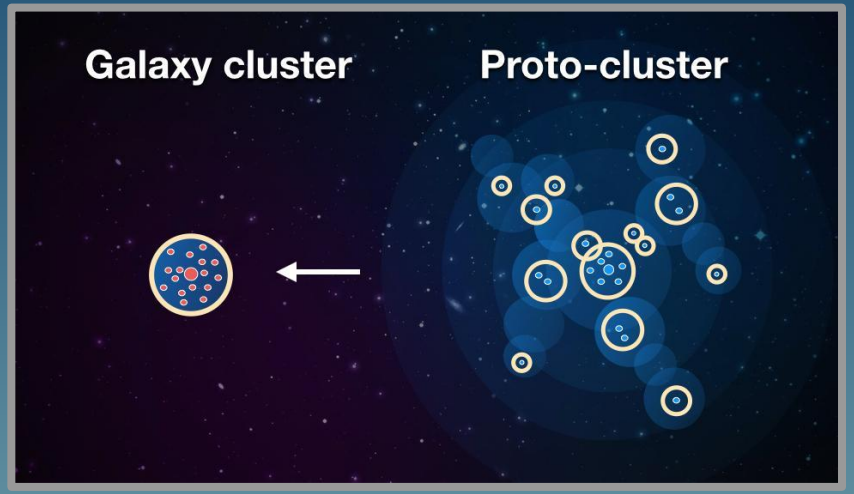
Paper I (in preparation):

Dusty star-forming galaxies as tracers of protoclusters: A simulated perspective

Pablo Araya-Araya; Rachel K. Cochrane; Christopher C. Hayward; Douglas Rennehan; Laerte Sodré Jr.; Robert M. Yates; Roderik A. Overzier; Marcelo C. Vicentin

Progenitors of galaxy clusters

◇ Overdense regions at high redshift that will evolve into a galaxy cluster at z=0 or before (Overzier 2016).

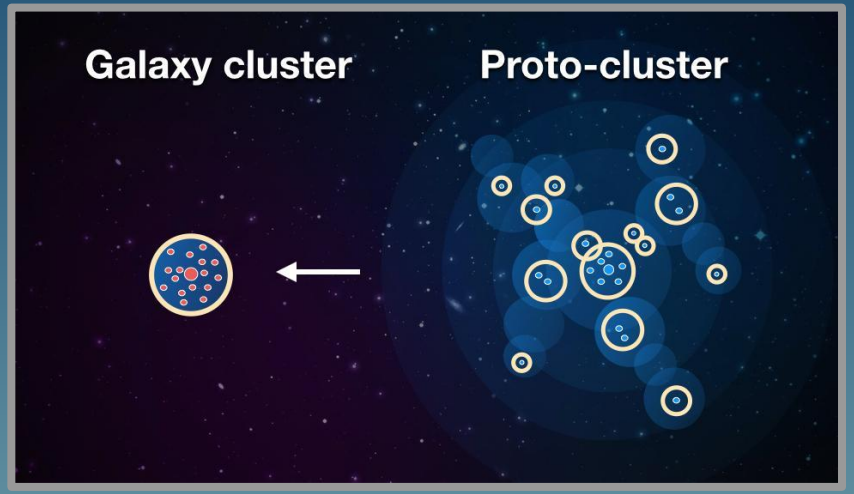


Credits: Yi-Kuan Chiang profile in University of Texas at Austin website

Progenitors of galaxy clusters

◇ Overdense regions at high redshift that will evolve into a galaxy cluster at z=0 or before (Overzier 2016).

◇ Ensemble of dark matter halos.



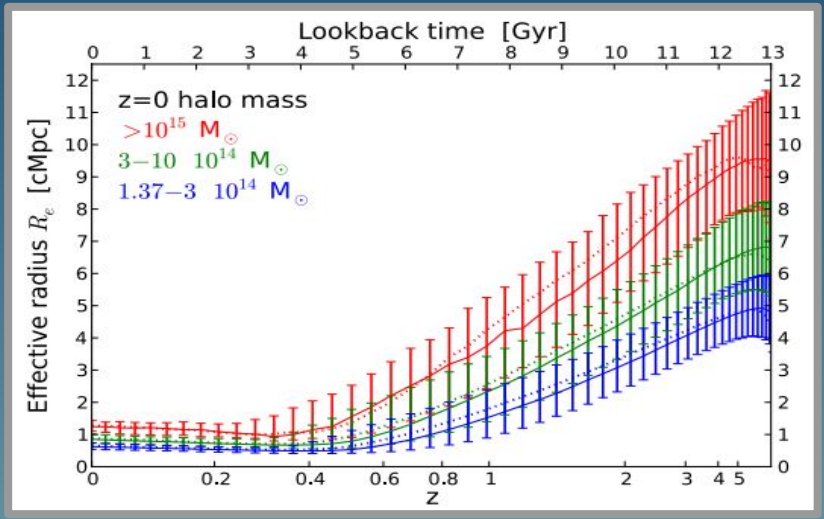
Credits: Yi-Kuan Chiang profile in University of Texas at Austin website

Progenitors of galaxy clusters

◇ Overdense regions at high redshift that will evolve into a galaxy cluster at z=0 or before (Overzier 2016).

◇ Ensemble of dark matter halos.

◇ Occupy larger (comoving) volumes than their descendant.



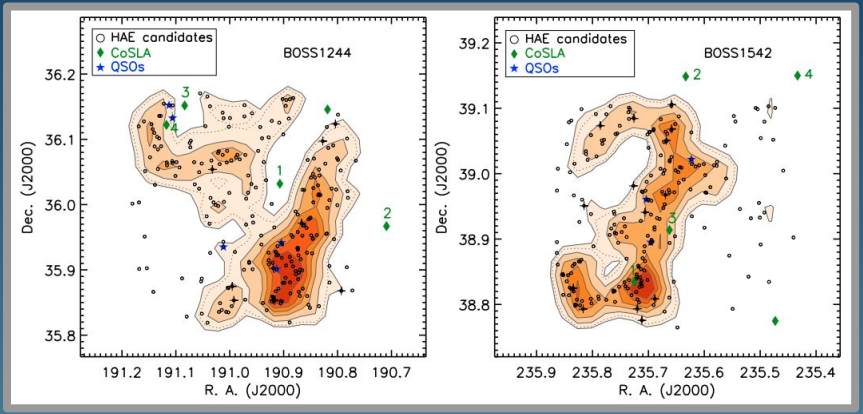
Chiang et al. (2013)

We detect protocluster candidates as:

Overdensity of galaxies

We detect protocluster candidates as:

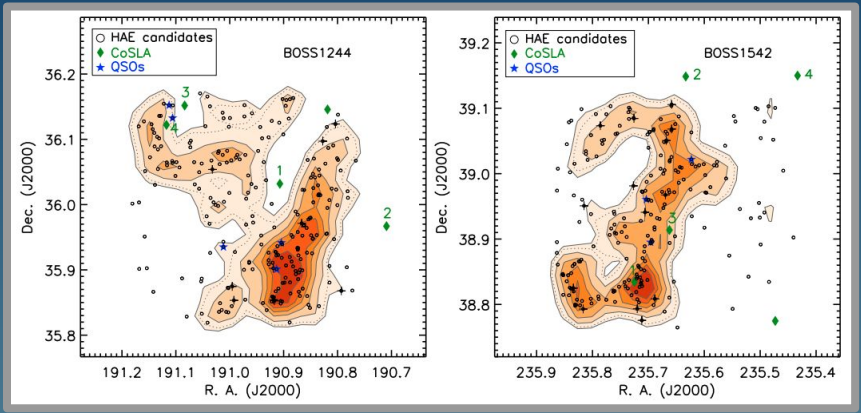
Overdensity of galaxies



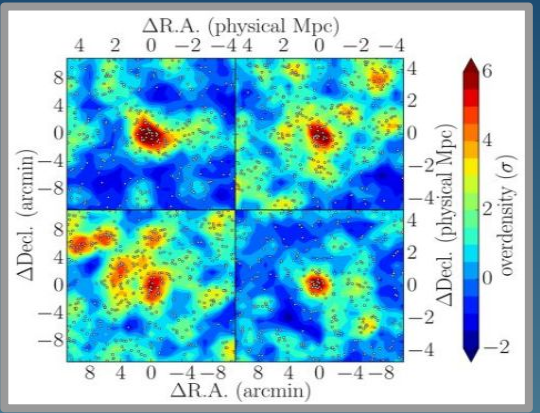
Zheng et al. (2021); HAE

We detect protocluster candidates as:

Overdensity of galaxies



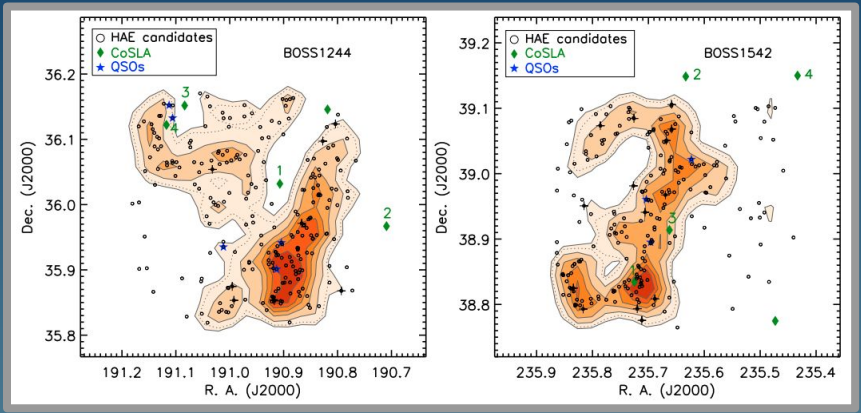
Zheng et al. (2021); HAE



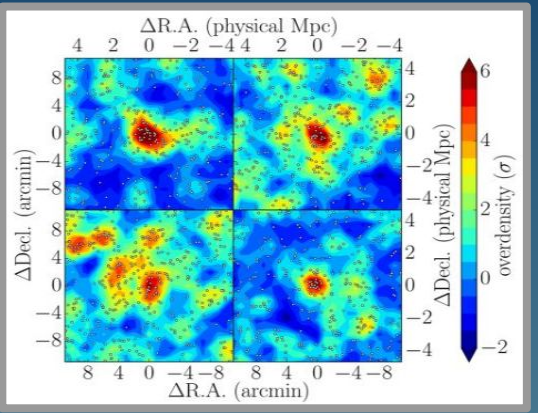
Toshikawa et al. (2018); LBGs

We detect protocluster candidates as:

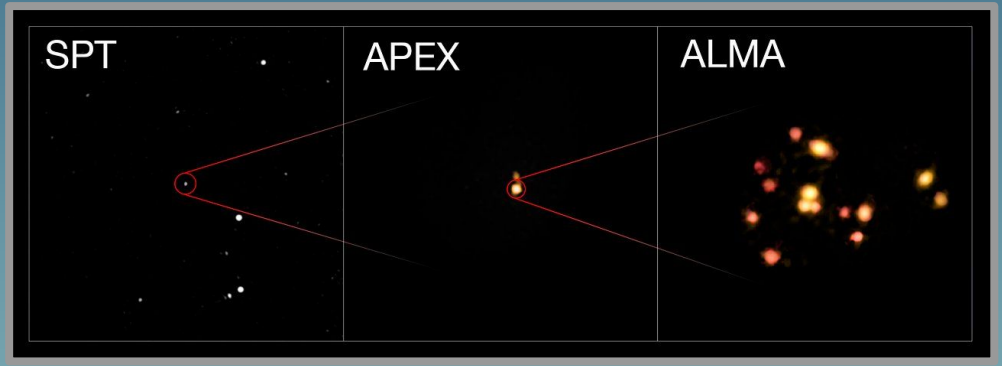
Overdensity of galaxies



Zheng et al. (2021); HAE

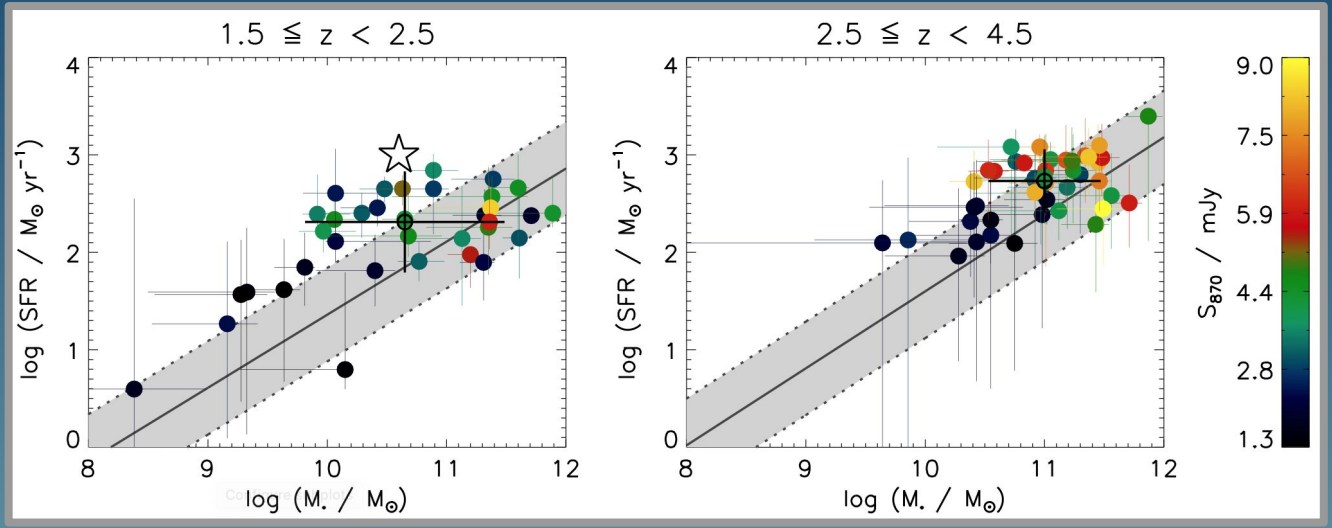


Toshikawa et al. (2018); LBGs



Miller et al. (2018); SMGs

Why do we find SMGs in protoclusters?



da Cunha et al. (2015)

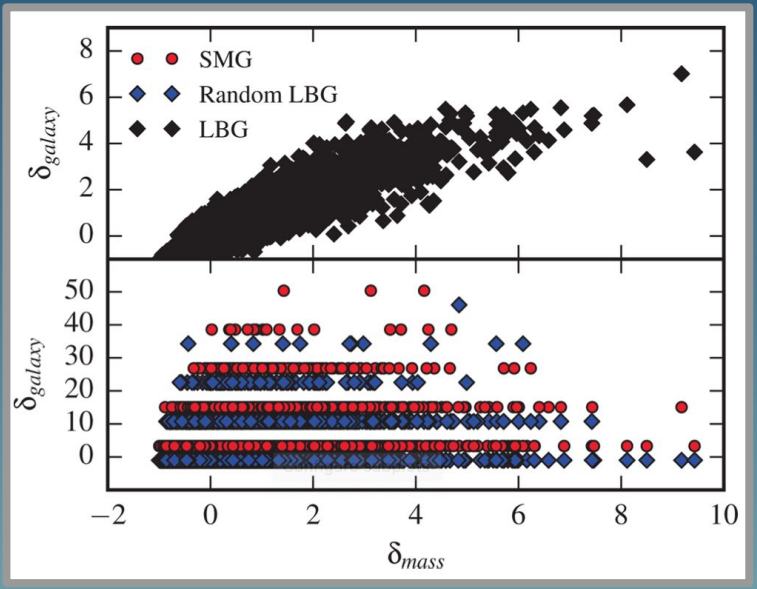
Typical SMGs

$\log(M_\star/M_\odot) \gtrsim 10.0$

SFR ~ 100 - 1000 $M_\odot$/ yr

Are SMG good tracers of protoclusters?

