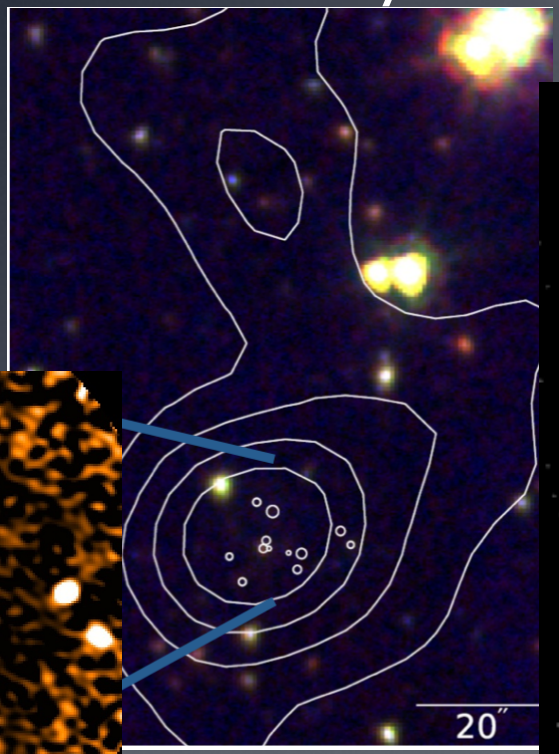
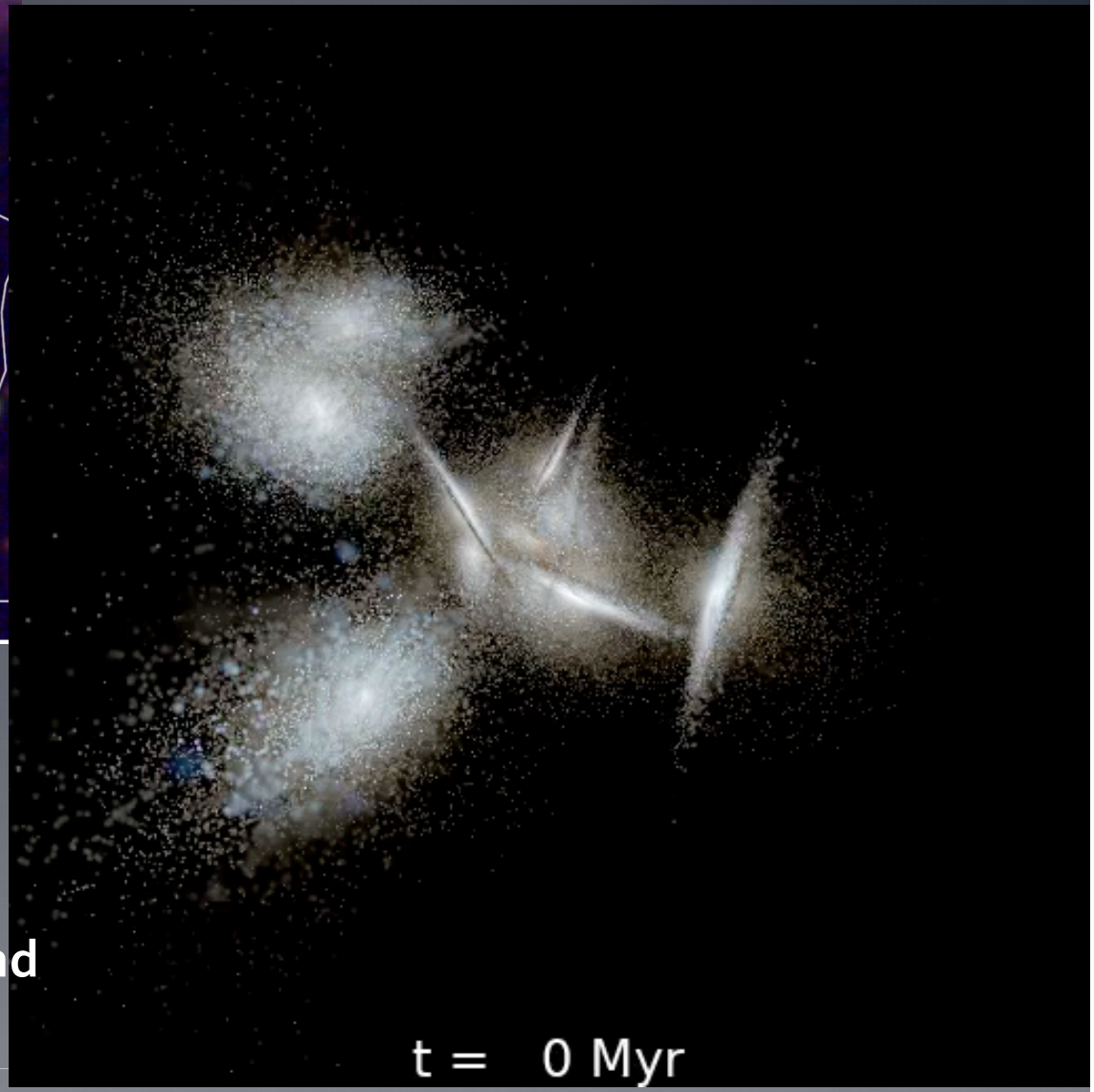
Massive Galaxy Protoclusters in the Early Universe uncovered by the South Pole Telescope

SPT2349

z=4.31







Scott Chapman

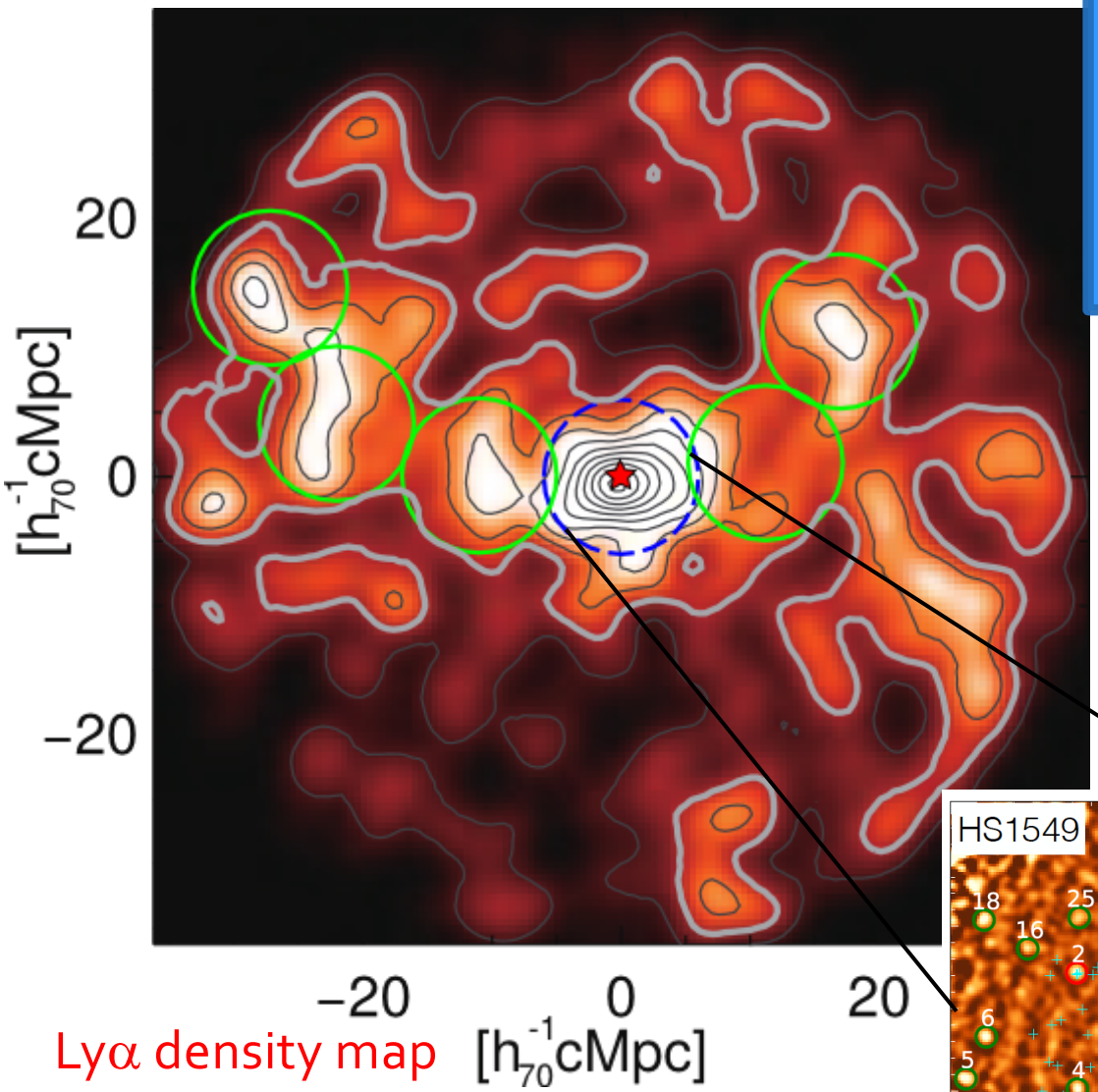
(NRC,UBC,Dalhousie)

Miller T., Hill R., Wang G., Rotermund K., Apostolovski Y., Canning R.,

Weiss A., Hayward C., de Breuck, C., Vieira, J., Spilker, J., Scott D., SPT collaboration

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

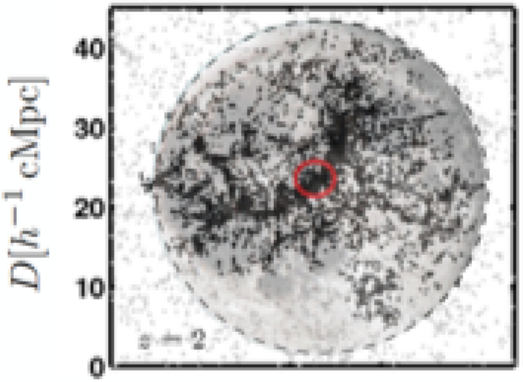
Protoclusters at z>3 are large, ~1 deg² region will collapse down by factor 100x



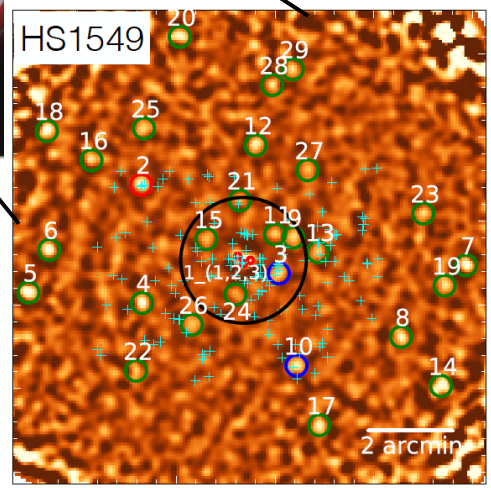
Lyα density map

Matsuda et al. in prep

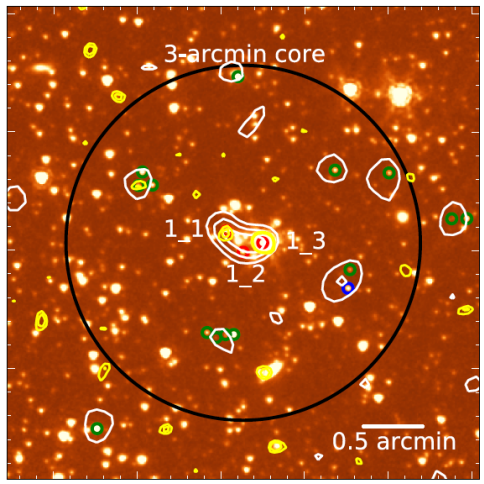
Looks like sims



(Lacaille et al. 2017)



