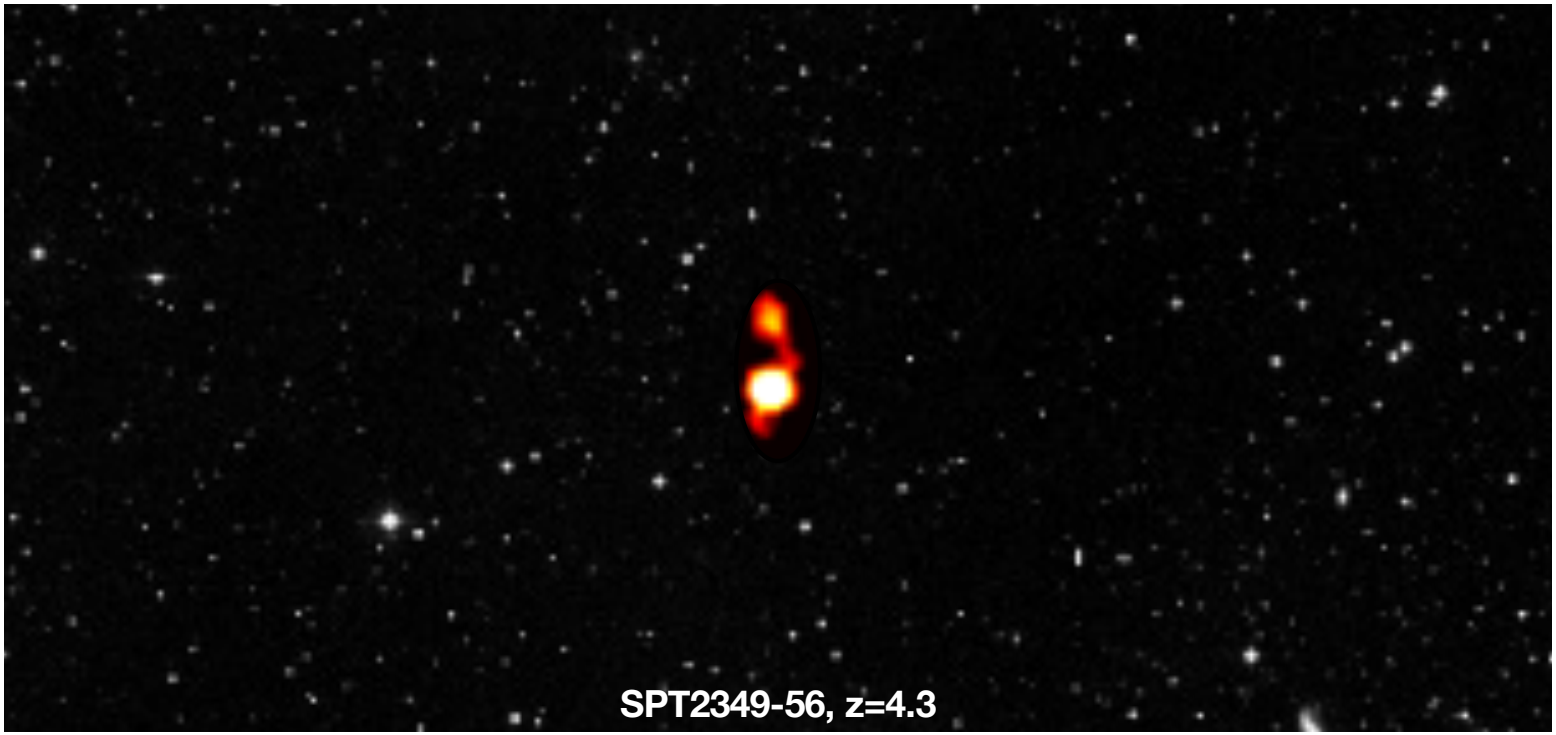
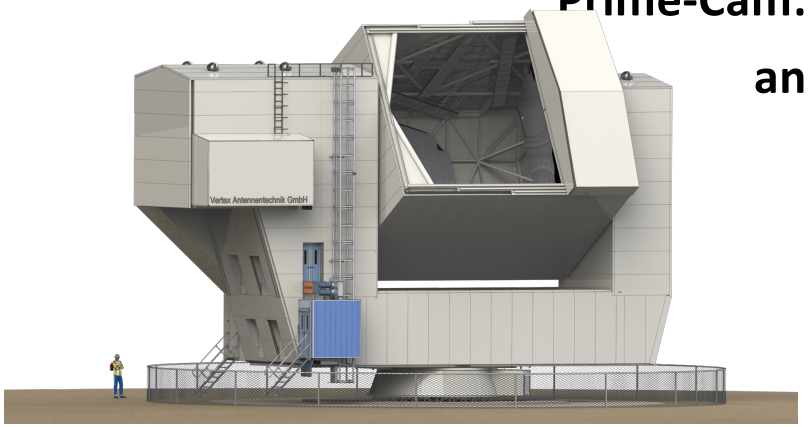
Scott Chapman – and SPT SMG Collaboration

Massive protoclusters from z=7 to z=3 observed in the submillimeter

First Structures, June24, 2024



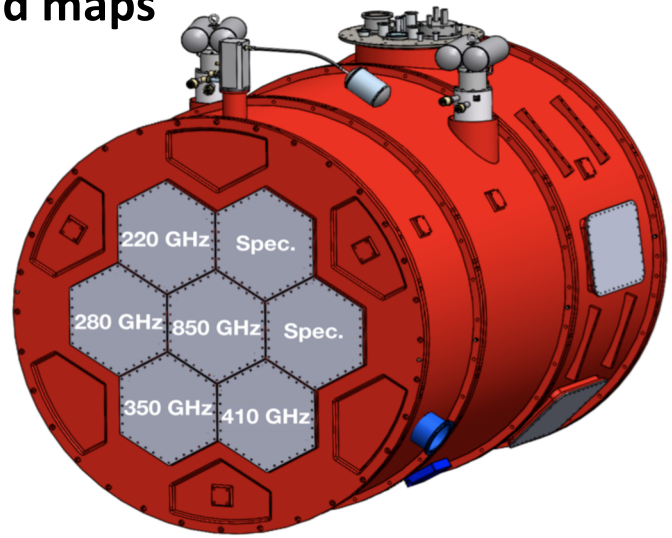
A wide field 350μm imager/polarimeter for CCAT / FYST



Prime-Cam: 1mm to 350um wide field maps

and C+ intensity mapping

First light 2025

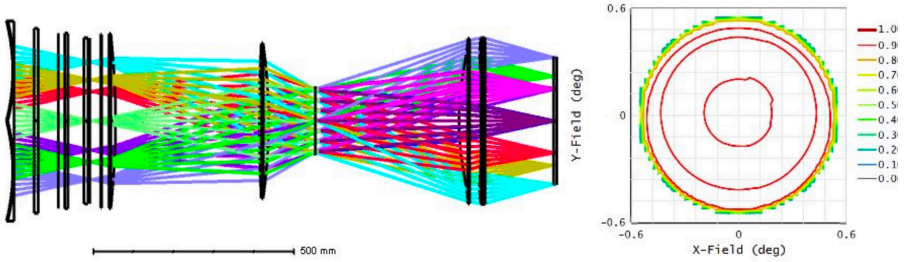


SPIE2022 on arXiv:

Chapman+ 2208.10634

Sinclair+ 2208.07465

Huber+ 2208.09560



Why observe protoclusters in the submillimeter?

- Forming/assembling clusters are forming lots of stars

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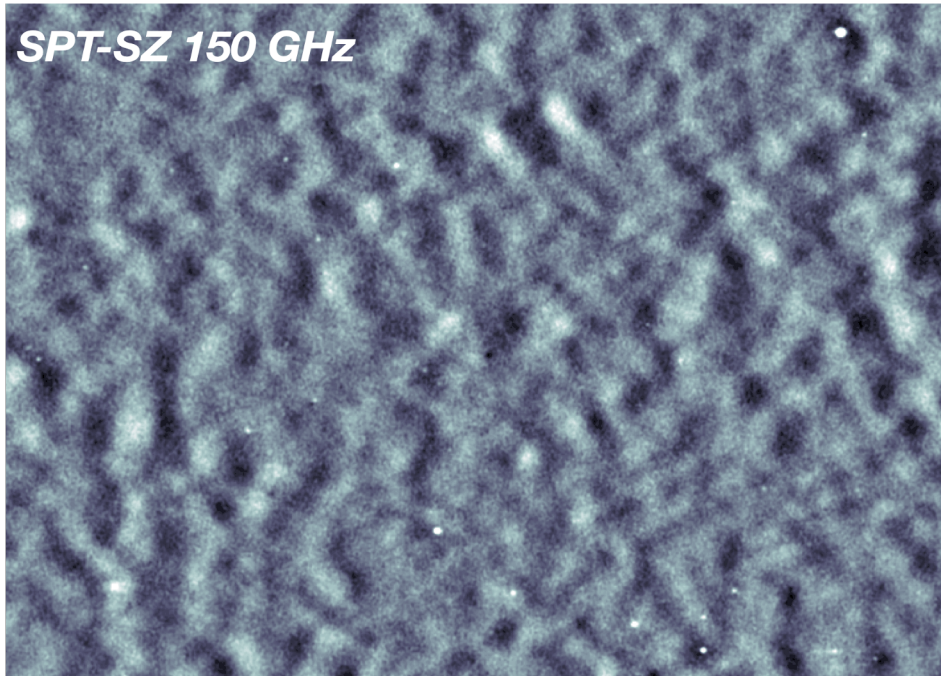
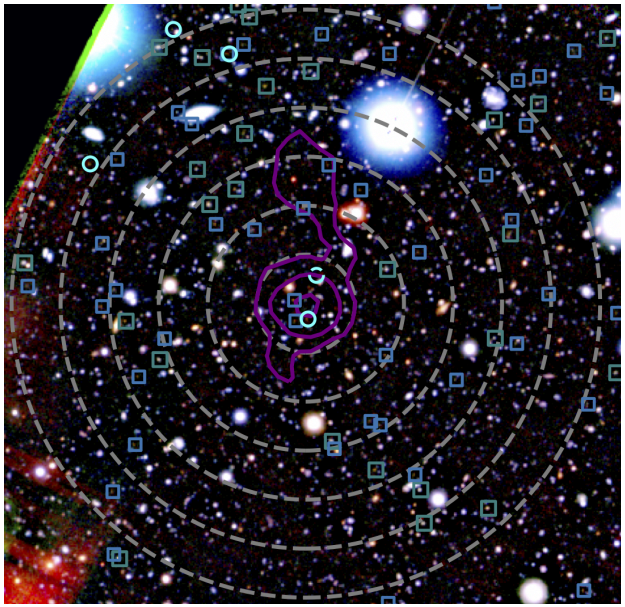
- **Wide field submm surveys can efficiently find them**



Why observe protoclusters in the submillimeter?

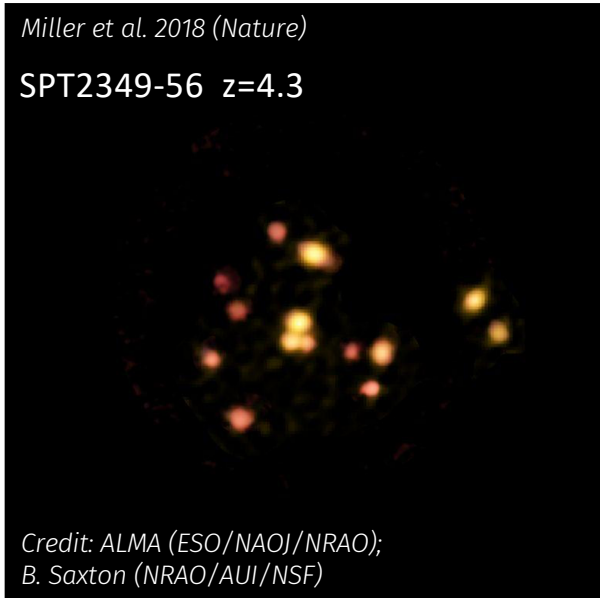
- Forming/assembling clusters are forming lots of stars
- Wide field submm surveys can efficiently find them
- **Some massive protoclusters can only be found in the submm!**



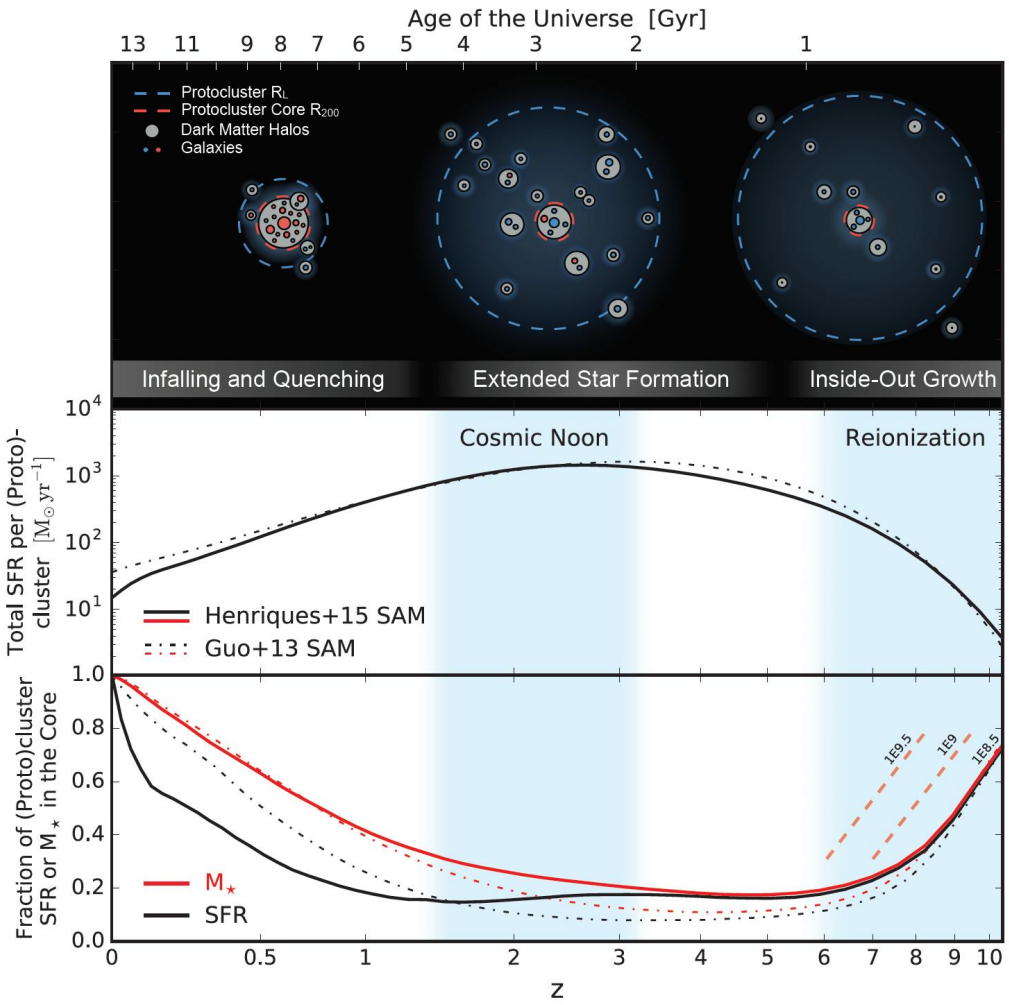
SPT2349 in z~4 LBGs
(*g,r,i* false colour)
Rottermund+2021

Can be identified by LBGs, but not very high contrast

Brightest source in 2500 deg^2



Early *inside-out* formation of protocluster cores (e.g. Chiang et al. 13,17)



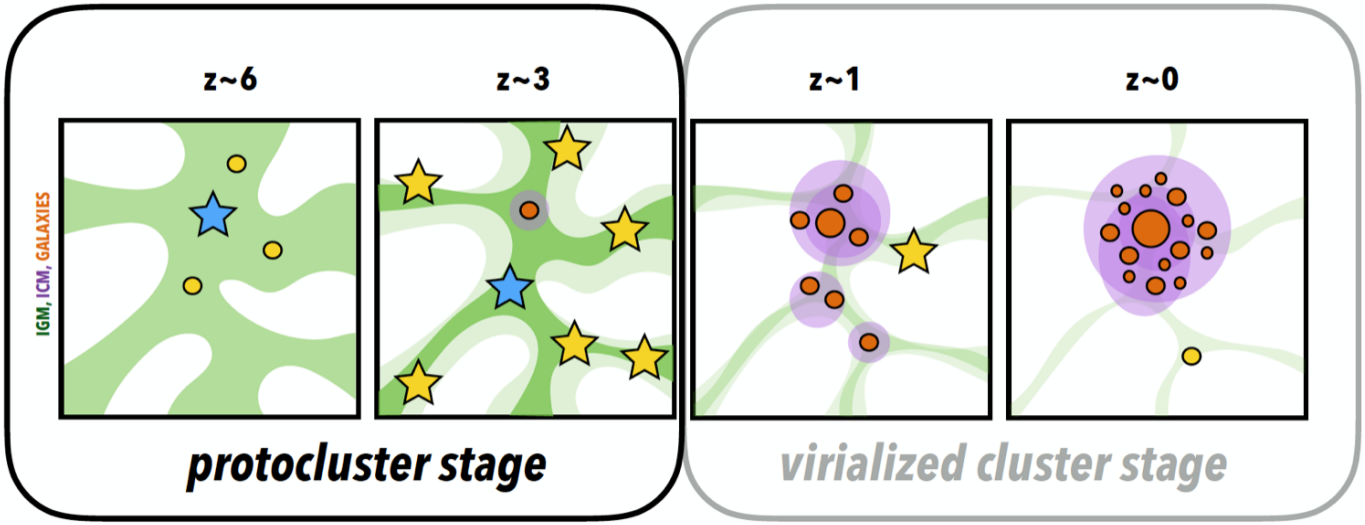
… SPT finding early forming ‘cores’ as protocluster signposts ?

