Tracing dark matter overdensities with dusty star-forming galaxies

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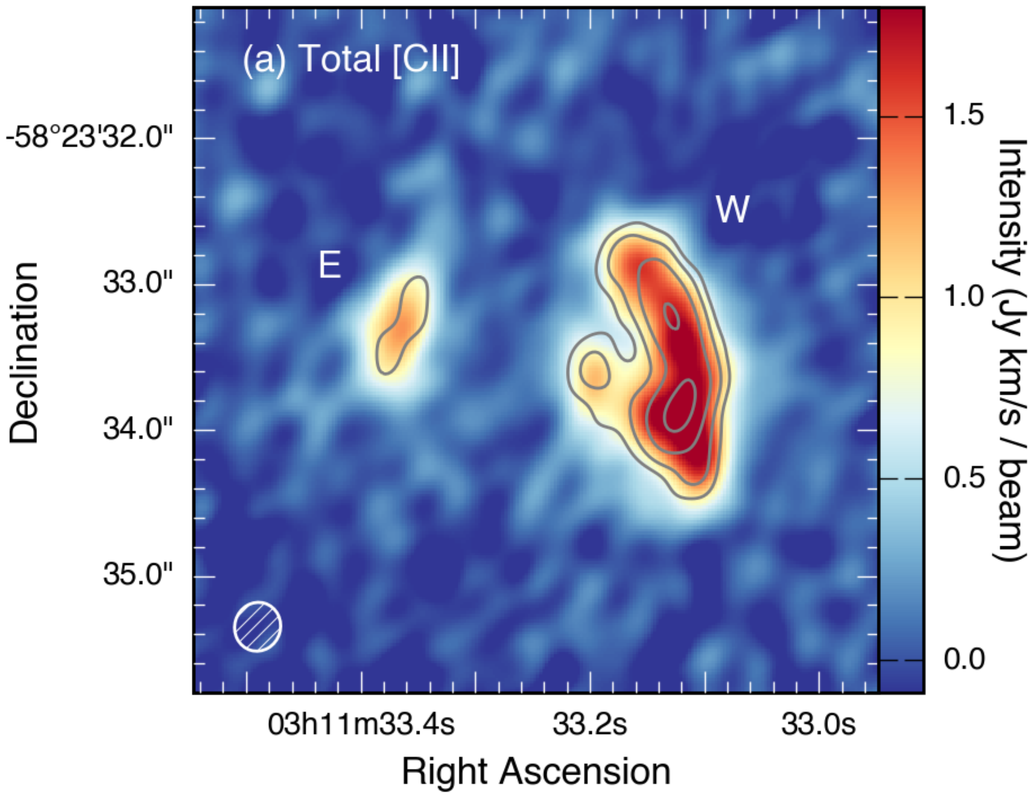
SIMONS FOUNDATION



Chris Hayward (Flatiron Institute)

“First Galaxies, First Structures”, 25 October 2019

Outline

- Why the (sub)mm?
- Modeling the relationship between dark matter overdensities and DSFGs
- A protocluster candidate at $z = 4.3$
- Pushing the limits of LCDM with high-z DSFGs

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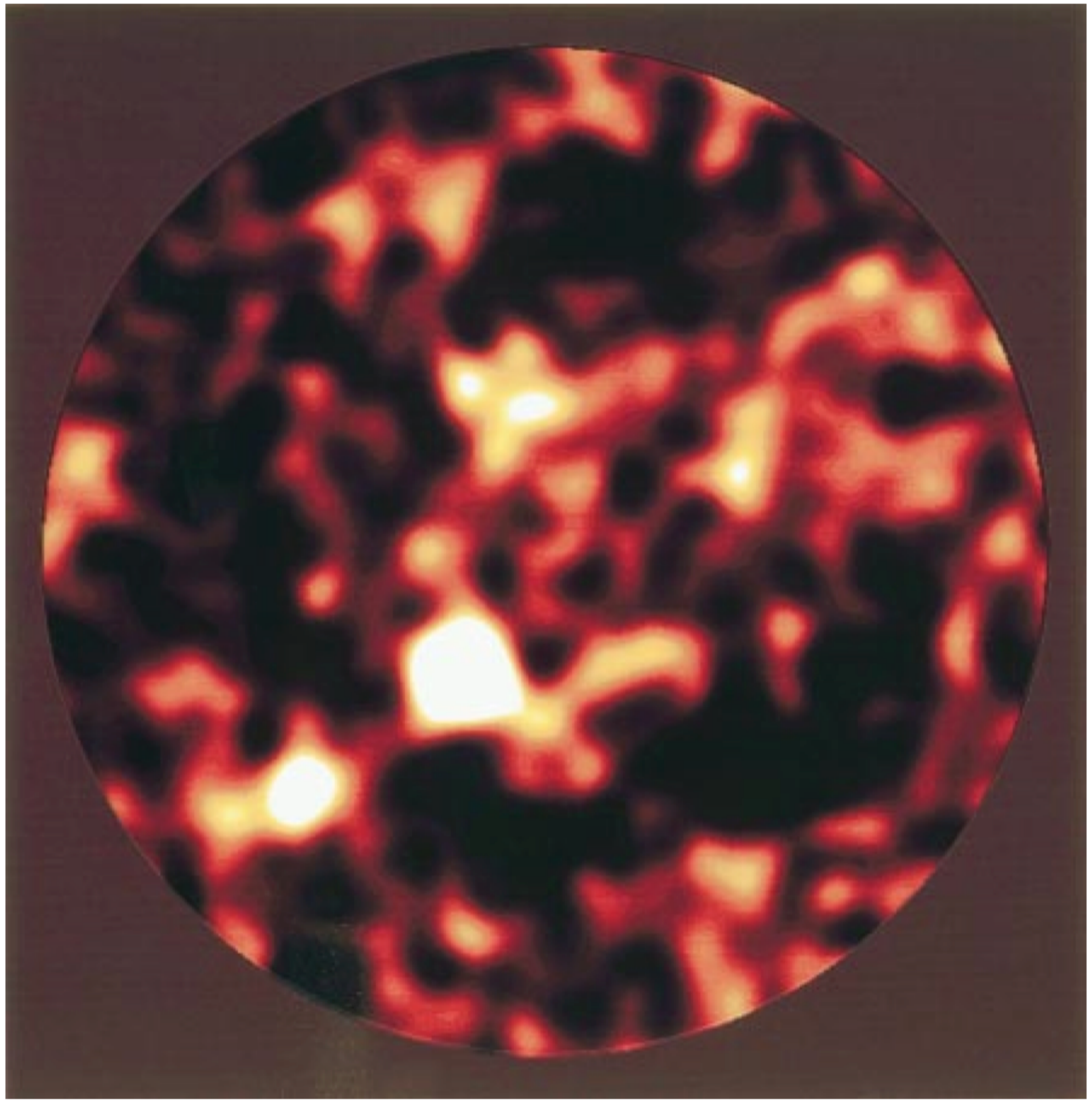
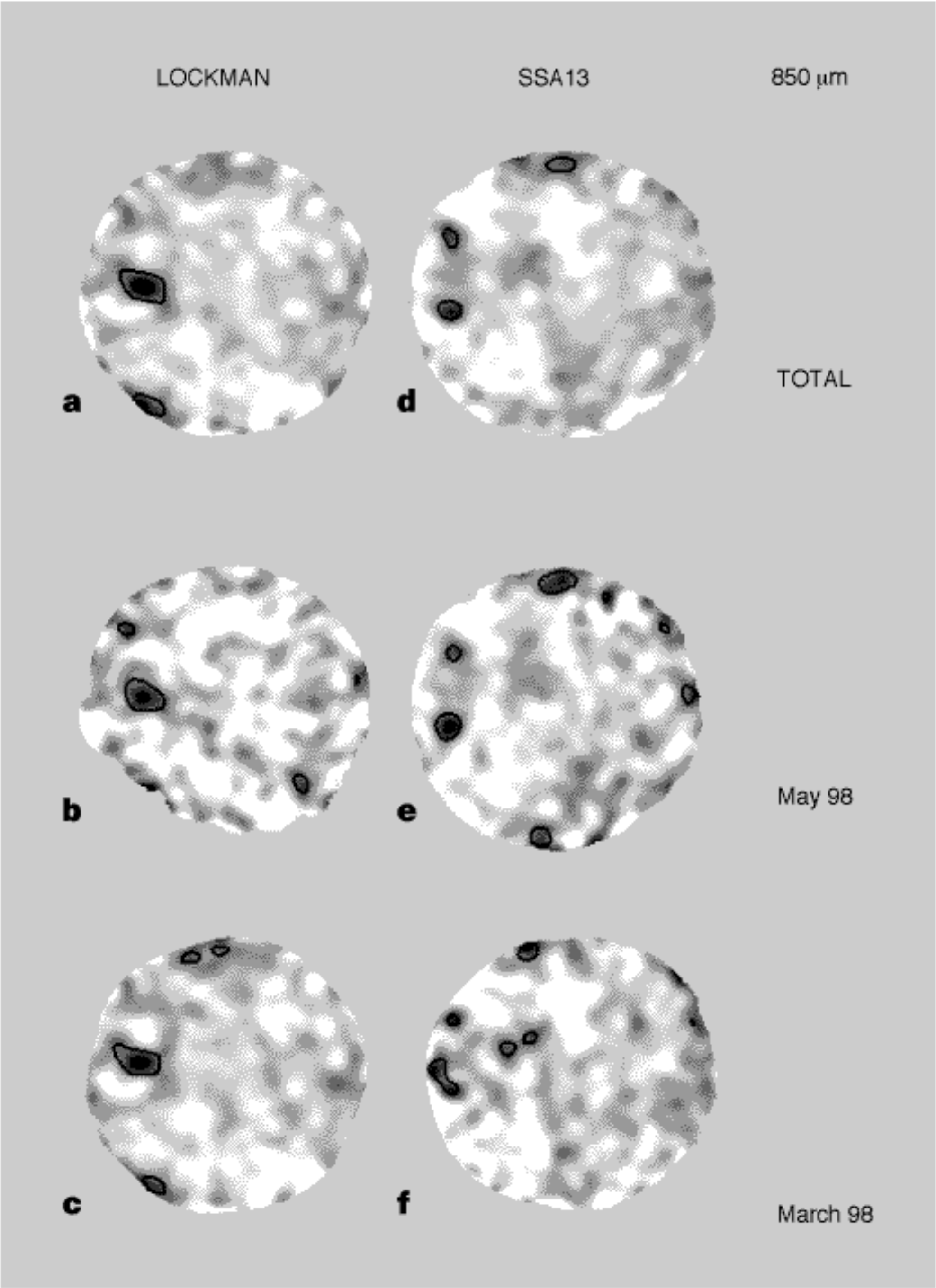
Submillimeter galaxies