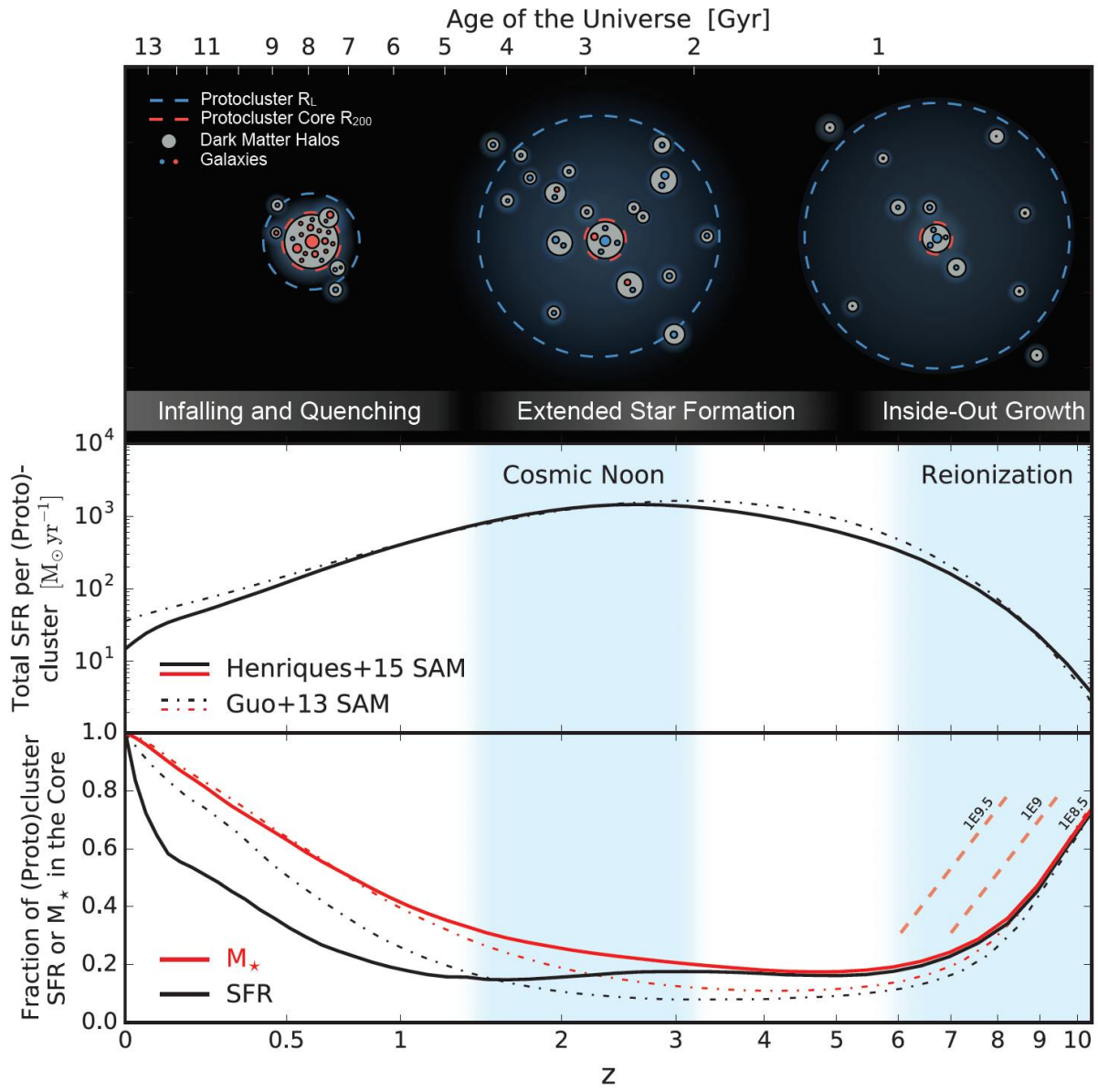
SCUBA-2 maps



SMA/NOEMA resolved core

Early *inside-out* formation in protocluster core

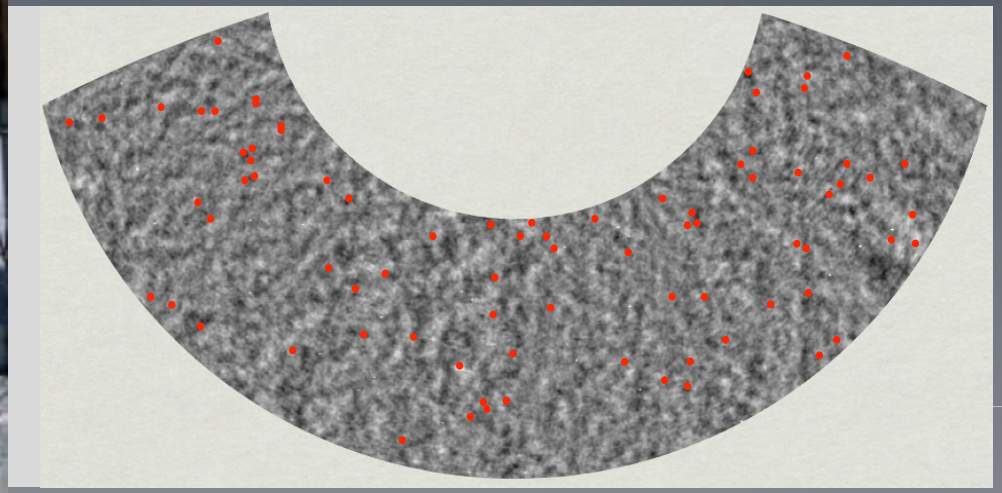
(Chiang et al 2013, 2017)

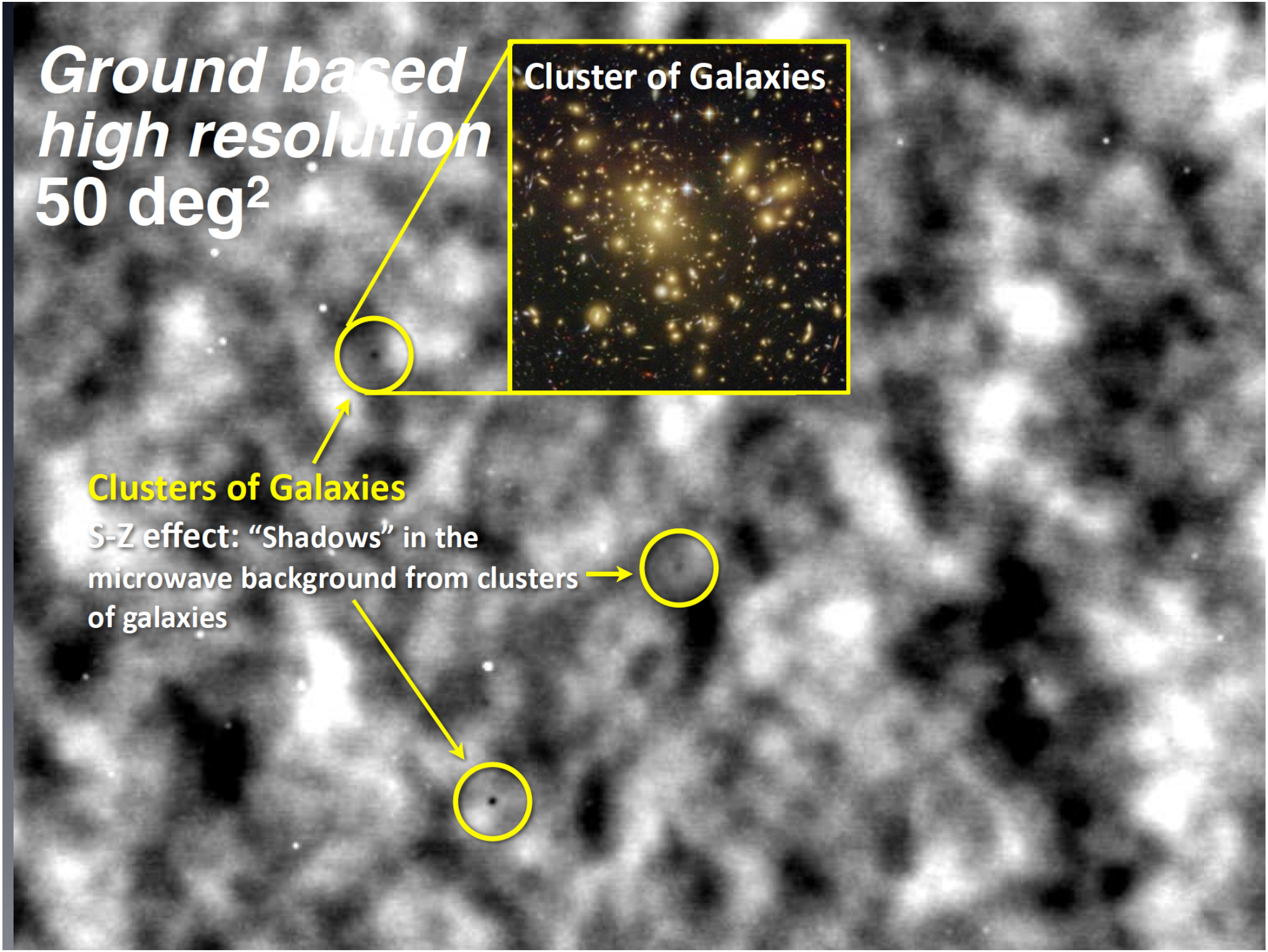


… finding very early ‘cores’ as protocluster signposts ?

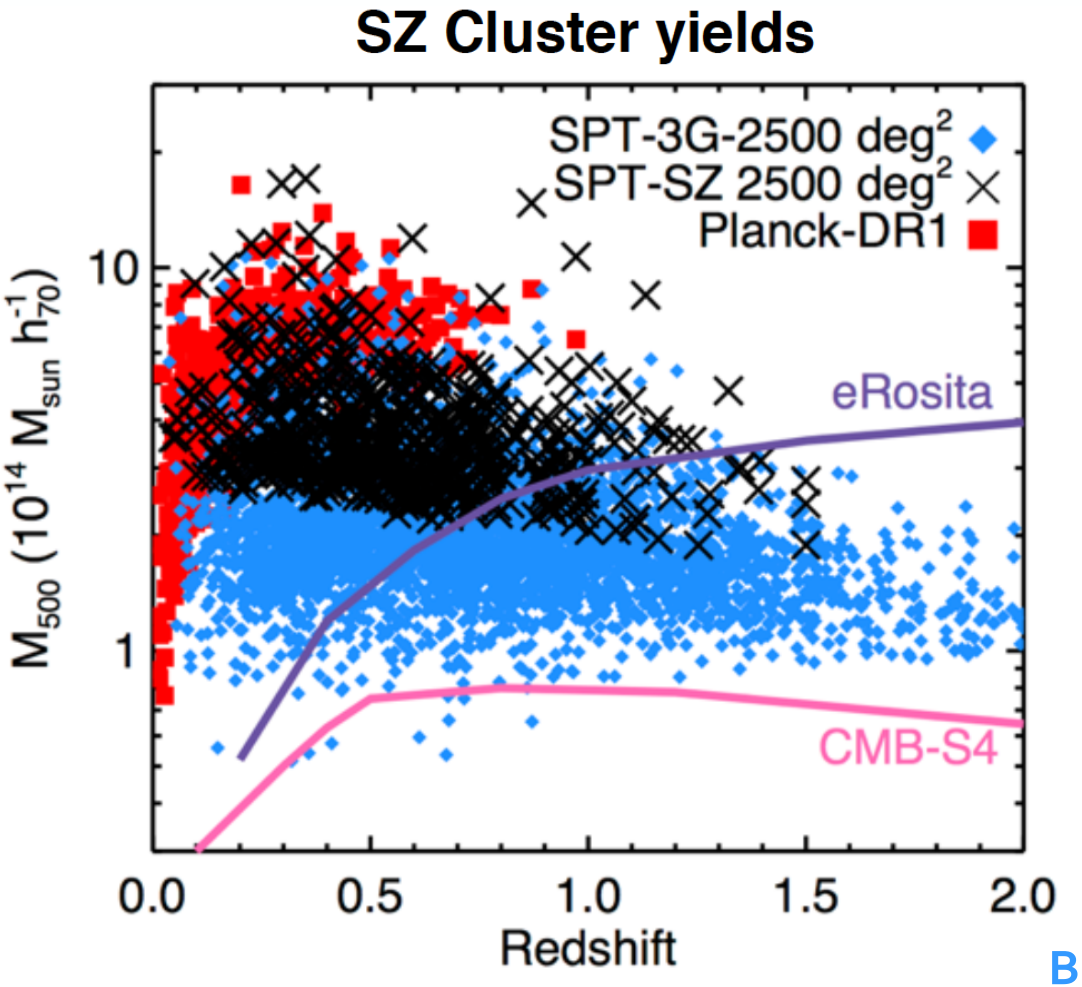
SPT-SZ 2500 deg^2 @ 3mm,2mm, 1.4mm

1 arcmin beam




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

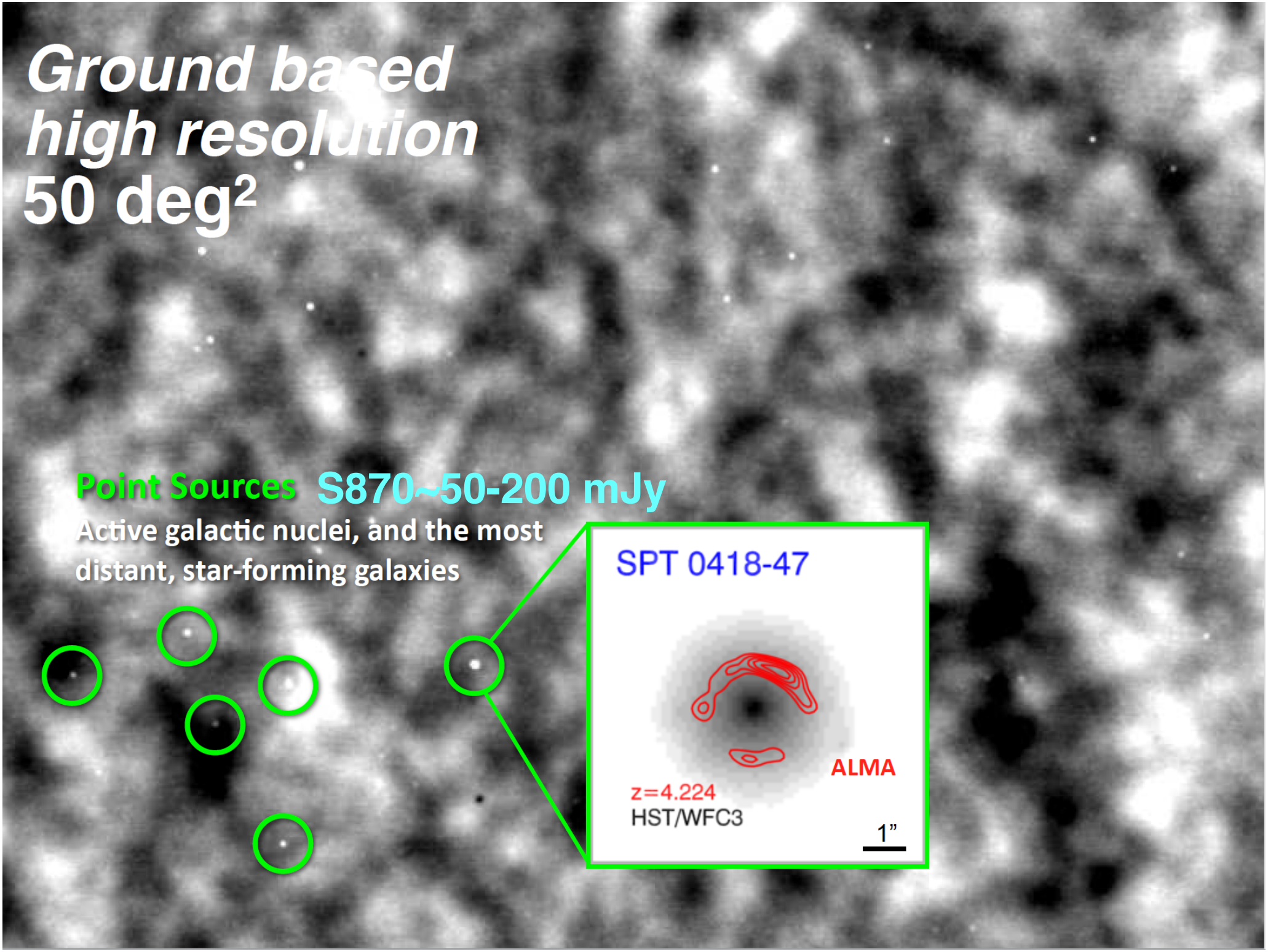
CMB-S4: $N_{\rm clust} \sim 100{,}000$

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.

