

“Good things come in threes”

cosmic web-scale protocluster assembly
behind SPT0303-59



Galaxy transformation in submillimeter-bright overdensities

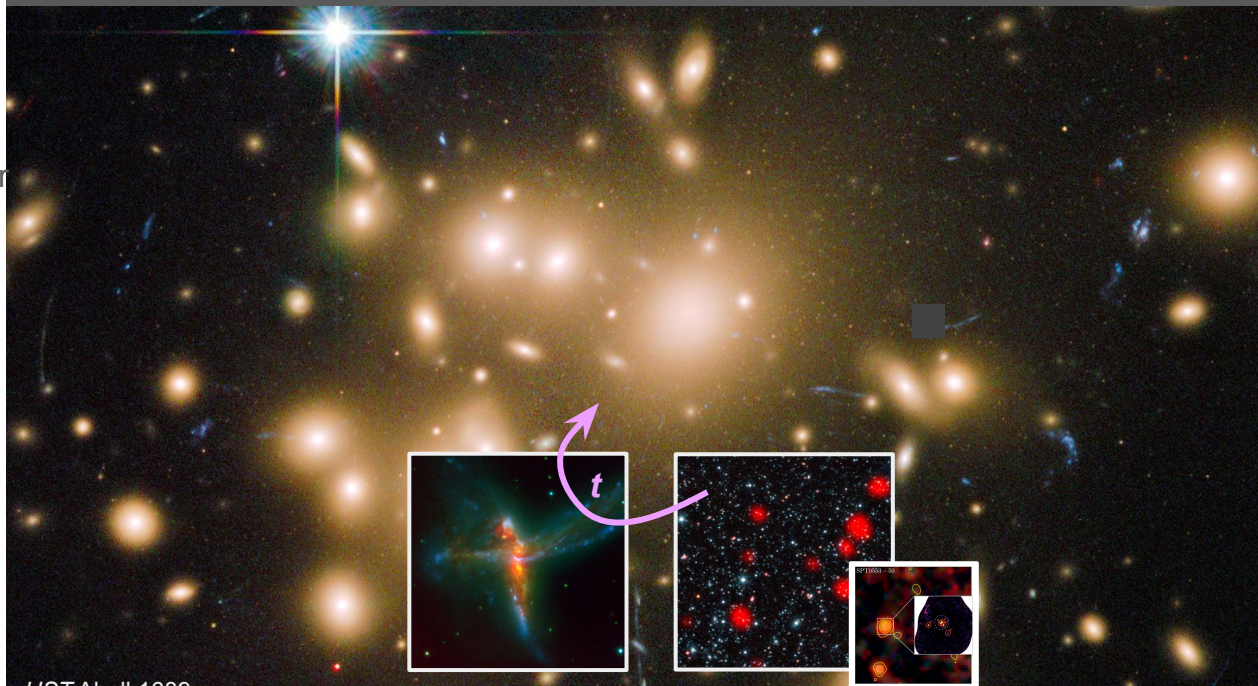
At redshift >2

- What drives extreme, correlated star-formation in groups of SMGs?
- **HyLIRGs** ($L_{\text{IR}} > 10^{13} L_{\odot}$), $\text{SFR} > 10^3 M_{\odot}/\text{yr}$

SPT-protocluster sample of non-lensed SMGs (Wang+2021, Hill+ in prep.)

At redshifts $\sim <2$

- Galaxy clusters characterized by red sequence of quiescent, giant galaxies
- Old stellar ages, late assembly times



HST Abell 1689

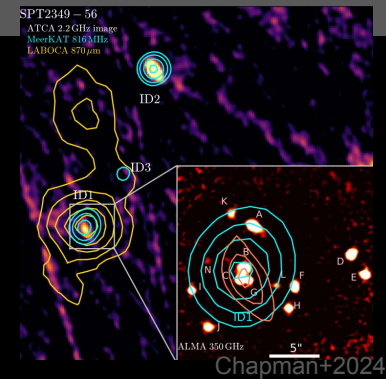
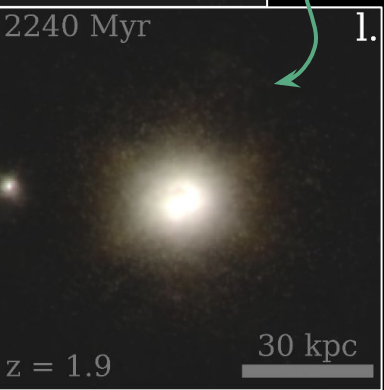
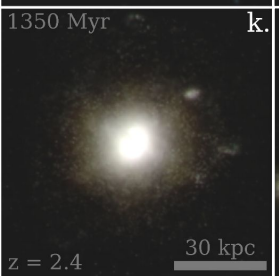
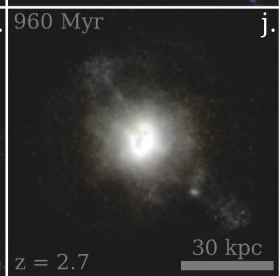
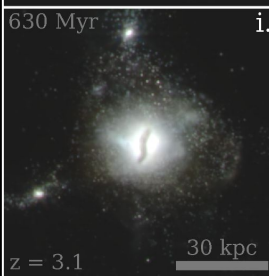
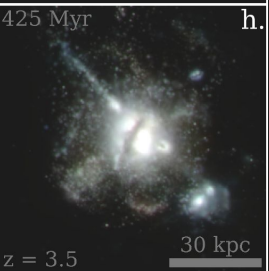
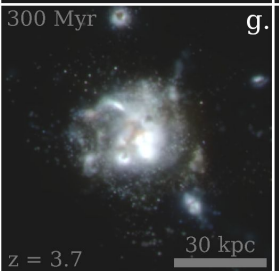
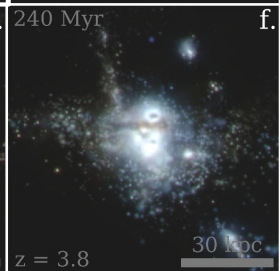
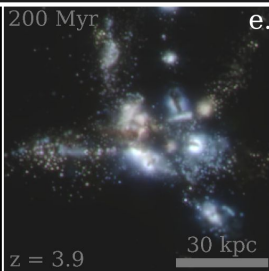
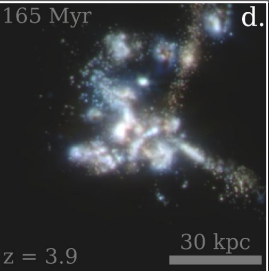
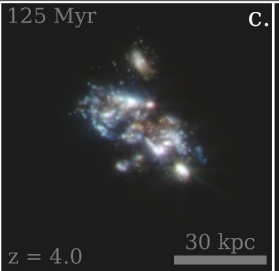
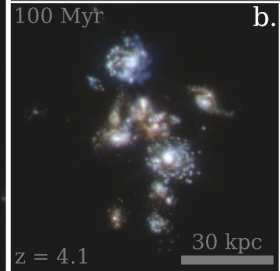
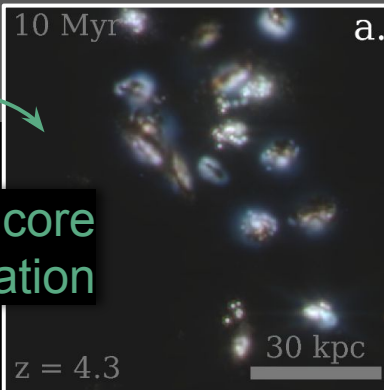
Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA), J. Blakeslee (NRC Herzberg Astrophysics Program, Dominion Astrophysical Observatory), and H. Ford (JHU)