Hughes+98, Nature



Barger+98, Nature

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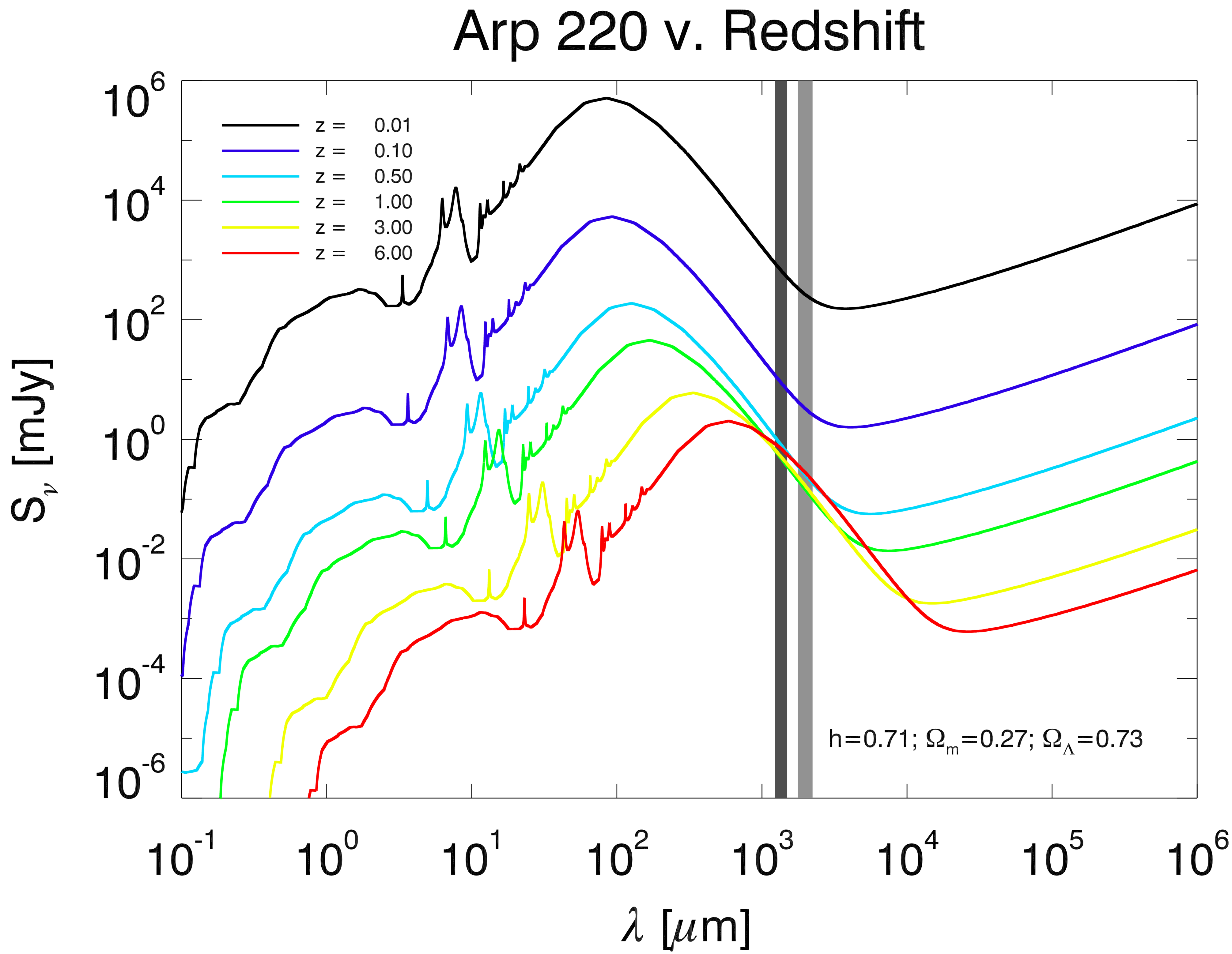
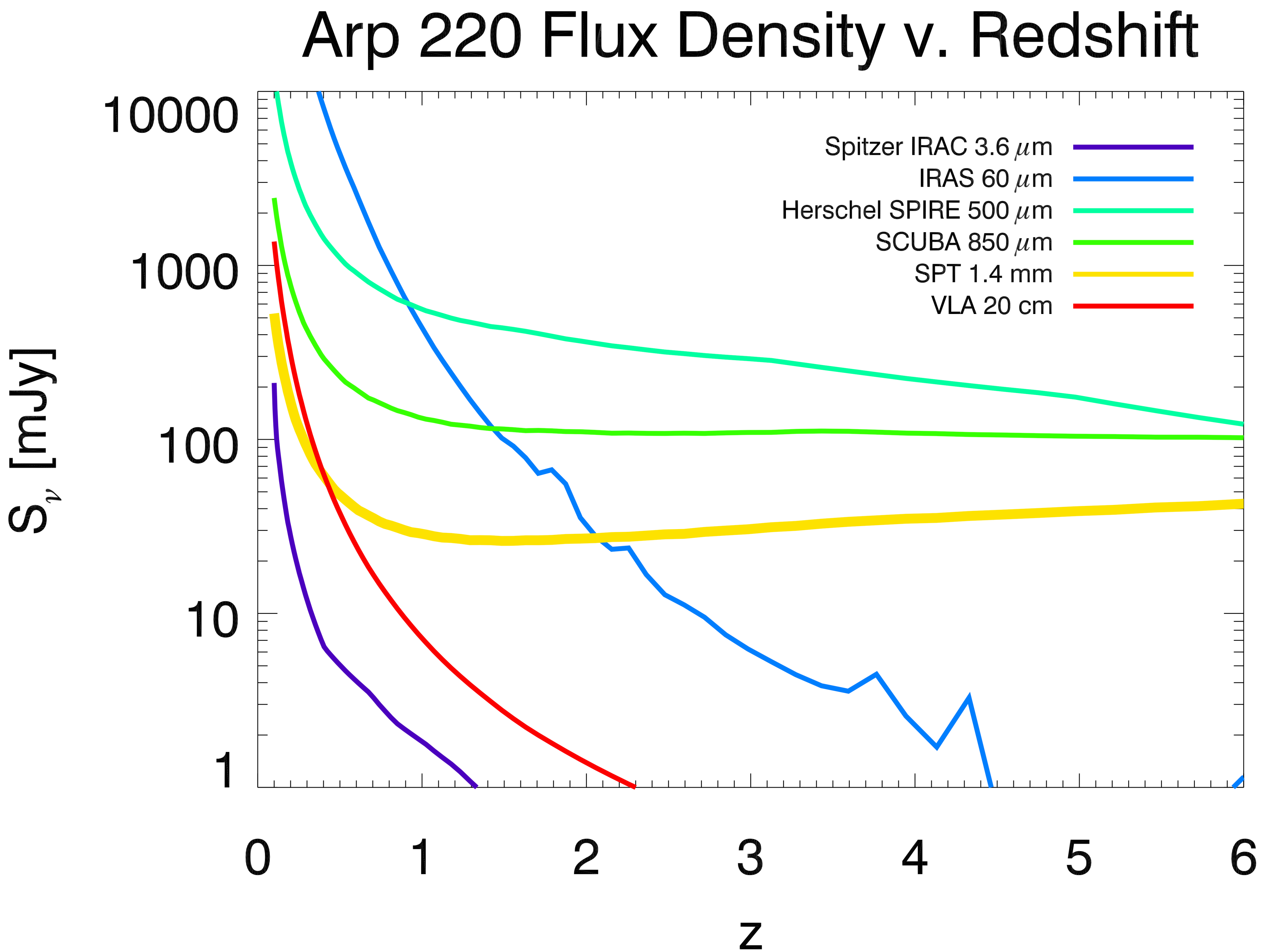
Why the (sub)mm?



Why the (sub)mm?



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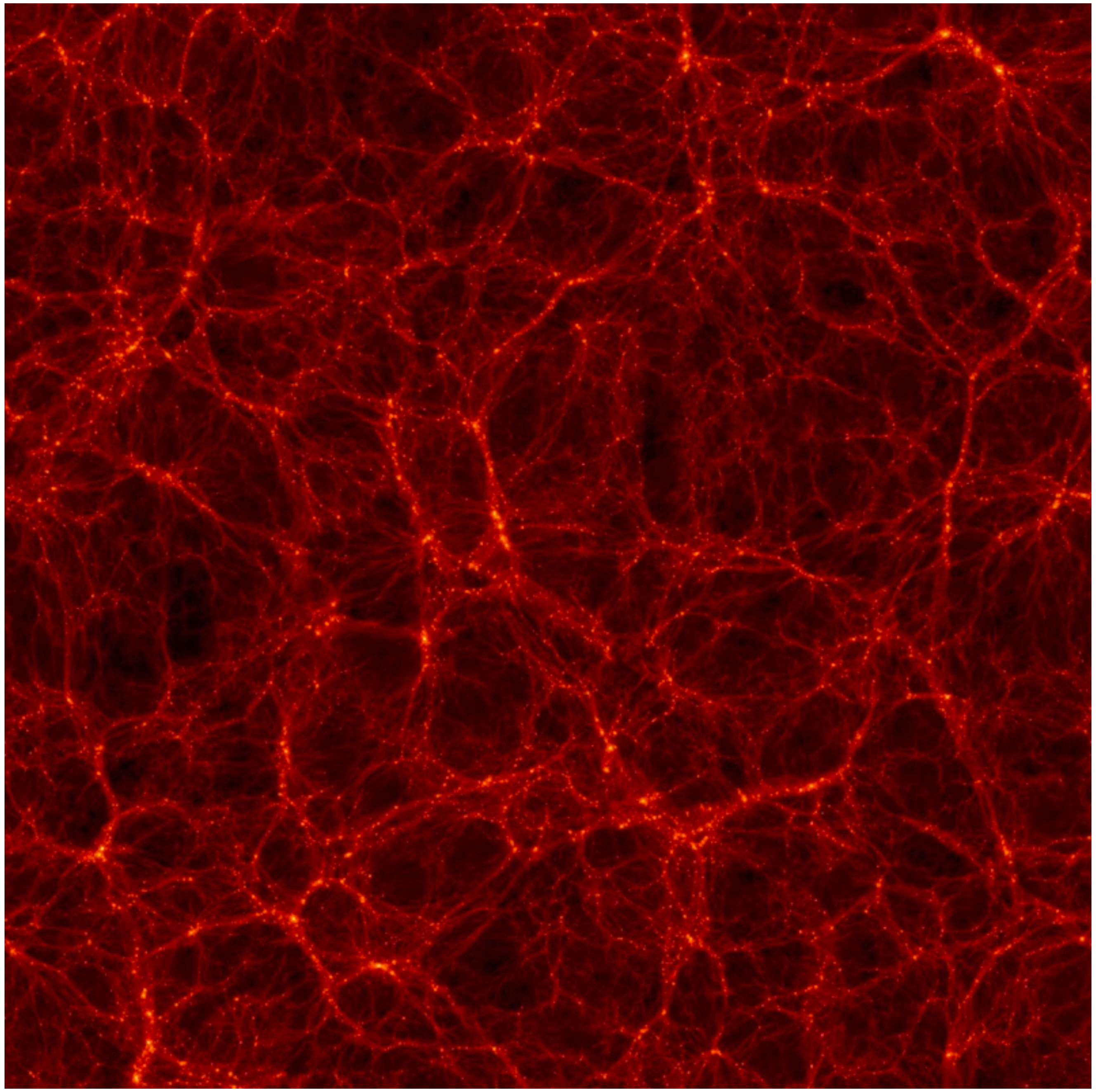
Model details