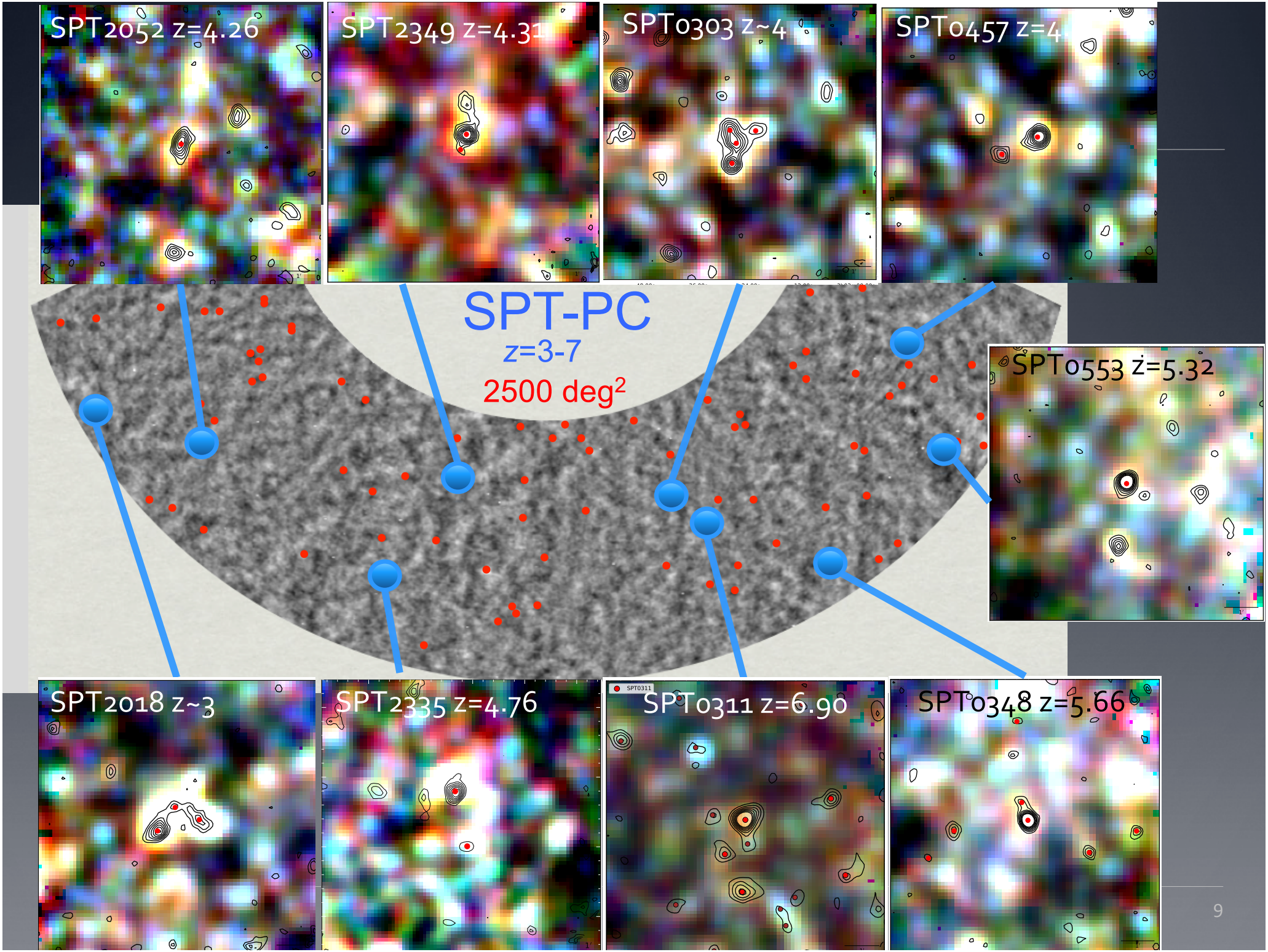
Beyond z>2, clearly in protocluster territory


Ground based
high resolution
50 deg²
Point Sources S870~50-200 mJy
Active galactic nuclei, and the most
distant, star-forming galaxies
SPT 0418-47
ALMA
z=4.224
HST/WFC3
1”

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

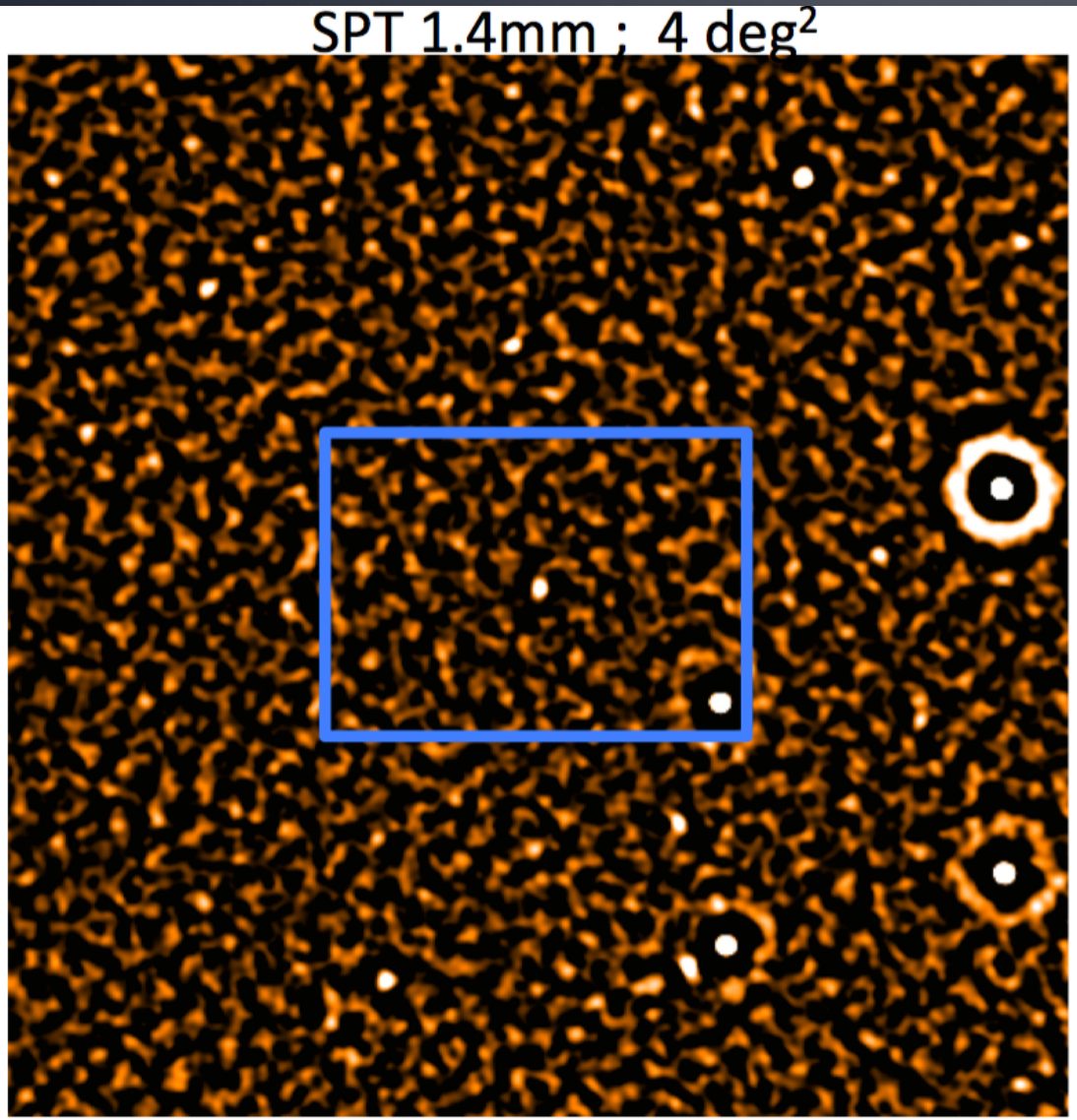
Extremely active 'proto-cluster' core regions in early Universe?

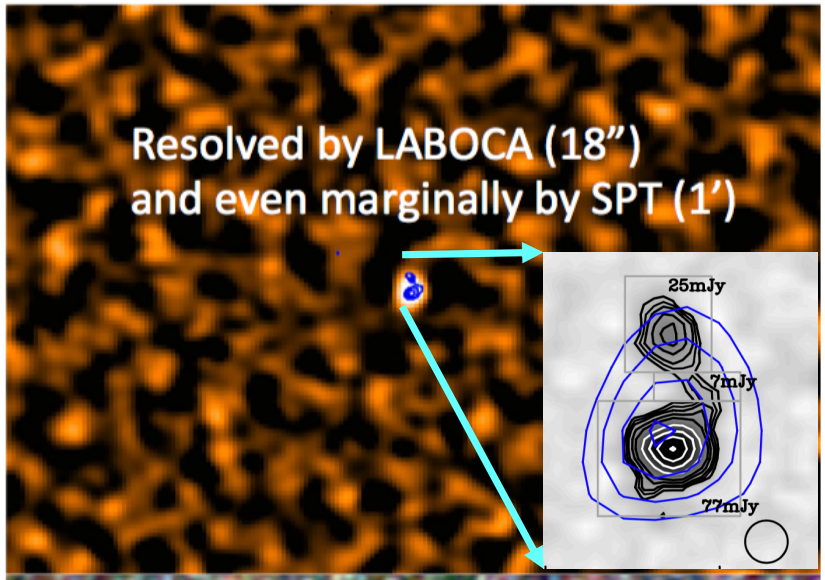

SPT2052 z=4.26
SPT2349 z=4.31
SPT0303 z~4
SPT0457 z=4
SPT-PC
z=3-7
2500 deg2
SPT0553 z=5.32
SPT2018 z~3
SPT2335 z=4.76
SPT0311 z=6.90
SPT0348 z=5.66

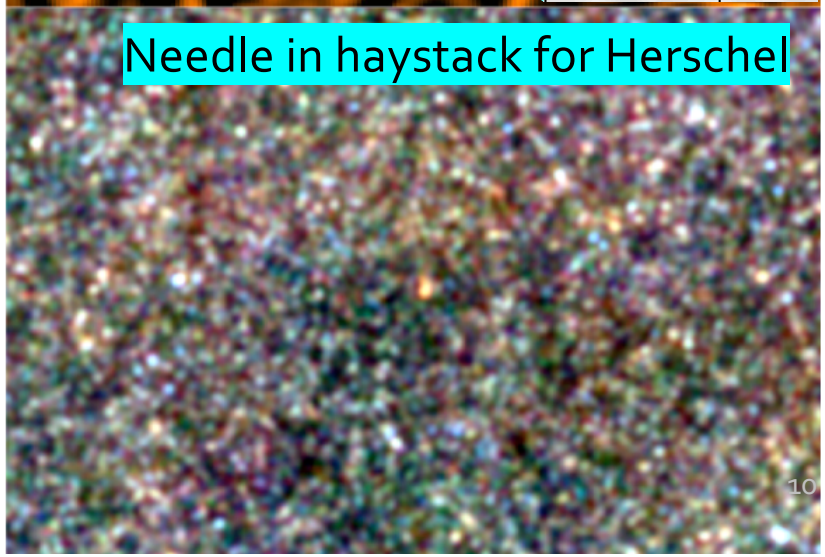
SPT-pol (deeper 400deg²)

SPT2349 detected at 12σ Clearly extended in SPT beam

Signature for deeper protocluster search







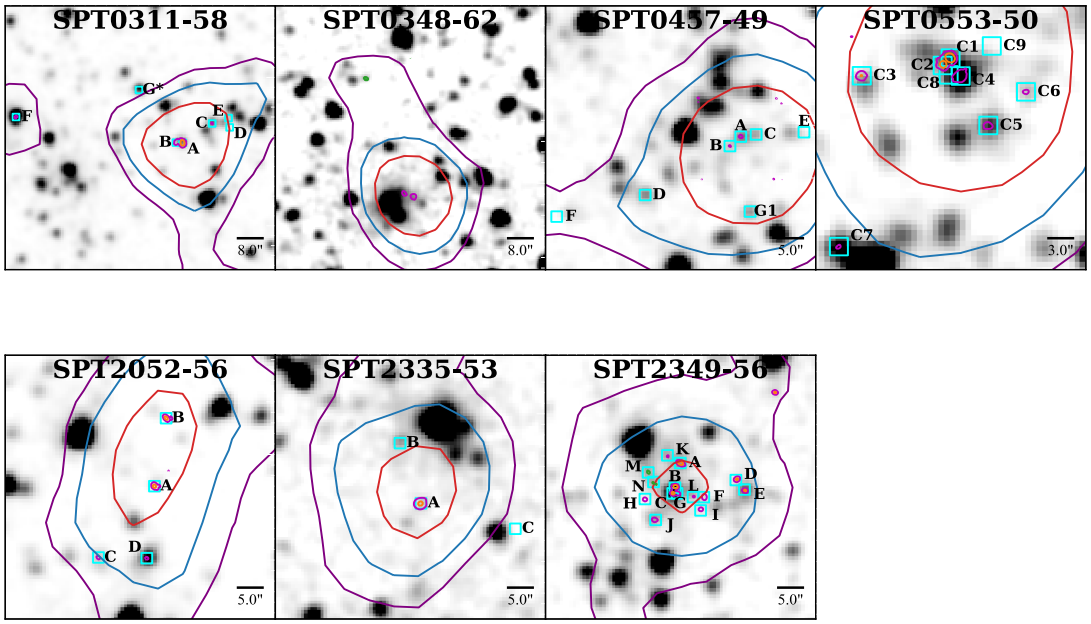
An SPT proto-cluster survey

SPT2349 is clearly the most spectacular object of its kind in SPT-SZ

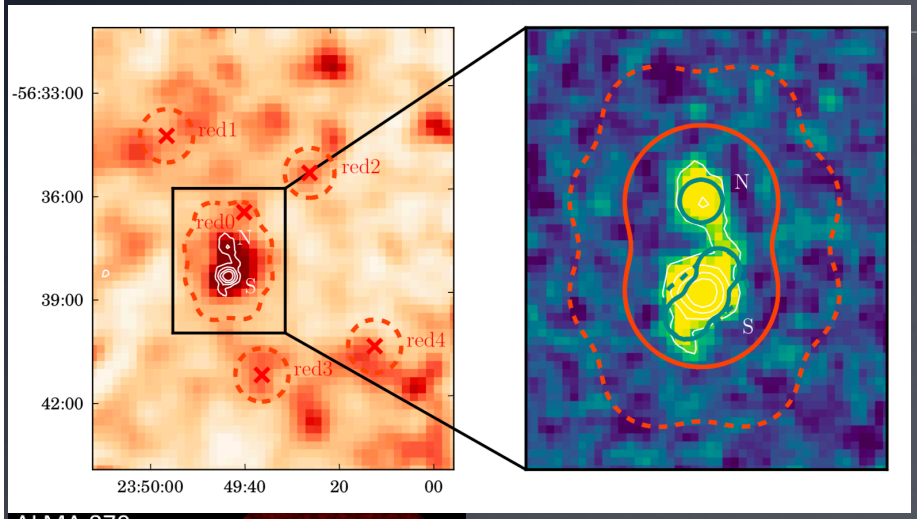
Knowing what to look for … can we find other SPT protoclusters?