(see also Ryley Hill and Nikolaus Sulzanauer talks)

Protoclusters traced by luminous galaxies?

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

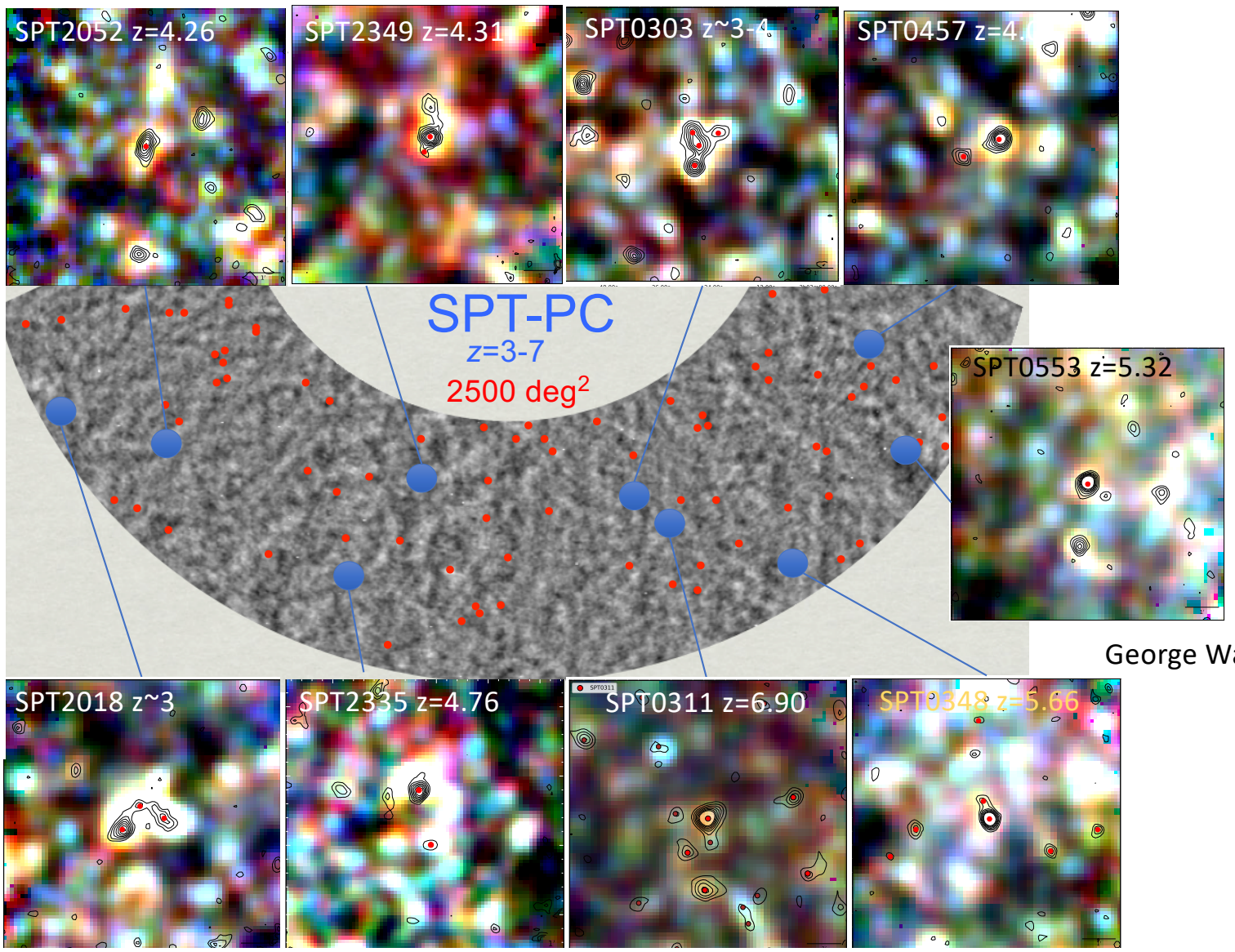
2. Do ULIRGs (at z>2) preferentially live in overdensities?



Courtesy of Caitlin Casey

Protoclusters form stars at higher-z than field

SPT-PC



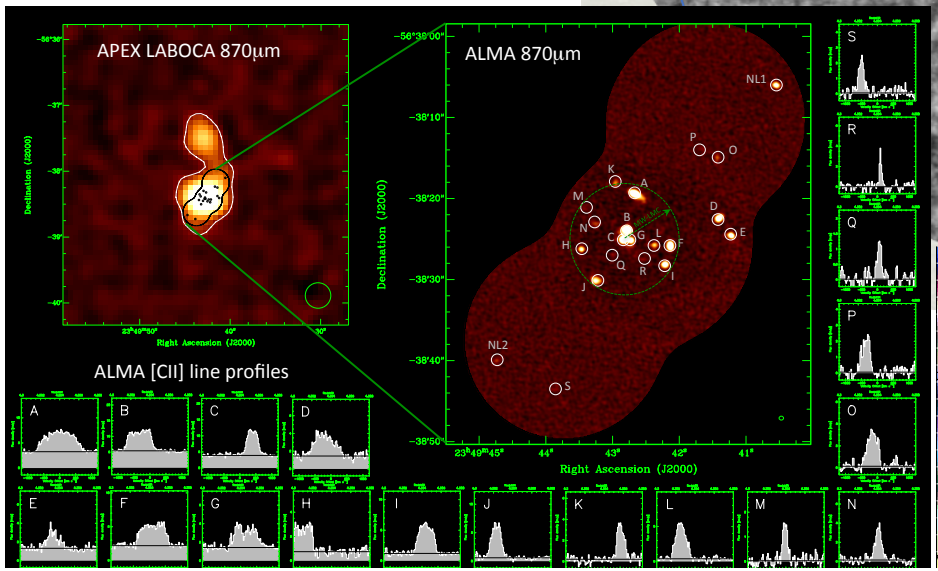
George Wang+2021

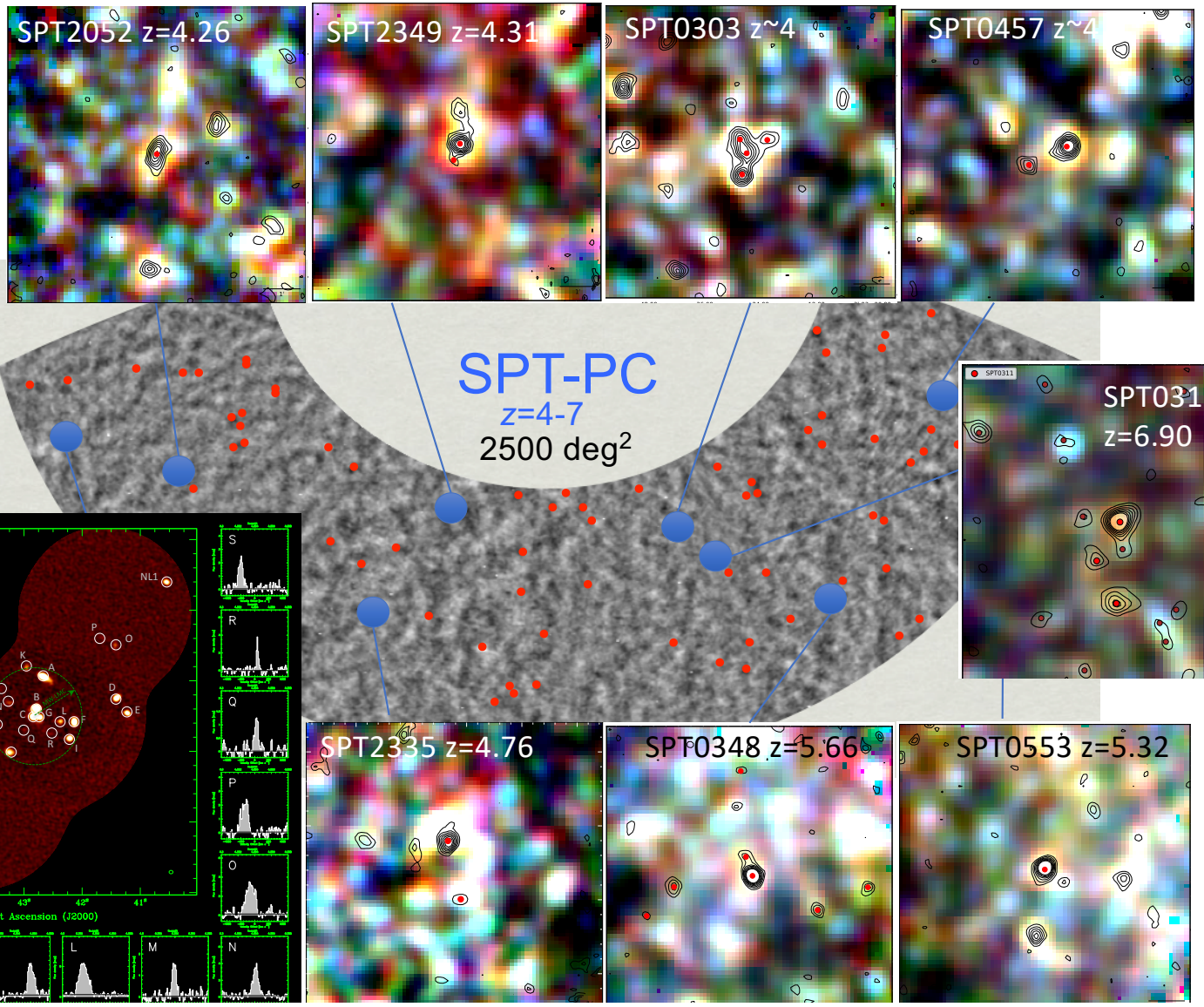
SPT-PC

ALMA followup for protocluster candidates

- Find redshifts with spectral scans
- resolve dusty sources into multiple SMGs

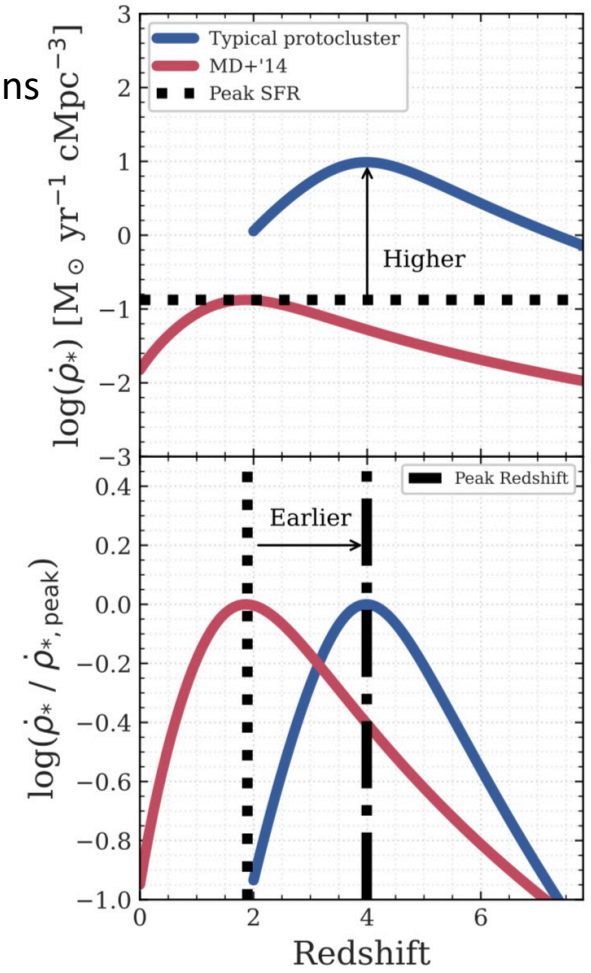
SPT2349-56 z=4.3



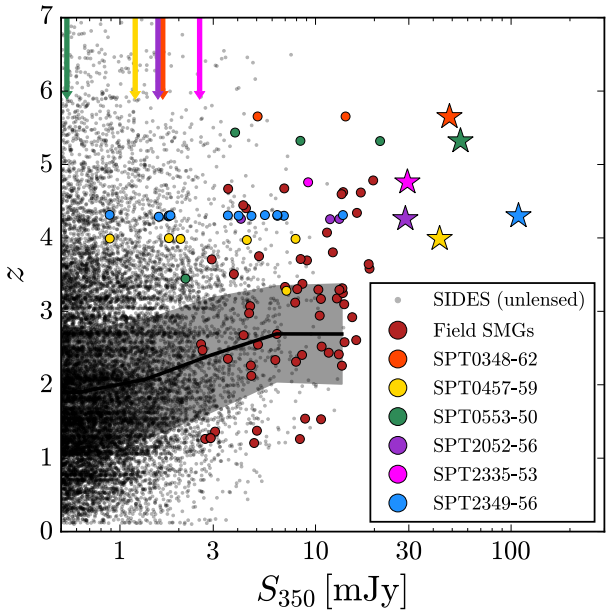


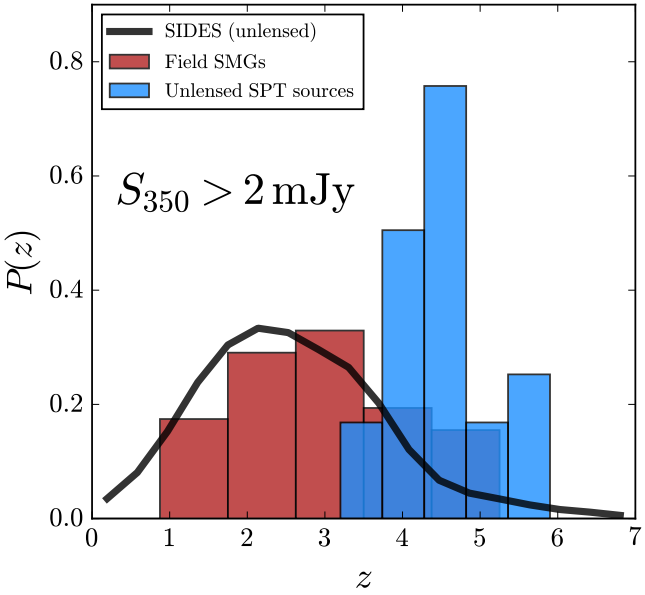
<z>~4.5 of SPT-PC redshifts indicates massive halos / protoclusters?