→ See talks by Ryley Hill, Scott Chapman, Dazhi Zhou

Dissipative collapse of a protocluster core at $z \sim 4$ leads to the formation of ultramissive, giant, early-type galaxy within < 1 Gyr

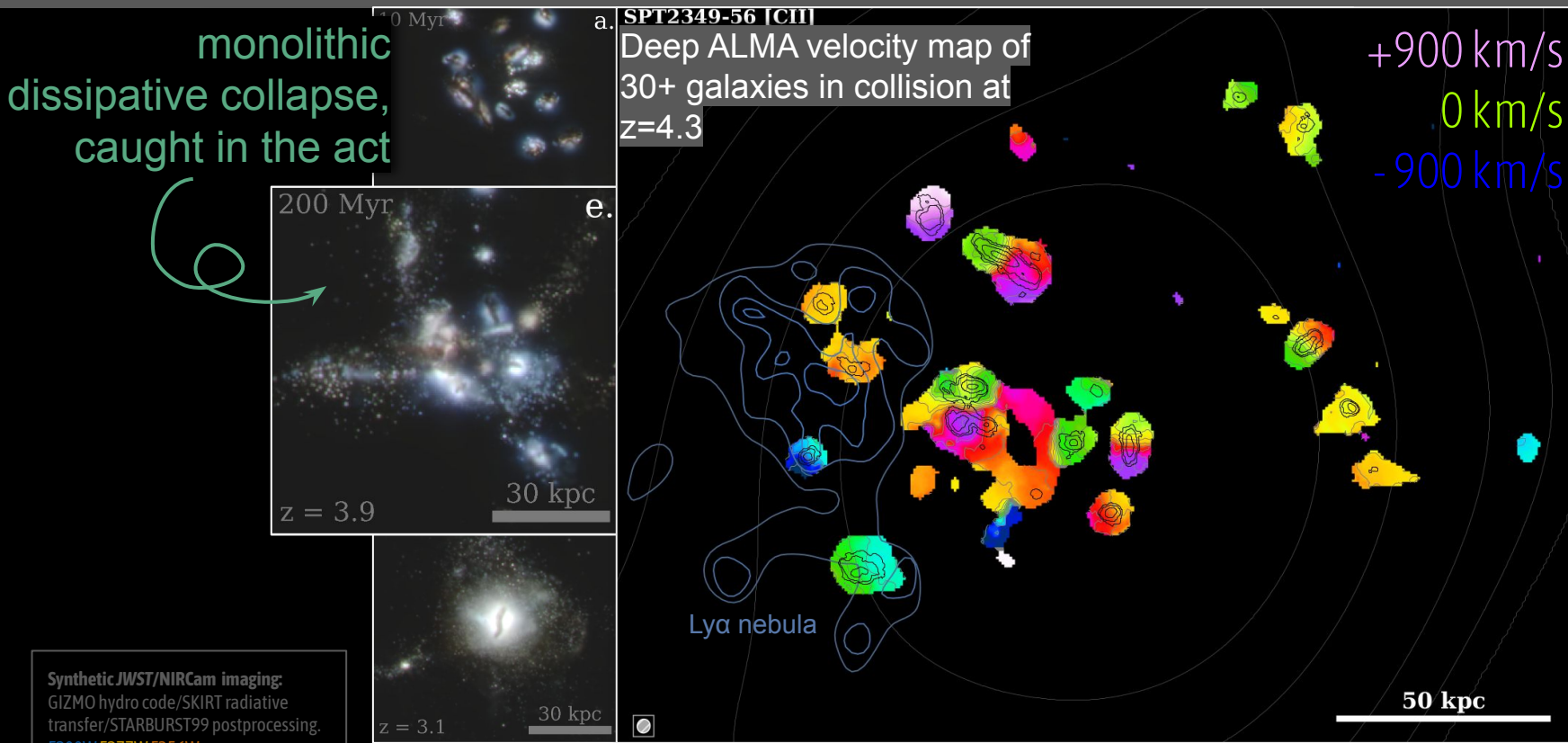
protocluster core configuration



A giant ETG

Synthetic JWST/NIRCam imaging:
GIZMO hydro code/SKIRT radiative transfer/STARBURST99 postprocessing.
F200W F277W F356W
Sims: D MacIntyre, J Tsuchitori,
D Rennehan, Hansen