- Start with Bolshoi N-body simulation
- Create lightcones
- Assign properties (M_{star}, SFR, M_{dust}, etc.) using empirically based relations
- Compute submm fluxes based on hydro+RT sims
- See CCH, Behroozi, Somerville+2013

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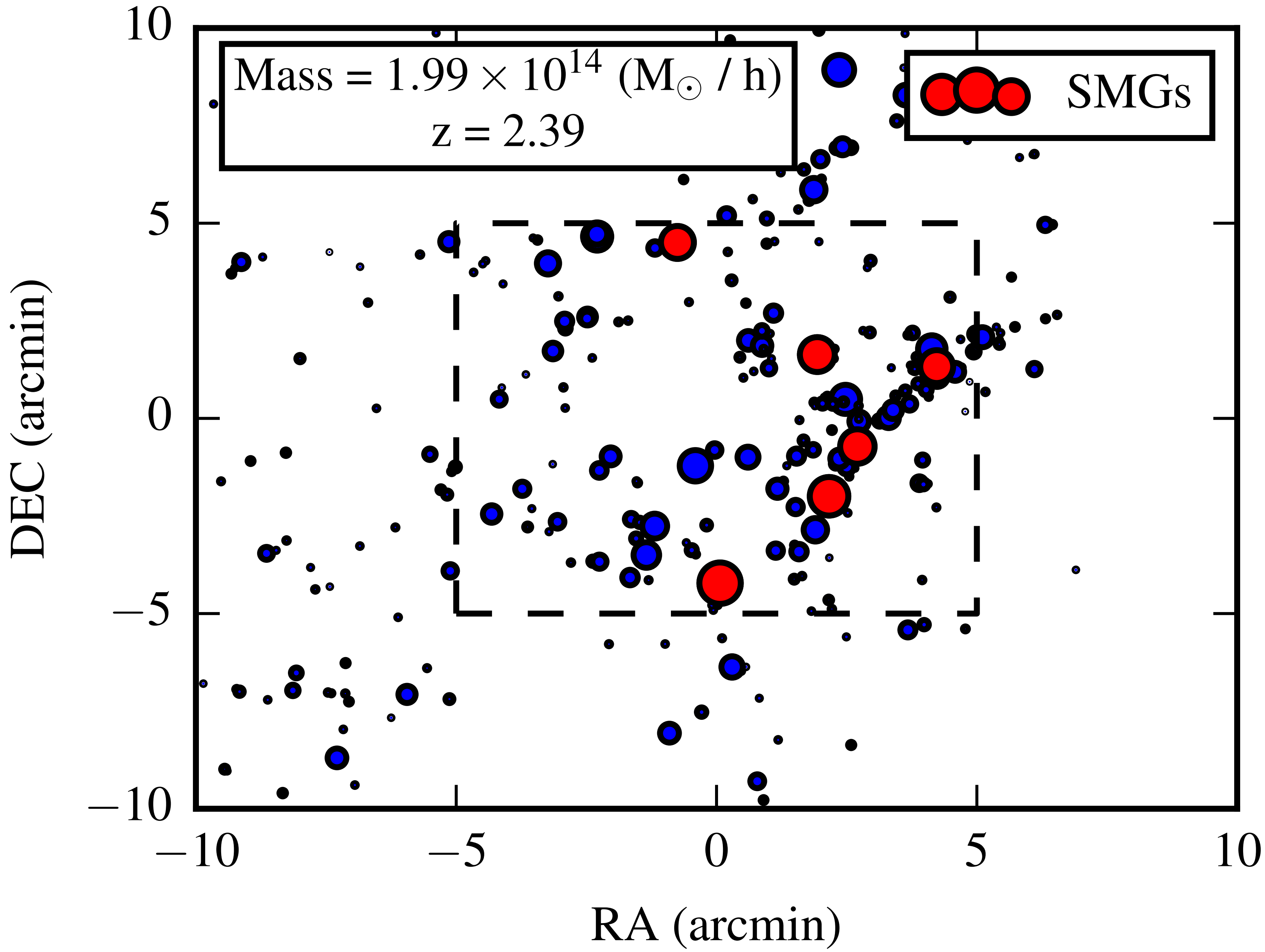
Example mock DSFG association



Miller, CCH, Chapman & Behroozi 2015

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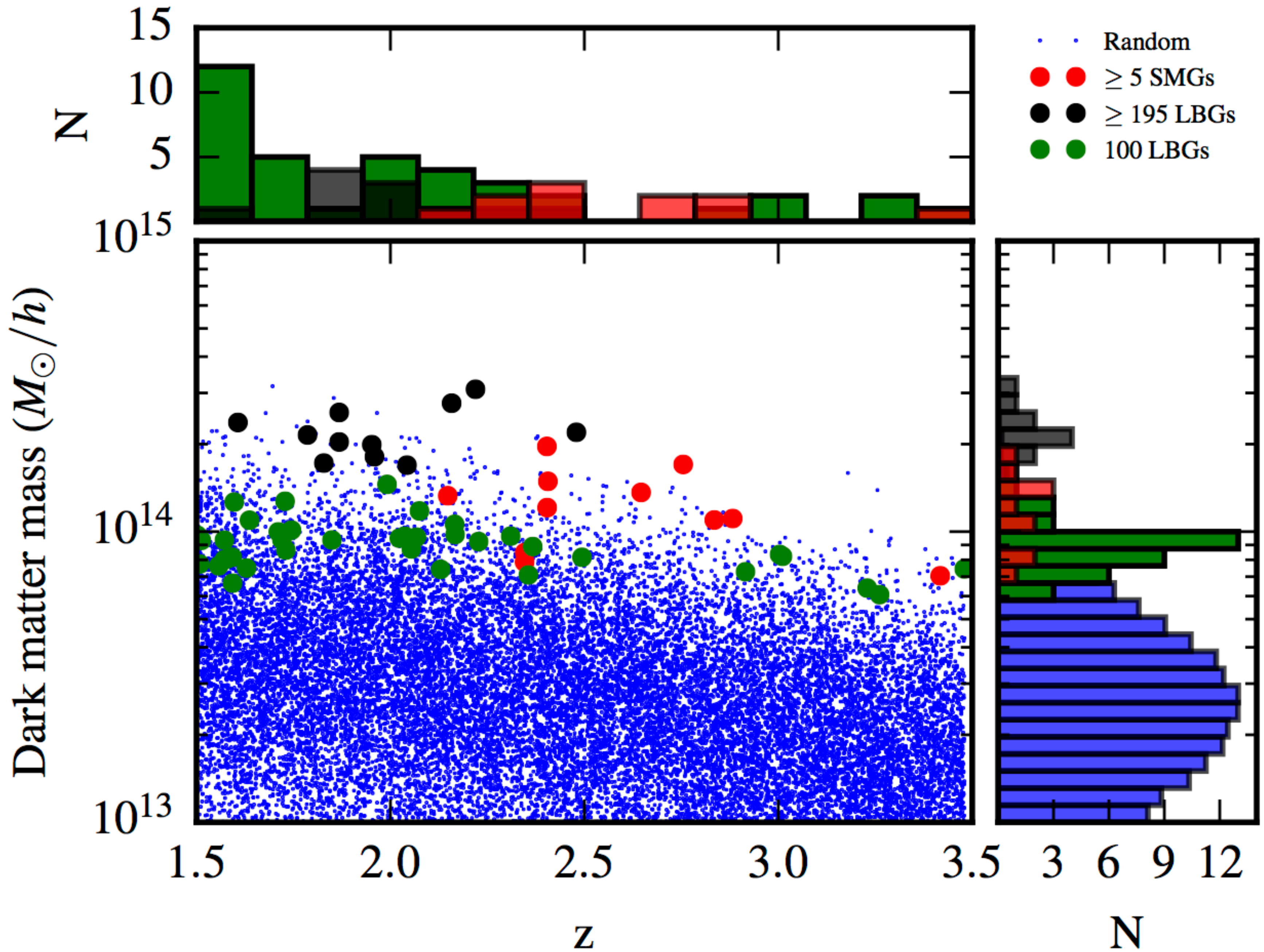
DSFG associations as tracers of DM overdensities