Rennehan+2024:
Assembly bias means
<z>~4 for PC SFRD



R.Hill+in prep: SPT-PC candidates higher-z than field SMGs





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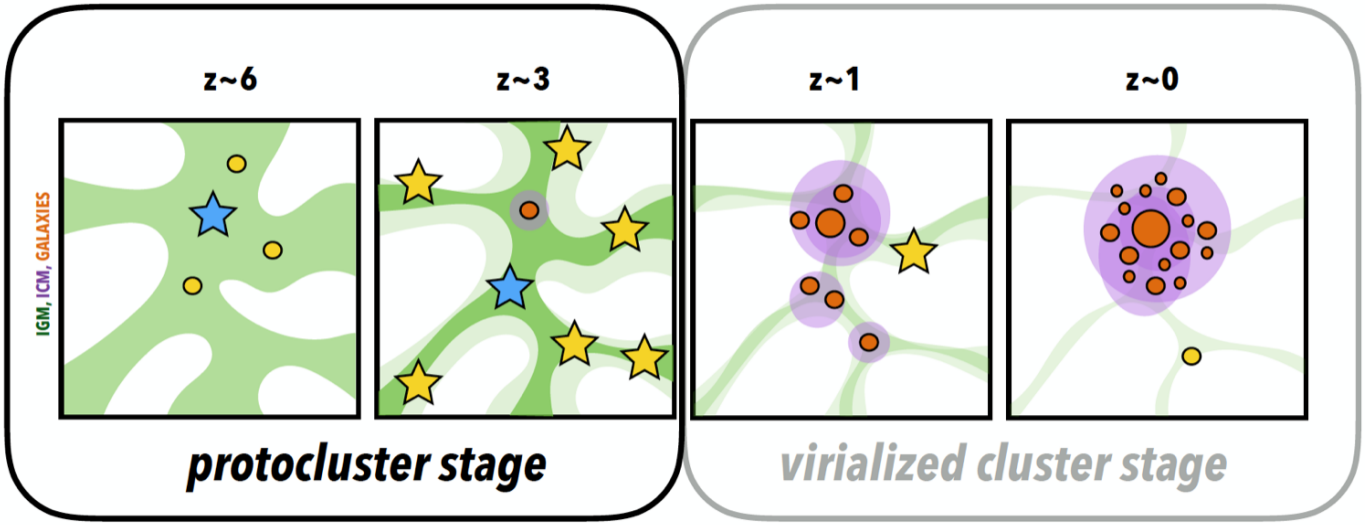


Courtesy of Caitlin Casey

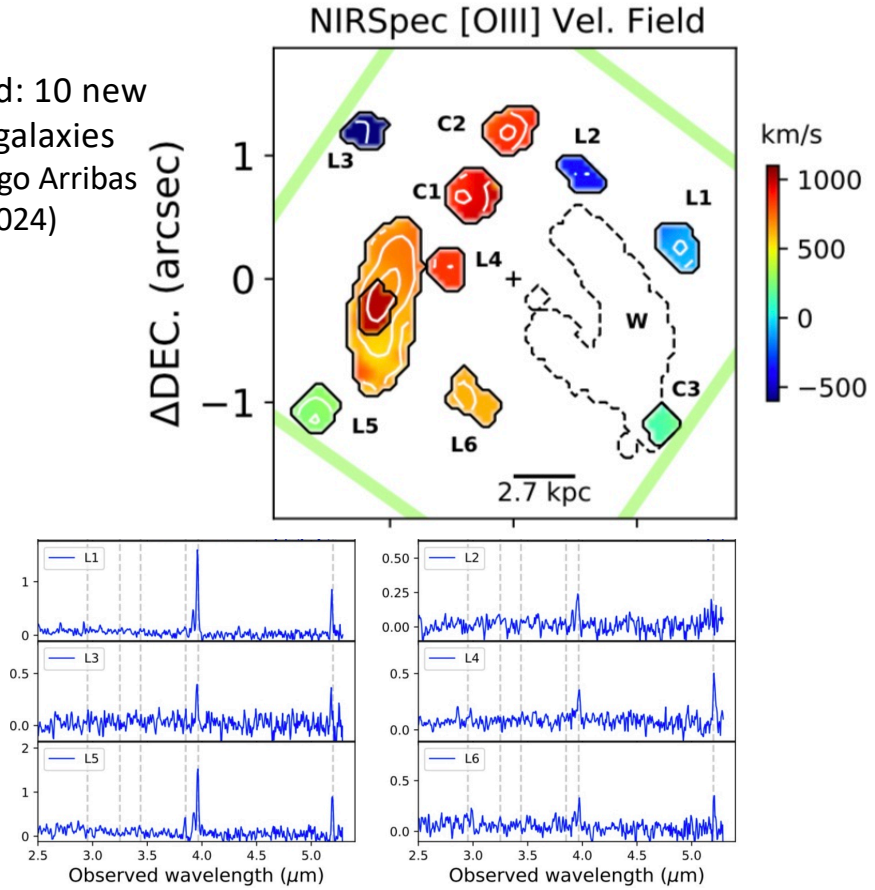
Massive protoclusters from z=7 to z=3 observed in the submillimeter

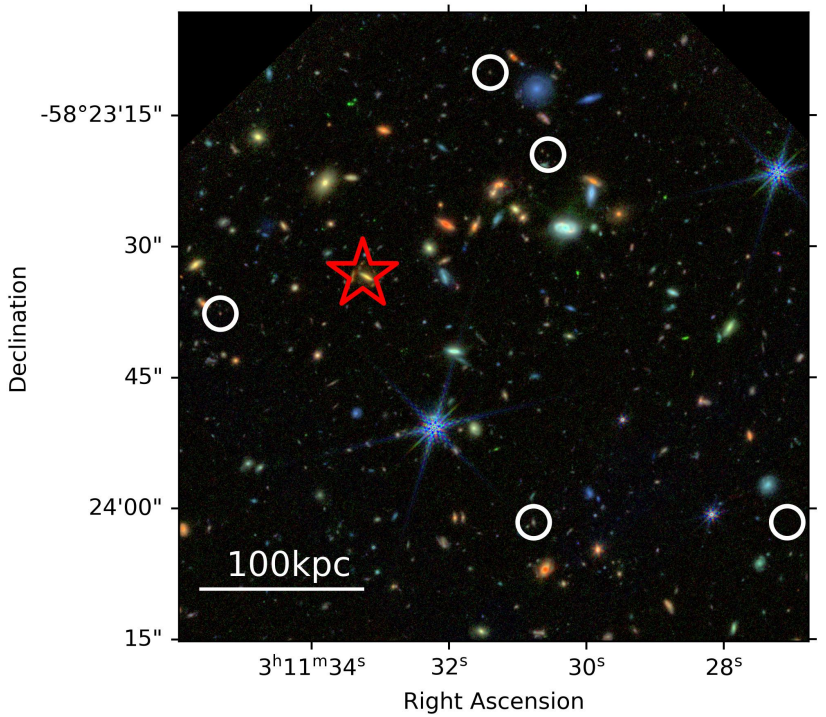
- **SPT0311** z=6.9 JWST + HST results
- SPT-PCs z~4 systems
  - **SPT2349**
  - **SPT0457**
  - **SPT2052**
- z~3 cores can be moderately active, but more submm action in wider collapsing structure
  - **SSA22**
  - **HS1549**

SPT0311-58 at z=6.9 *Is it a protocluster?*

JWST NIRSpec and NIRCam+HST results

3” field: 10 new z~6.9 galaxies (Santiago Arribas et al. 2024)



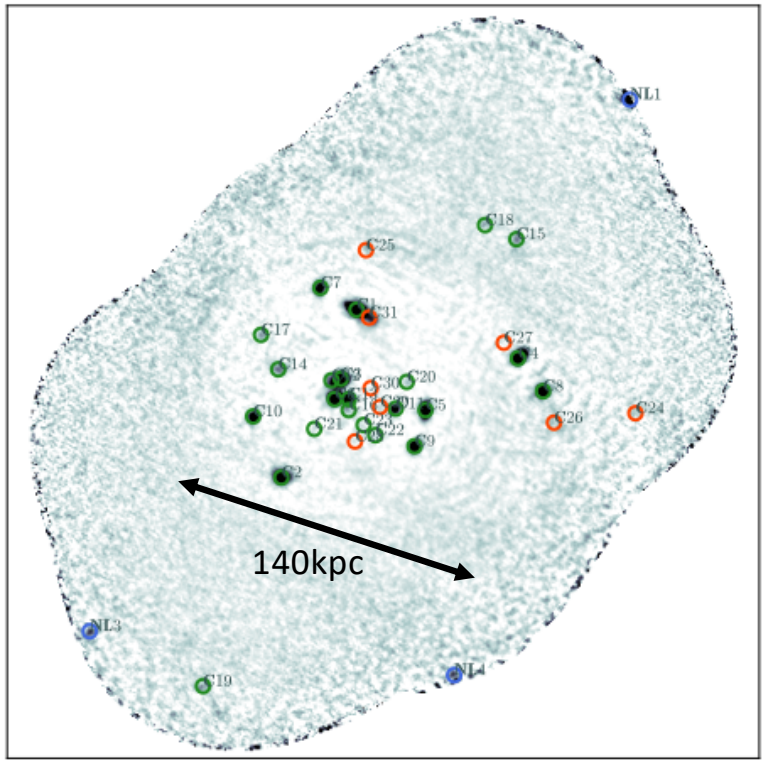


NIRCam + HST find robust LBG and double-break candidates in wider field

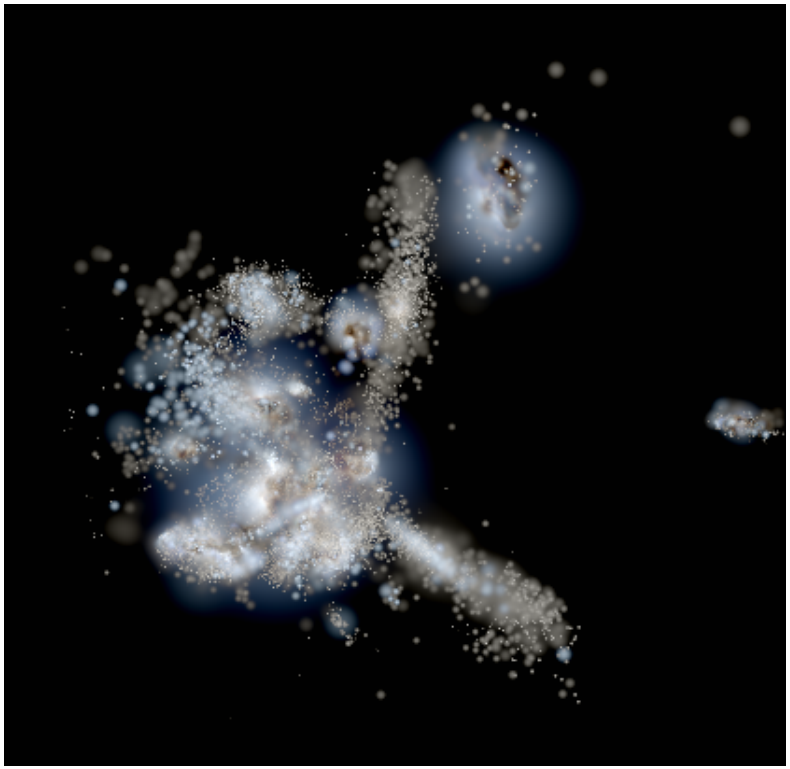
5 very massive LBGs! (D. Zhou+ in prep).

Updates on SPT2349 (last year's 4th favourite PC)

- >30 ``SMG" members in 200kpc core with ultra-deep C+ data (Hill+in prep)



New GIZMO simulation suite (Hansen+ in prep)
30 galaxies with initial positions/velocities and gas/stellar masses consistent with SPT2349 SMGs



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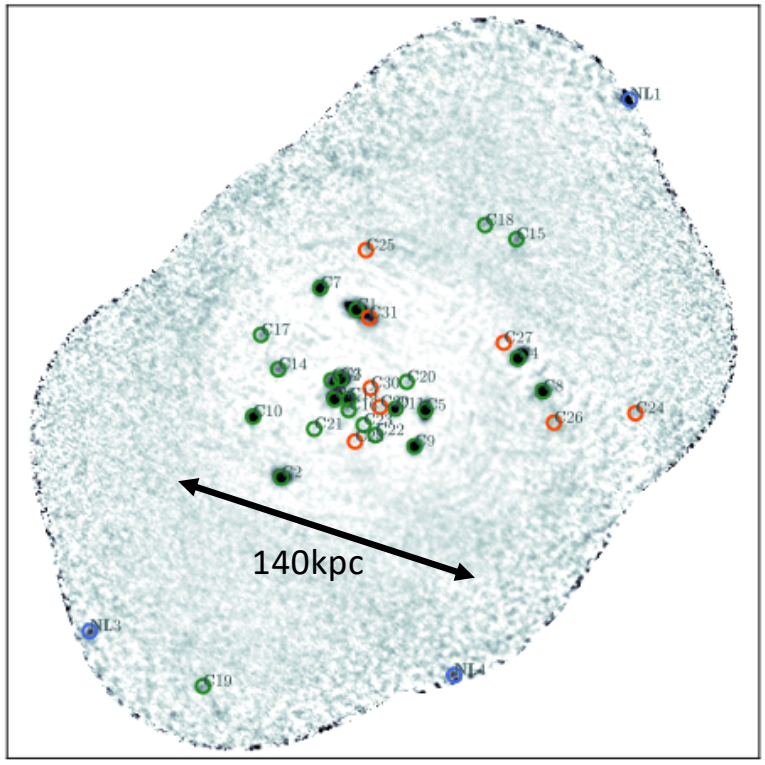
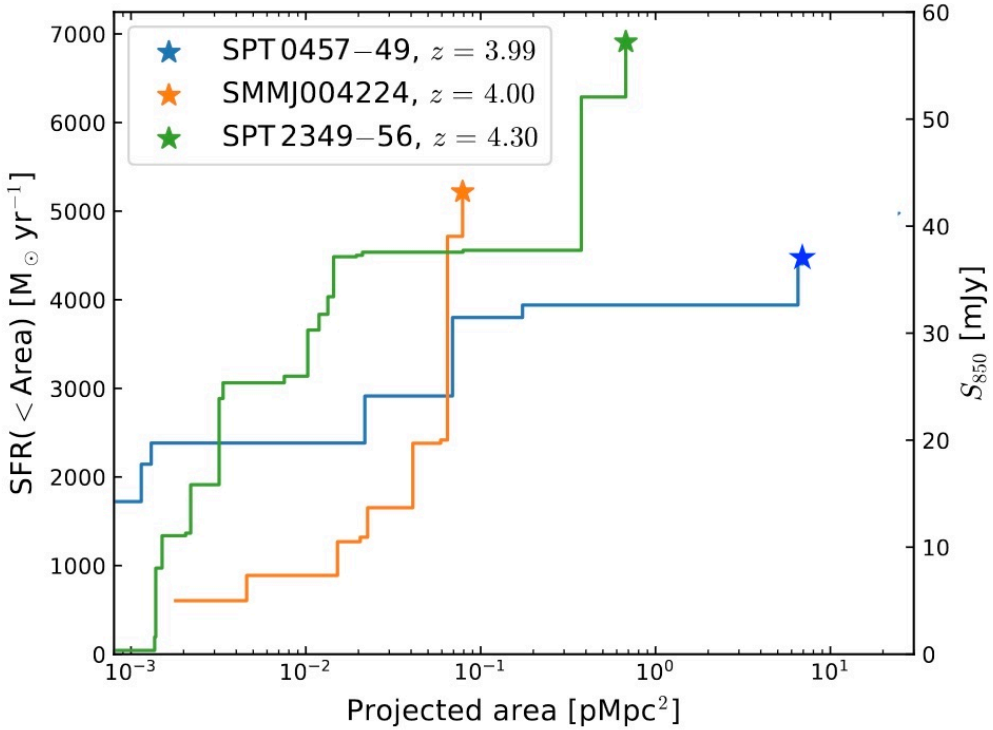
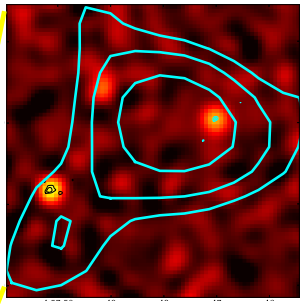