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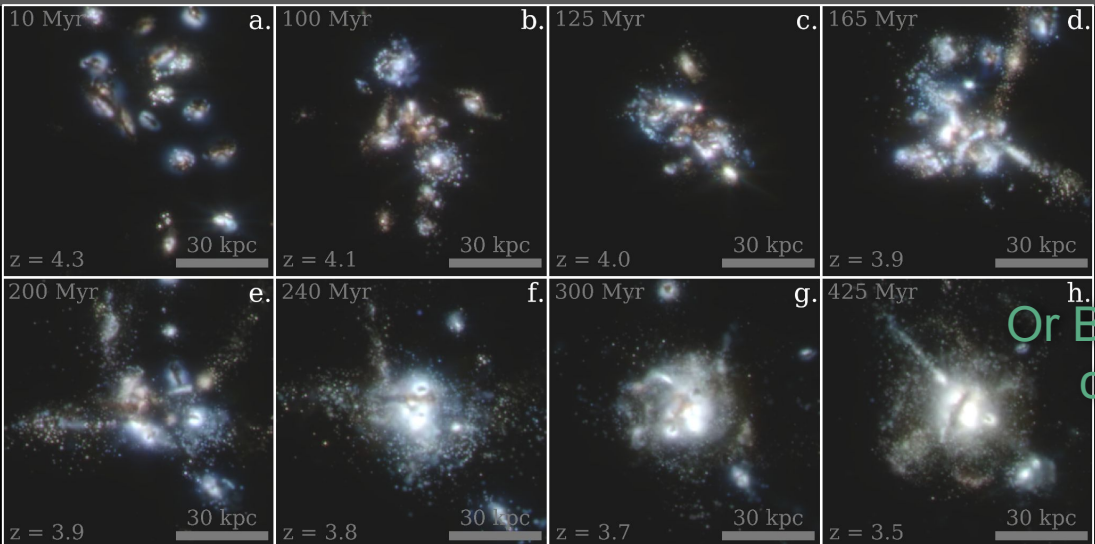


Synthetic *JWST/NIRCam* imaging:
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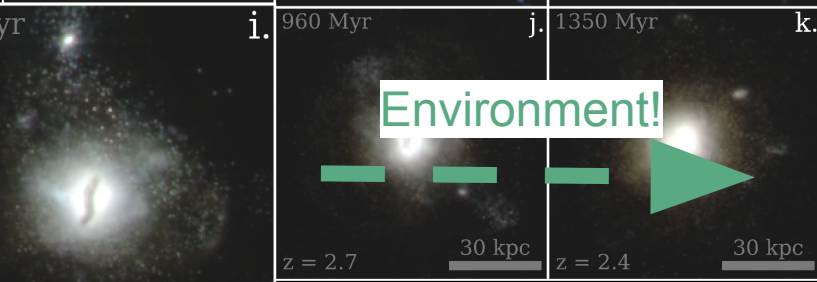
Sulzenauer et al. in prep

Dissipative collapse of a protocluster core at $z \sim 4$ leads to the formation of ultramissive, giant, early-type galaxy within < 1 Gyr

ultra massive galaxy by $z \sim 3$



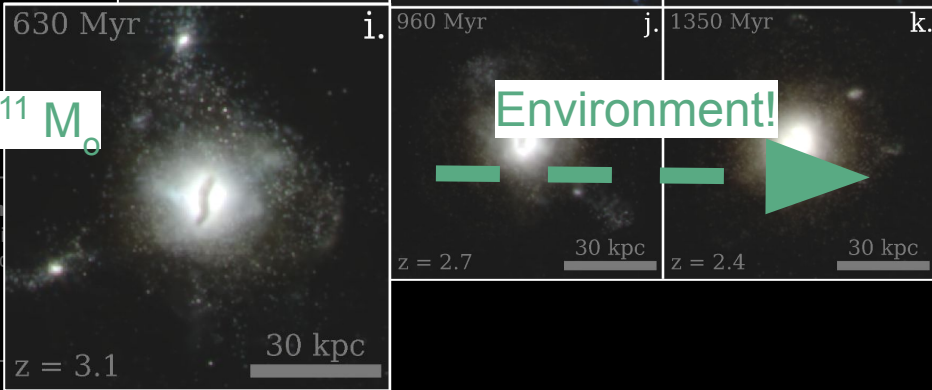
Or BCG in rich galaxy cluster by $z < 2$???



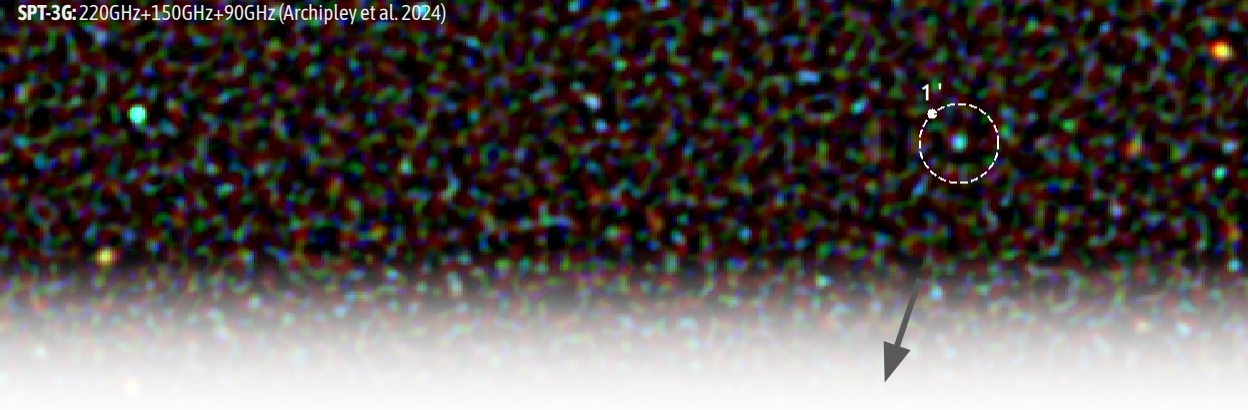
$M_* \sim 8 \times 10^{11} M_\odot$

Environment!