Miller, CCH, Chapman & Behroozi 2015

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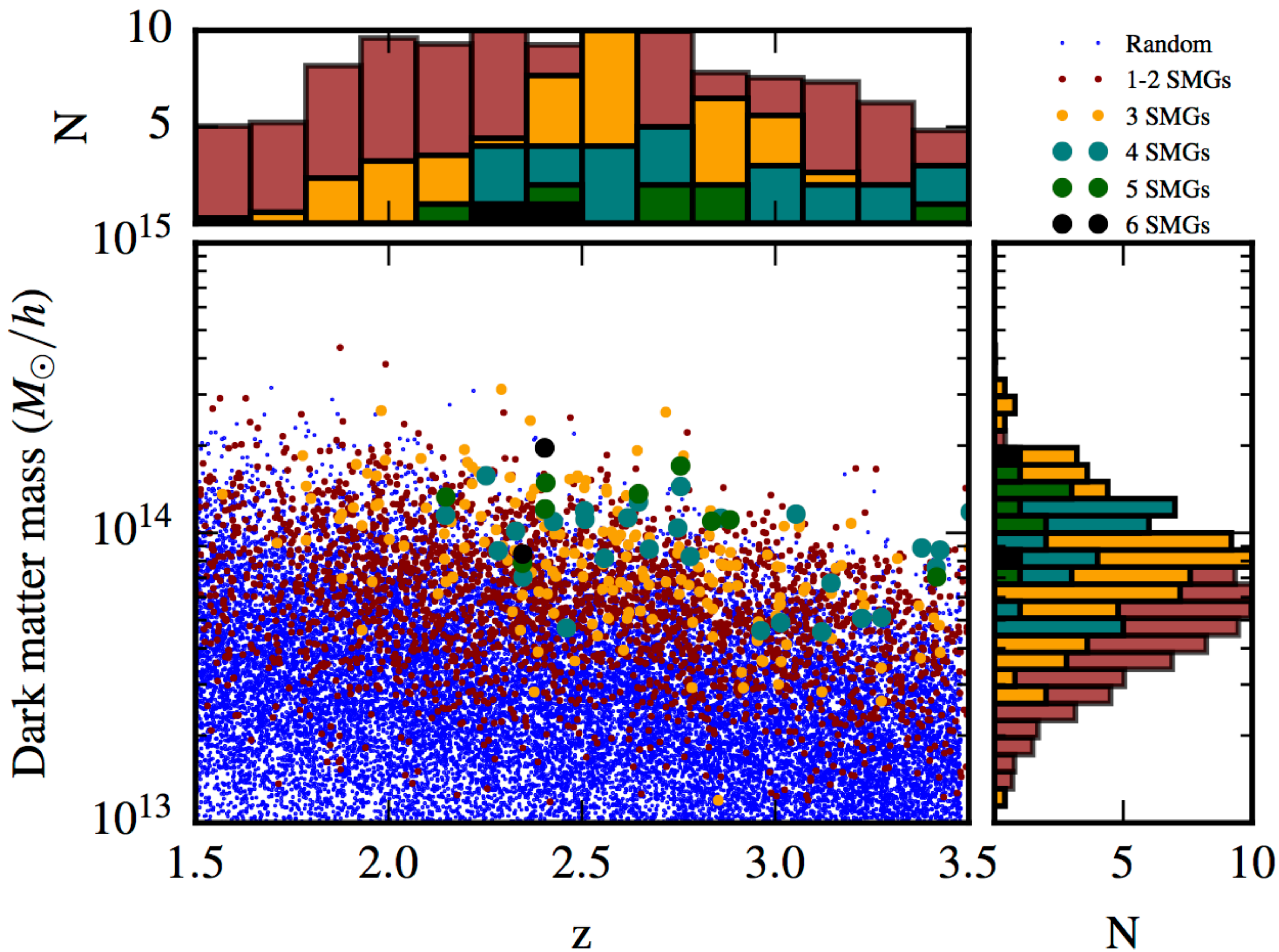
Typical DSFGs probe range of overdensities



Miller, CCH, Chapman & Behroozi 2015

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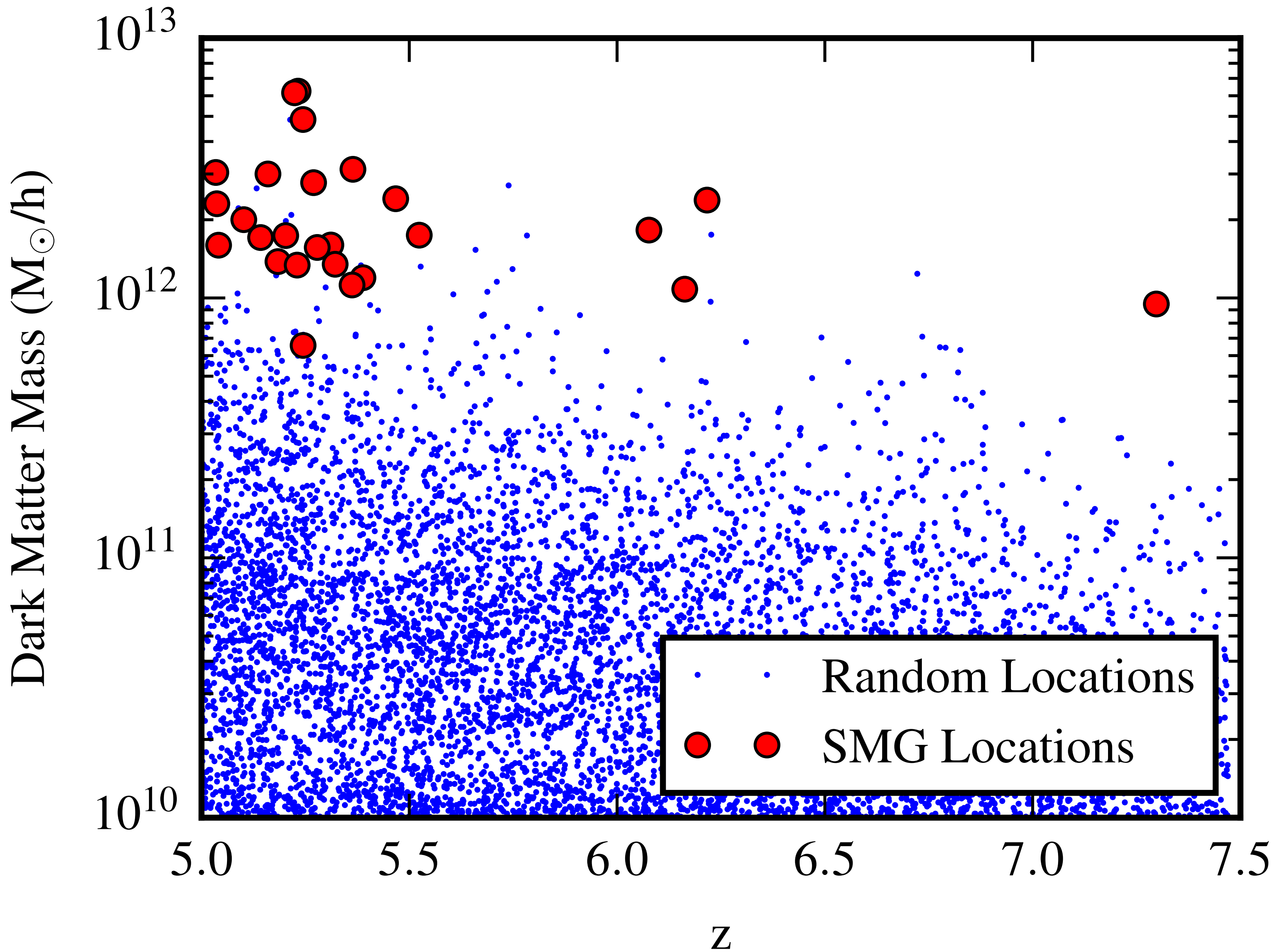
Key physical effects

- At all redshifts, DSFG associations are incomplete tracers of highest overdensities b/c they only stochastically sample high-mass halos
- At $z < \sim 2.5$, ‘downsizing’ causes most-massive galaxies to be quenched and thus not DSFGs; very highest overdensities are thus not traced by DSFG associations

At high z, individual DSFGs trace highest overdensities



Miller, CCH, Chapman & Behroozi 2015

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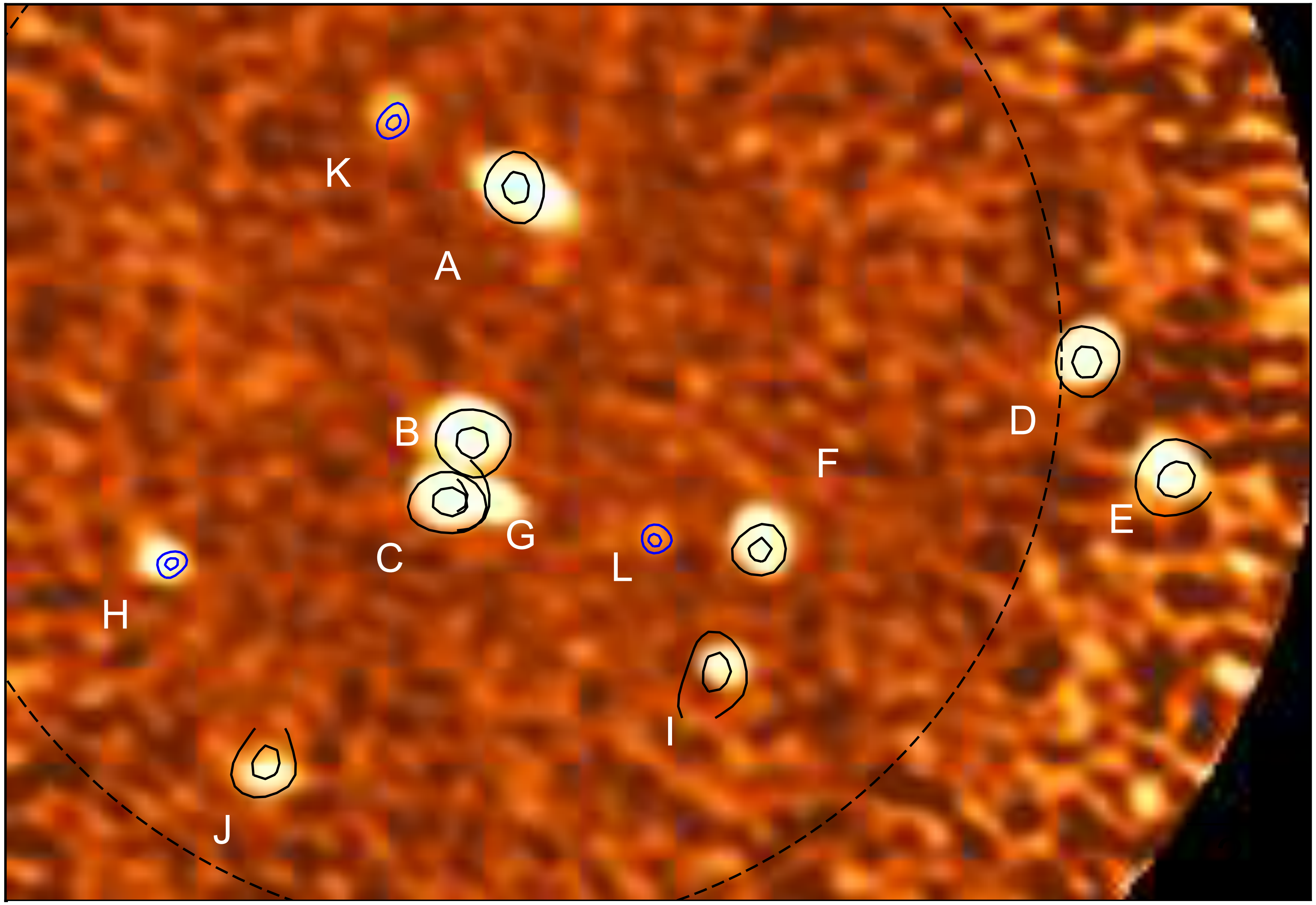
SPT2349-56: a protocluster revealed by the submm



Miller, Chapman, Aravena, Ashby, CCH, Vieira, Weiß+ SPT-SMG collaboration 2018, Nature

