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An insight into Spitzer-selected (proto-)clusters

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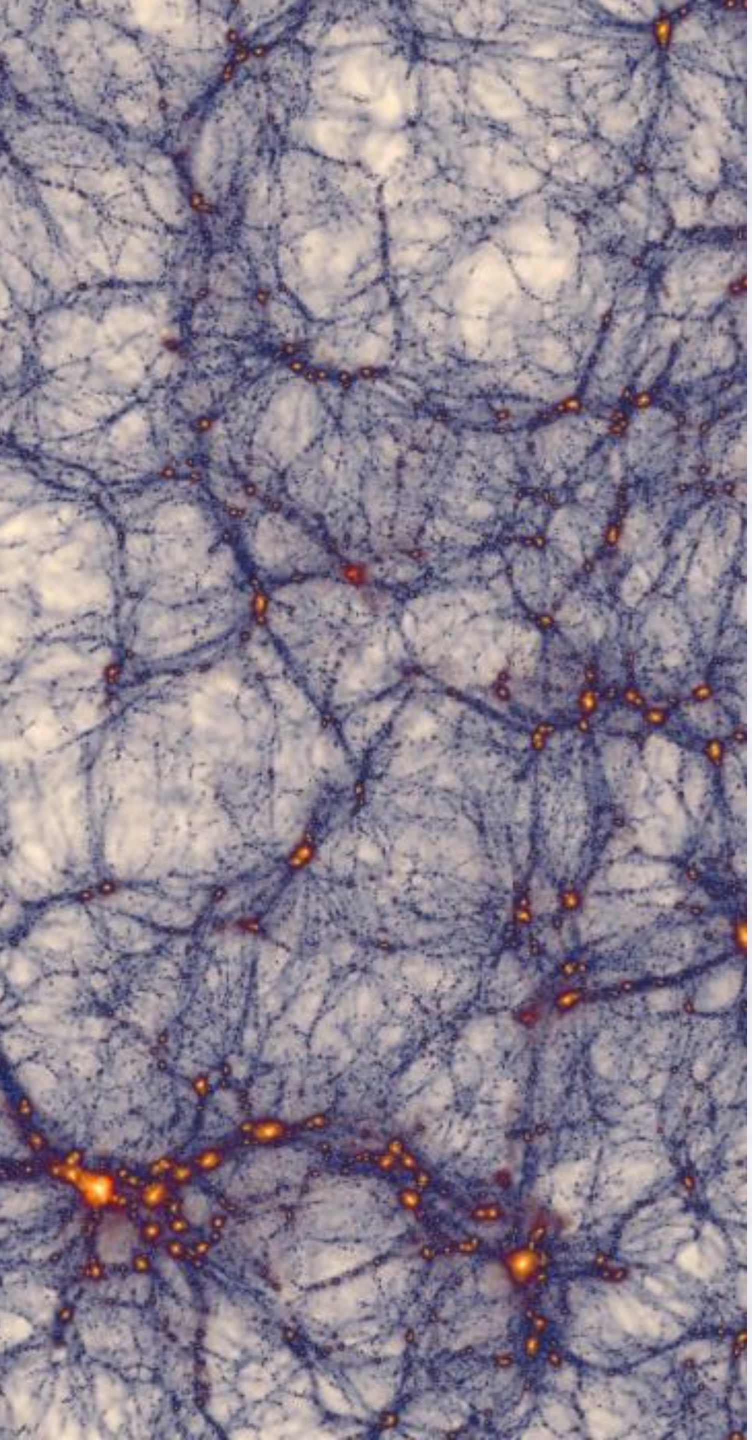