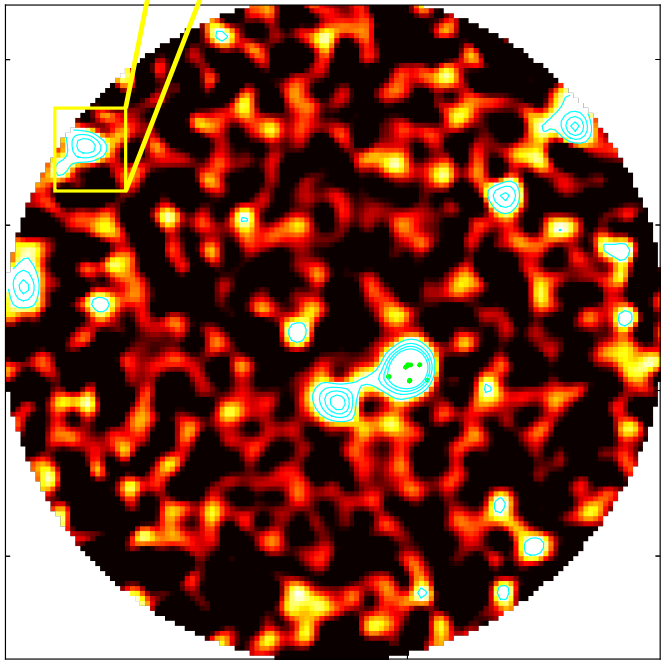
Are SPT2349 and DRC (Oteo+2018) unique?
Despite 6 years since 2018 discovery papers,
more emerging now with deep ALMA followup:
e.g., SPT0457-49 at *z*=4.0



SPT0457 z=4.0

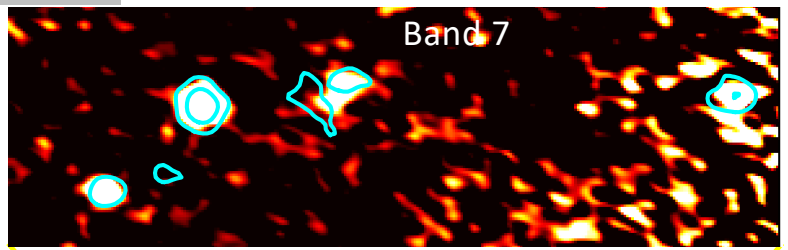
One (of 7) satellite confirmed at z=4.0

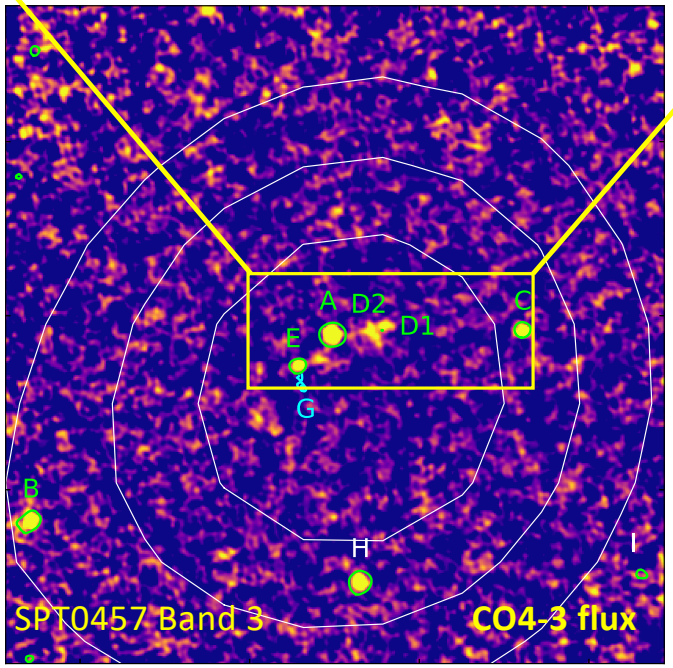




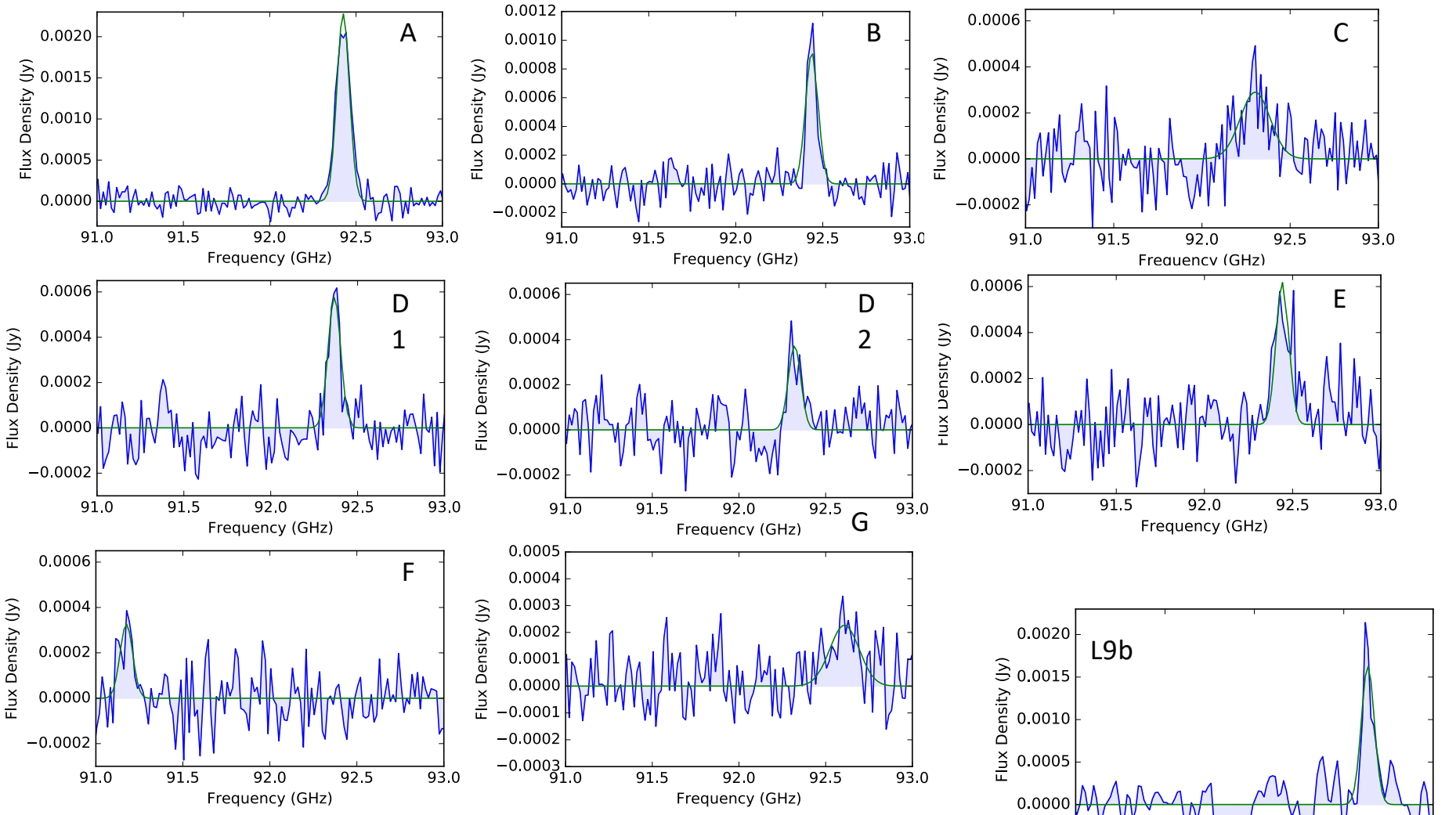
LABOCA 870um map

10’
4Mpc



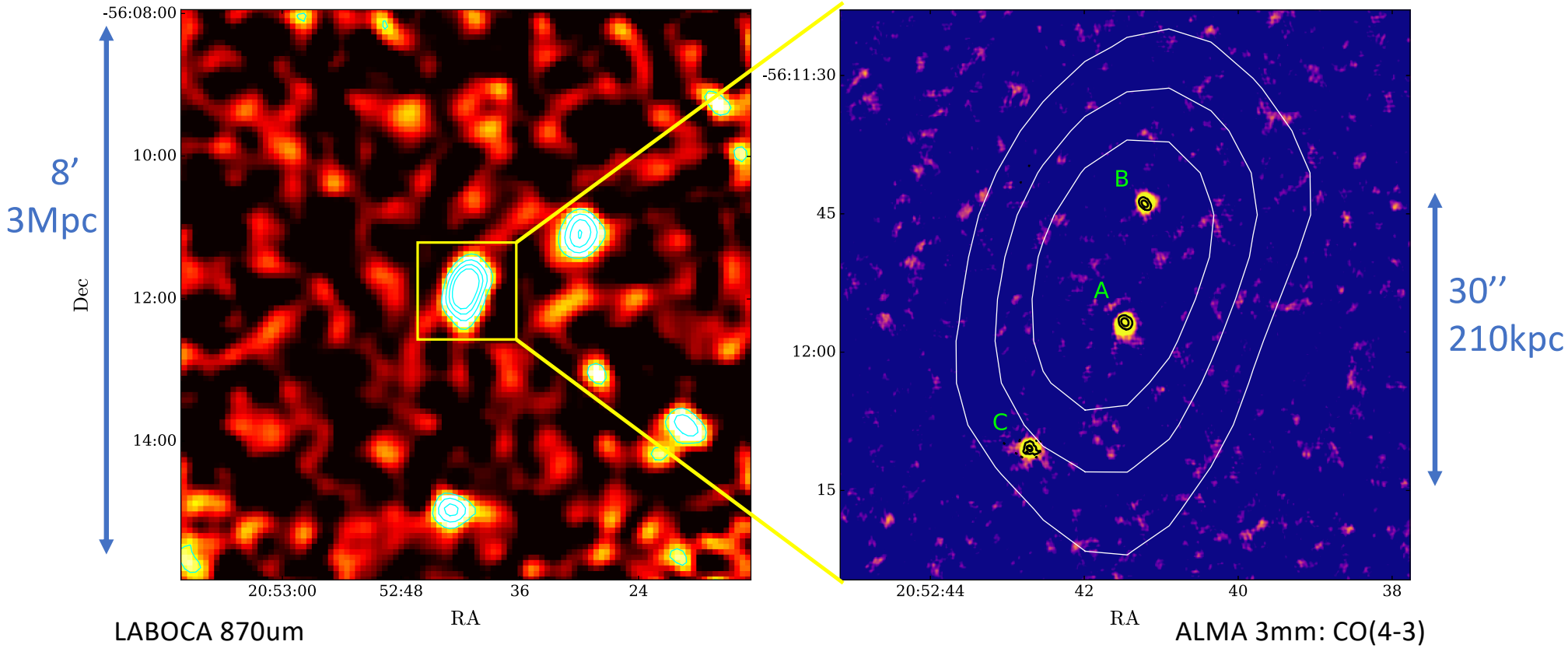


30’’
210kpc

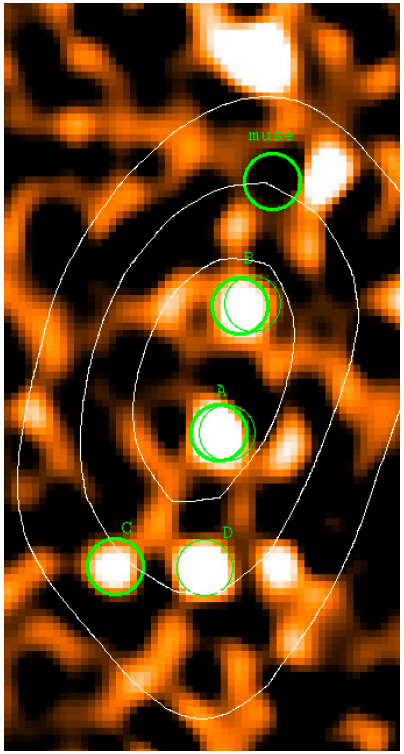


CO4-3 lines in SPT0457 at z=4

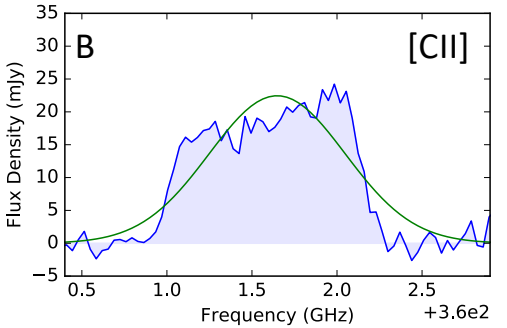
SPT2052-56 at z=4.26 – even more extreme than SPT2349 or DRC?