- ALMA resolves LABOCA into multiple sources (*Cy3-7 programs)*
- No plausible lens galaxy or cluster/group lens
- Deep LABOCA shows overdensity of red satellites in larger field

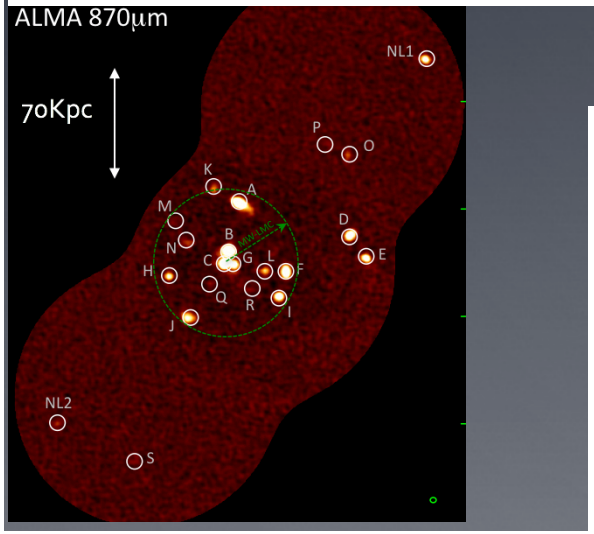
Chapman+2020

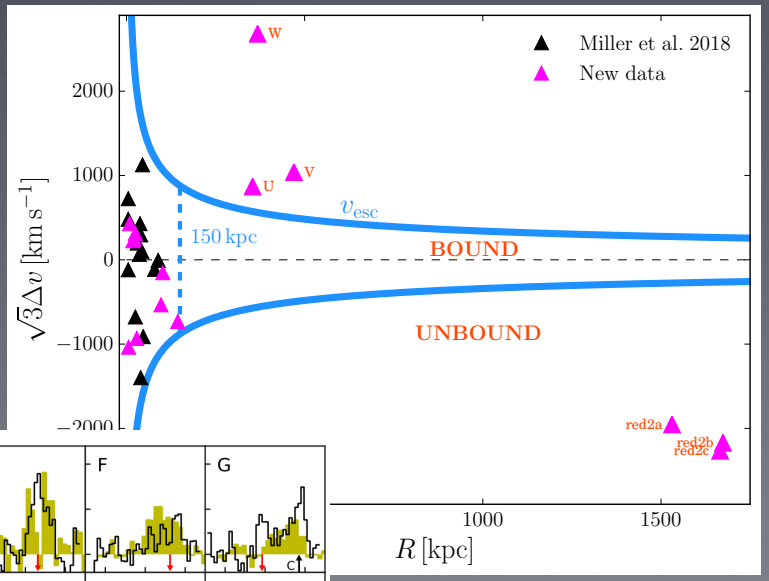


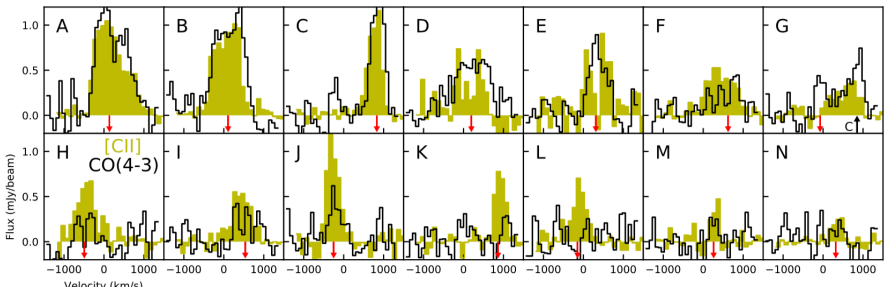
SPT2349-56 z=4.3 (Miller,Chapman+2018; Hill,Chapman+2020)

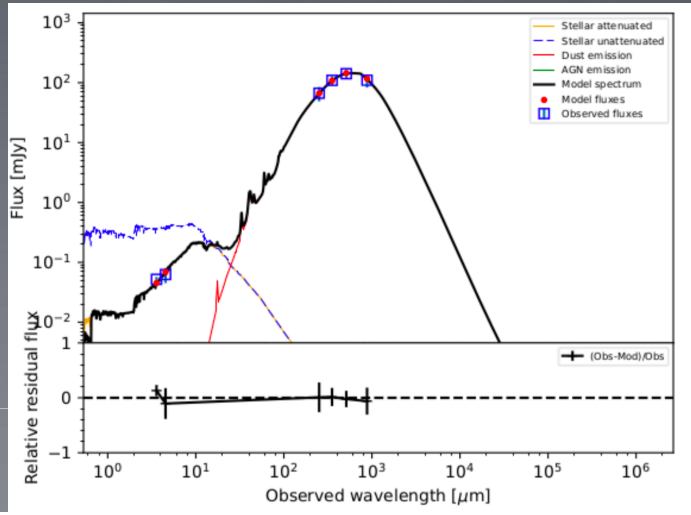


- 33 galaxies ID'd by ALMA at z=4.3
  - ~66o% resolved in core
- ALMA central mosaic, and satellite candidates to ~2 pMpc.
- L_{IR}~10^{14} Lsun. SFR ~ 17,000 M/yr, *and most concentrated system known*





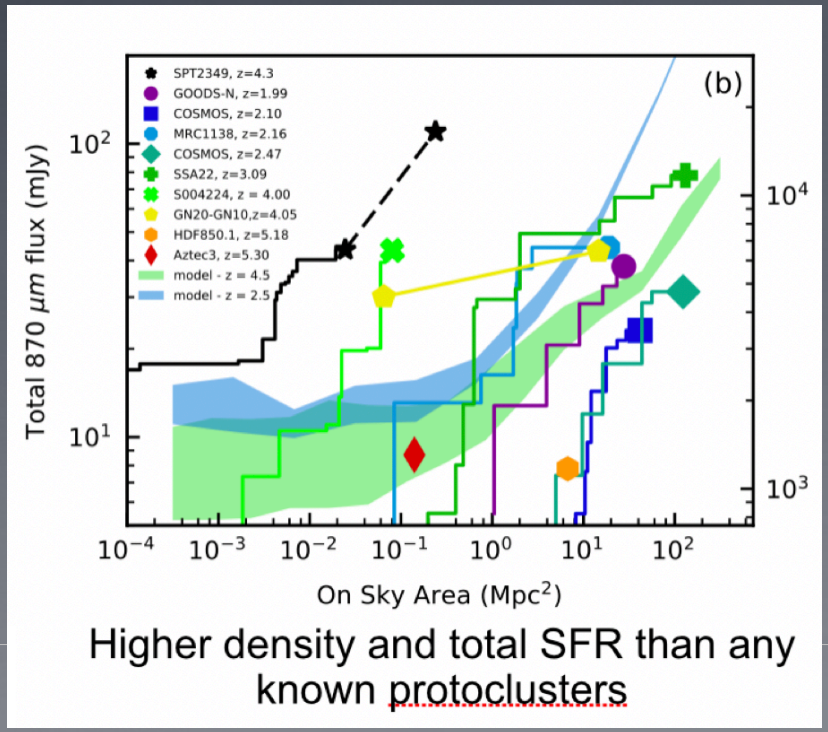




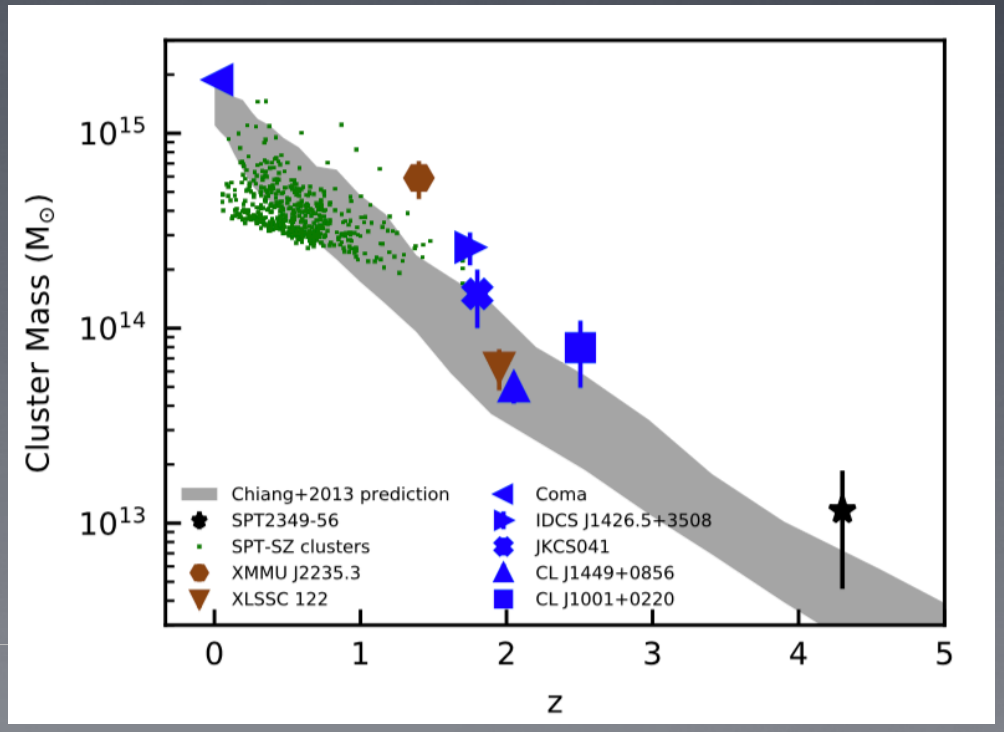
Key results Miller,Chapman+18

- *Most concentrated, and highest total SFR system known*
- *17,000 M./yr*
- *Core: 1e6 M./yr / Mpc³*

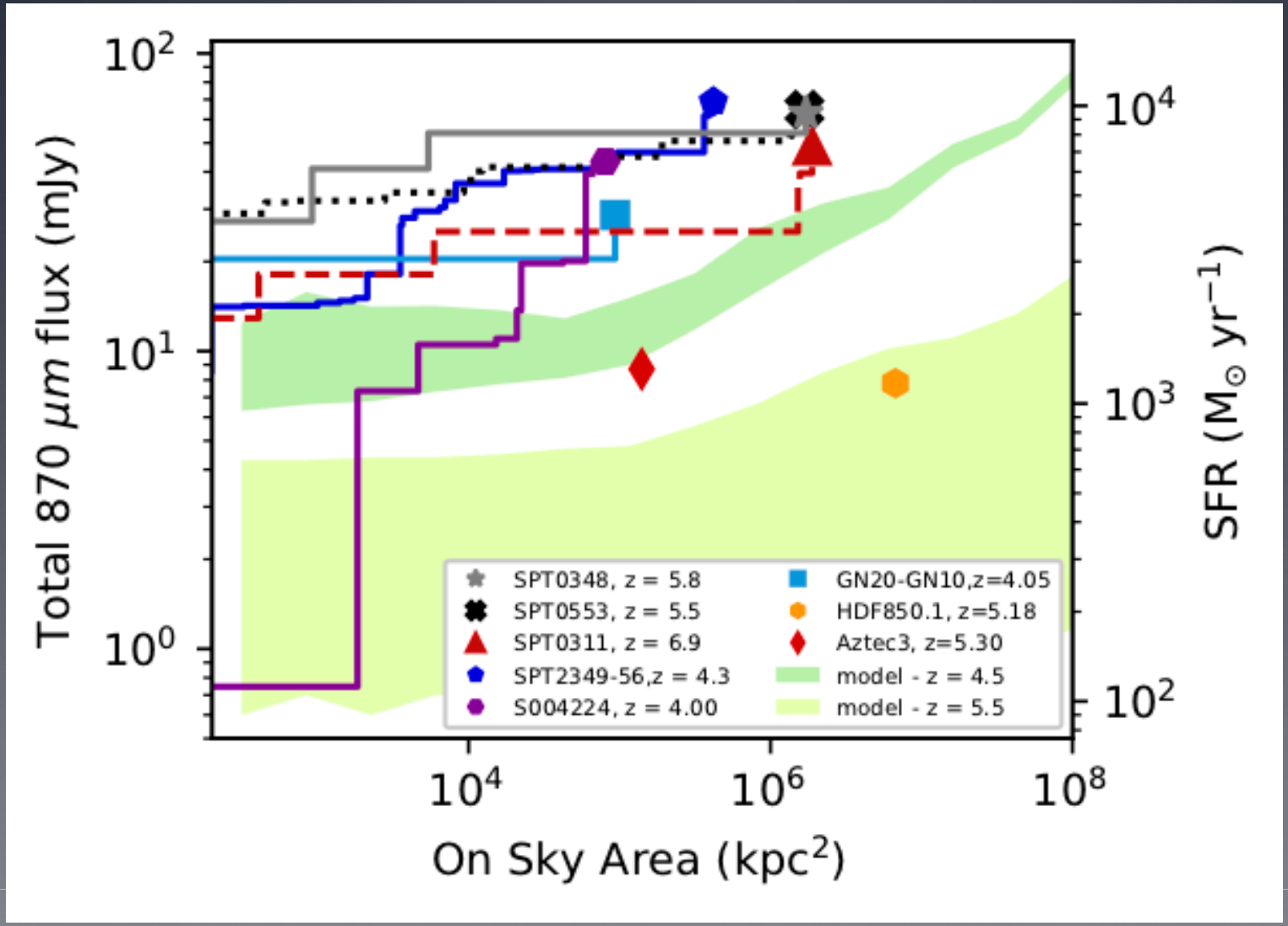
- massive halo (>10^{13} Msol) observed kinematically at z>4
- Progenitor of Coma-like cluster?