It is still in debate:
simulations

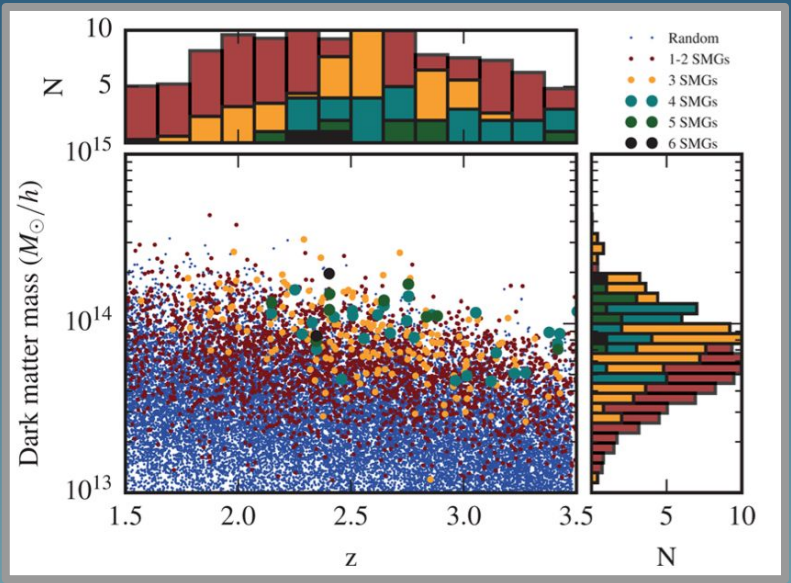


Miller et al. (2015)

Are SMG good tracers of protoclusters?

Some massive halos do not host even a single SMG/ Incompleteness bias

It is still in debate: simulations

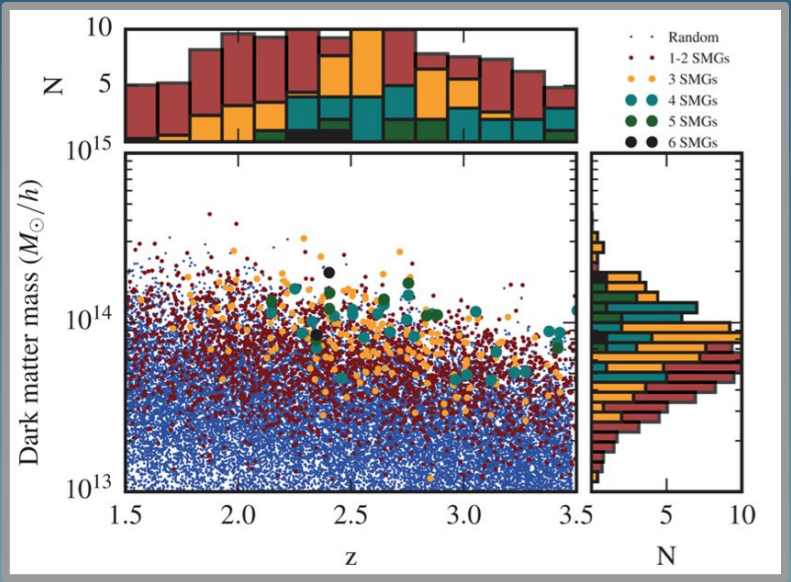


Miller et al. (2015)

Are SMG good tracers of protoclusters?

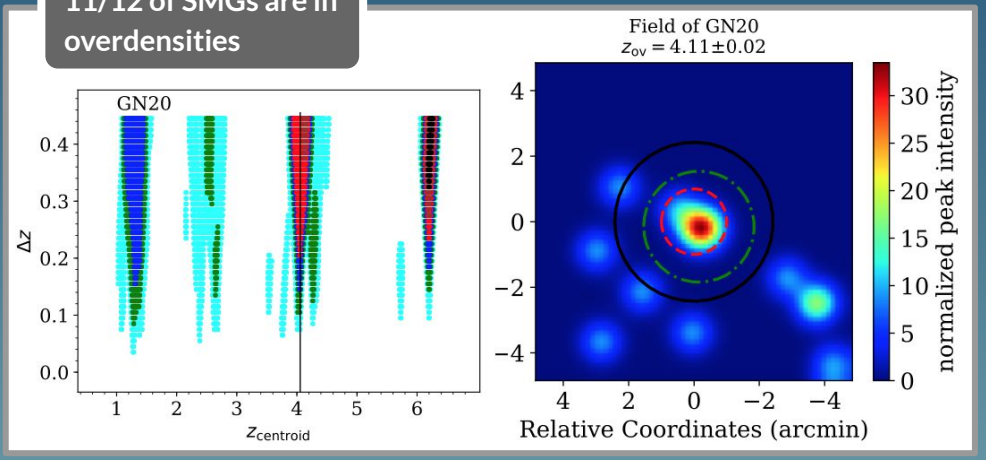
Some massive halos do not host even a single SMG/ Incompleteness bias

It is still in debate:
simulations vs observations



Miller et al. (2015)

11/12 of SMGs are in overdensities



Calvi et al. (2023)

Questions…

- Are SMGs common in (proto)cluster regions?

Questions…

- Are SMGs common in (proto)cluster regions?
- Is there an environmental/epoch preference?

Questions…

- Are SMGs common in (proto)cluster regions?
- Is there an environmental/epoch preference?
- On our simulation context, what mechanism trigger the sub-mm emission in protocluster galaxies?

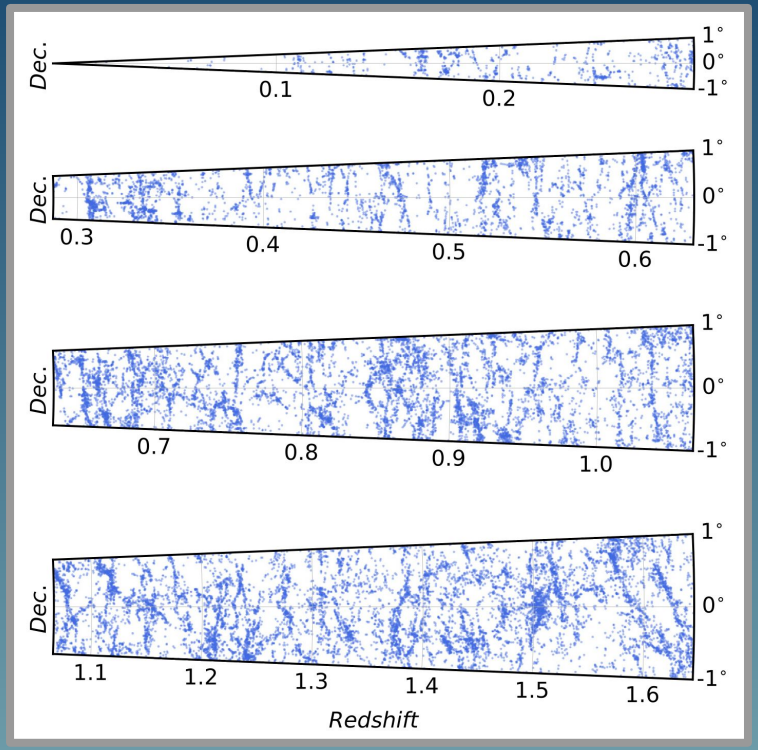
Questions…

- **Are SMGs common in (proto)cluster regions?**
- **Is there an environmental/epoch preference?**
- **On our simulation context, what mechanism trigger the sub-mm emission in protocluster galaxies?**
- *Is it easy to find optical counterpart of SMGs?*

Insights from simulations: Mock

36 deg² mock constructed similarly to Araya-Araya+21 mocks:

- Millennium Simulation scaled Planck1 cosmology + L-GALAXIES SAM (Henriques+15).
- Post-processing magnitudes by using the galaxies SFHs.