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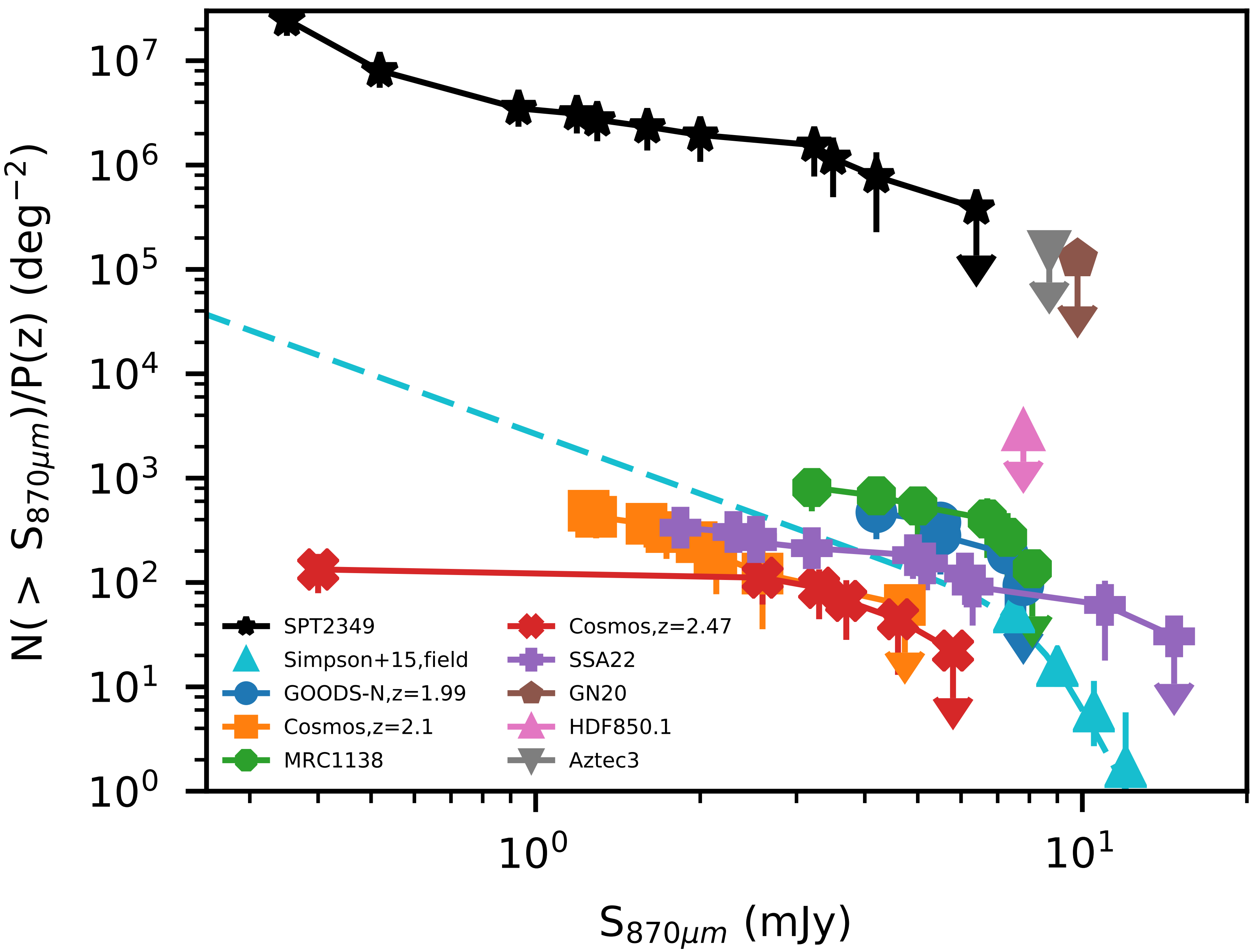
Number density significantly enhanced relative to blank field & other 'protoclusters'



Miller, Chapman, Aravena, Ashby, CCH, Vieira, Weiß+ SPT-SMG collaboration 2018, Nature

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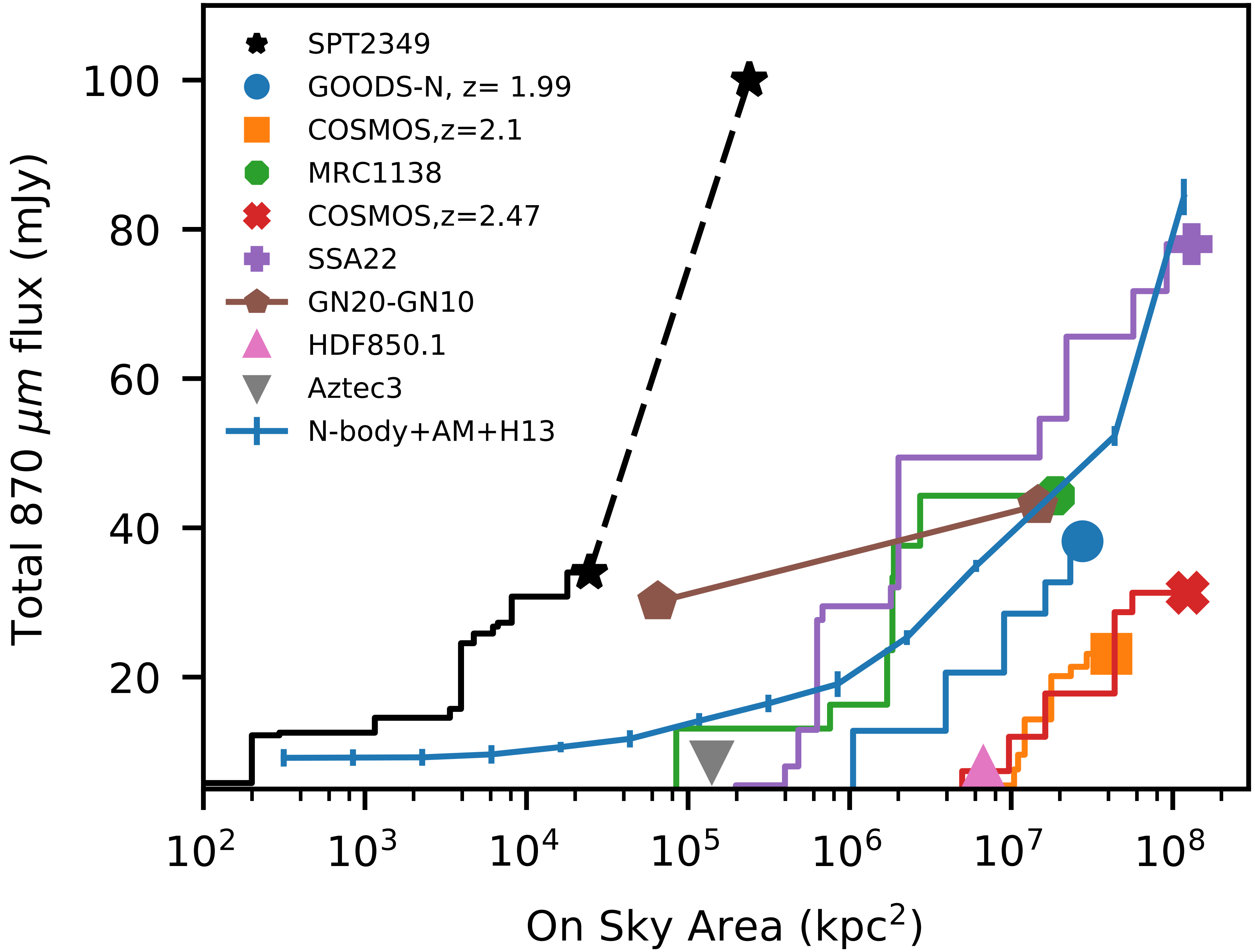
Concentrated SFR suggests protocluster core



Miller, Chapman, Aravena, Ashby, CCH, Vieira, Weiß+ SPT-SMG collaboration 2018, Nature