Higher density and total SFR than any known protoclusters



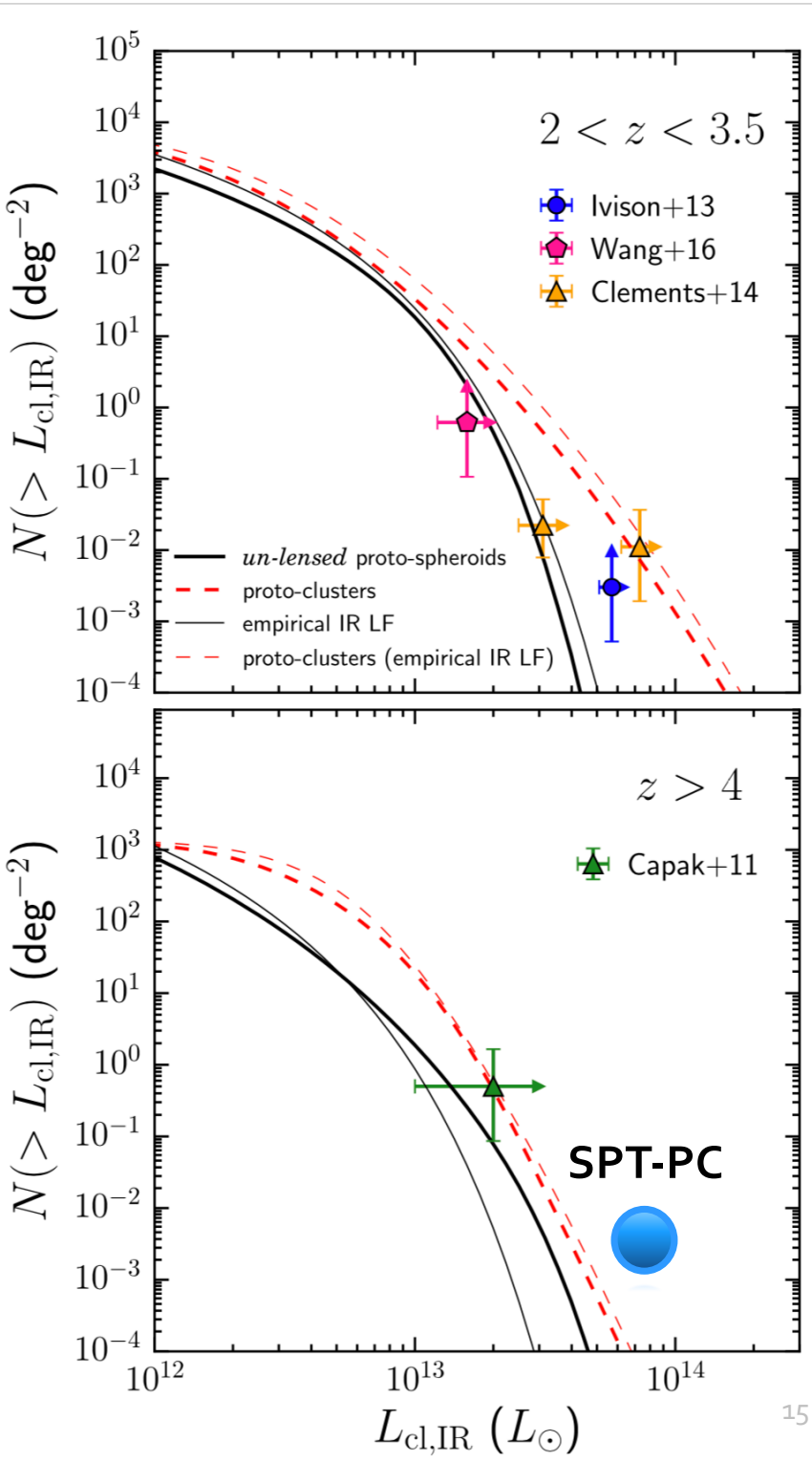
At z>5 the contrast with models even more severe



SPT clearly shows more than predicted

Compare to recent PC counts predictions

Negrello+2017: counts of protoclusters/cores

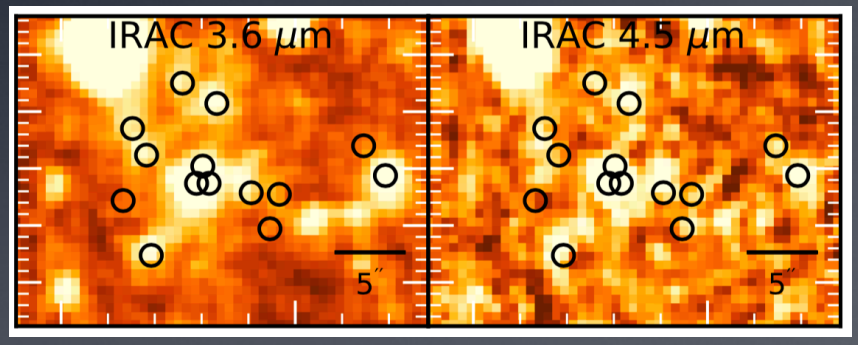


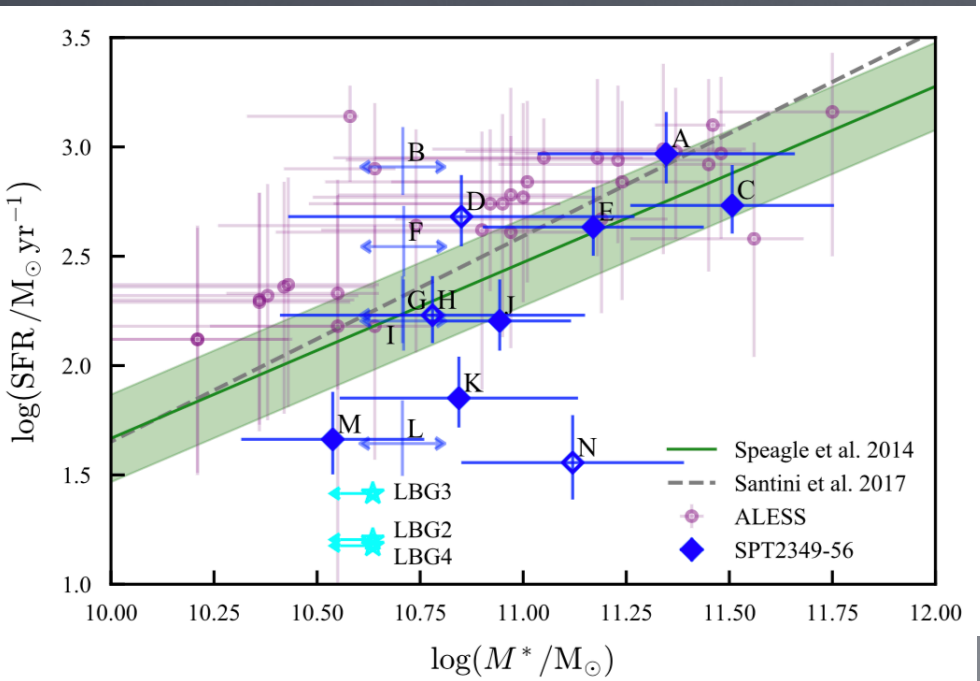
SPT2349-56: Characterizing galaxy properties

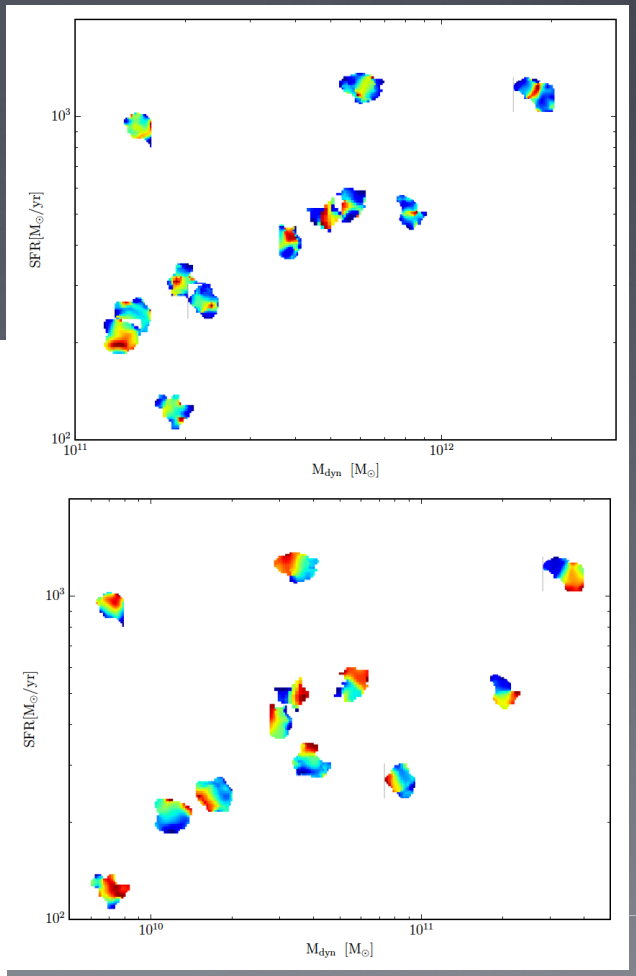
Rotermund, Chapman + 2020 Hill + in prep

- M* from opt-IRAC and SED fitting:
  Comparable to field ***Main Seq.*** at z=4

Mass budget ~50% DM.