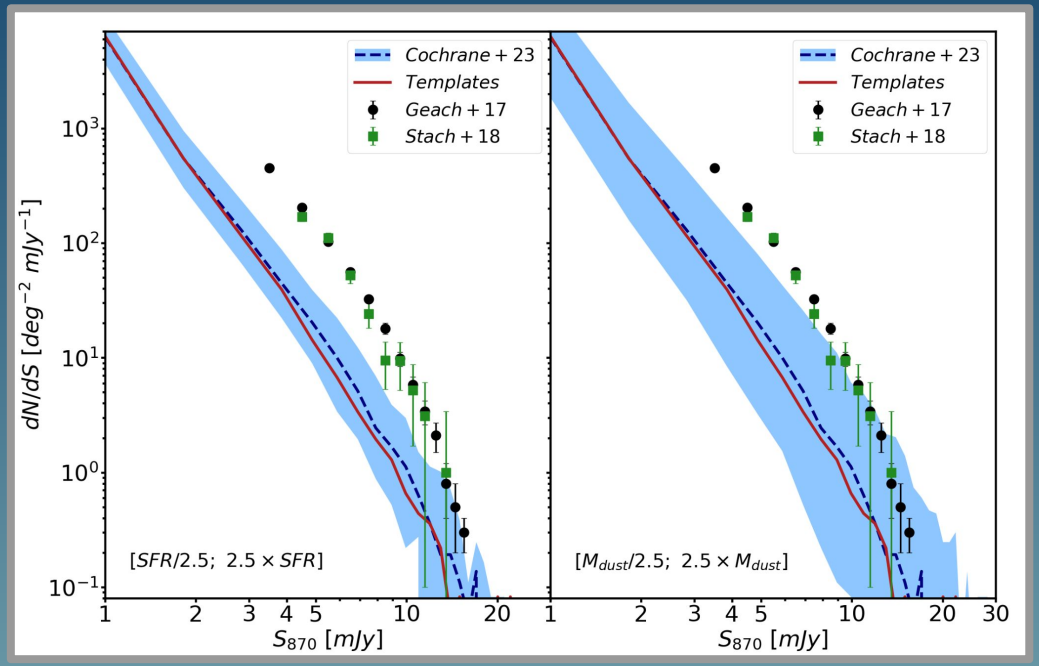


Sub-mm Emission modeling

◇ Cochrane+23 scaling relations

$$S_\nu/\mathrm{mJy} = \alpha \left(\frac{\mathrm{SFR}_{10}}{100\,\mathrm{M}_\odot \mathrm{yr}^{-1}}\right)^{\beta} \left(\frac{\mathrm{M}_\star}{10^{10}\,\mathrm{M}_\odot}\right)^{\gamma} \left(\frac{\mathrm{M}_{\mathrm{dust}}}{10^{8}\,\mathrm{M}_\odot}\right)^{\delta} (1+z)^{\eta}. \quad (2)$$

λ/μm	$\log_{10}\alpha$	β	δ	γ	η
345	0.86 ± 0.02	0.49 ± 0.01	0.46 ± 0.02	0.19 ± 0.01	-0.86 ± 0.03
462	0.31 ± 0.03	$0.43^{+0.01}_{-0.02}$	0.53 ± 0.02	0.18 ± 0.01	-0.18 ± 0.05
652	$-0.29^{+0.09}_{-0.08}$	0.36 ± 0.04	$0.60^{+0.03}_{-0.04}$	0.15 ± 0.03	0.36 ± 0.11
870	-0.77 ± 0.2	0.32 ± 0.08	0.65 ± 0.07	0.13 ± 0.07	0.65 ± 0.25



Structures in the mock

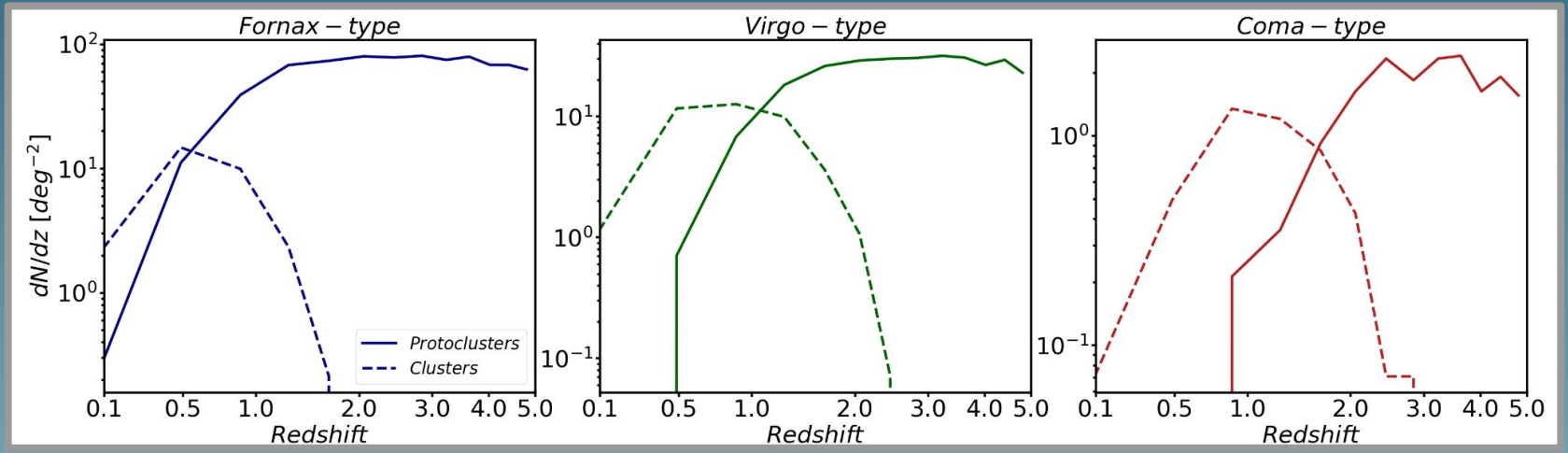
Cluster: A FOF group with main dark matter halo's $M_{200} \geq 10^{14}\ M_\odot$ at any redshift.

Protocluster: Progenitors of z = 0 clusters but with main dark matter halo's $M_{200} < 10^{14}\ M_\odot$