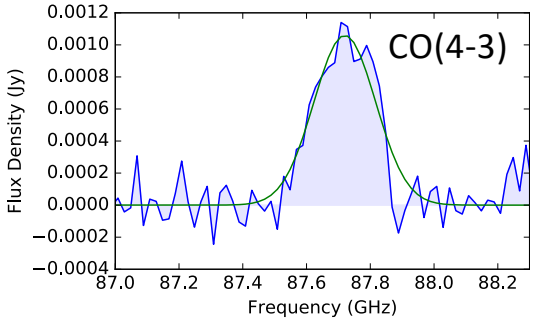


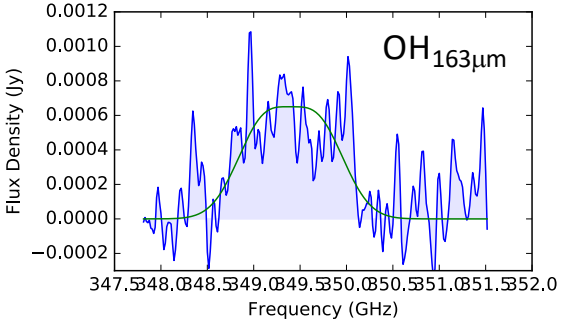
3 HyLIRGs with bright / broad lines (FWHM~800 km/s)

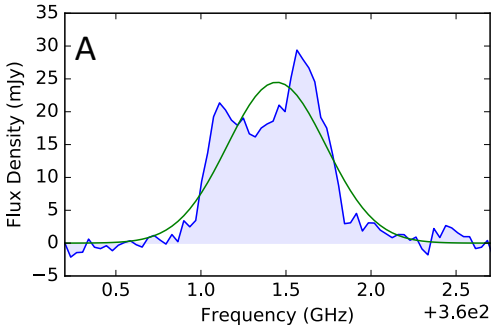


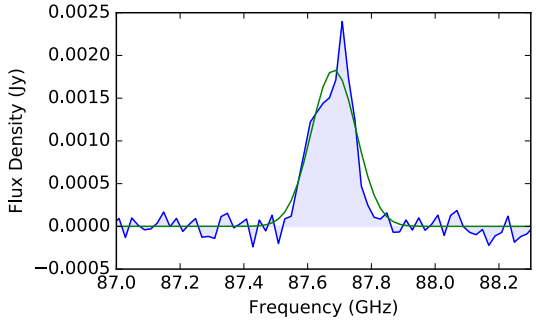
Meerkat 2GHz
Similar radio fluxes
SFRs~2000Ms/yr

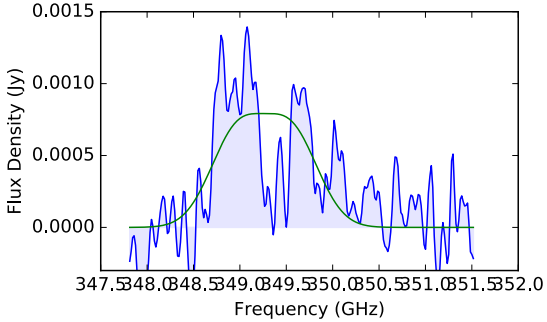


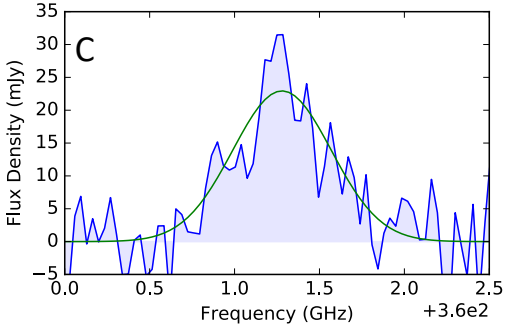


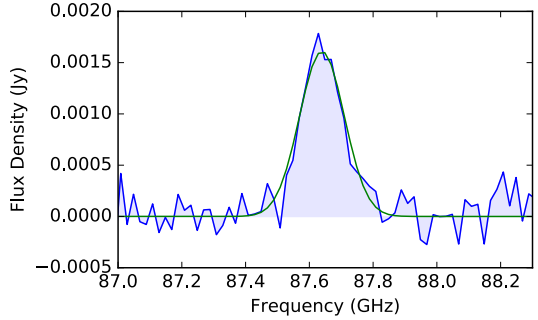


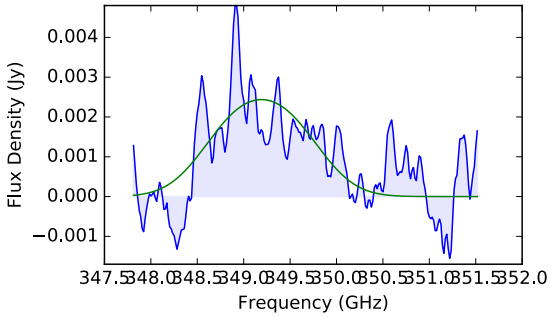






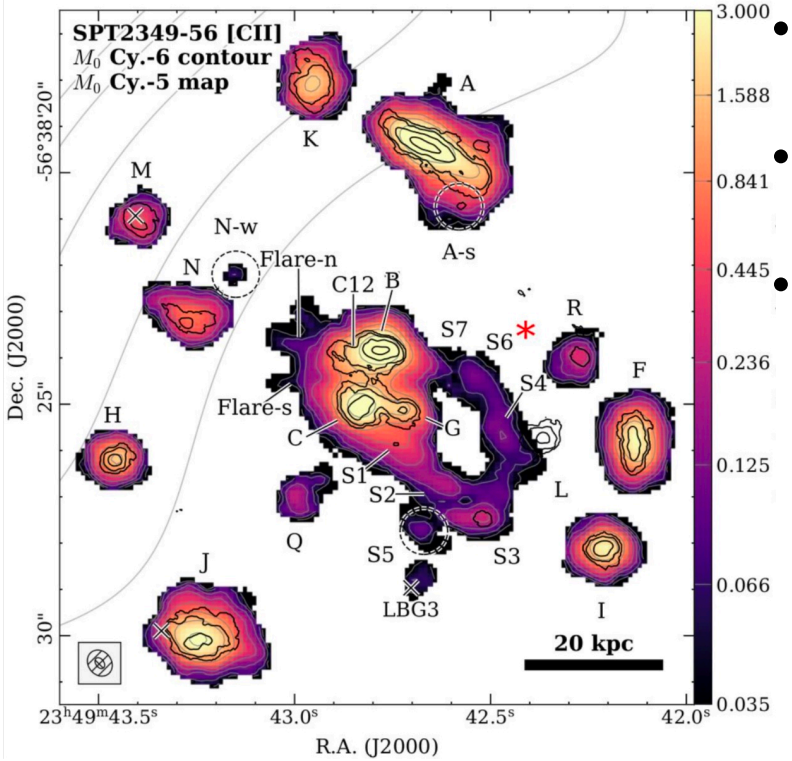






SPT2052 C+ neighbours / streams

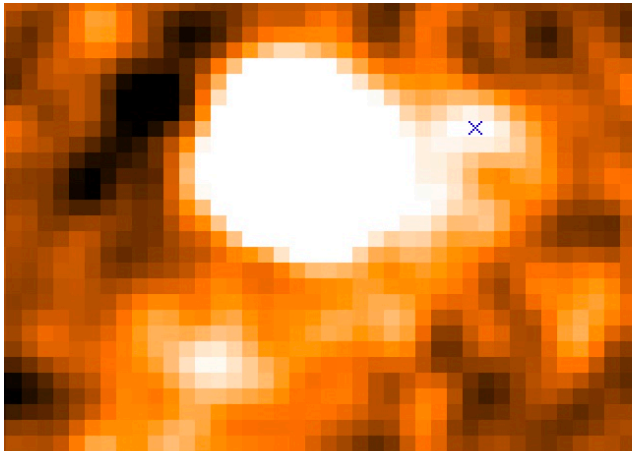
SPT2349 (Hill+20, Sulzanauer+24)



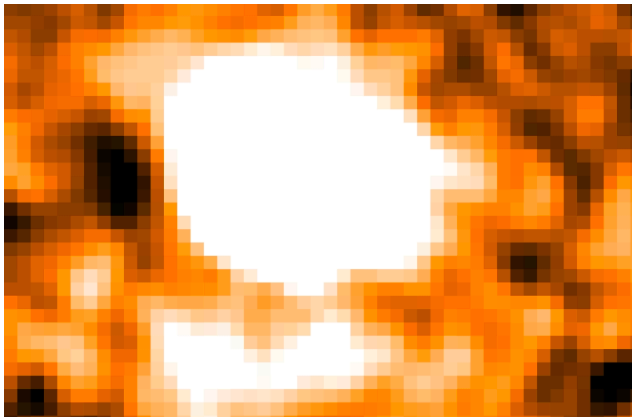
- >5sigma structures surrounding all 3 HyLIRGs: SPT2052A,B,C
- Faint neighbouring galaxies?
- Streamer/halo like SPT2349?
- Evidence of significant merger activity surrounding these HyLIRGs

SPT2052

Vel= 100 to 400 km/s



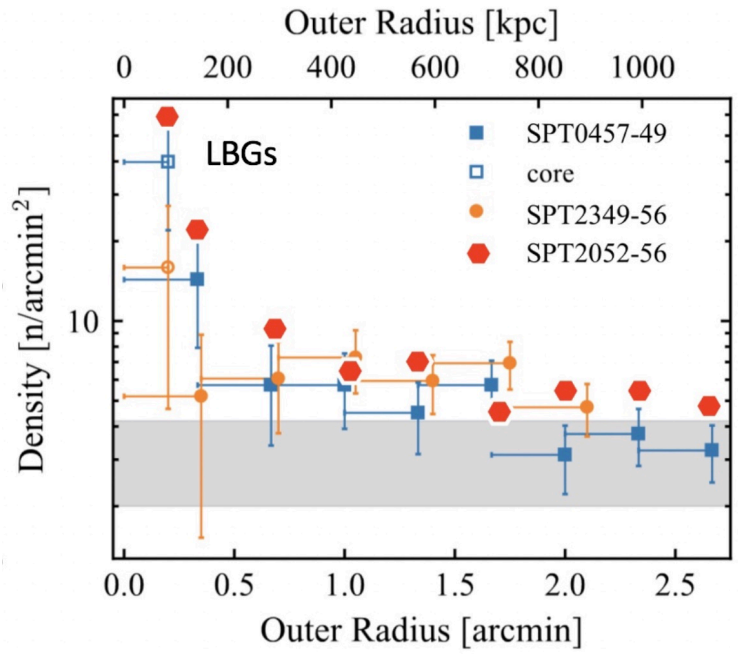
SPT2052 [CII] streamer in source A



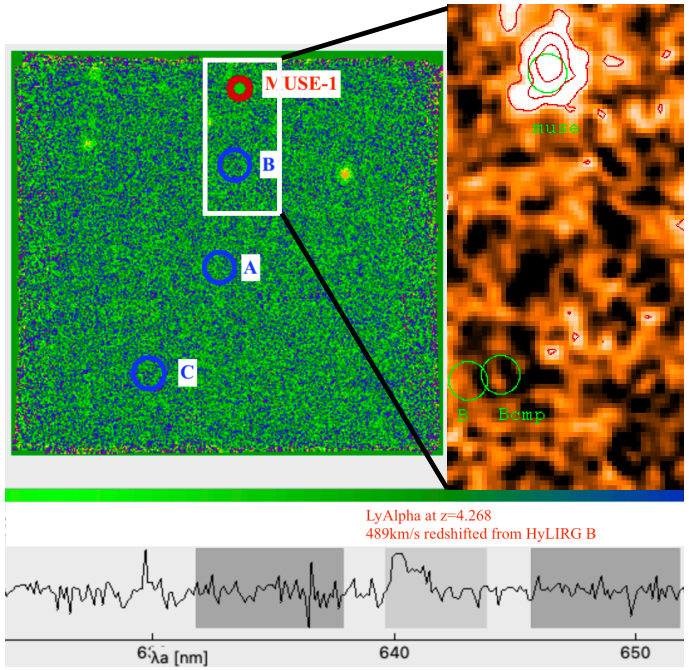
Vel=-300 to + 200 km/s

SPT2052 protocluster in optical: other 'cluster' ingredients

LBGs overdense, MUSE LAB/LBG



(annotated from old Kaja plots)

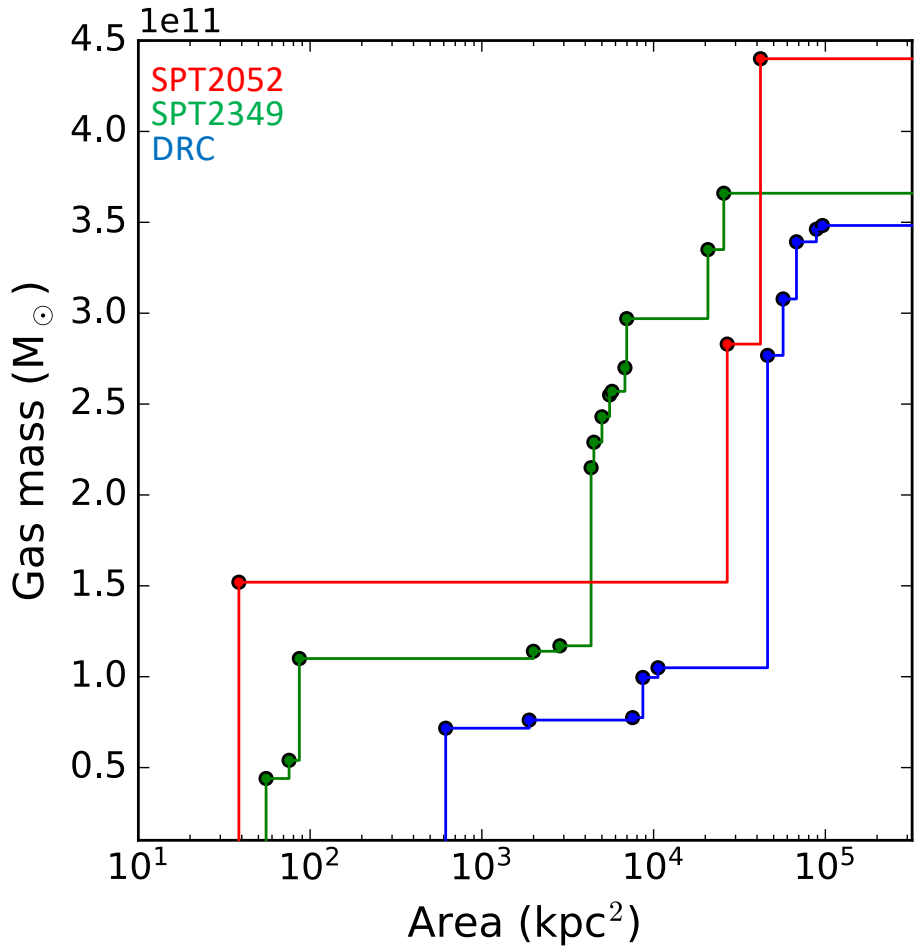


(Manuel working on optimizing the LAB contrast)

SPT2052-56 – even more spectacular than SPT2349 or DRC?