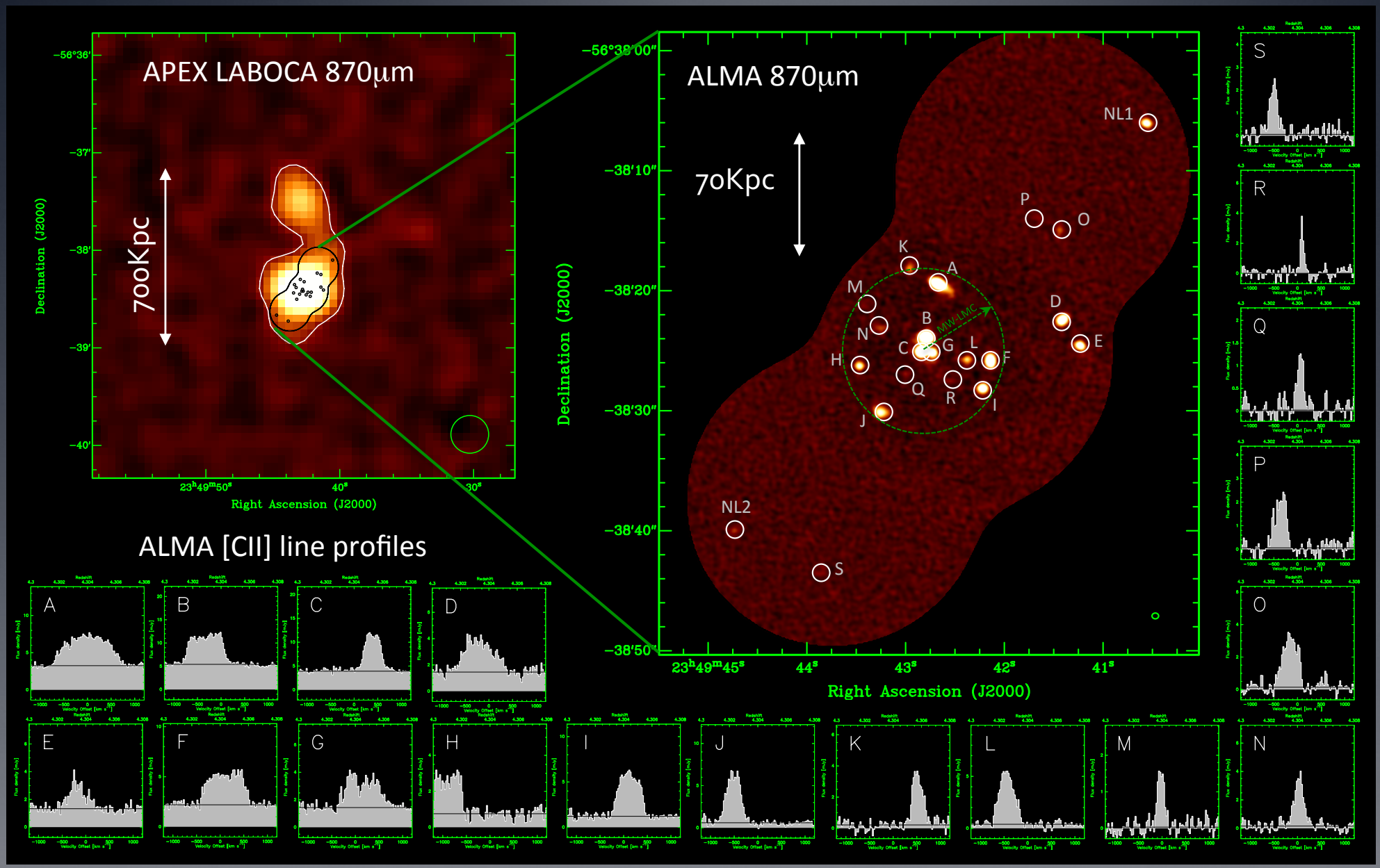




Mass estimates in 2 ways

- Dispersion
- rotation

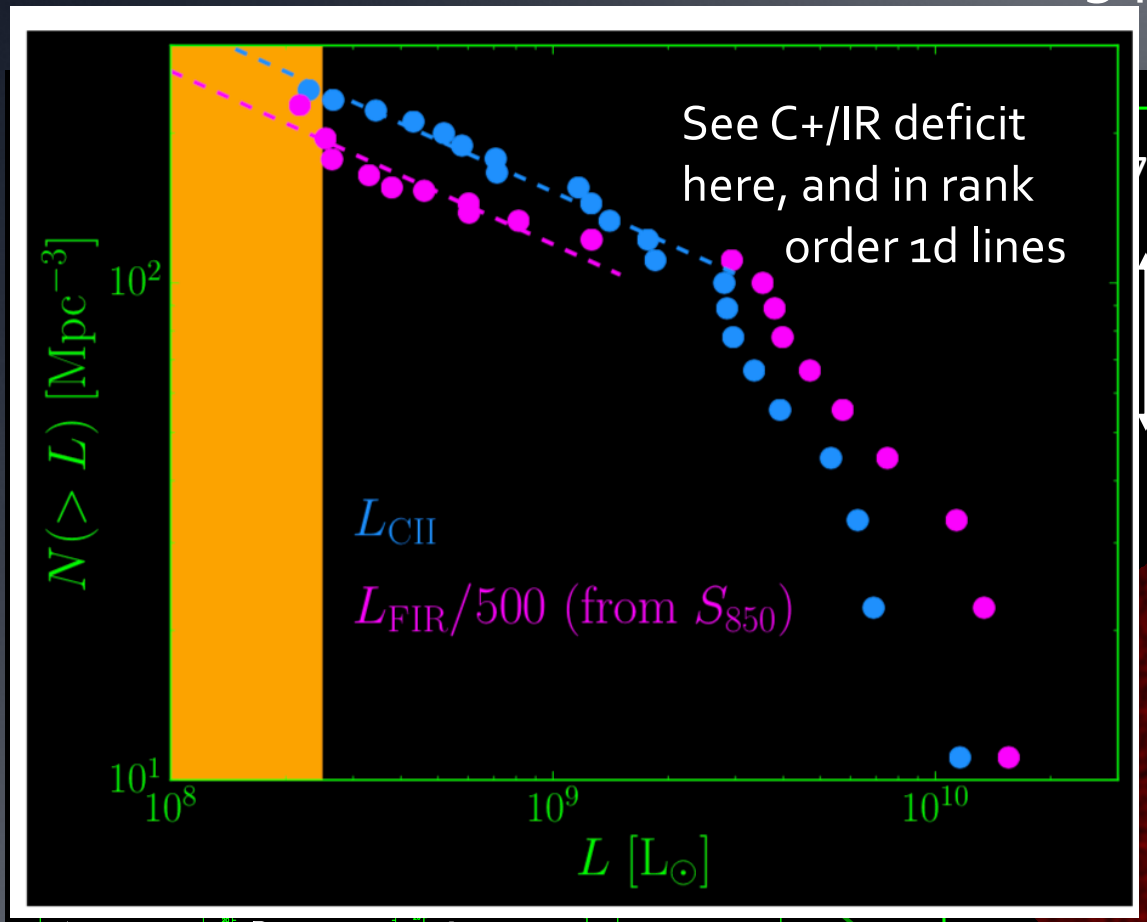
Proto-cluster SPT2349-56 @ z=4.3



update on Miller T.B., et al. 2018, Nature, 556, 469

25 individual members within 150kpc

Proto-cluster core SPT2349-56 @ z=4.3



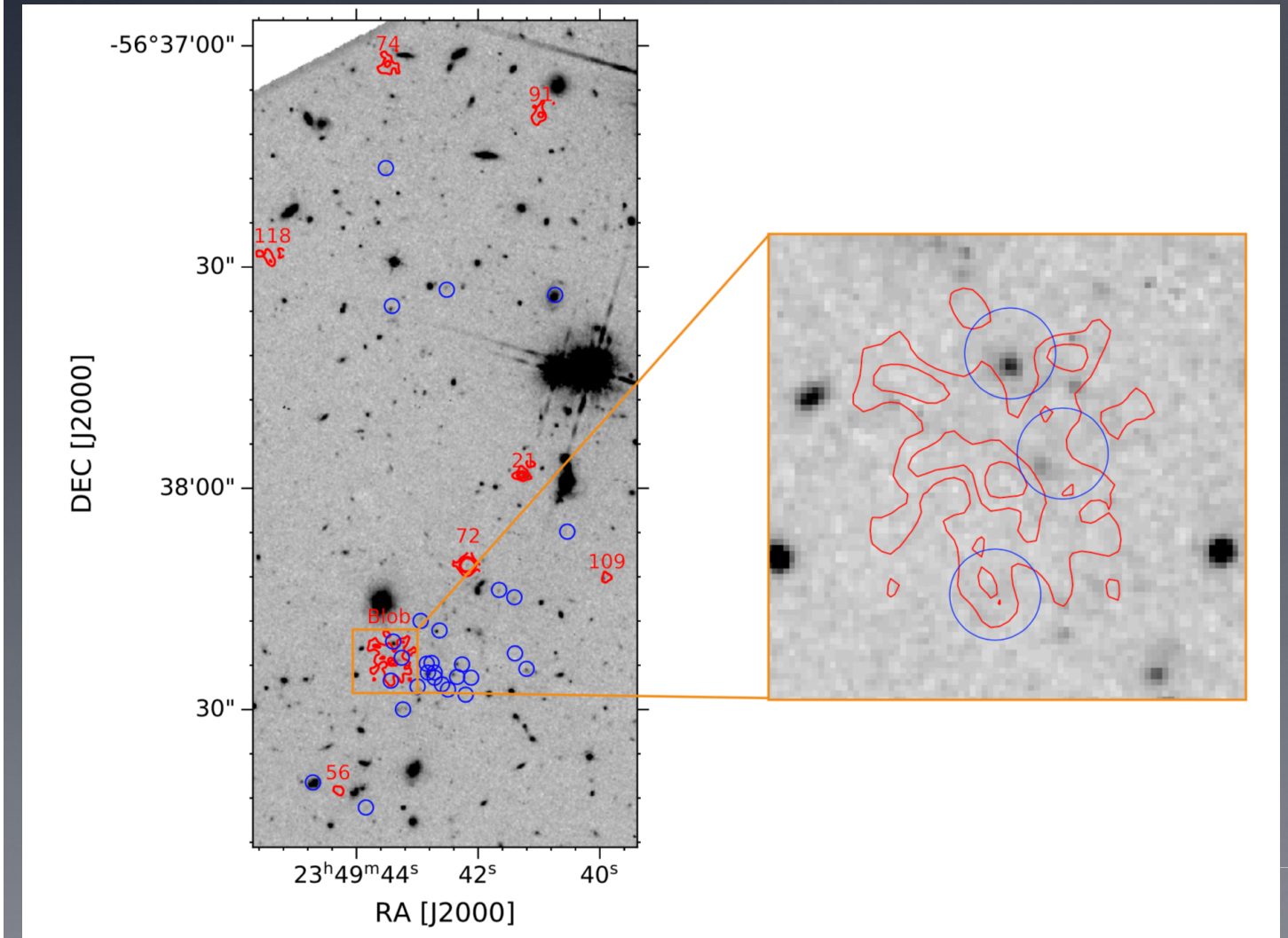
update on Miller T.B., et al. 2018, Nature, 556, 469

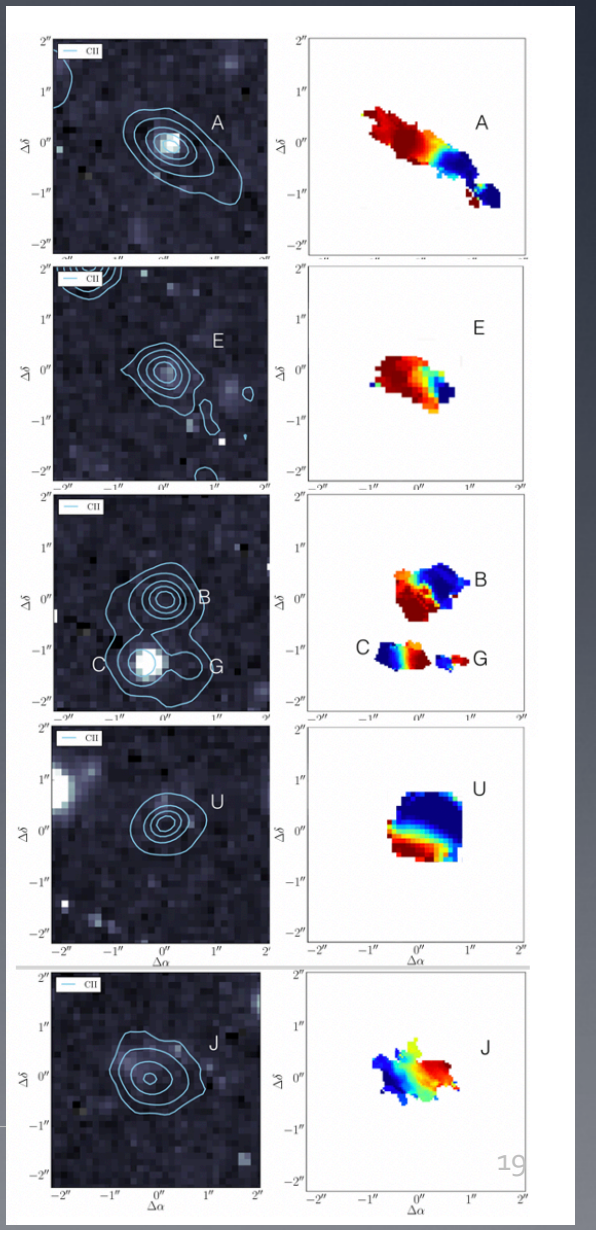
25 individual members within 150kpc

PC Galaxy properties from HST

Need for Roman and JWST

- WFC3 field too small: **doesn't cover extended structure.**
- 5 orbit program **not nearly deep enough** to characterize galaxies



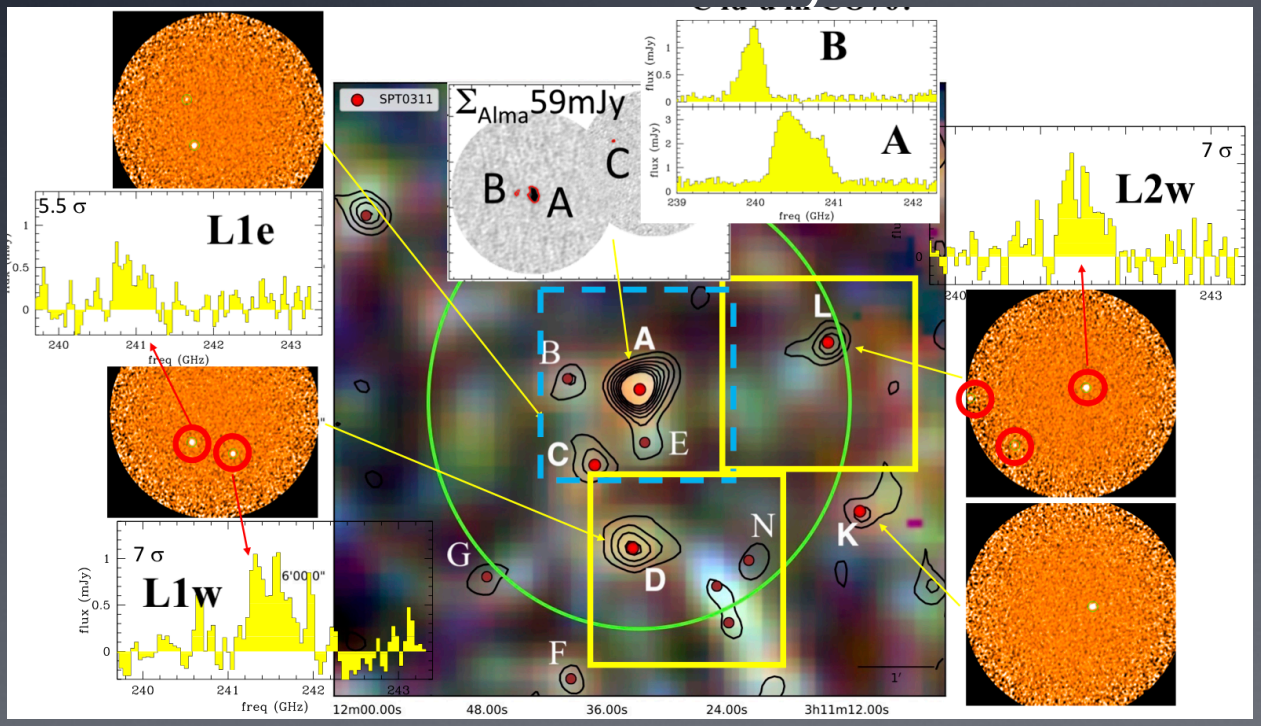


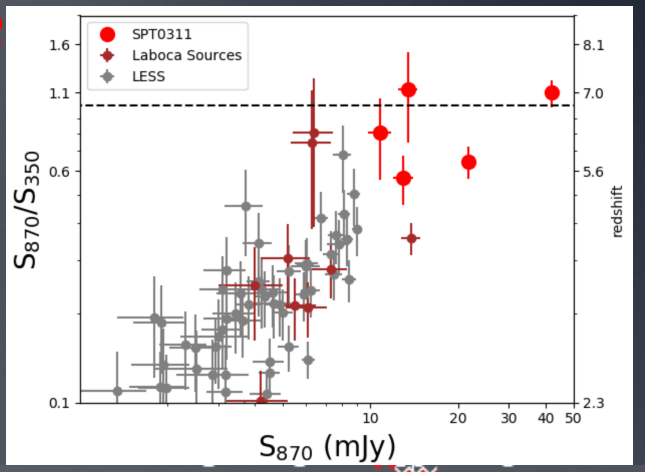
HST followup to SPT0311-58 (z=6.9)

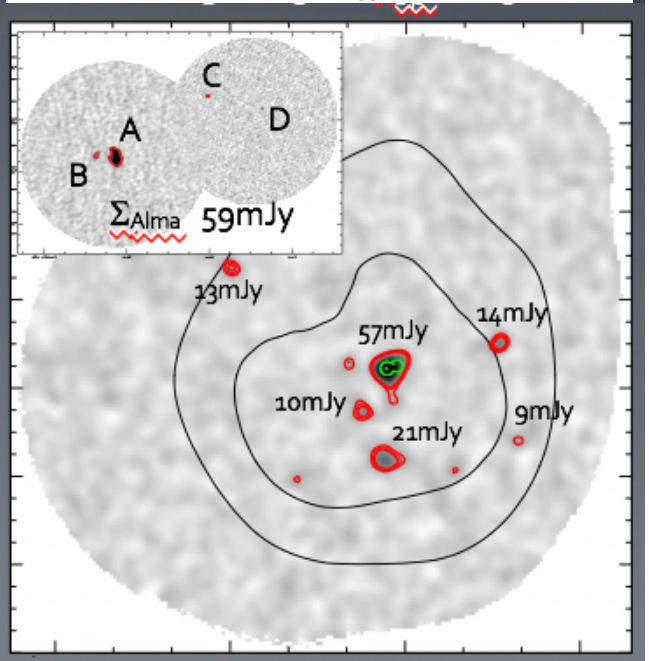
WFC3 field small relative to extended structure.