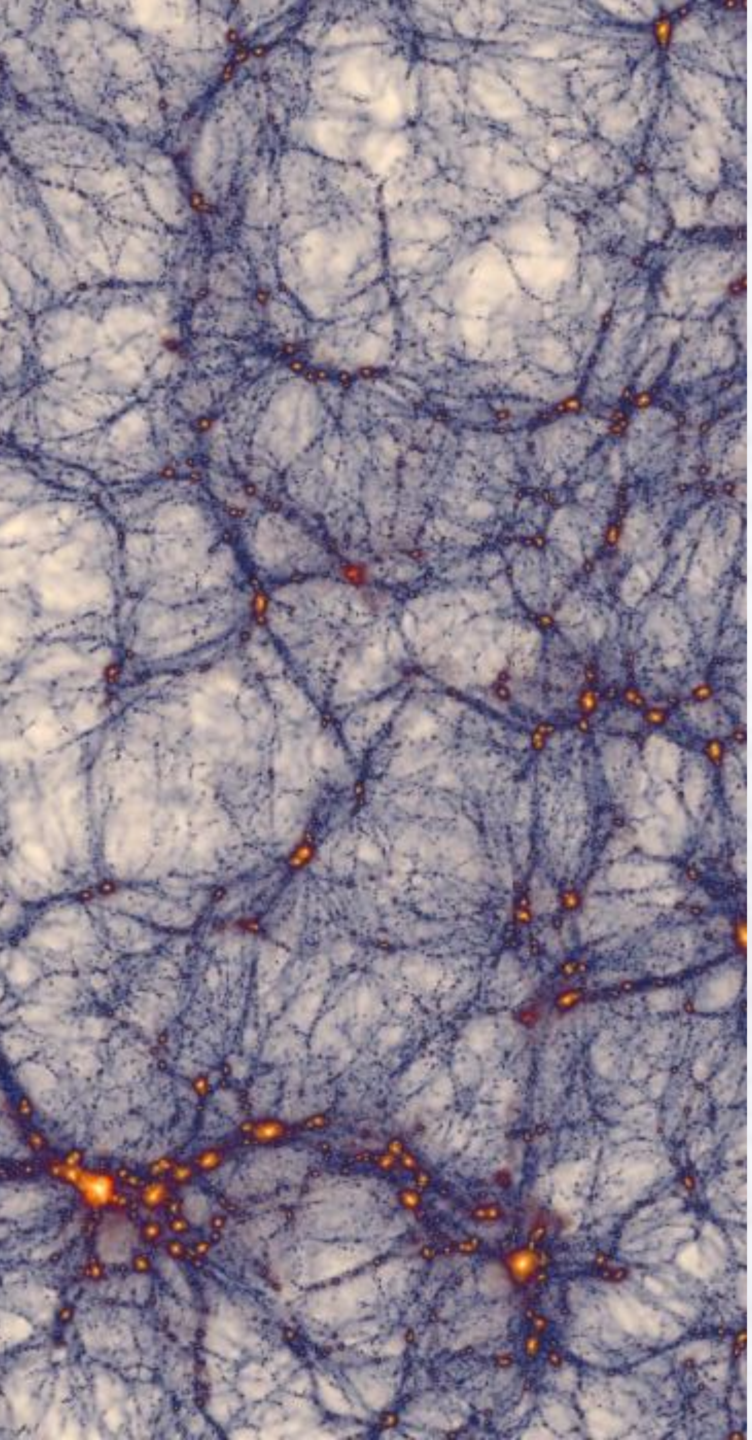
Introduction

- The Spitzer/IRAC method is one of the most commonly use detection methods for high redshift clusters

- For example, Papovich (2008), Wylezalek et al. (2013), Rettura et al. (2014), Martinache et al. (2018) present over 500 cluster candidates at $z > 1.3$

- However, its efficacy and biases are poorly understood

- This brings into question how representative this sample of (proto)clusters is compared to the wider population



Introduction

- We therefore test the method on simulated data – the MAMBO lightcone
- We compare how different implementations of the method throughout the literature perform
- We also optimize the method in order to create a new catalogue of high redshift clusters in the LSST deep drilling fields
- Finally, we determine the biases of this new sample

How well does the Spitzer/IRAC method perform?

The Method

- The IRAC cut, [3.6] – [4.5] > -0.1, efficiently select z > 1.3 galaxies
- This utilizes the 1.6µm bump which causes z > 1.3 galaxies to appear red, regardless of galaxy age or type
- This removes a significant amount of low redshift contaminants
- From this colour-selected sample, galaxy overdensities are located