- **SPT2052** has 3 massive nodes of molecular gas, companions/streamers indicate merger/activity
- *But C+ data deep enough to detect SPT2349 galaxies from Miller+18/Hill+20.*

- *SPT2052 is a different kind of environment.*
- *Only 1 comparable found in 2 Gpc^3 simulation*
  (courtesy Pablo Araya Araya)



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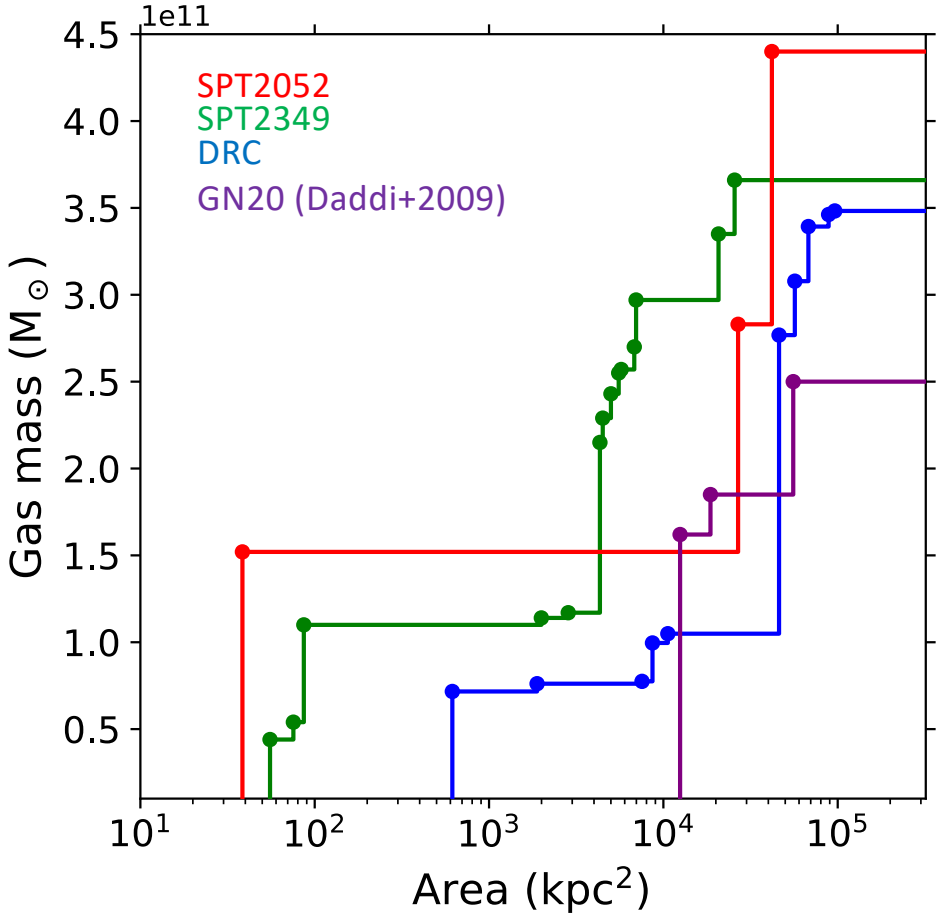


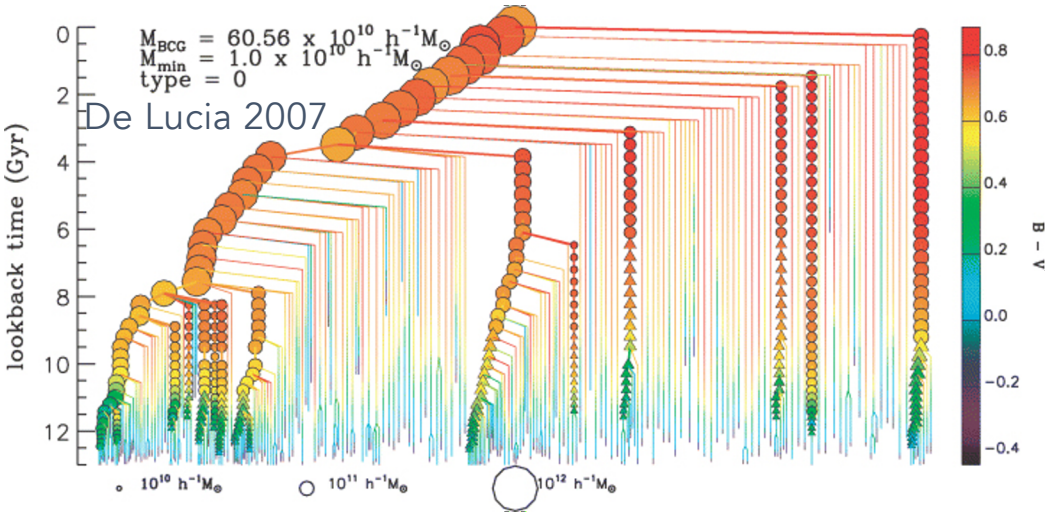
~Degree scale fields

- GOODS-N, **GN20** system is pretty extreme
- COSMOS, 5 bright SMGs z>4 (Chen+2023), only one has a faint companion
- ALESS, Lockman, UDF, etc. have none.

Extreme gas rich PC-cores are pretty rare?

Ruminations on protocluster cores and BCG growth

- No question : BCGs can have an incredibly active and violent, gas-rich, 'mega-merger' formation epoch at z>4.
- Unclear how typical this is in massive clusters
- Duty cycle is short, *but these 'spectacular' examples only ~ 1 per 100 deg^2*



- GN20 z=4, COSMOS z=4.3, Herschel systems: argues for almost as extreme systems, ~1/5 to 1/10 deg^2
- SIMULATIONS? Lots of directions at this conference

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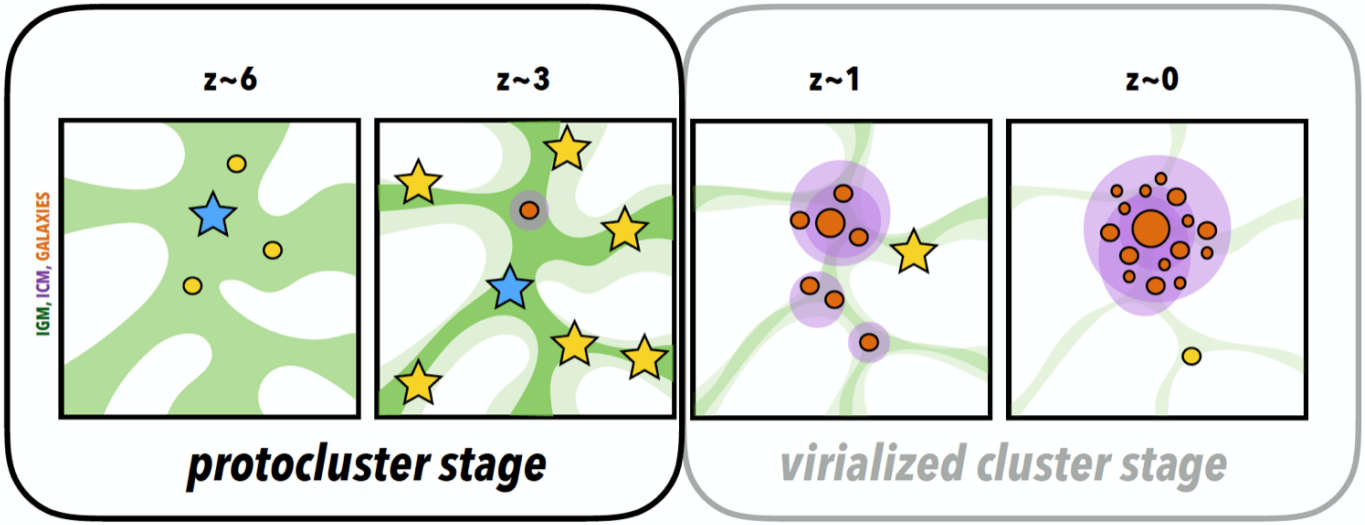


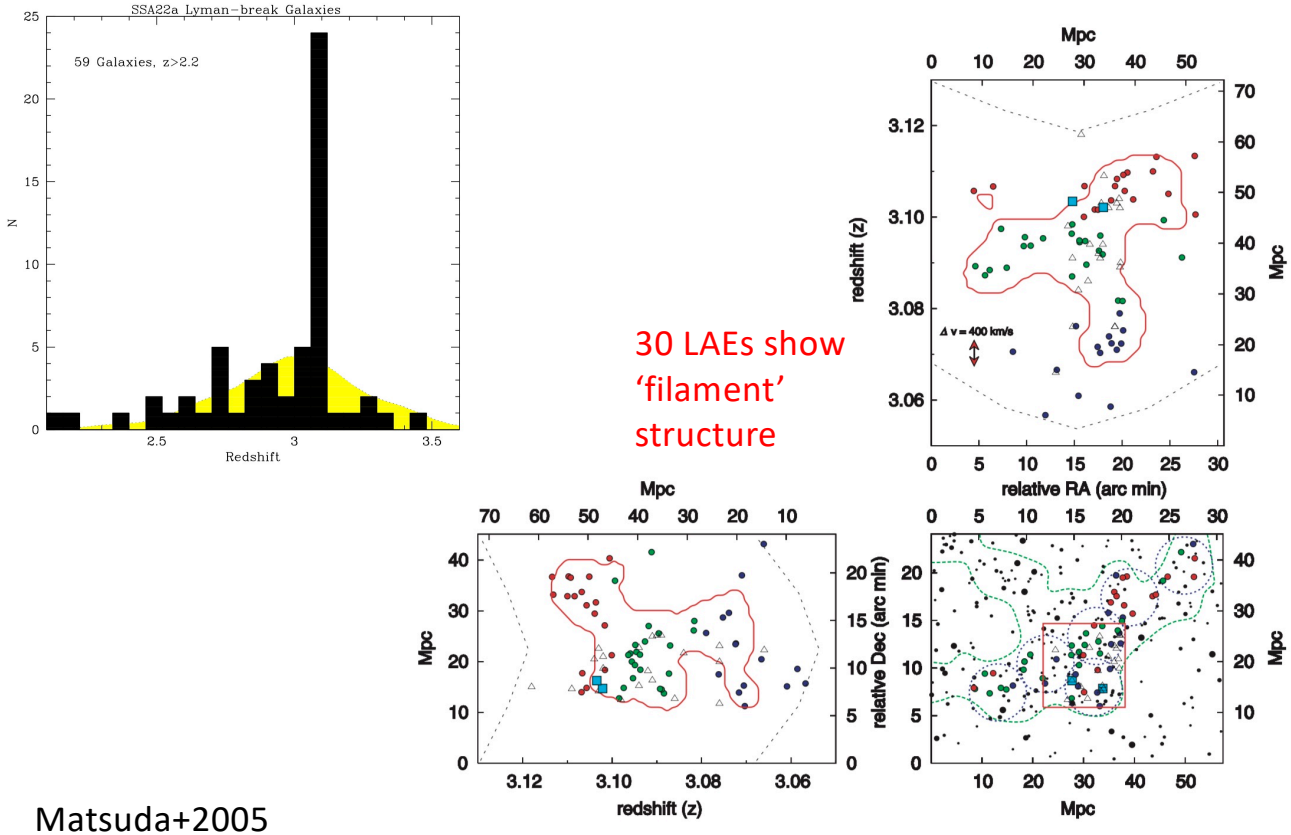
Courtesy of Caitlin Casey

Two recent case studies: bright ***submm sources*** in extended ~30' (~15pMpc) scale protoclusters at **z~3**

HS1549 z=2.9
SSA22 z=3.1

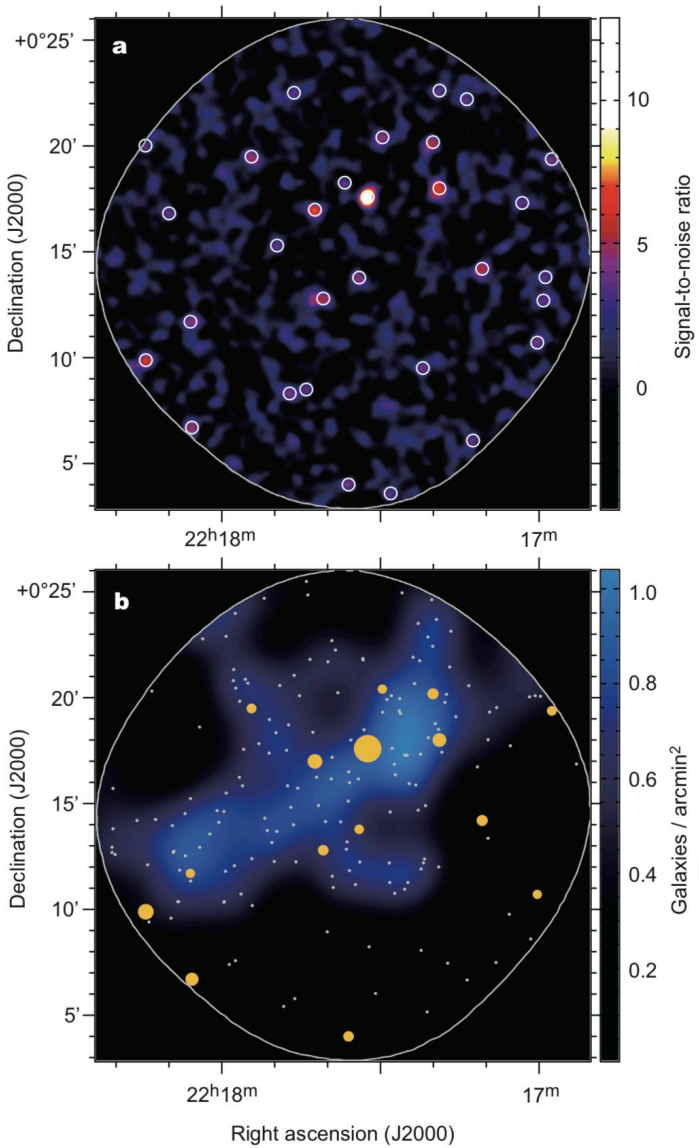
Do bright SMGs trace the very extended collapsing structure of protoclusters?
Is this important for forming ellipticals in PCs?

z=3.1 SSA22 protocluster (Steidel+2000)



Matsuda+2005

FIG. 1.—*Bottom right*: Sky map of the 283 candidate LAEs detected in Hayashino et al. (2004). The green line shows the average local surface density of LAEs in this field (see text). Cyan squares show two giant LABs. Blue circles show the field of view of six masks. Blue, green, and red points show the LAEs at $z = 3.05–3.08$, 3.08–3.10, and 3.10–3.12, respectively. The triangles show the LBGs in the SSA 22a field (*red box*; 8′.7 × 8′.9; Steidel et al. 2003). *Top right and bottom left*: Redshift-space distribution of 56 LAEs with spectroscopic redshifts. The red line shows the projected contour of the local volume density of LAEs of 2×10^{-3} Mpc^{-3} (see text). The predicted peculiar velocity dispersion of 400 km s^{-1} is shown by red arrows. The dotted lines show the redshift range sampled within ≥50% of the peak transmittance of our narrowband filter.