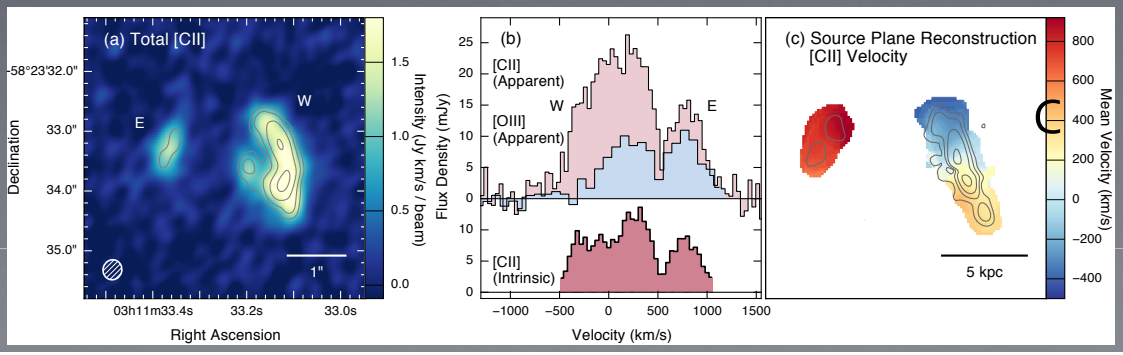
25orbit program just scratching surface

6 SMGs identified at z=6.9 in C+









Chapman+ in prep

Marrone+18 Nature, 553, 51

5hr on MUSE: LAB in SPT2349

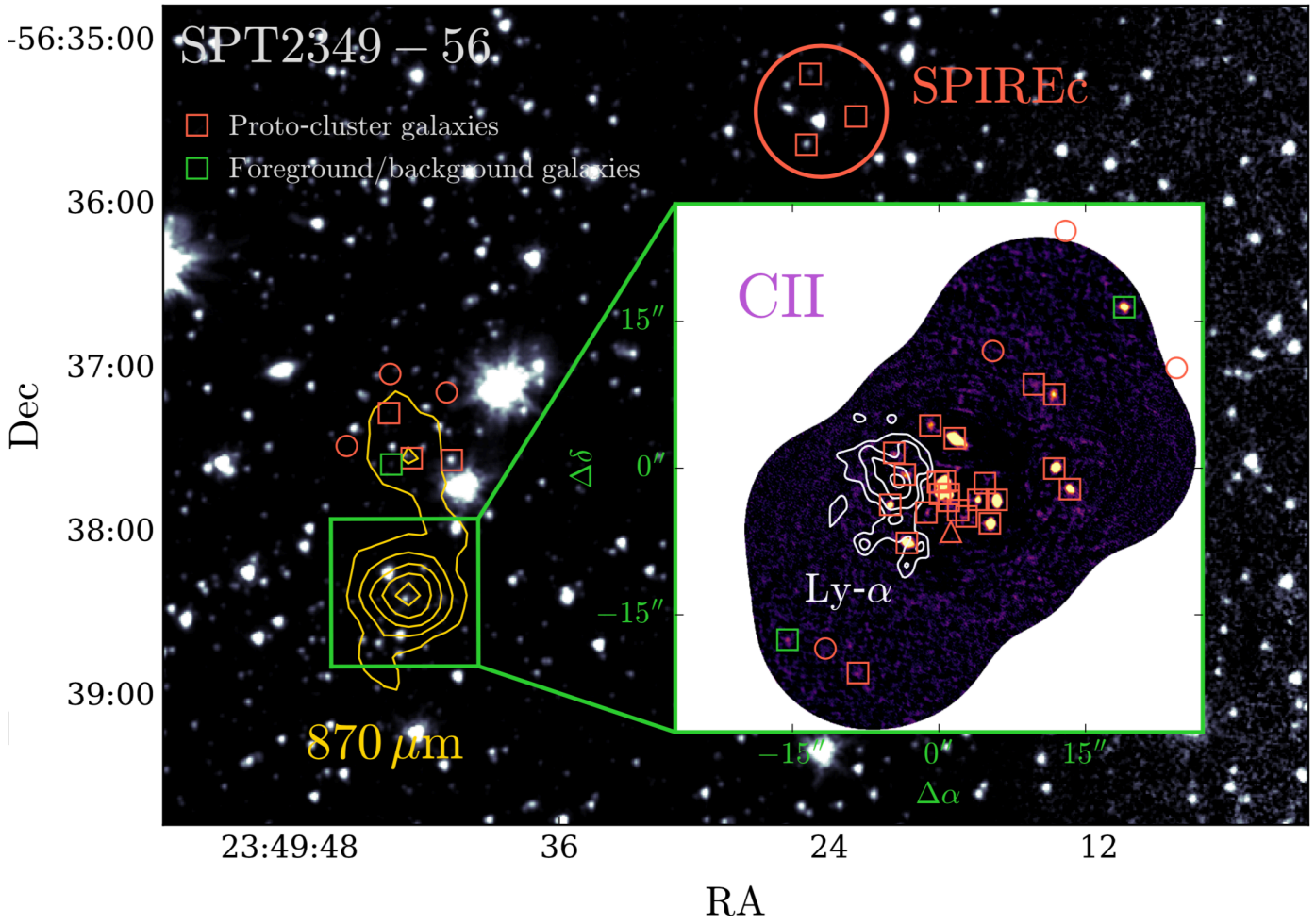
Extended Lya halo detected: ~0.5x10^{43} erg/s LAB not at the center of potential!

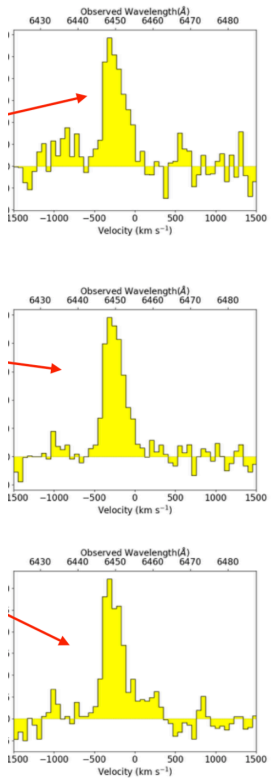
Considering core SFR~10,000 M/yr … LAB could be

blueshifted shell ejected

Hole in dusty structure where UV photons escaping?