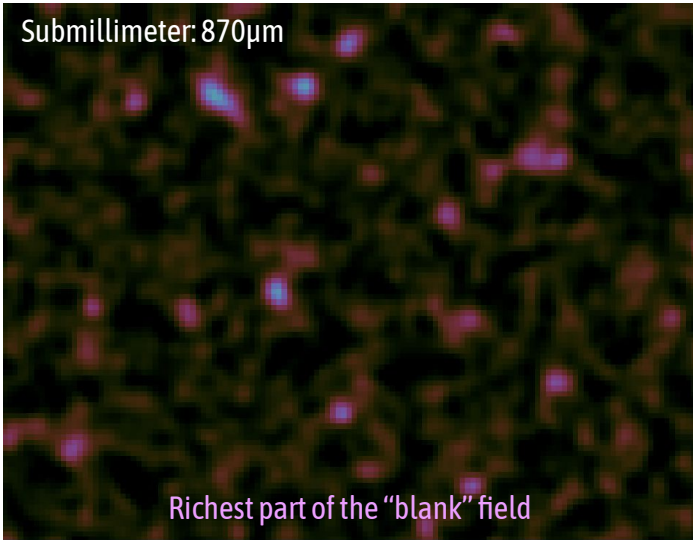
Dictates formation of red sequence...ect.



Synthetic JWST/NIRCam images
 GIZMO hydro code/SKIRT radiative transfer/STARBURST99 postprocessor
 F200W F277W F356W
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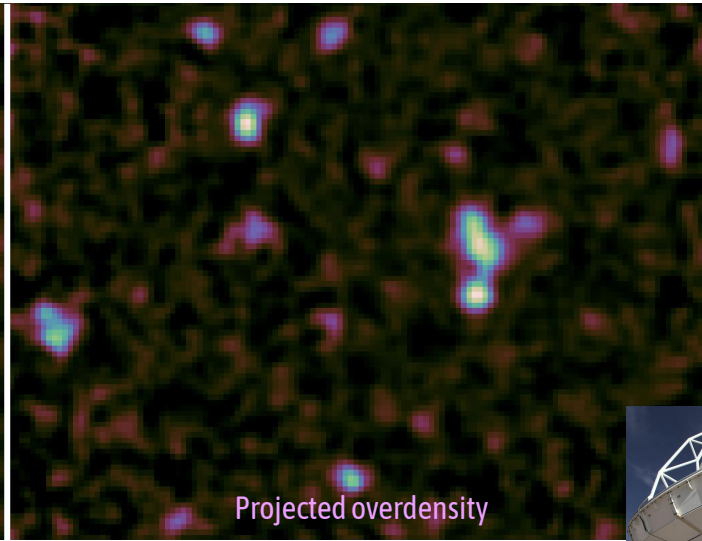


The 870 μ m-brightest region among the SPT-PC's: SPT0303-59



Richest part of the "blank" field

APEX/LABOCA survey (LESS)