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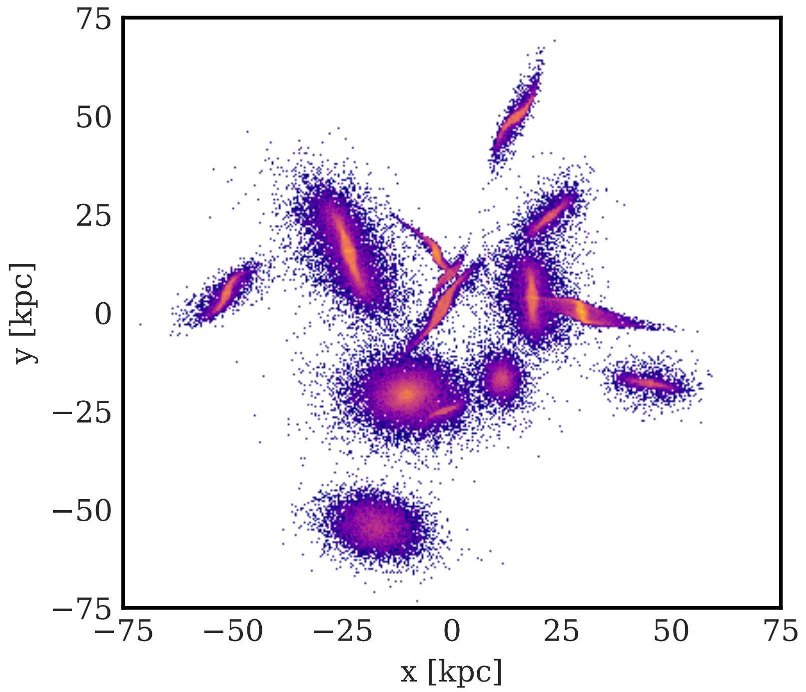
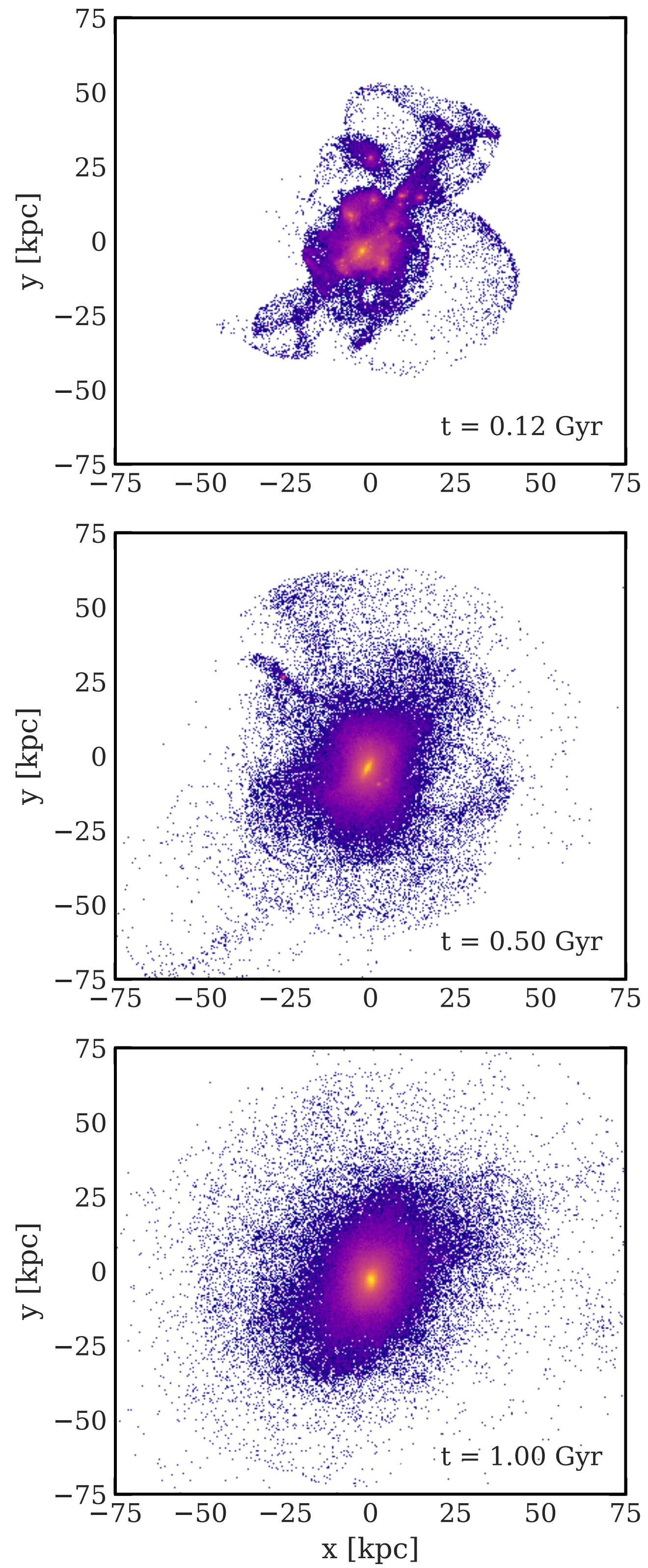
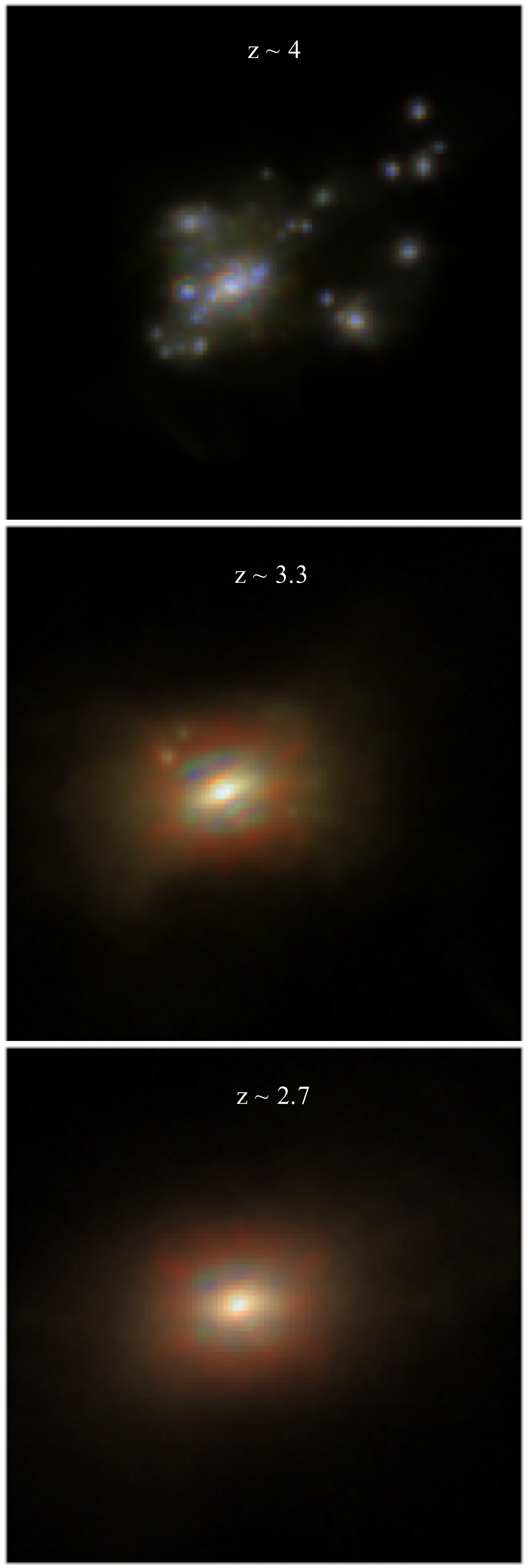
Future of SPT2349-56



Rennehan, Babul, CCH, Bottrell, Hani, & Chapman 2019





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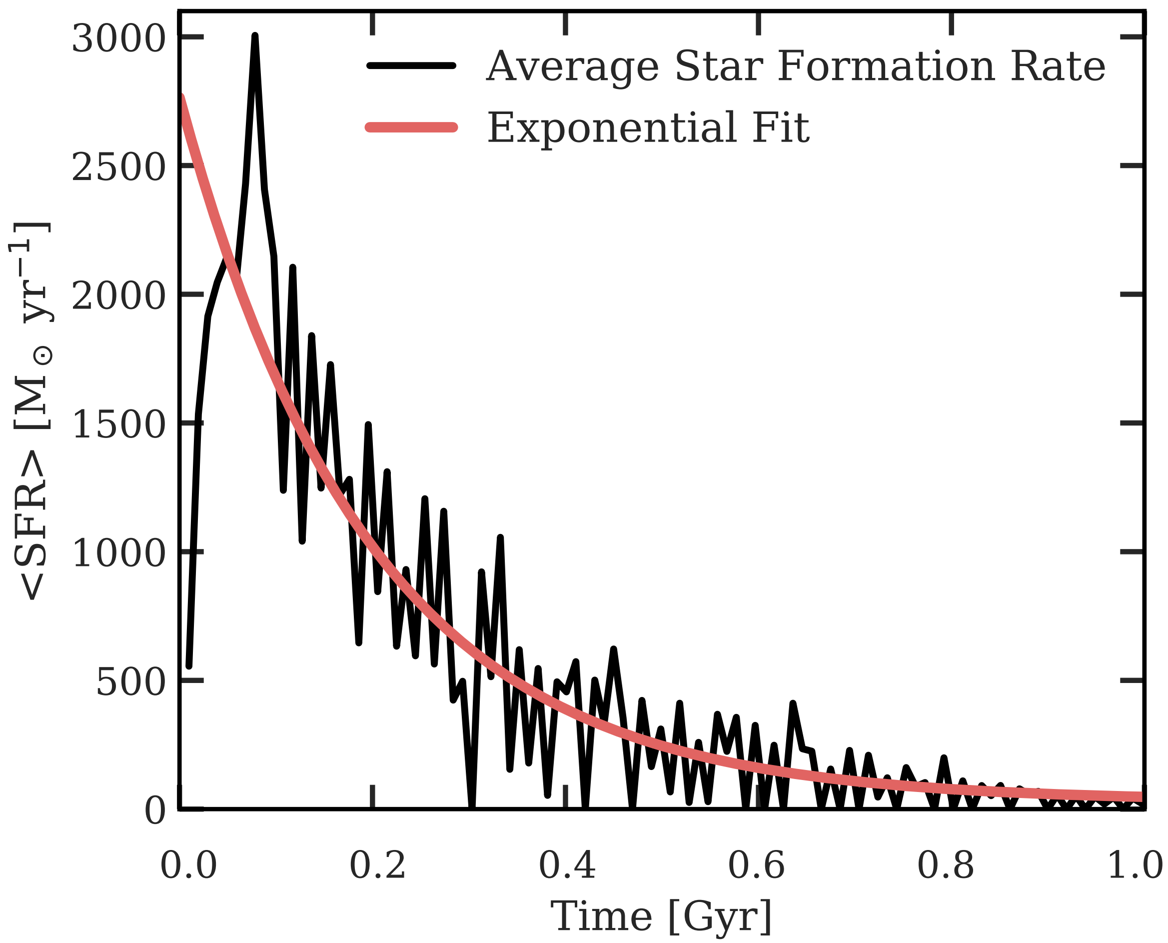
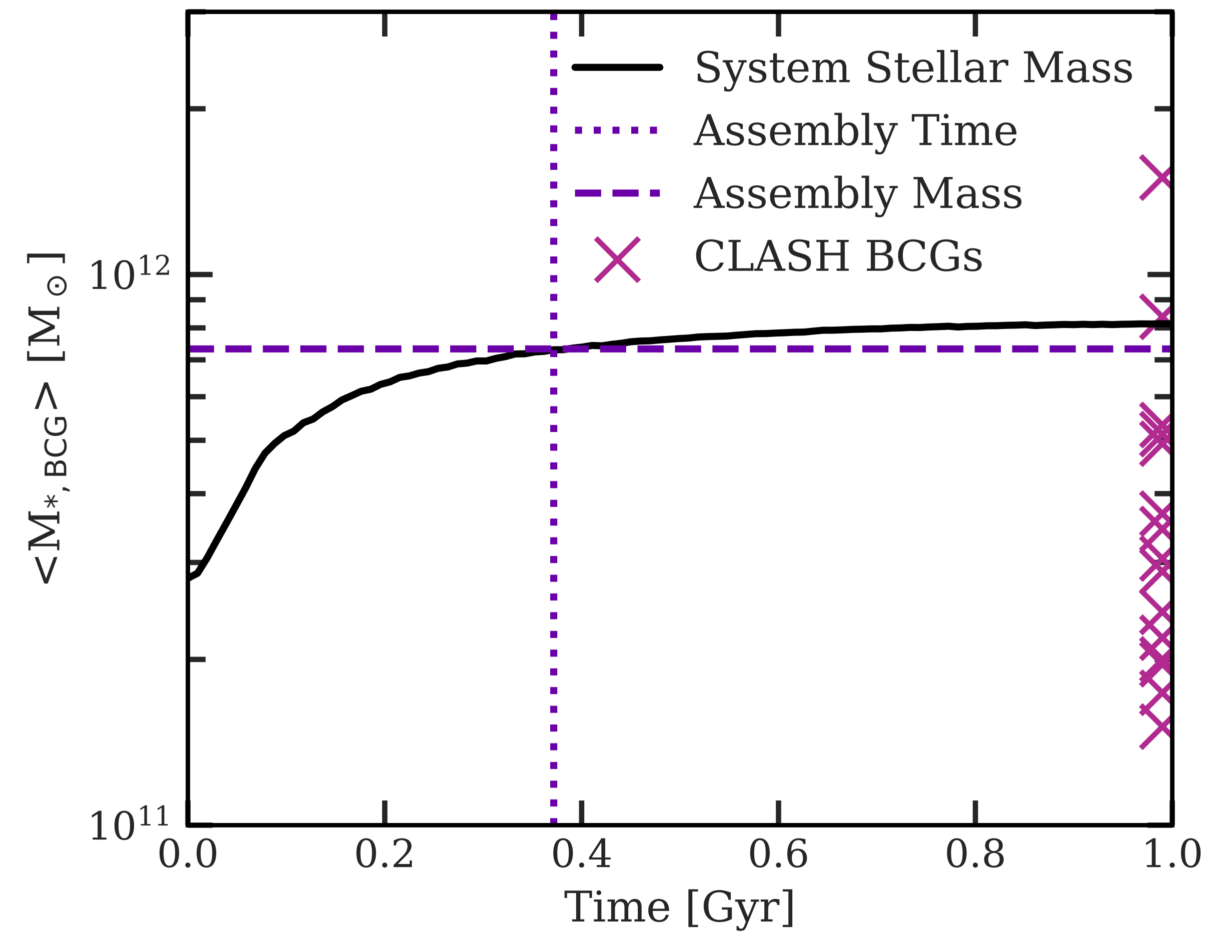
Future of SPT2349-56