Apostolovski + 2020

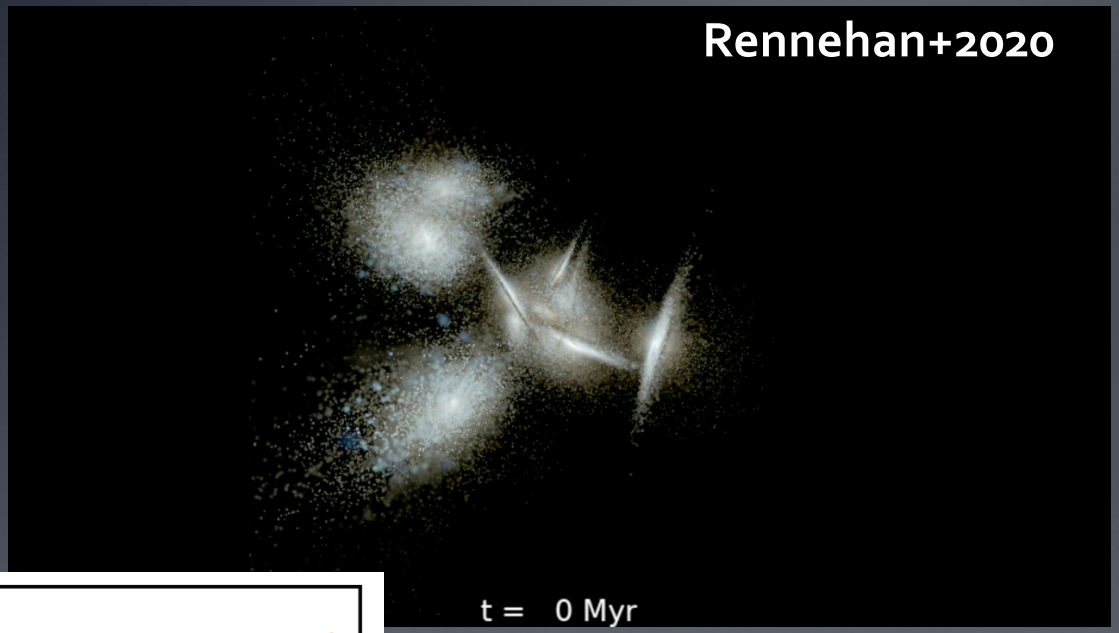


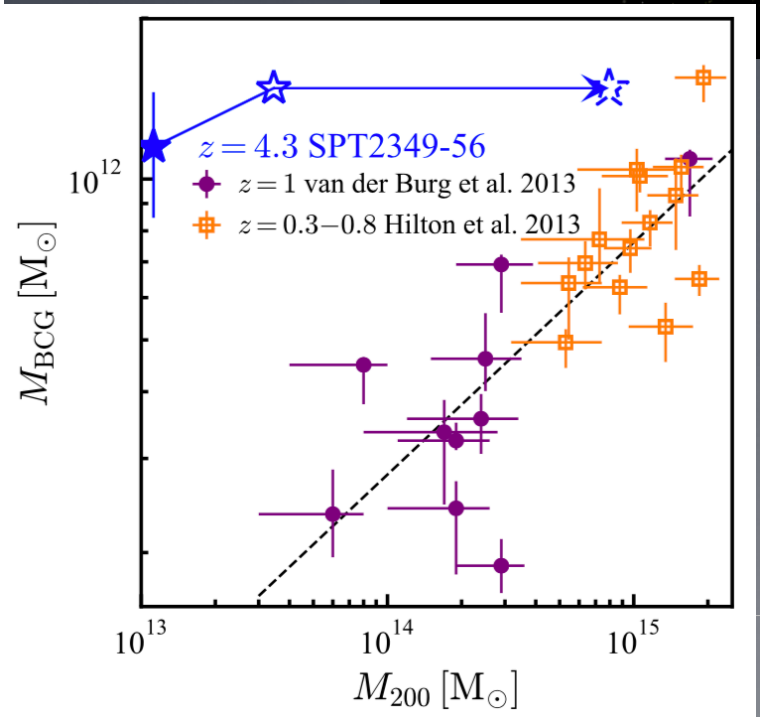


7 LAE detected (no ALMA emission)

Witnessing cluster BCG formation

C. Hayward; Flatiron Institute





BCG in place after ~500Myr

M* increases >2x in this event

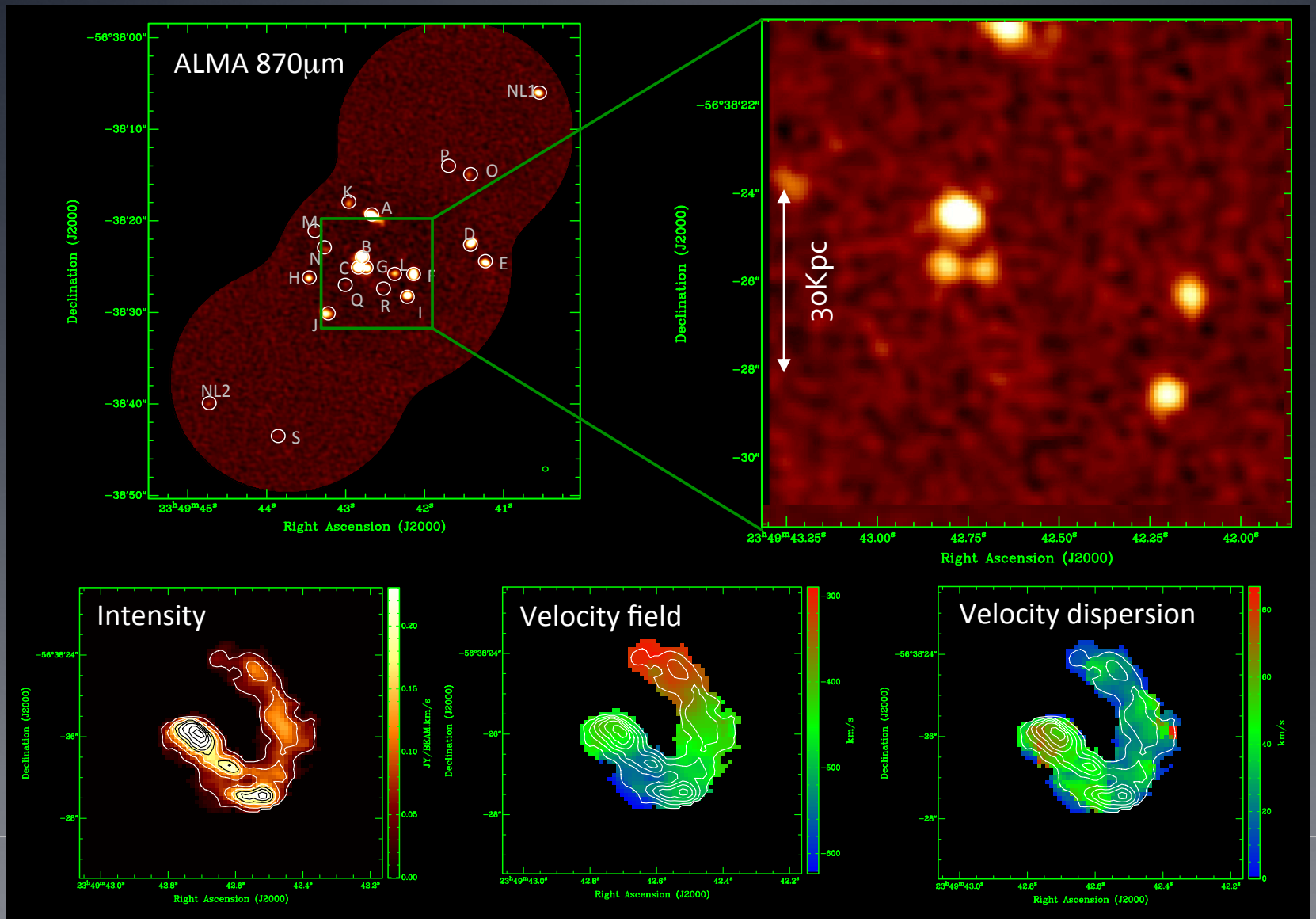
@ z=0: M* > few x 10^{12} $M_\odot$

Simulation

Rotermund+2020

SPT2349-56 [CII] "halo" – *ejecta or tidal streamers*

Weiss, Chapman, et al. 2020

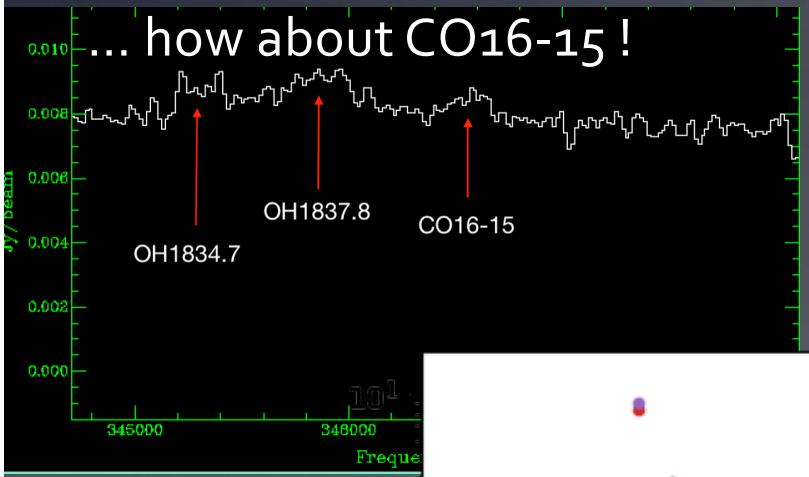


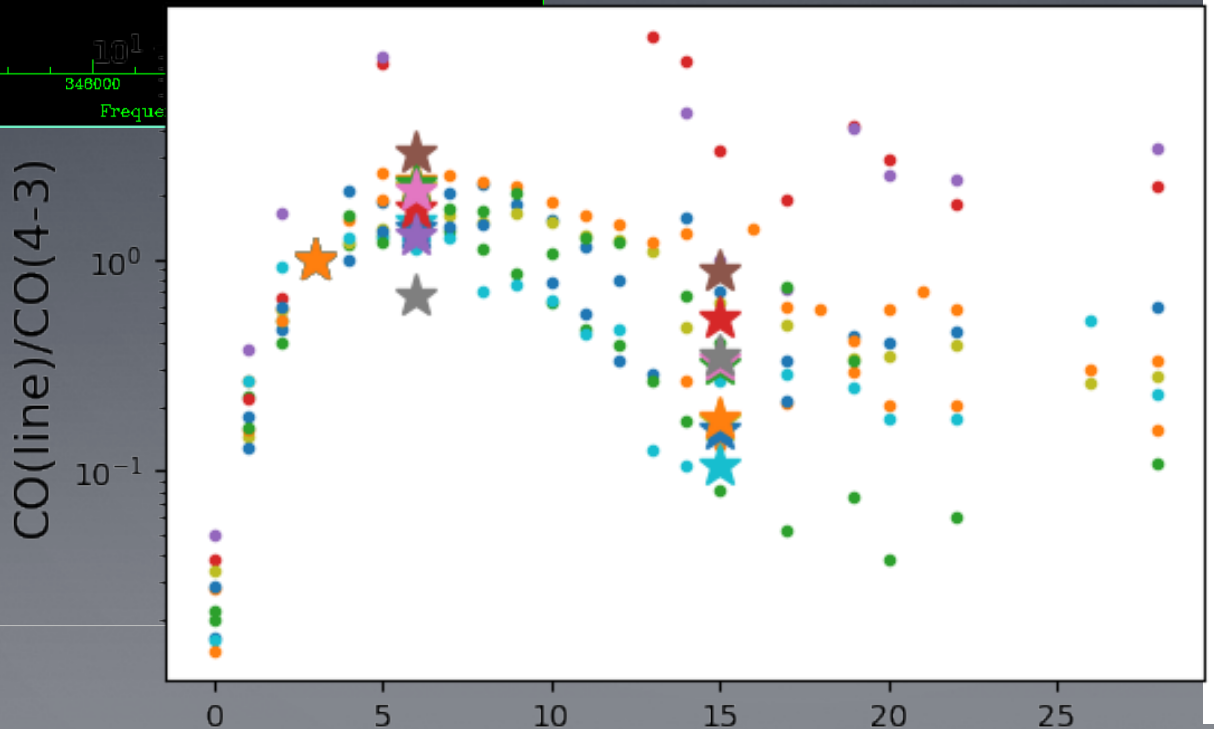
AGN in SPT2349?

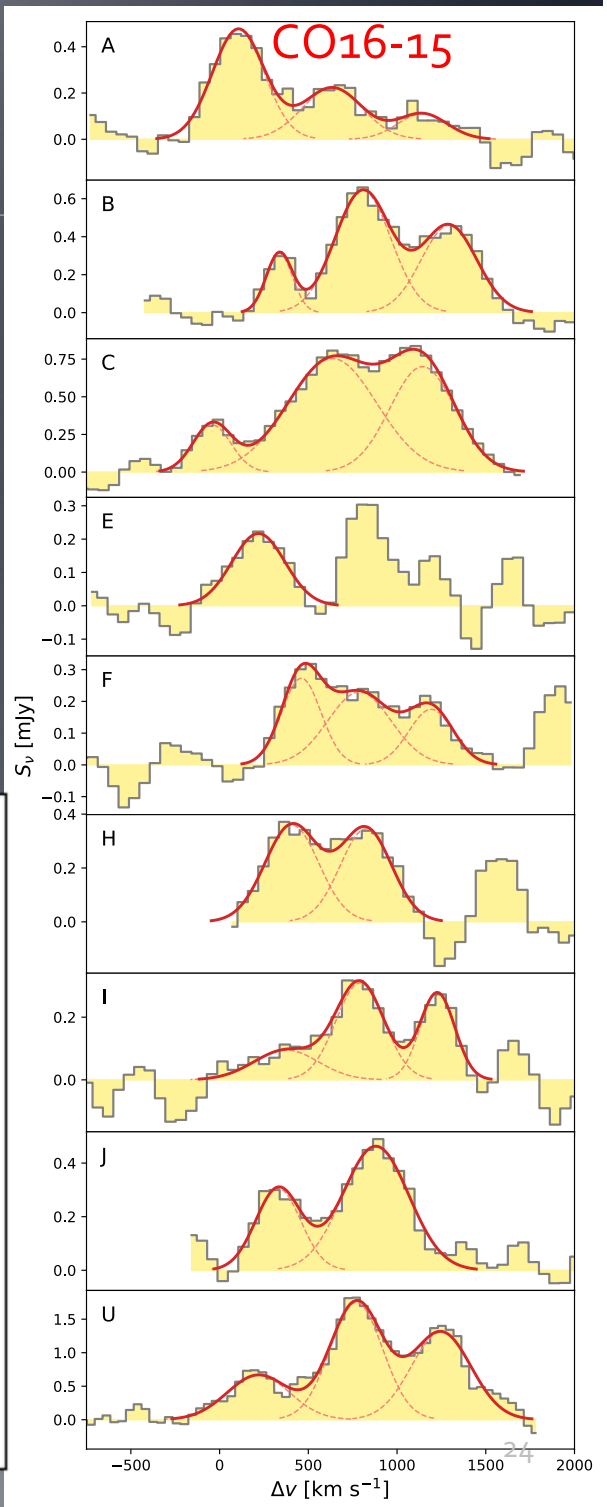
R. Canning et al. in prep

- XMM and Chandra proposals
- High-J CO line diagnostics

Of interest, as AGN feedback important in cluster/BCG formation

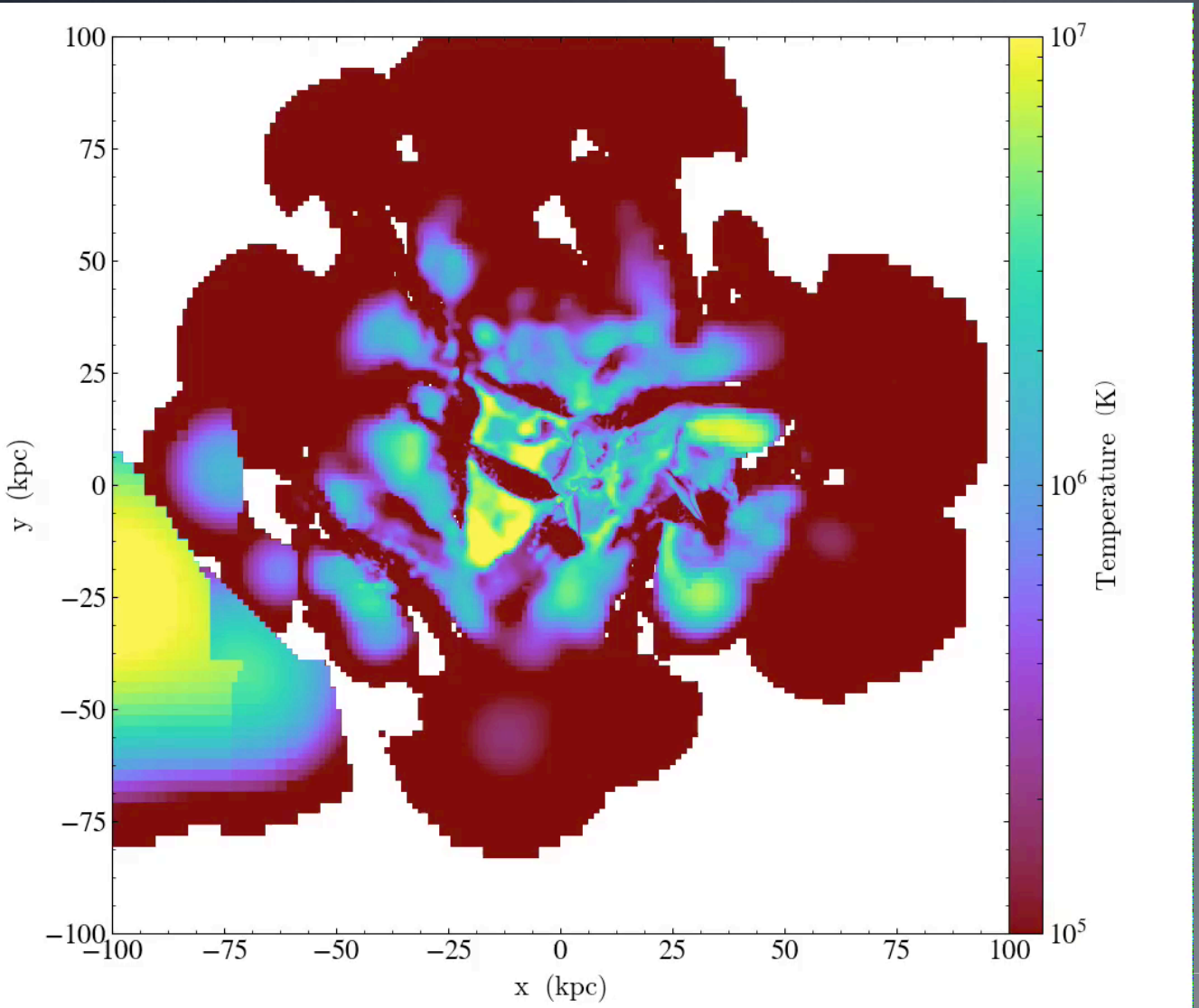






Helping to establish the hot ICM?

Rennehan,Babul et al.



- Gas seen is either

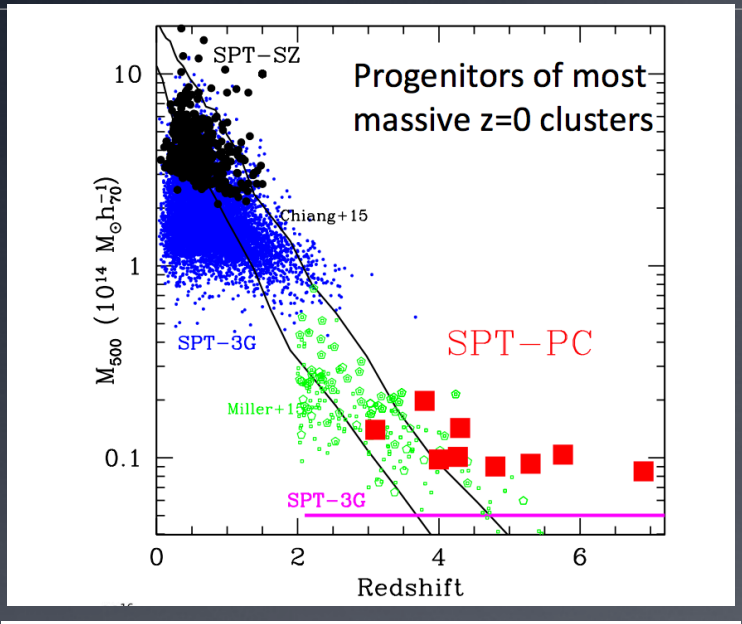
1) expelled from galaxies due to stellar feedback
2) heated/expelled as a result of shock-heating during collision.

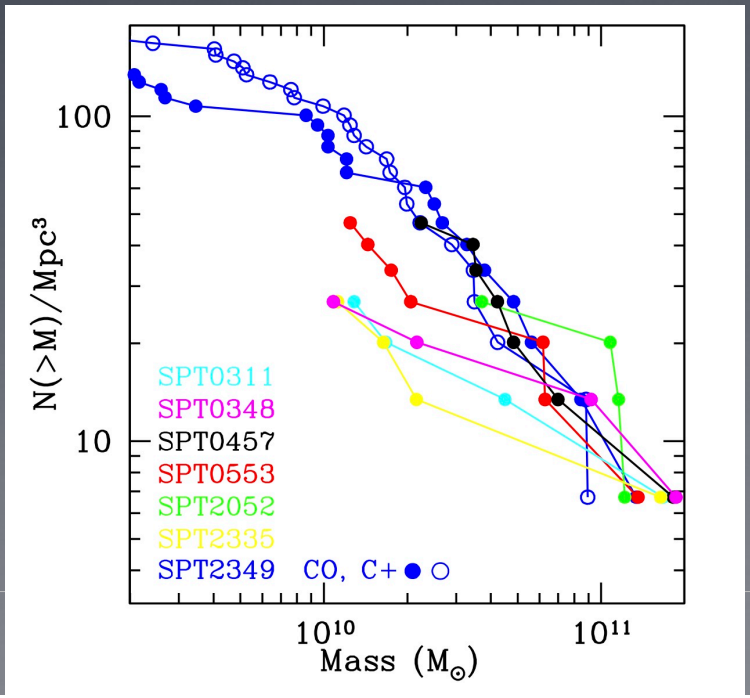
- not included:

1) cosmic gas that would normally be falling in
2) any halo gas associated with the galaxies

- 0.1Gyr: 80% above 10^6K, and 15% above 10^7K
- 1Gyr: 96% above 10^6K, and 30% above 10^7K

Summary





- Discovery of these PCs is possible due to synergy between large area mm-wave surveys and sensitive interferometers in the submm
- SPT-PCs are unique systems to study earliest phase of massive galaxy and cluster formation … the most massive DM halos out to z=7!
- BCGs form earlier than expected from simulations and current observational wisdom (z>4 vs z~1-2)
- High-z PCs : evolution of the CO, CII and dust luminosity functions in cluster environments
- investigate differences in evolution between cluster and field galaxies.
- **Study the PC galaxy properties in detail with Roman and JWST**