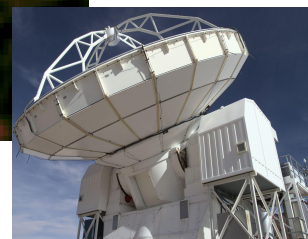


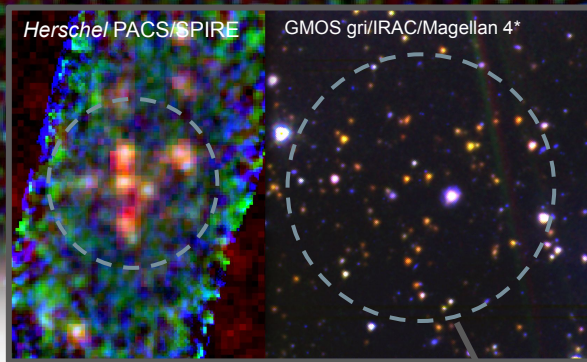
Projected overdensity

APEX/LABOCA on SPT0303-59

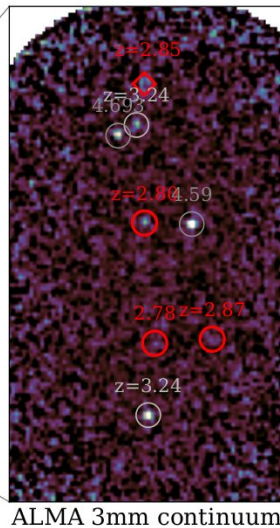
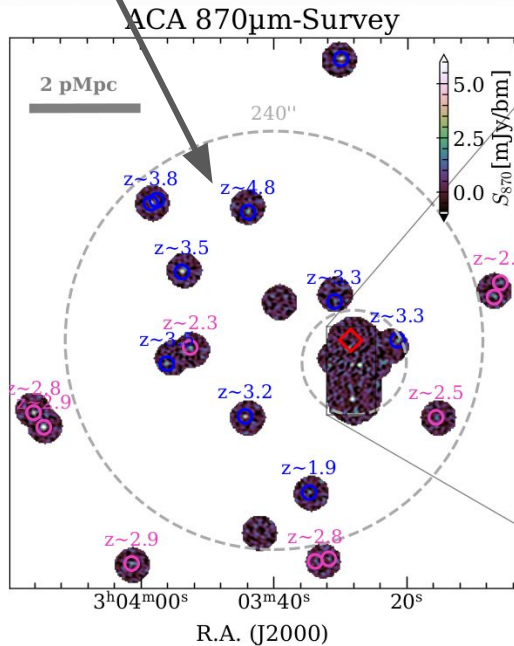
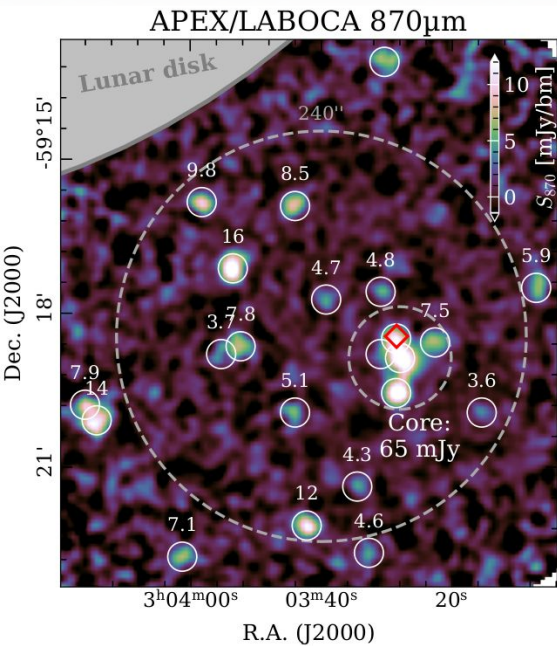
- Extended core at 220 GHz
- Rich satellite system
- \sim x5 overdensity of bright SMGs over the field
- Together 50% brighter than SPT2349-56!
- Spread over many HyLIRGs

- At $z=3.3 \rightarrow 12'000 M_{\odot} \text{ yr}^{-1}$





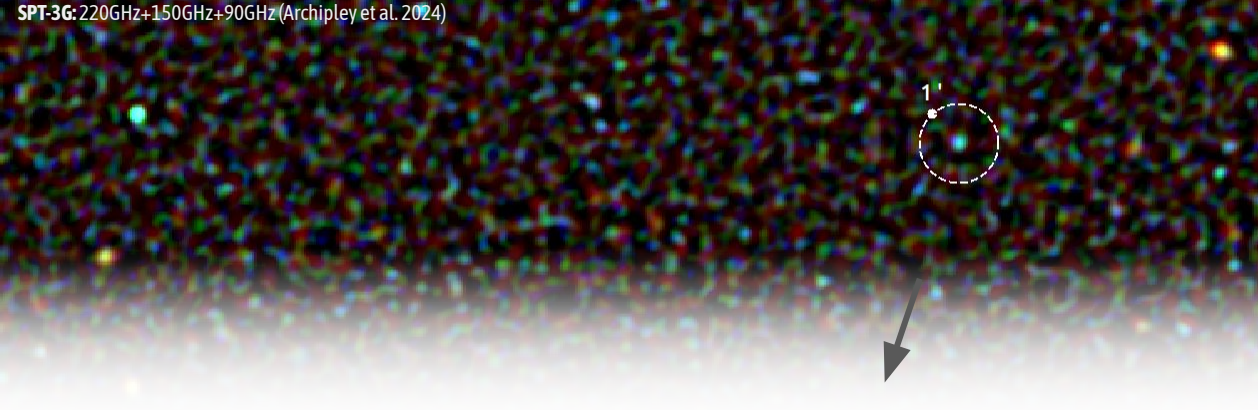
The 870 μ m-brightest region among the SPT-PC's: SPT0303-59