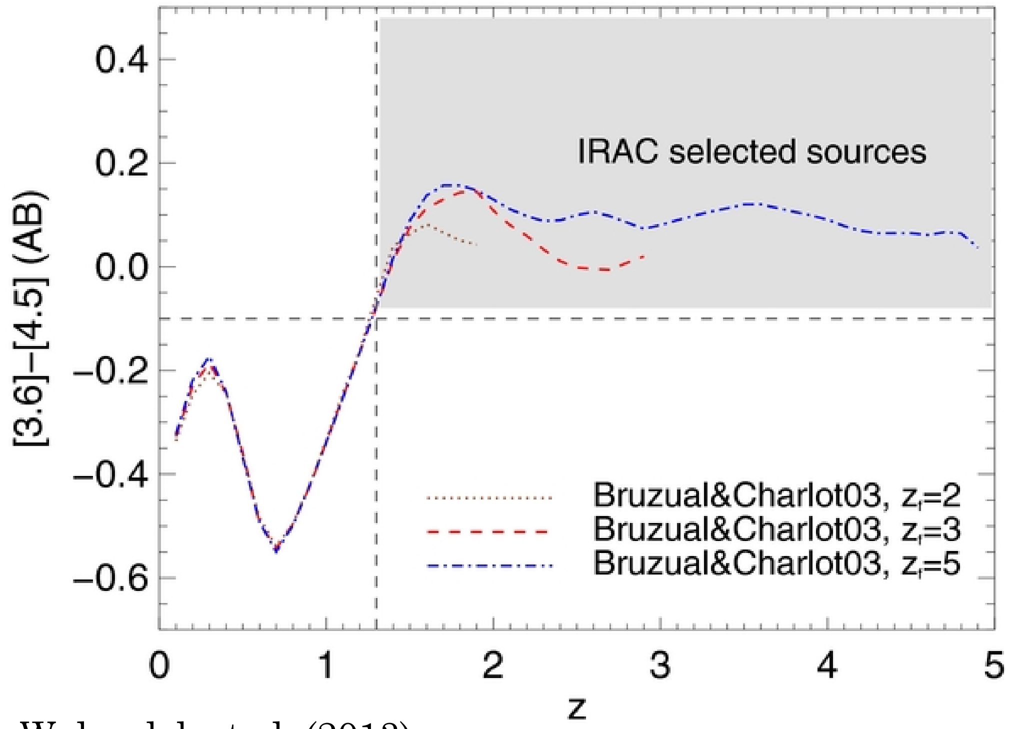
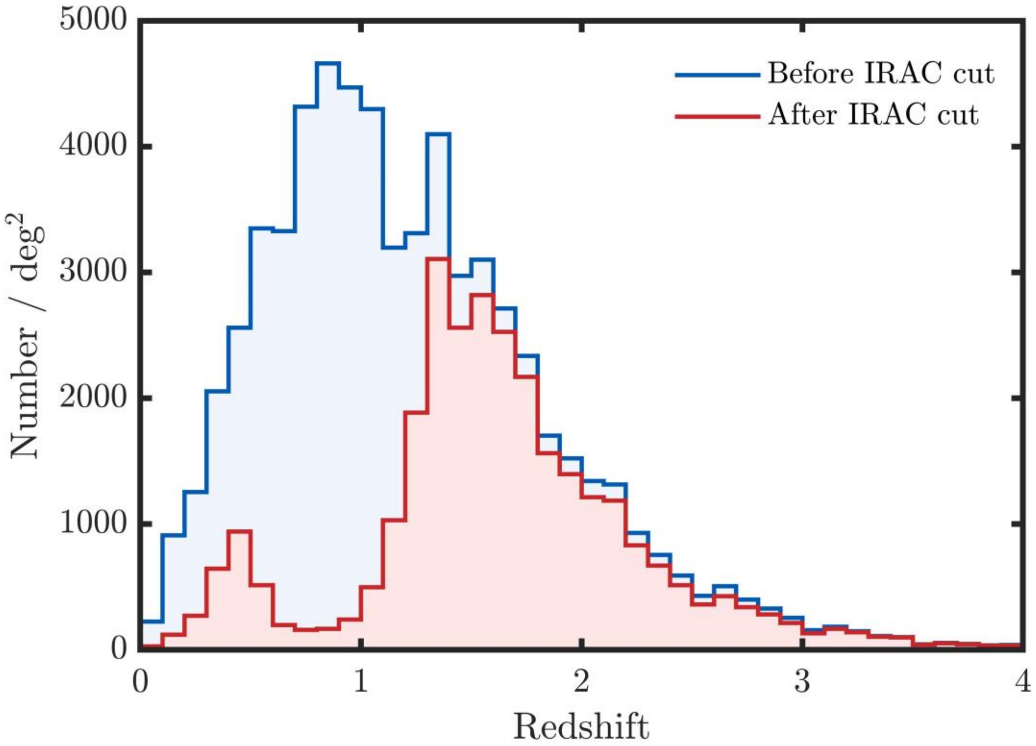


Image: Wylezalek et al. (2013)



How well does the Spitzer/IRAC method perform?