Rennehan, Babul, CCH, Bottrell, Hani, & Chapman 2019

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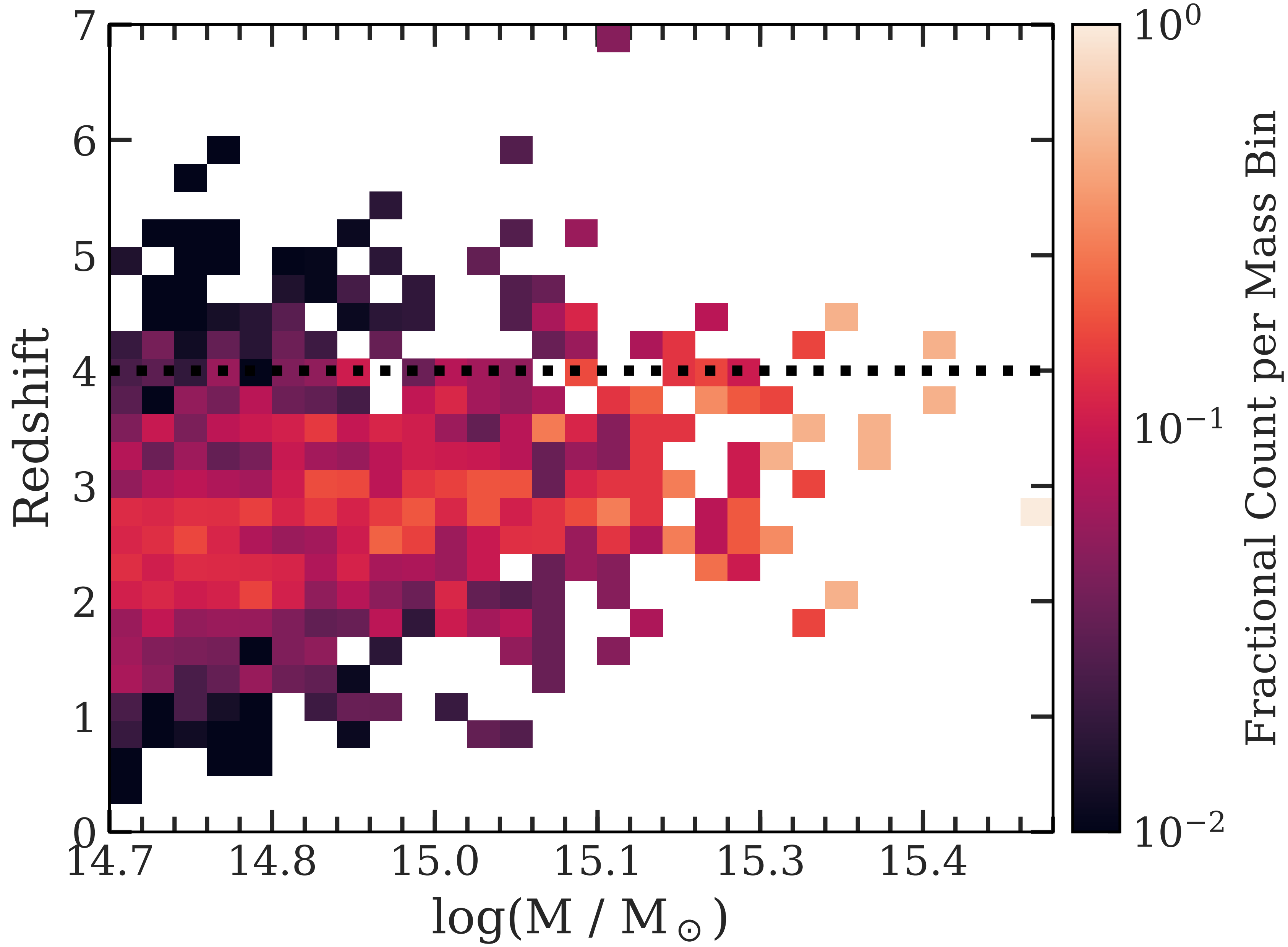
SPT2349-56 analogues in a cosmological simulation



Rennehan, Babul, CCH, Bottrell, Hani, & Chapman 2019

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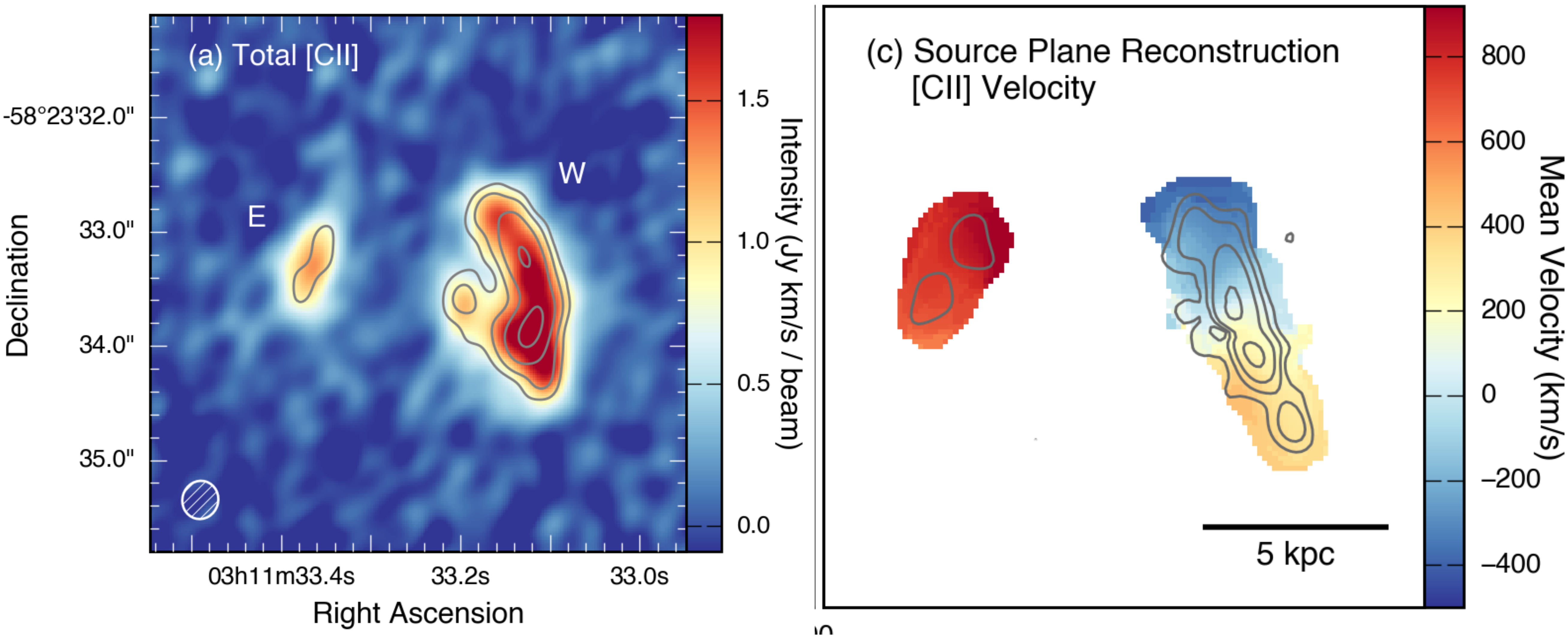
SPT0311-58 — z = 6.9



SFR ~ 2900 & 540 M_{sun}/yr

μ = 2.0

M_{gas} ~ 2.7 & 0.4 x 10^{11} M_{sun}

M_{dust} ~ 2.5 & 0.4 x 10^{9} M_{sun}

Marrone, Spilker, CCH, Vieira + SPT-SMG collaboration 2018, Nature
Strandet+ (inc. CCH) 2017, ApJL