Fornax-type: $M_{z=0}$ **(1.37-3)x10^{14} M⊙**

Virgo-type: $M_{z=0}$ **(3-10)x10^{14} M⊙**

Coma-type: $M_{z=0}$ **>1x10^{15} M⊙**



Structures in the mock

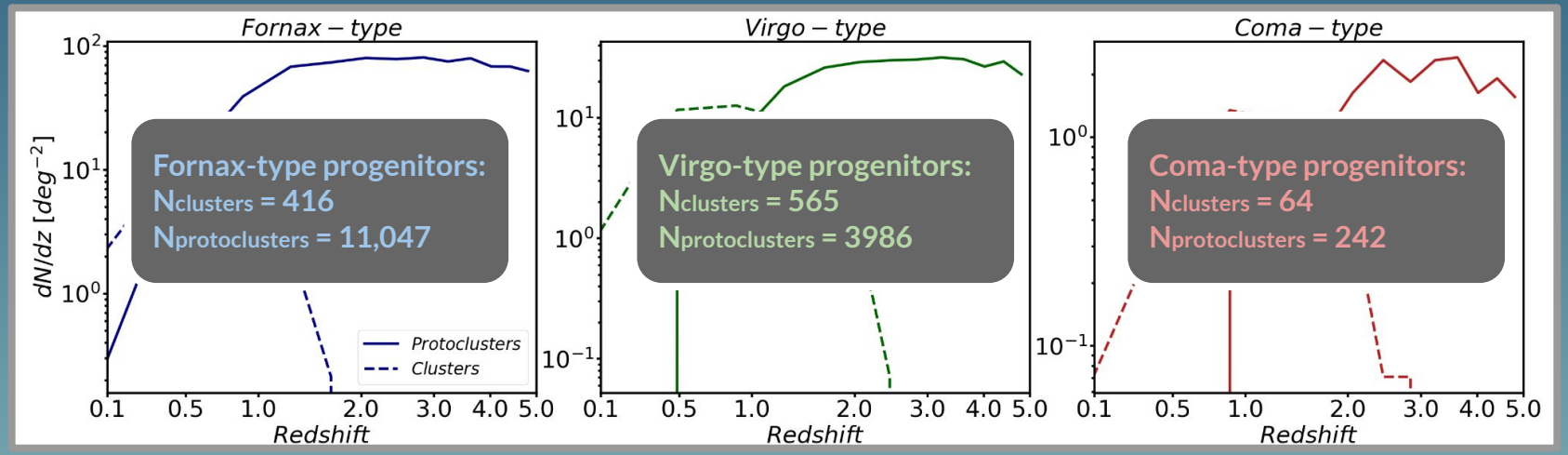
Cluster: A FOF group with main dark matter halo's $M_{200} \geq 10^{14}\ M_\odot$ at any redshift.

Protocluster: Progenitors of z = 0 clusters but with main dark matter halo's $M_{200} < 10^{14}\ M_\odot$

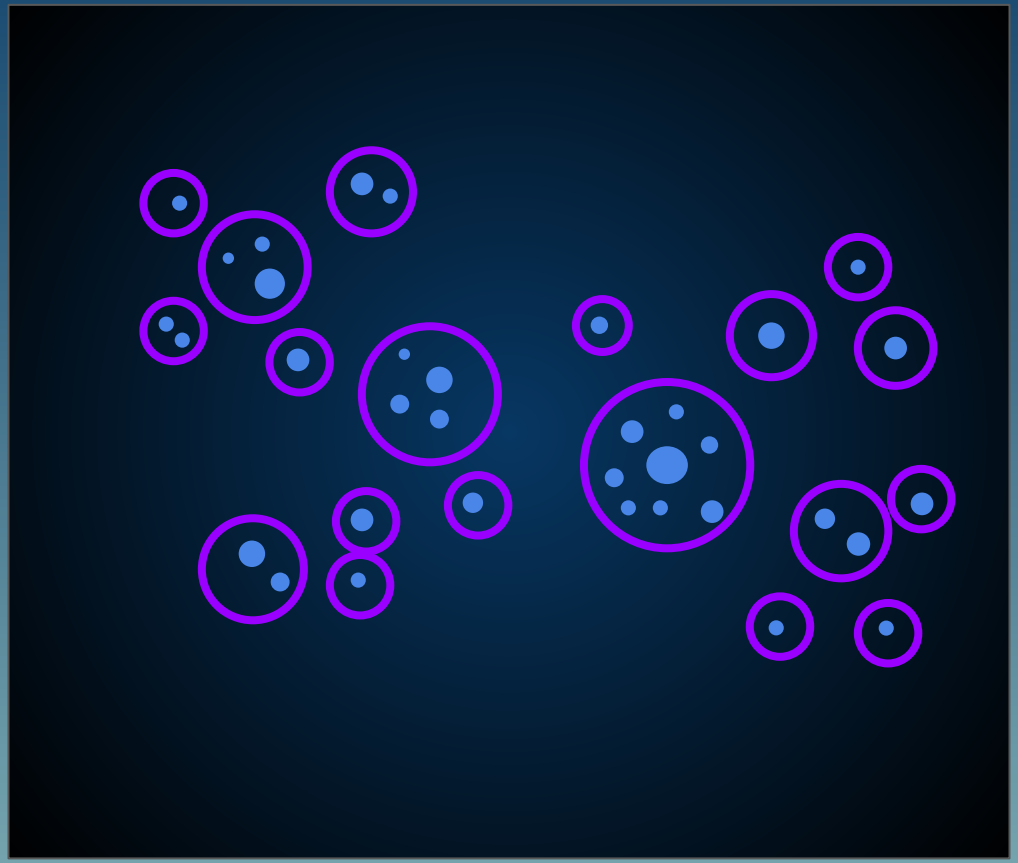
Fornax-type: $M_{z=0}$ (1.37-3)x10^{14} $M_\odot$

Virgo-type: $M_{z=0}$ (3-10)x10^{14} $M_\odot$

Coma-type: $M_{z=0}$ >1x10^{15} $M_\odot$

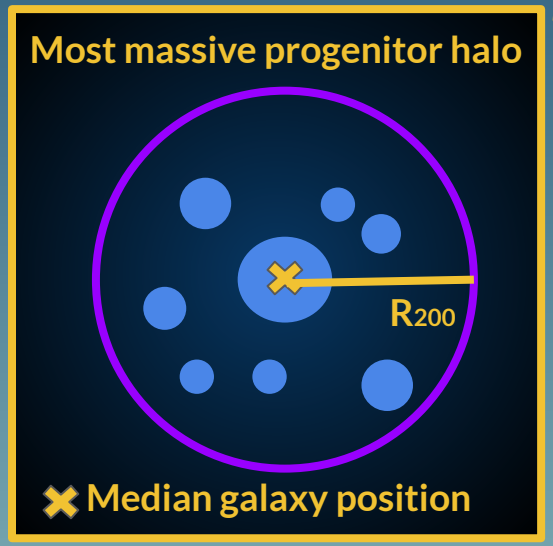


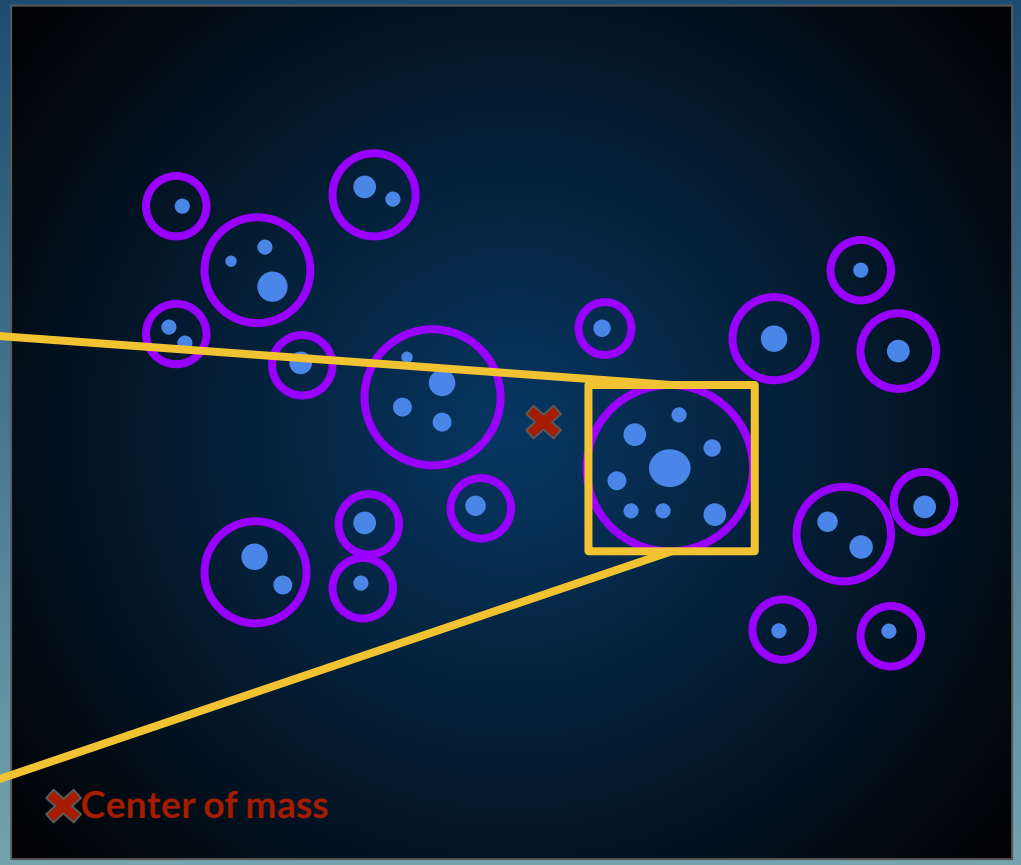
Protocluster members selection



Protocluster members selection: Core

Core: Galaxies enclosed in a sphere centered at the median position of galaxies in the most massive progenitor halo with radius R_{200}