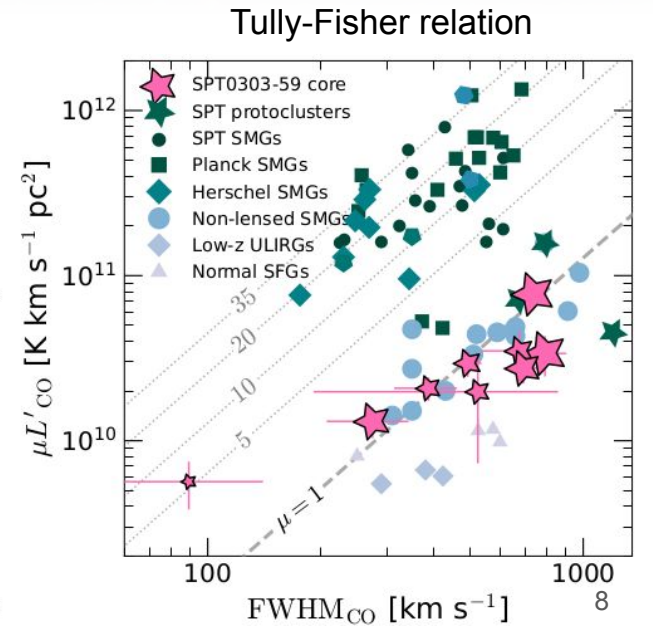
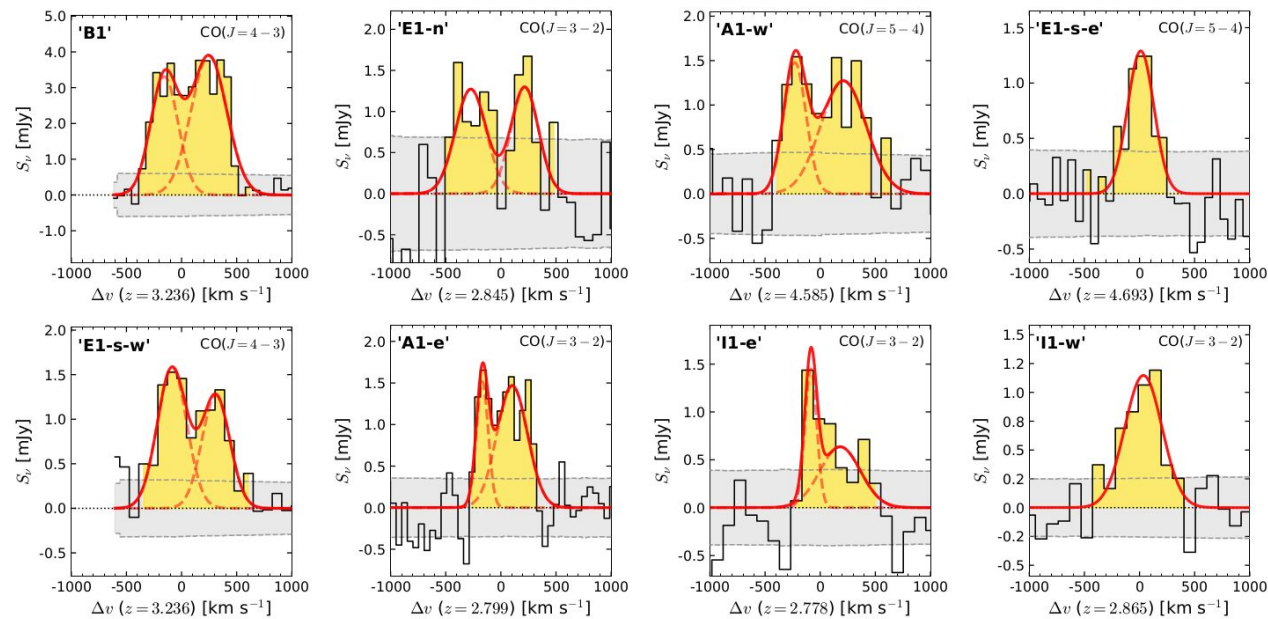
- Higher resolution follow-ups
- ALMA 3mm follow-up
- Combination of *Herschel* PACS/SPIRE FIR and optical+NIR imaging for photo-zs

⇒ ALMA blind CO-scans



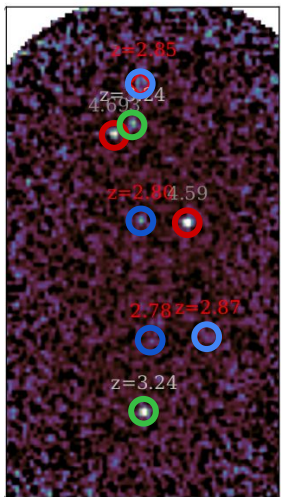


Redshifts for the protoellipticals in SPT0303-59



Redshifts for the protoellipticals in SPT0303-59 ... don't line up

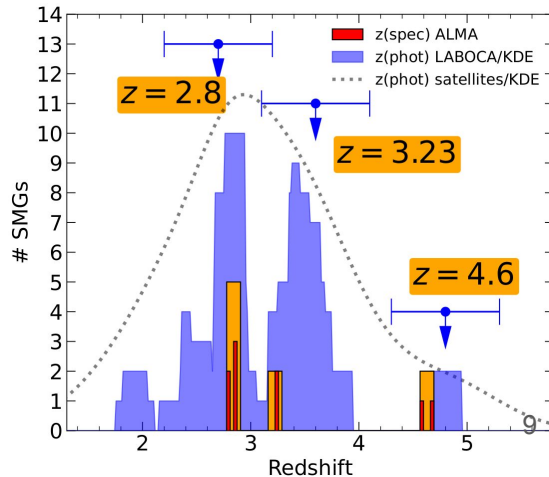
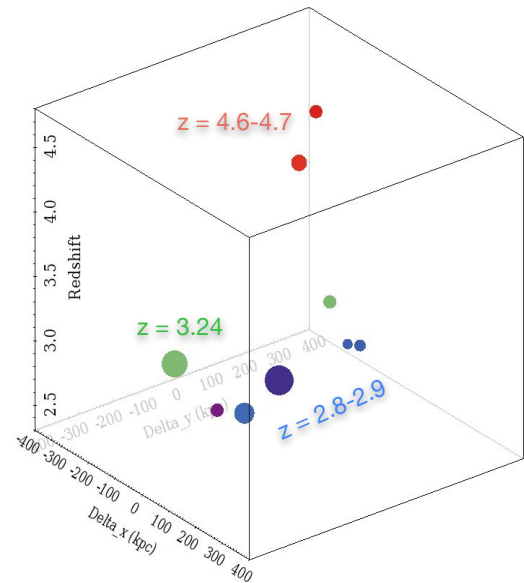
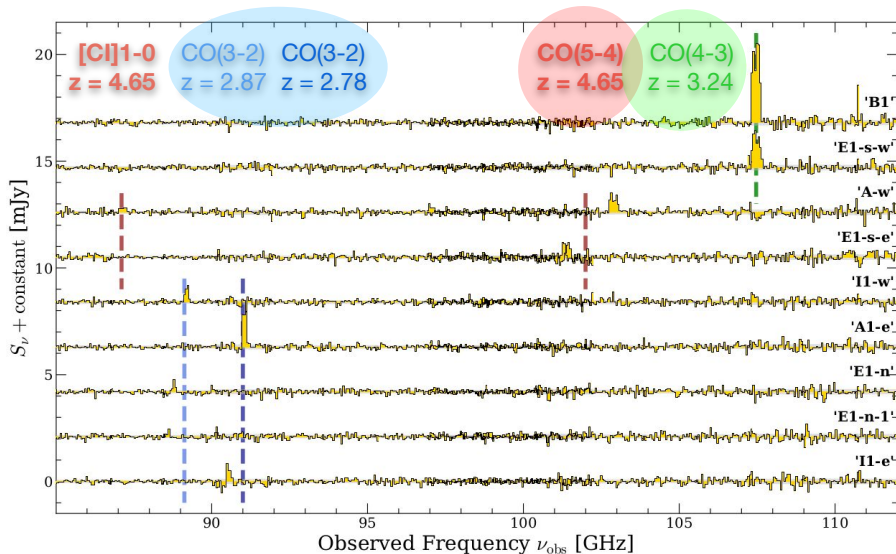
3 redshift groups
Few 100s of kpc of separation