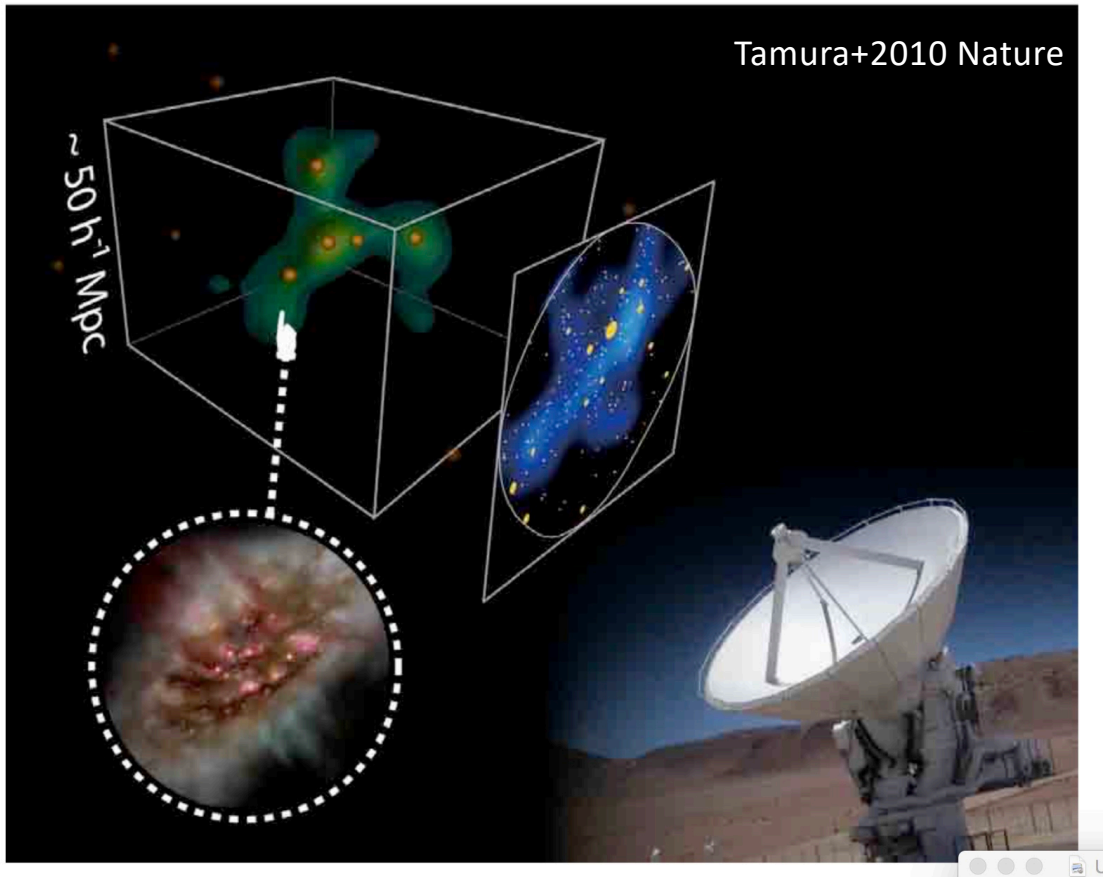
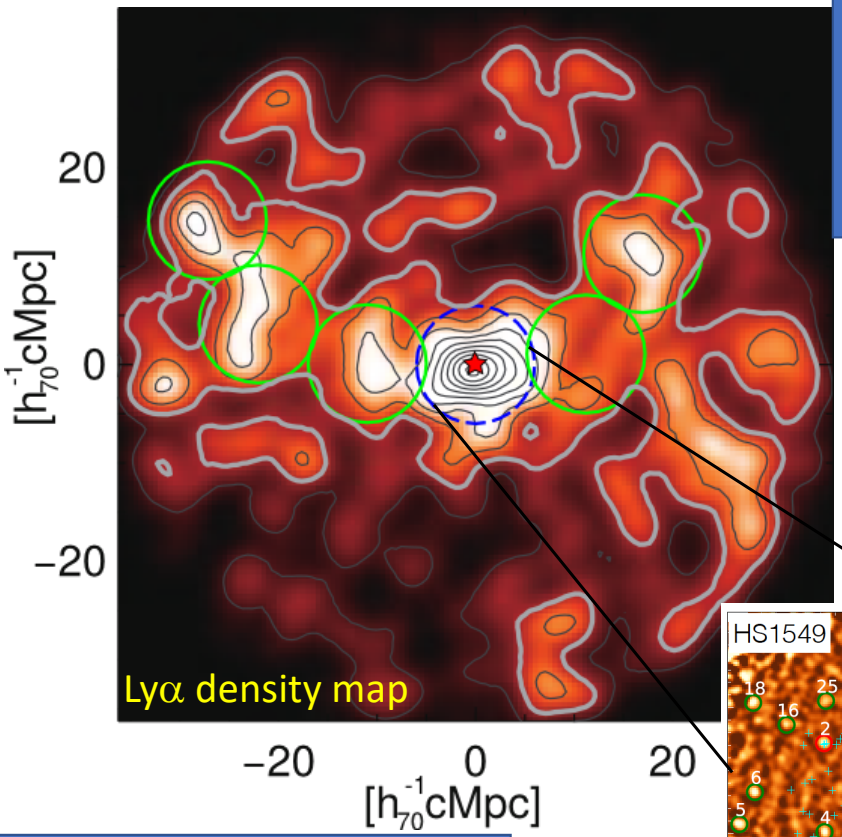


Figure S1 | Schematic picture of this work. The filamentary structure in green shown in the top-left corner represents the proto-cluster outlined by Lyman-α emitting galaxies in the SSA 22 field. We found an apparent clustering of submillimetre galaxies, which are believed to be massive dusty starburst galaxies (orange dots; an artist's conception of a submillimetre galaxy is shown in the bottom-left corner), towards the proto-cluster using the AzTEC camera mounted on the ASTE telescope (shown in the bottom-right corner). Although the 1,100-μm map shows only the projected distribution of the submillimetre galaxies on the plane of the sky, it is likely that some fraction of our submillimetre galaxies actually belongs to the proto-cluster, marking the local peak of underlying mass distribution.

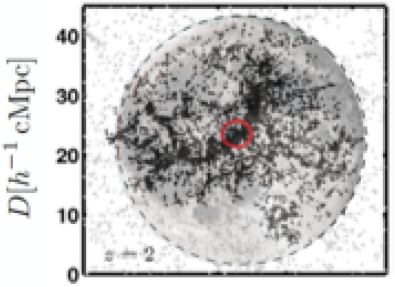
HS1549+19 z=2.9 protocluster (Steidel et al. 2011)



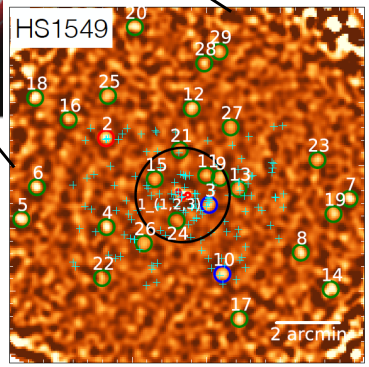
Kikuta+2019

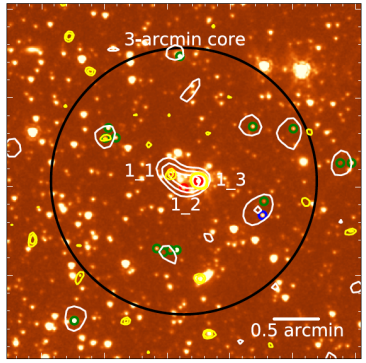
Protoclusters at z>3 are large, ~1 deg^2 region will collapse down by factor 100x

Looks like sims



(Lacaille et al. 2017)



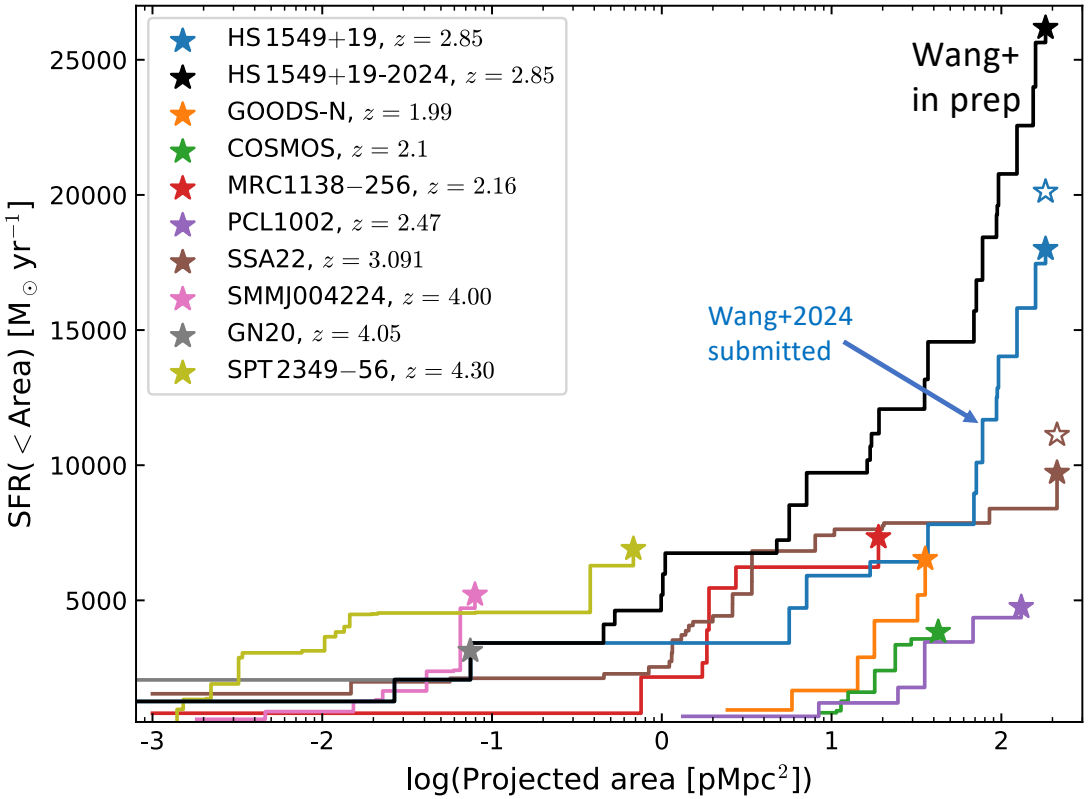


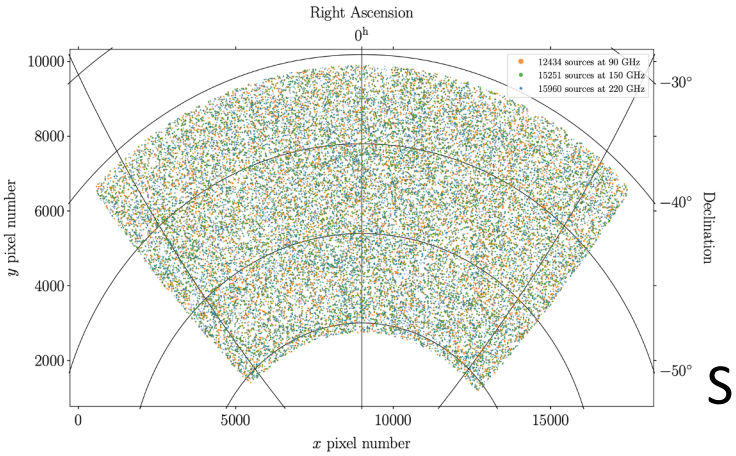
HS1549+19: SFRD from SMGs alone.

see George Wang talk Tuesday

Survey of all *HyLIRG* SMGs with S850>8mJy demonstrated a unique wide field SFRD in PC (Wang et al. 2024, arXiv240616637)

Recent followup of fainter SMGs with NOEMA reveals HS1549 is an SMG monster!

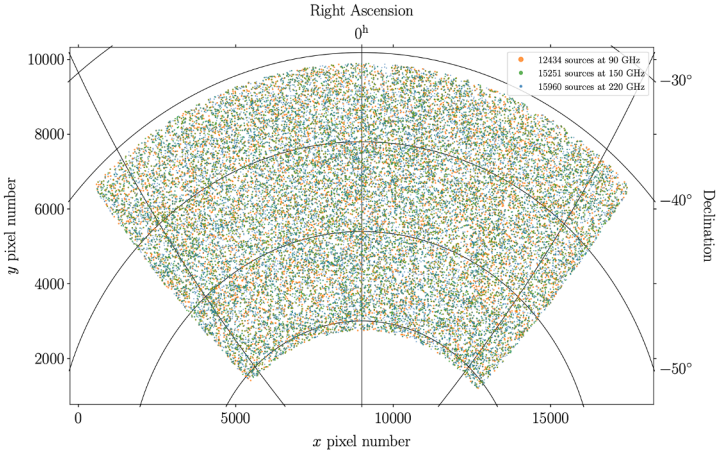




SPT-3G: 1500 deg^2 $S_{220Ghz} > 4.6$mJy 5σ

Prospects for efficient selection at 1.4mm-2mm of next luminosity tier of protocluster cores

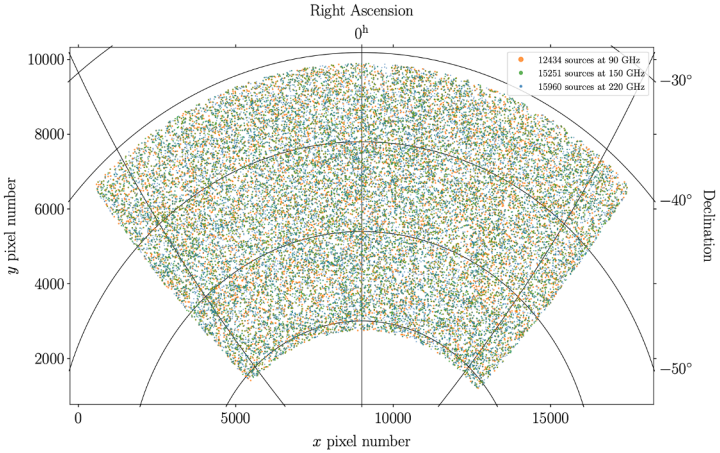
The SPT-3G millimeter wave point source catalog comprises 28736 emissive extragalactic sources.



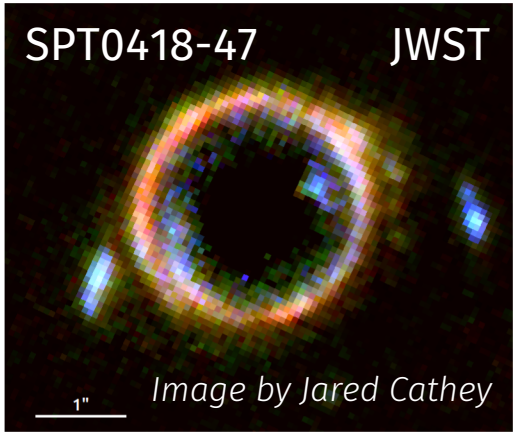
SDSS image of blazar Markarian 421

The SPT-3G millimeter wave point source catalog comprises 28736 emissive extragalactic sources.

About half of the sources are active galactic nuclei. Most have multi-wavelength counterparts.



SDSS image of blazar Markarian 421

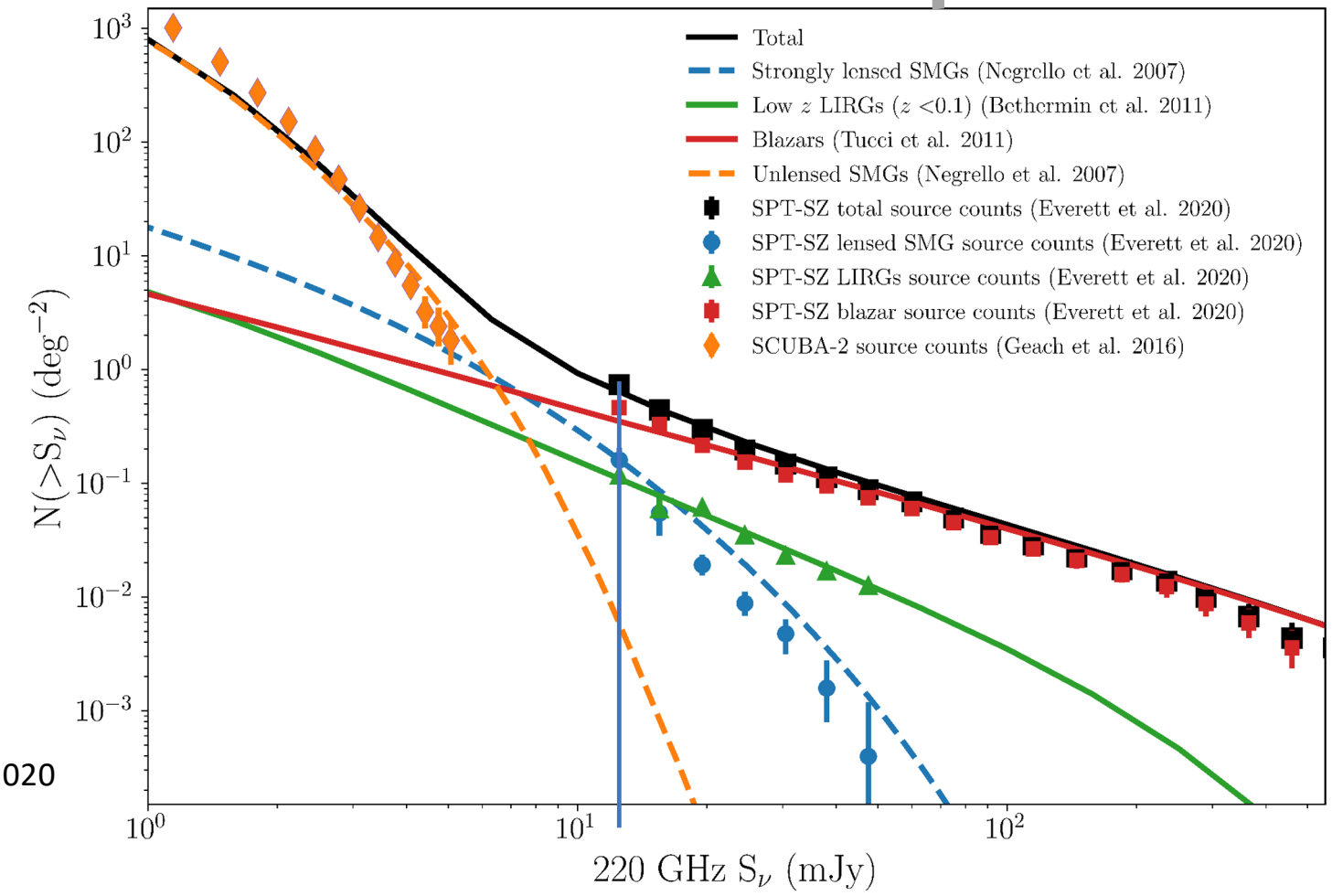


The SPT-3G millimeter wave point source catalog comprises 28736 emissive extragalactic sources.