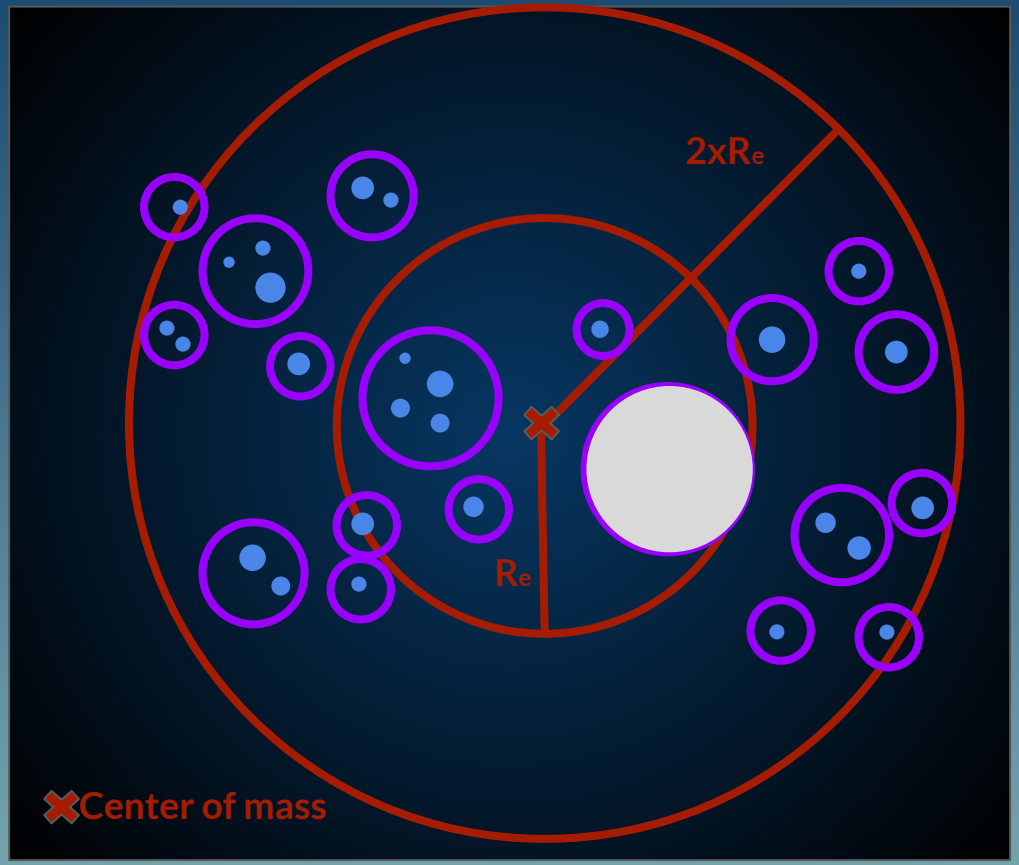




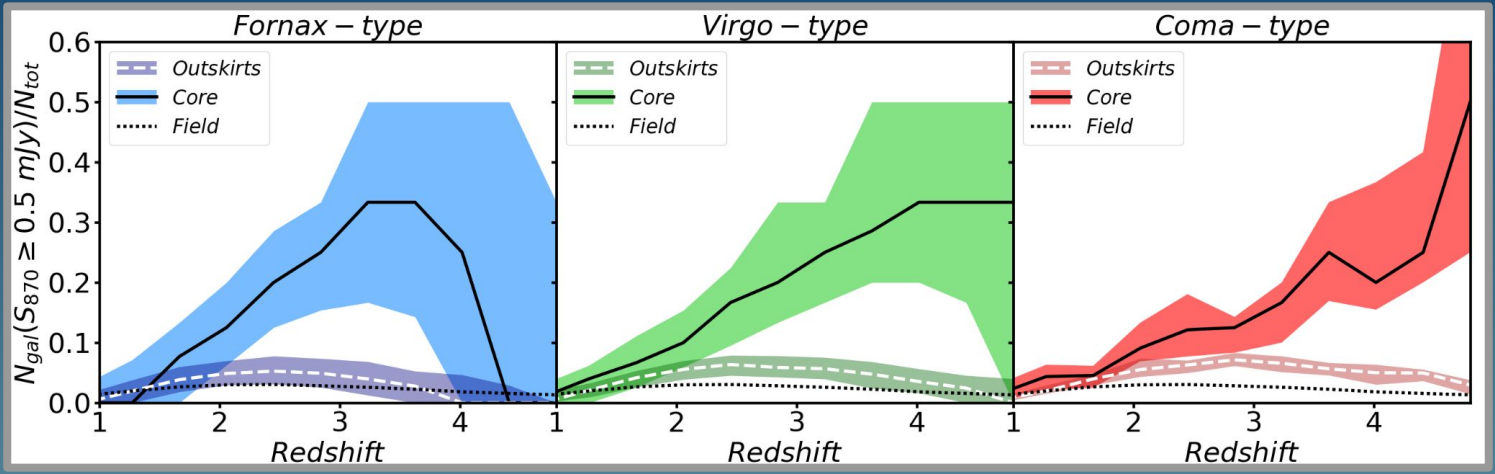
Protocluster members selection: Outskirts

Outskirts: Galaxies enclosed in a sphere centered at the center of mass with radius 2 x R_e ; excluding the core galaxies

$$R_e = \sqrt{\frac{1}{M_{\star,tot}} \sum_i M_{\star,i}(\mathbf{x_i} - \mathbf{x_c})^2};$$



Fraction of sub-mm sources in protoclusters

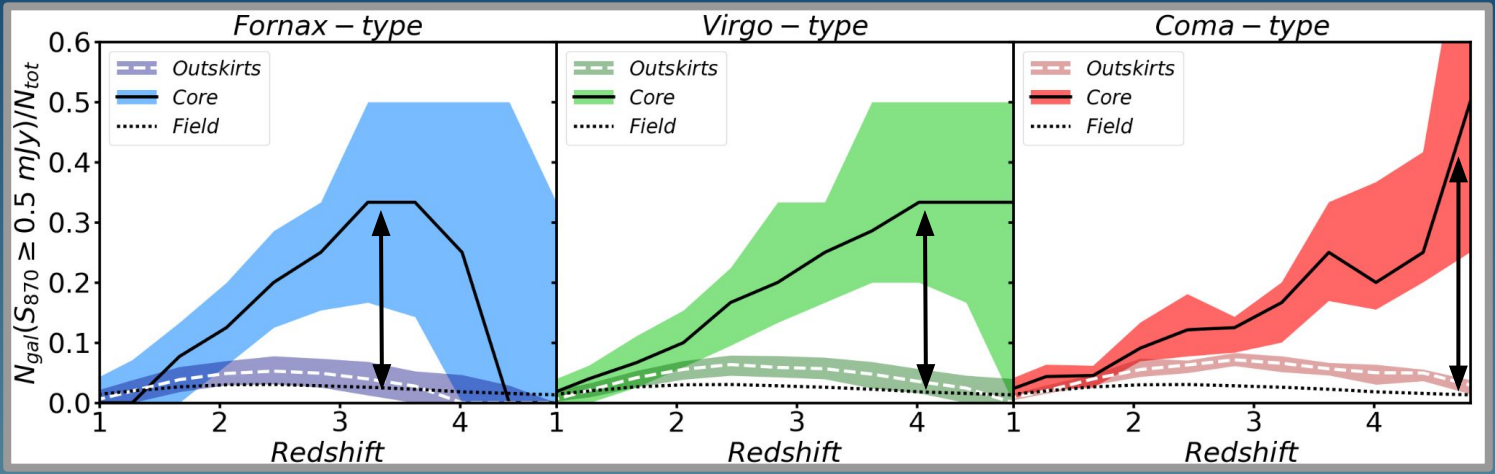


Sub-mm galaxies (SMGs): Galaxies with S_{870} > 0.5 mJy (lower limit of Miller+18)