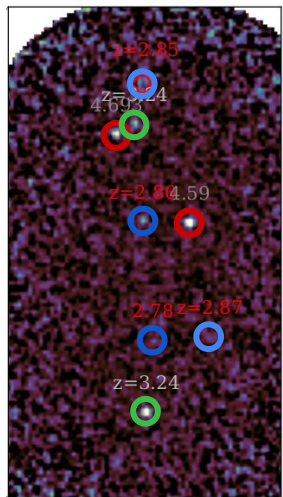
ALMA 3mm continuum

- Relatively large redshift offsets
- $\Delta z = 0.11$: physically realistic at $z > 4$, but problematic at lower z

⇒ However, **satellite photometric redshifts** fall into three groups as well



Redshifts for the protoellipticals in SPT0303-59 ... don't line up



ALMA 3mm continuum

$\Delta z = 0.11$ ($z=2.8$)

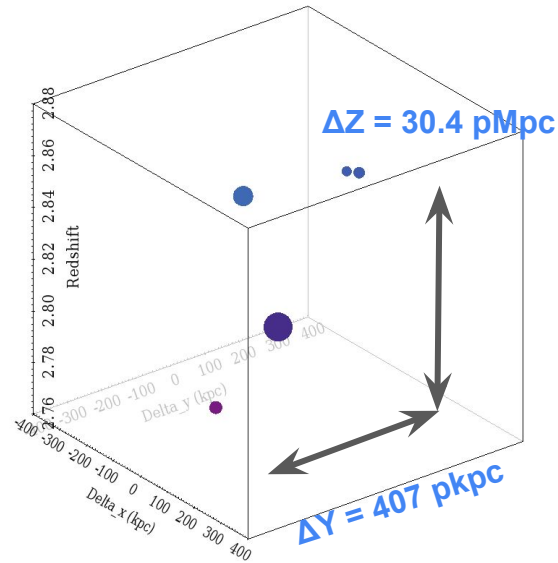
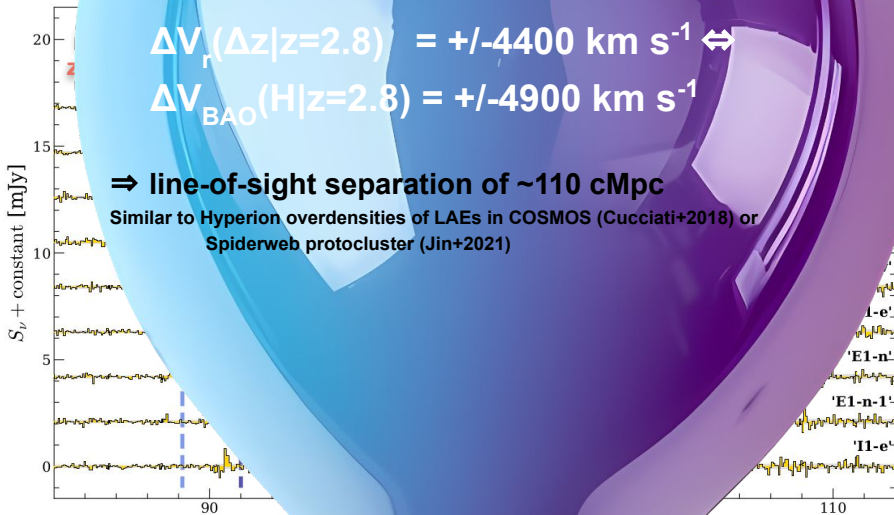
Size of BAOs: 130 cMpc \rightarrow dominated by Hubble flow $H(z)$:

$$\Delta V_{\perp}(\Delta z|z=2.8) = \pm 4400 \text{ km s}^{-1} \leftrightarrow$$

$$\Delta V_{\text{BAO}}(H|z=2.8) = \pm 4900 \text{ km s}^{-1}$$

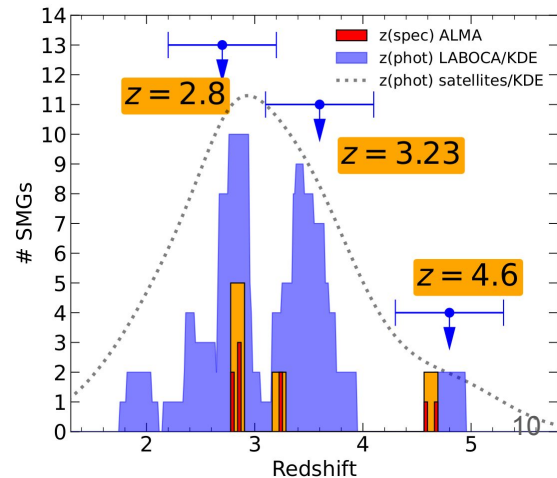
\Rightarrow line-of-sight separation of ~ 110 cMpc

Similar to Hyperion overdensities of LAEs in COSMOS (Cucciati+2018) or Spiderweb protocluster (Jin+2021)