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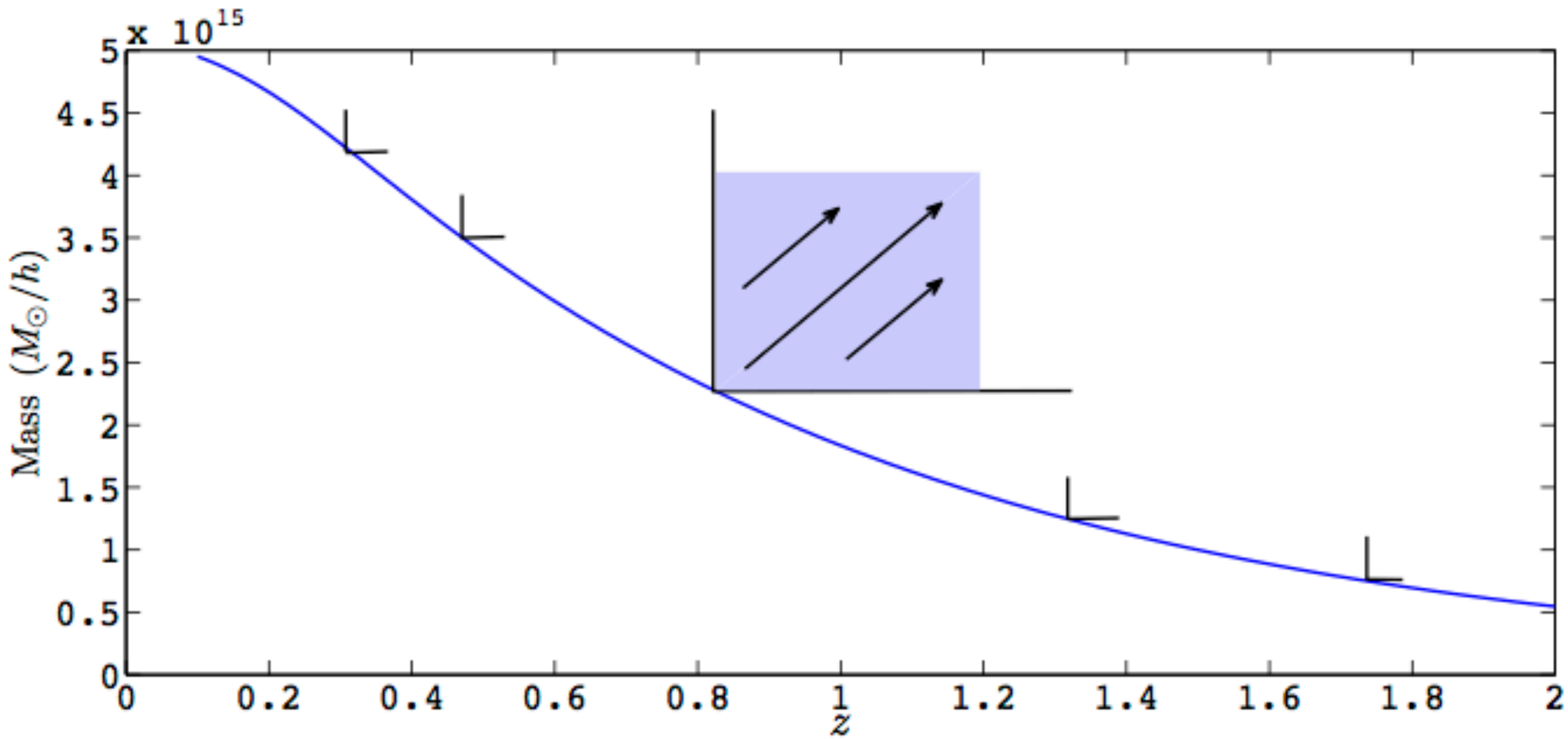
Quantifying the rareness of collapsed structures

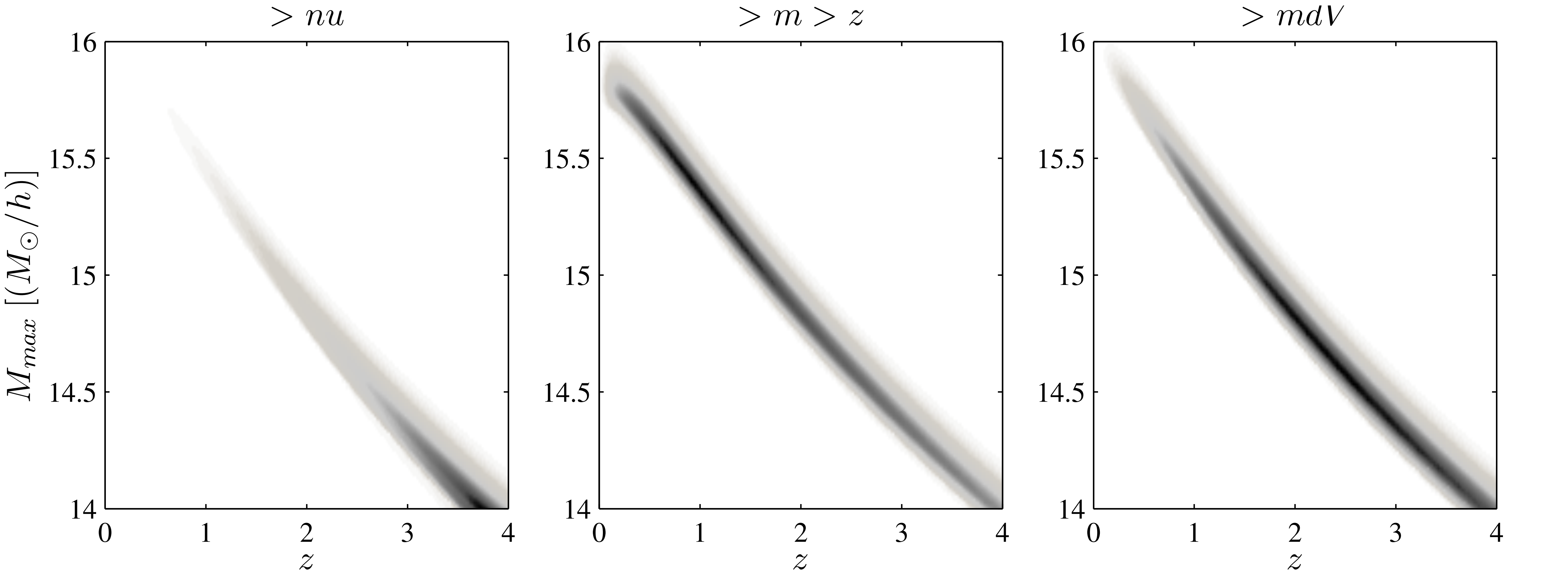


Hotchkiss 2011

$$\langle N \rangle = f_{\rm sky} \left[\int_{z_{min}}^{z_{\rm max}} \int_{m_{min}}^{m_{max}} dz\, dM \, \frac{dV}{dz} \frac{dn(M,z)}{dM} \right]$$

$$\hat{R}_{>\hat{m}>\hat{z}} = 1 - \exp\left(- \langle N_{>\hat{m}>\hat{z}} \rangle \right)$$

Different rareness measures



Harrison & Hotchkiss 2013

$$\nu(m,z) \propto \frac{1}{D_+(z)\sigma(m)}$$

$$\langle N_{>mdV} \rangle = \left[\int_m^\infty dM \, \frac{dn(M,z)}{dM} \right]$$

$$\langle N_{>m>z} \rangle = \left[\int_z^\infty \int_m^\infty dz \, dM \, \frac{dV}{dz} \frac{dn(M,z)}{dM} \right]$$

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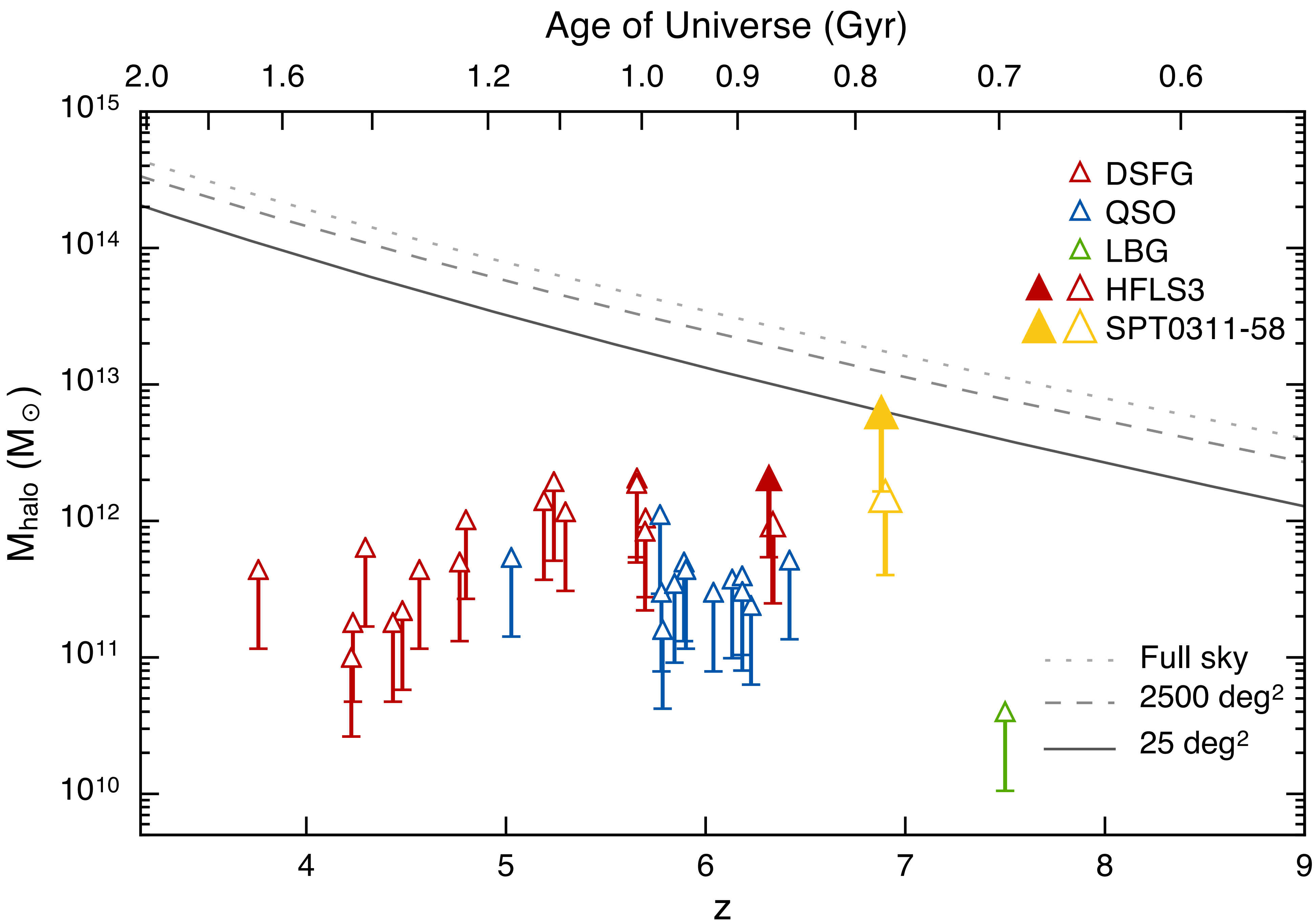
A ‘maximally massive’ halo?



Marrone, Spilker, CCH, Vieira + SPT-SMG collaboration 2018, Nature

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Summary

- DSFG associations are incomplete tracers of protoclusters because of stochastic sampling and downsizing
- At z >~ 4, individual DSFGs are good beacons of DM overdensities
- One example is SPT2349-56, a z = 4.3 protocluster core
- Another example: SPT0311-58, a lensed massive z ~ 6.9 galaxy with an inferred halo mass $>10^{12}$ M_{sun}, near maximum mass allowed by LCDM

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