To be more conservative (with simulation resolution), we consider just galaxies with $M\star > 10^9\ M\odot$.

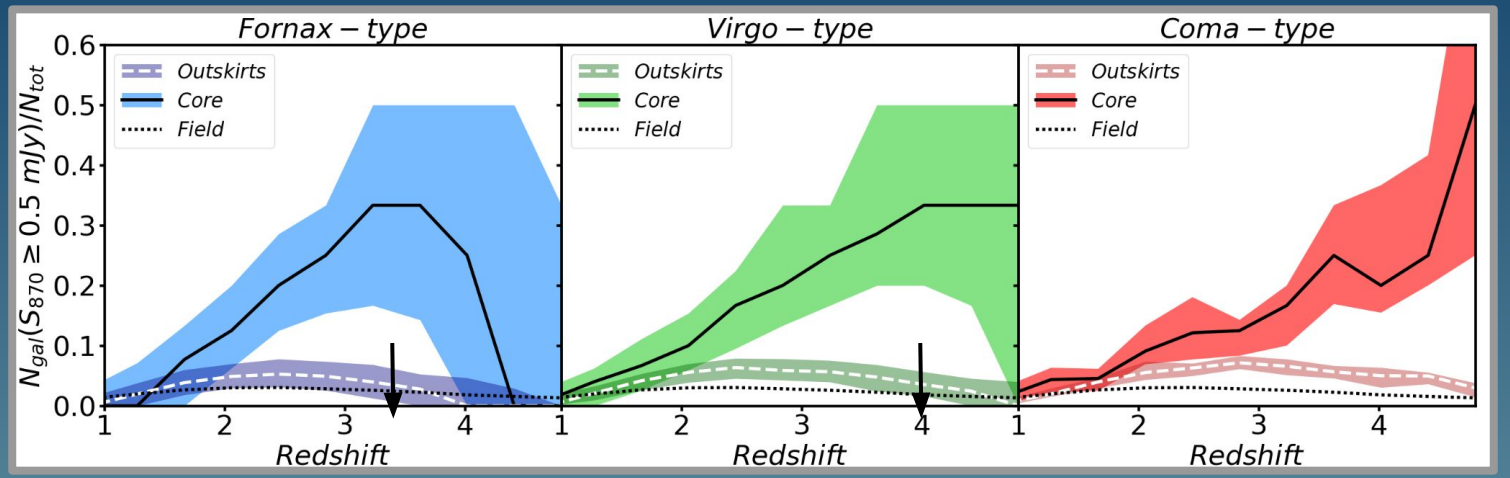
For each redshift bin ($\Delta z = 0.4$), we stack all protoclusters within it and estimate the percentiles 25, 50 and 75% (colored area and lines).

Fraction of sub-mm sources in protoclusters



Protocluster cores exhibit an enhancement of sub-mm sources, which depends on the redshift.

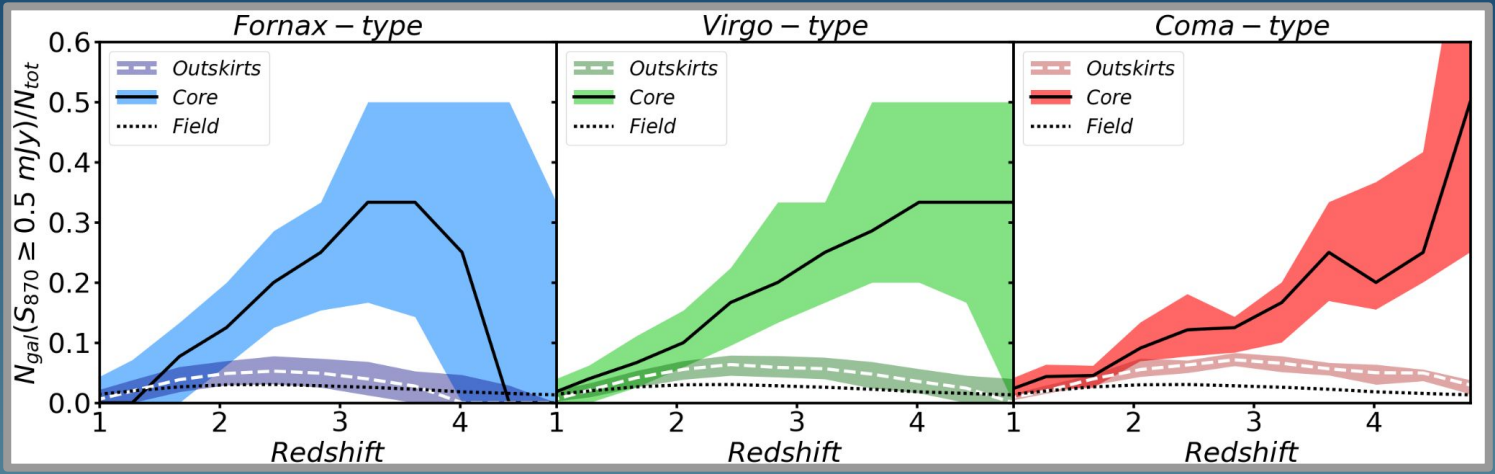
Fraction of sub-mm sources in protoclusters



Protocluster cores exhibit an enhancement of sub-mm sources, which depends on the redshift.

The redshift peak and duration of the SMGs fraction present a clear dependence on the protocluster types.