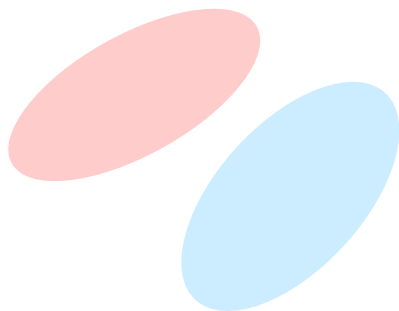
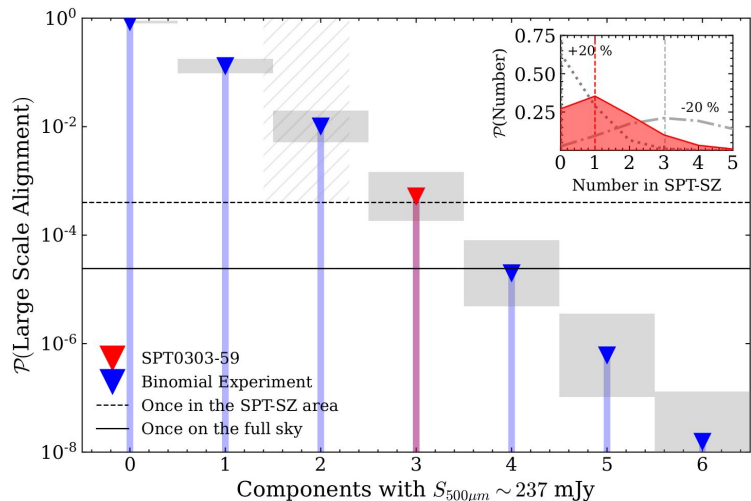
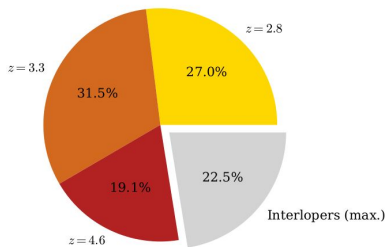
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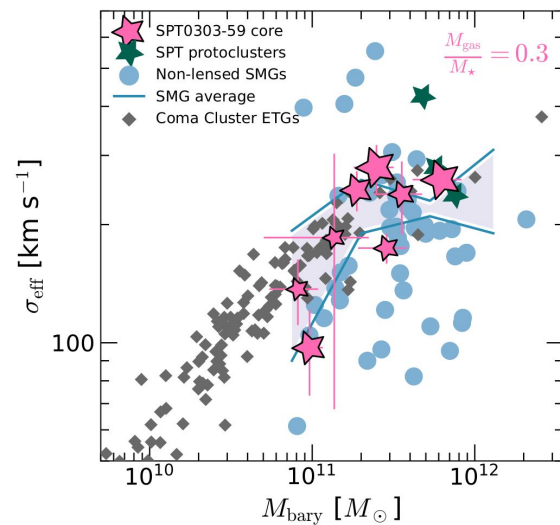


Three Coma-type galaxy cluster progenitors behind SPT0303-59?

$\Sigma S_{500\mu\text{m}} = 178 \text{ mJy}$
(including photometric members)



- Massive SMGs on track to grow into giant ETGs



What is the probability?

$\frac{1}{3} \Sigma S_{500} = 237 \text{ mJy} \rightarrow N(S > 237 \text{ mJy})$ [Negrello+2017]

$\Rightarrow n=0: 27\%, n=1: 35\%, n=2: 23\%$ Only once in SPT-SZ survey (2500 deg²)

— **within 1σ : single SPT0303-like projection is expected!**

Ultra massive galaxies tracing the first structures

Detection of ultra massive galaxies in SPT0303-59

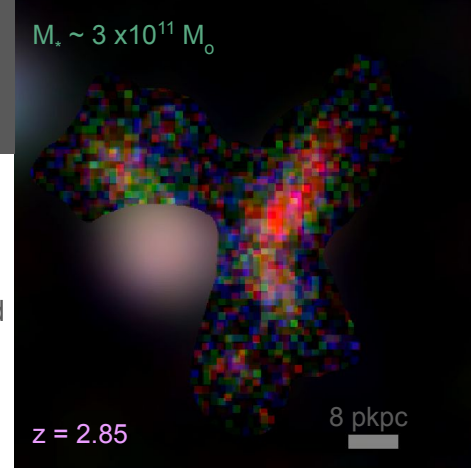
- SMGs are stochastic/poor tracer of structure (Miller+2015)
- Gravitational quenching (Dekel+2006)
- Tentative overdensity of $M_* > 2 \times 10^{11} M_\odot$ galaxies at $z \sim 2.8$ centered on core region

Example: possible triple merger 'E1-n' ($z=2.85$)

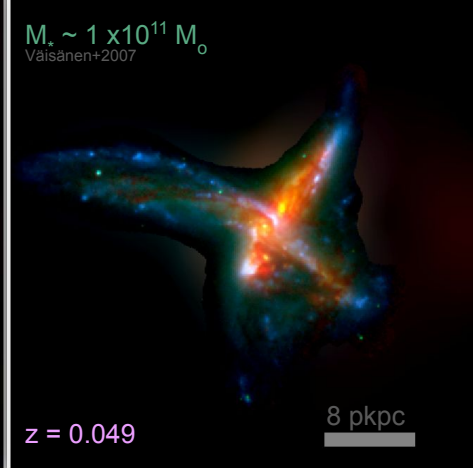
Both UMGs and bright SMG: $M_* = 2.9 \times 10^{11} M_\odot$ (CIGALE)

$SFR_{UV} = 450 M_\odot \text{ yr}^{-1}$ | $SFR_{FIR} = 560 M_\odot \text{ yr}^{-1}$

- CO map extremely extended: $>30 \text{ kpc}$ is length
- Evolution into Fornax-type BCG by $z=0$ (Behroozi+2013)



'E1-n' at $z=2.85$ (GMOS/gri)
"The Super Tinker Bell" :)



IRAS 19115-2124 (Credit: ESO)
"The Tinker Bell triplet"