About half of the sources are active galactic nuclei. Most have multi-wavelength counterparts.

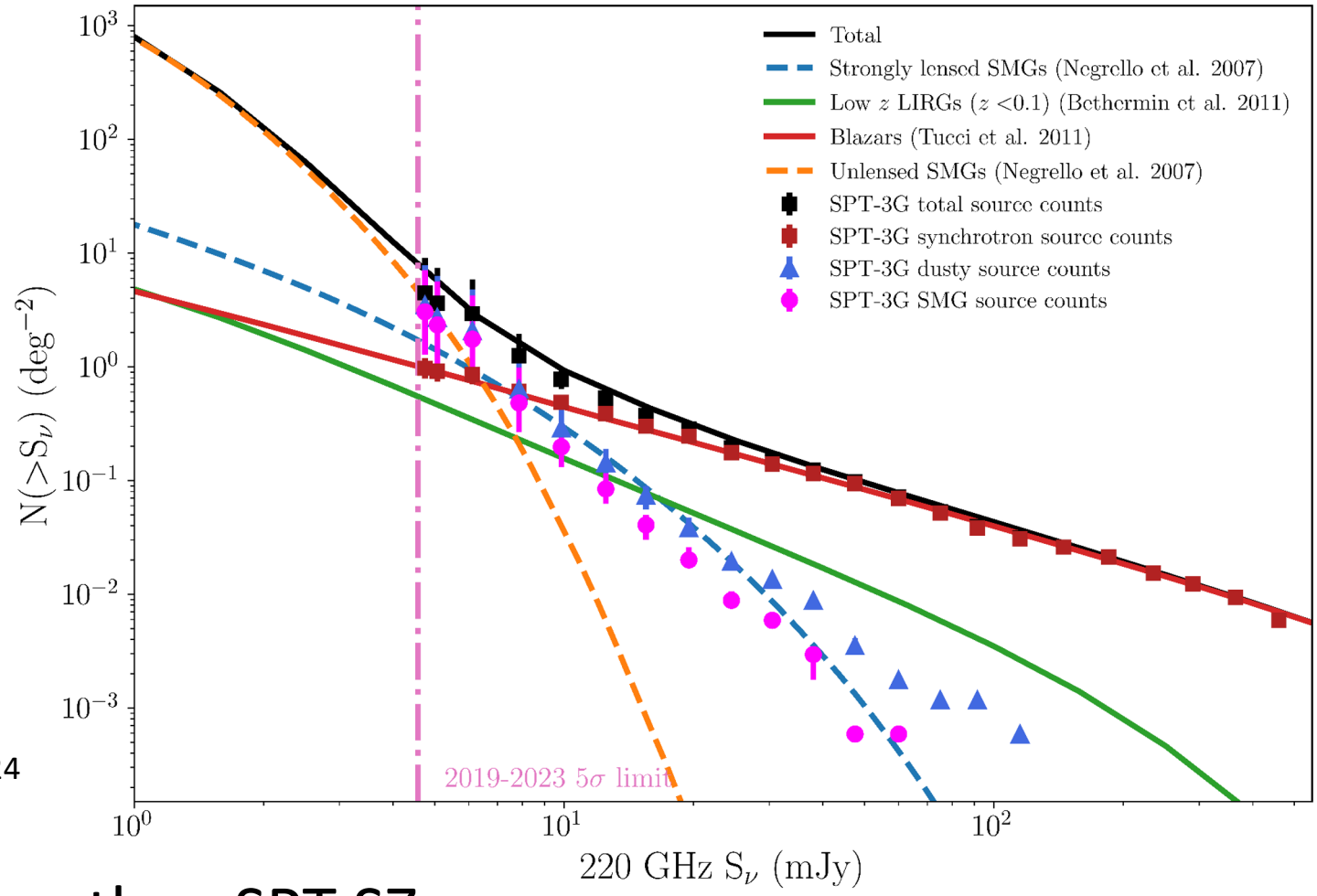
The other half are dusty star-forming galaxies. Many of these lack counterparts and are high-z SMGs and PCs.

Cumulative counts at 220 GHz **prior to** SPT-3G



Everett+2020

Cumulative source counts at 220 GHz **with** SPT-3G

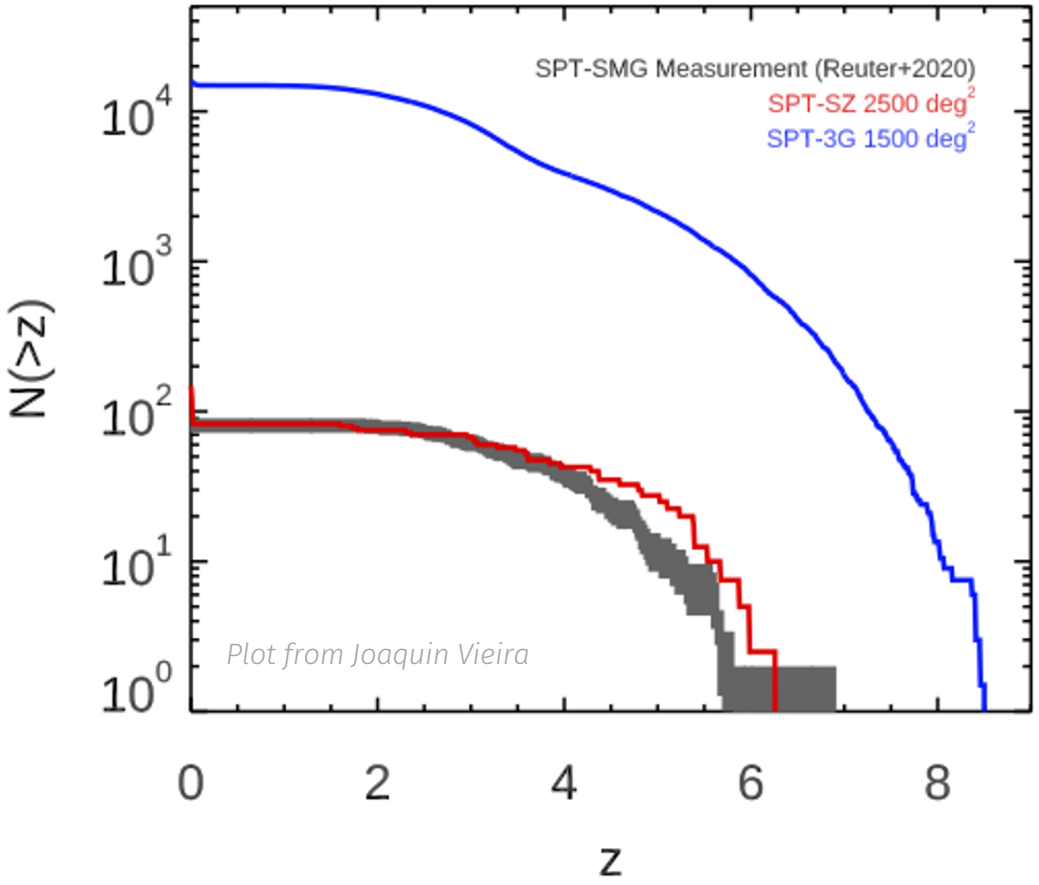


Archipley+2024

>4x deeper than SPT-SZ

Forecasts of SPT-3G sources (Bethermin+ models)

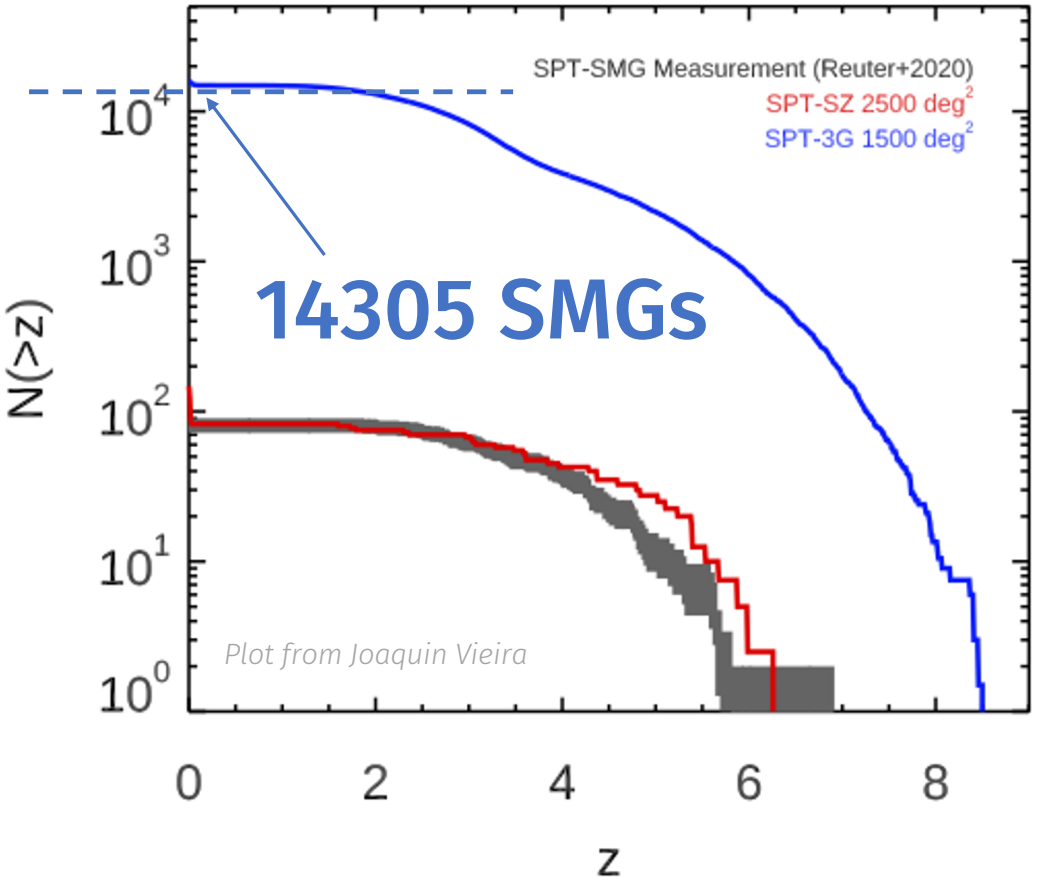
Redshift forecasts of SPT-3G :
predicts *10 z~7 sources*
in 100 deg^2 pilot field
(with SPIRE overlap)



Two ALMA cycle 11 proposals: **imaging** and **highest-*z***

Imaging 226 sources with 30hr ALMA Band 6 (1.2mm)
(PI Chapman)

Spectroscopy: 7 sources selected with no SPIRE, or steep rising emission at 500 μm → red, high *z*
(PI Reuter)



Two ALMA cycle 11 proposals: imaging and **highest-*z***

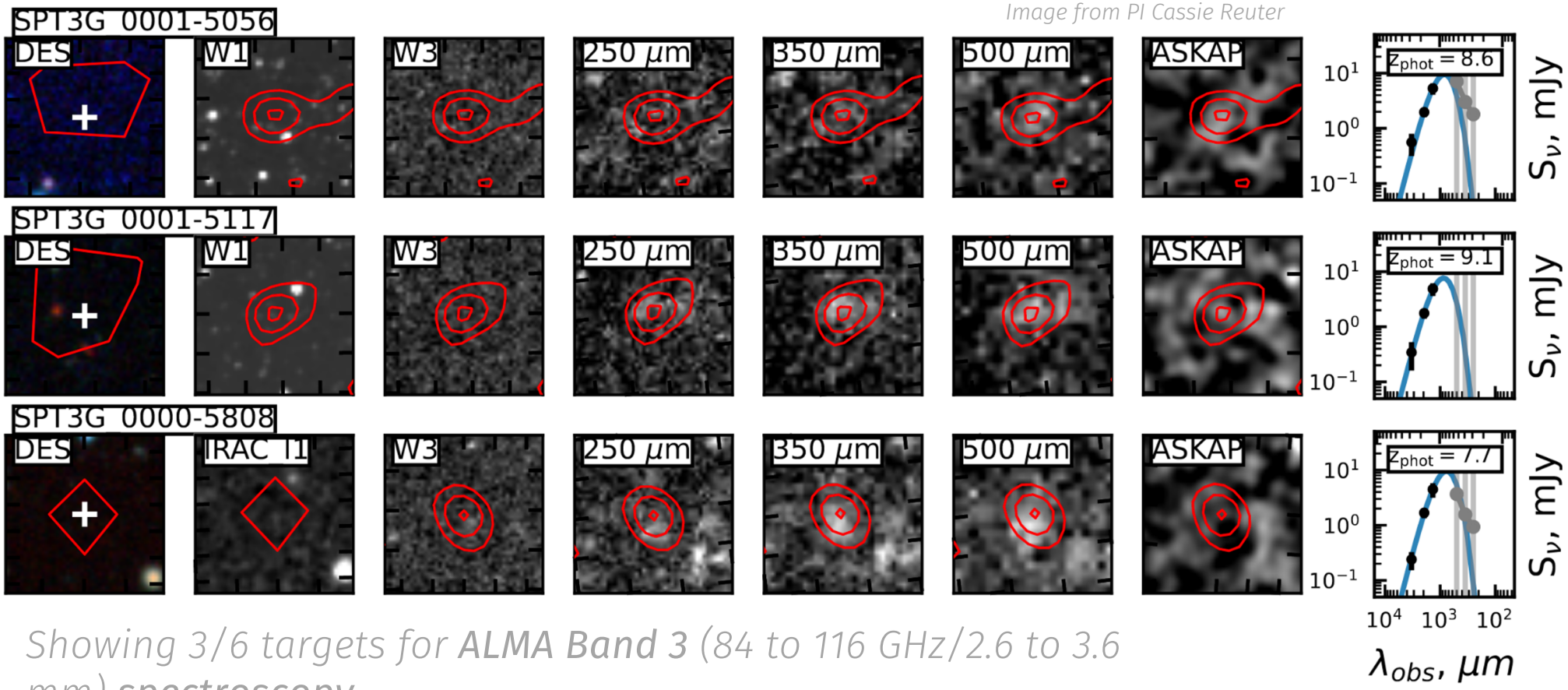


Image from PI Cassie Reuter

*Showing 3/6 targets for **ALMA Band 3** (84 to 116 GHz/2.6 to 3.6 mm) **spectroscopy***

Conclusions

- Assembling protoclusters are forming lots of stars
- Wide field submm surveys can efficiently find them
- Some massive protoclusters can only be found in the submm!
- Extreme submm-luminous protocluster cores at z>4 (e.g., SPT2349 & DRC):
  - More have been found and studied (SPT0457 z=4.0; SPT2052 z=4.3)
  - Highlight an important mode for BCG assembly
  - May be beacons of most massive z=0 clusters?
- Studying z~3 protoclusters with SMGs in wide field is important
  - SSA22 and HS1549
- SPT-3G and CCAT will be protocluster finding machines

END