Fraction of sub-mm sources in protoclusters

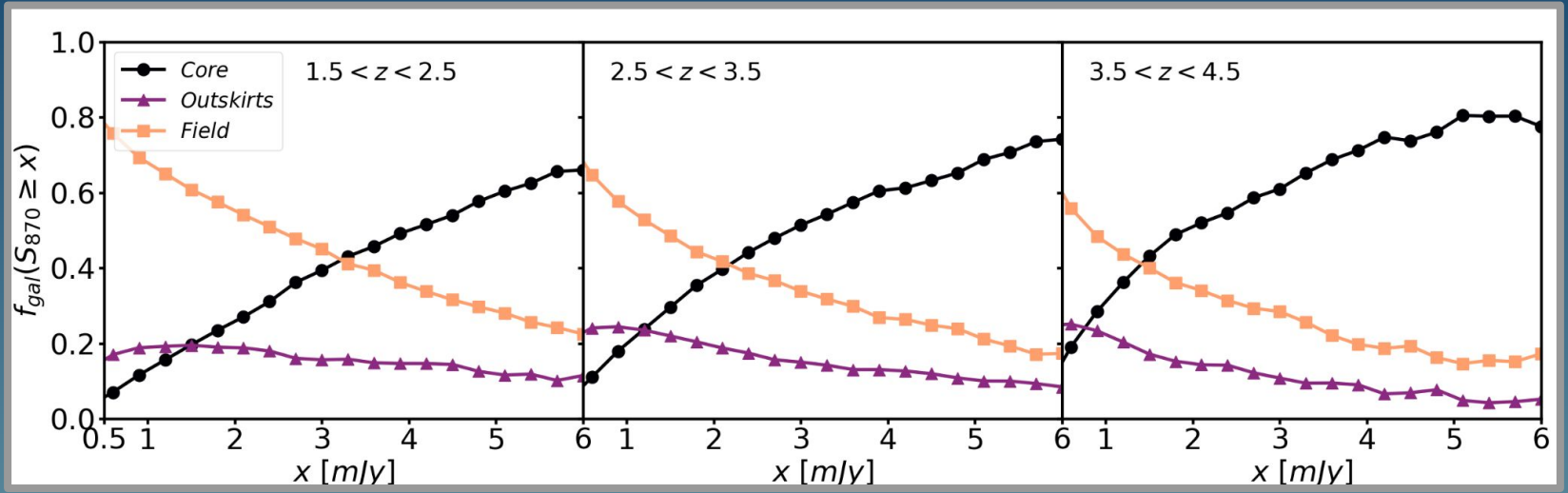


Protocluster cores exhibit an enhancement of sub-mm sources, which depends on the redshift.

The redshift peak and duration of the SMGs fraction present a clear dependence on the protocluster types.

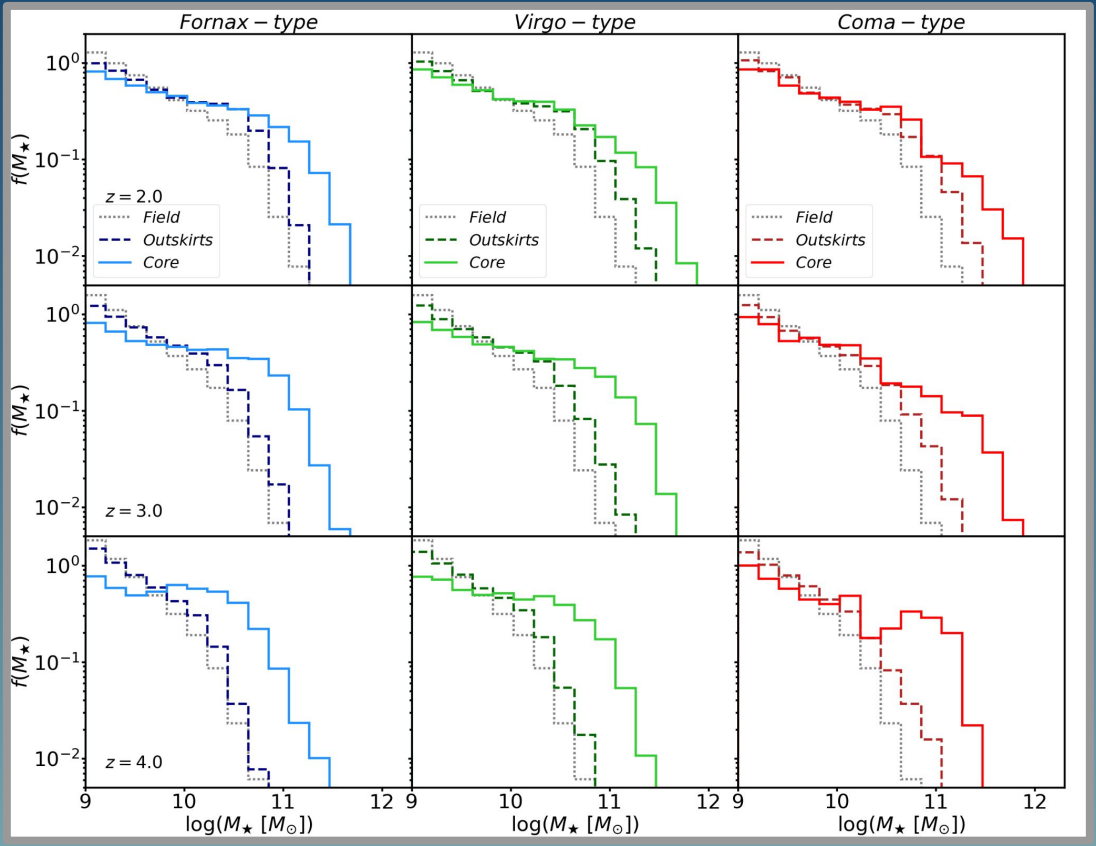
Protocluster outskirts present a fraction of SMGs comparable with the field.

Fraction of SMGs in each environment



Although field galaxies are more abundant, bright SMGs prefer the protocluster cores, mainly at high redshifts.

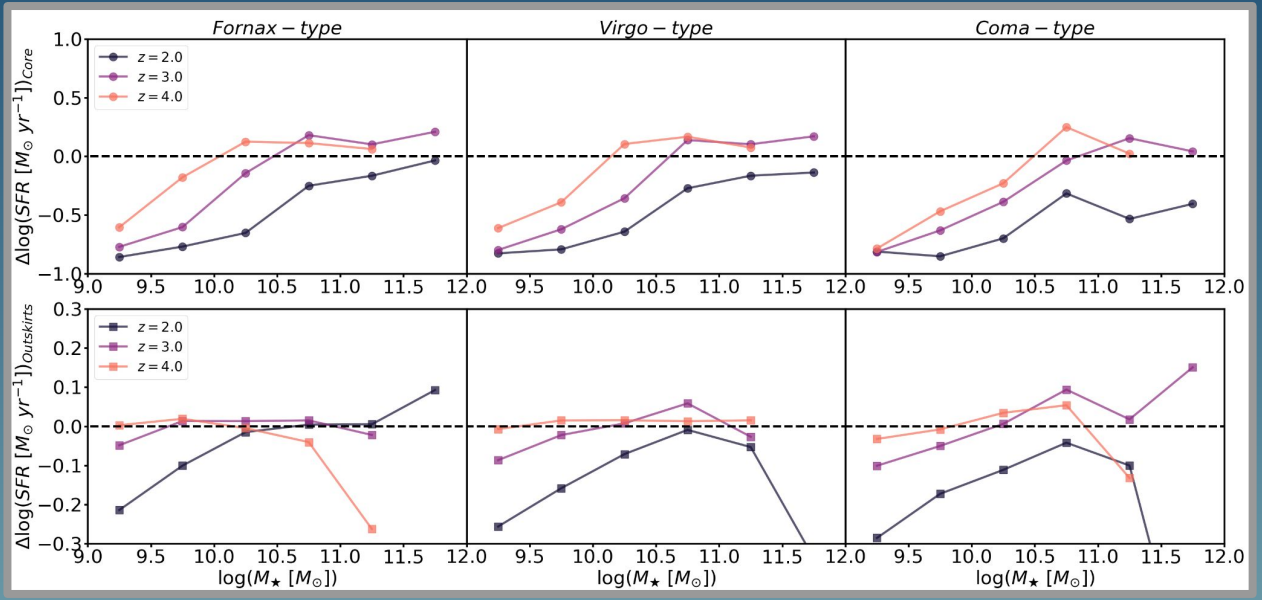
Protocluster cores already host massive galaxies by z ~4



It is significantly more likely to find galaxies with higher stellar masses in protocluster cores than in the outskirts and field.

Main sequence galaxies at high redshift, quiescents at z ~ 2

For protocluster cores, there is a stellar mass threshold where galaxies with higher masses present SFRs comparable with the Field MS but at z = 2, which is always below.



Summary

Given our simulation and dust emission modeling, we predict that:

☐ SMGs, mainly the bright ones, are more likely to reside in protocluster cores, which experience a sub-mm phase.

☐ Cores host SMGs due to the early evolution of these galaxies, since they belong to the massive-end and the Field Main Sequence in the SFR-M★ diagram. Direct consequence of downsizing.

Thanks!
Questions?