Literature Comparison

- Using the lightcone, we can determine how successful the method is at selecting genuine protoclusters
- We do this by calculating the purity – the ratio of true detections to total detections
- This value depends on the depth of the data, the value of the colour cut and search radius, and the overdensity threshold

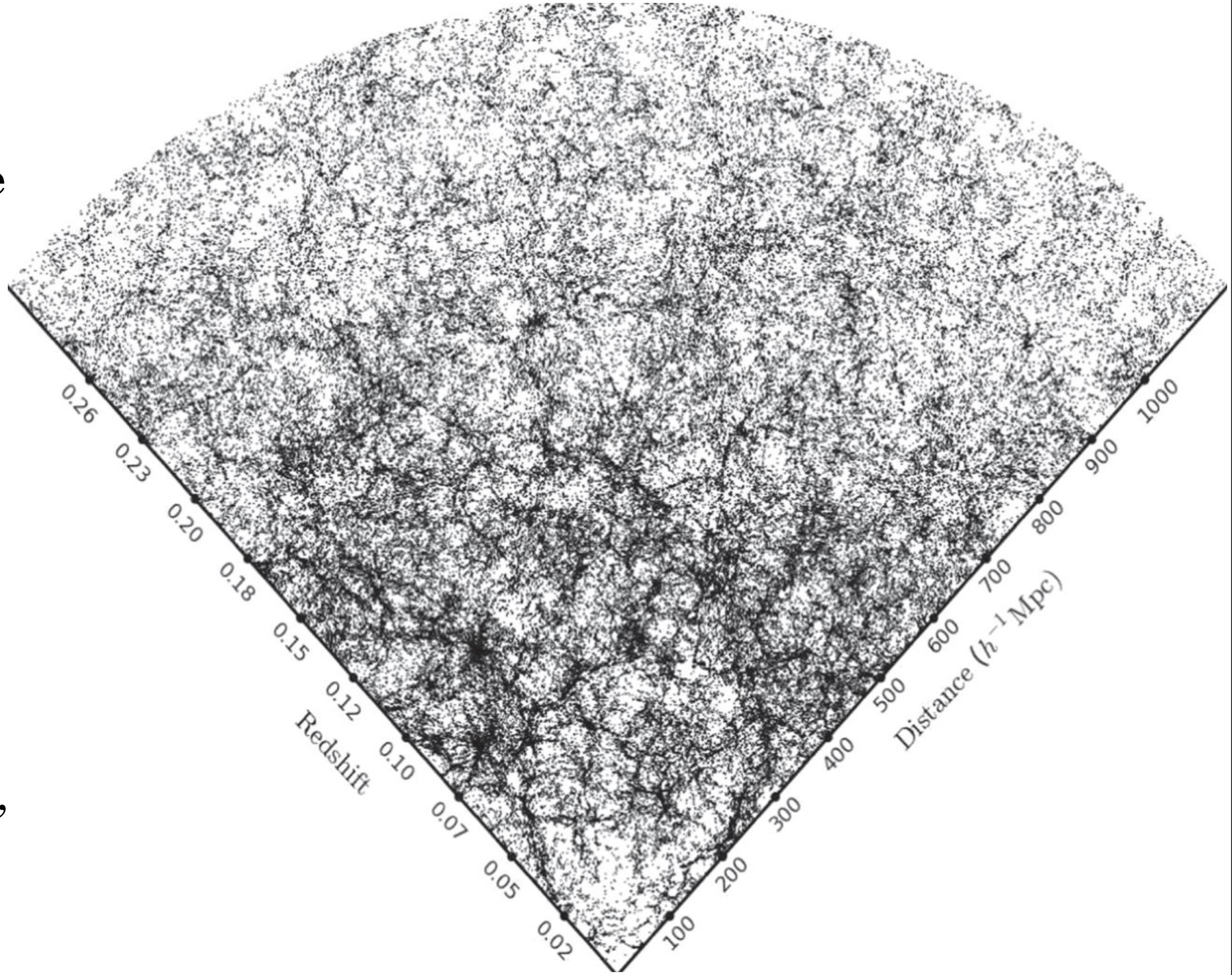


Image: Bernyk et al. (2016)

How well does the Spitzer/IRAC method perform?

<u>Literature Comparison</u>

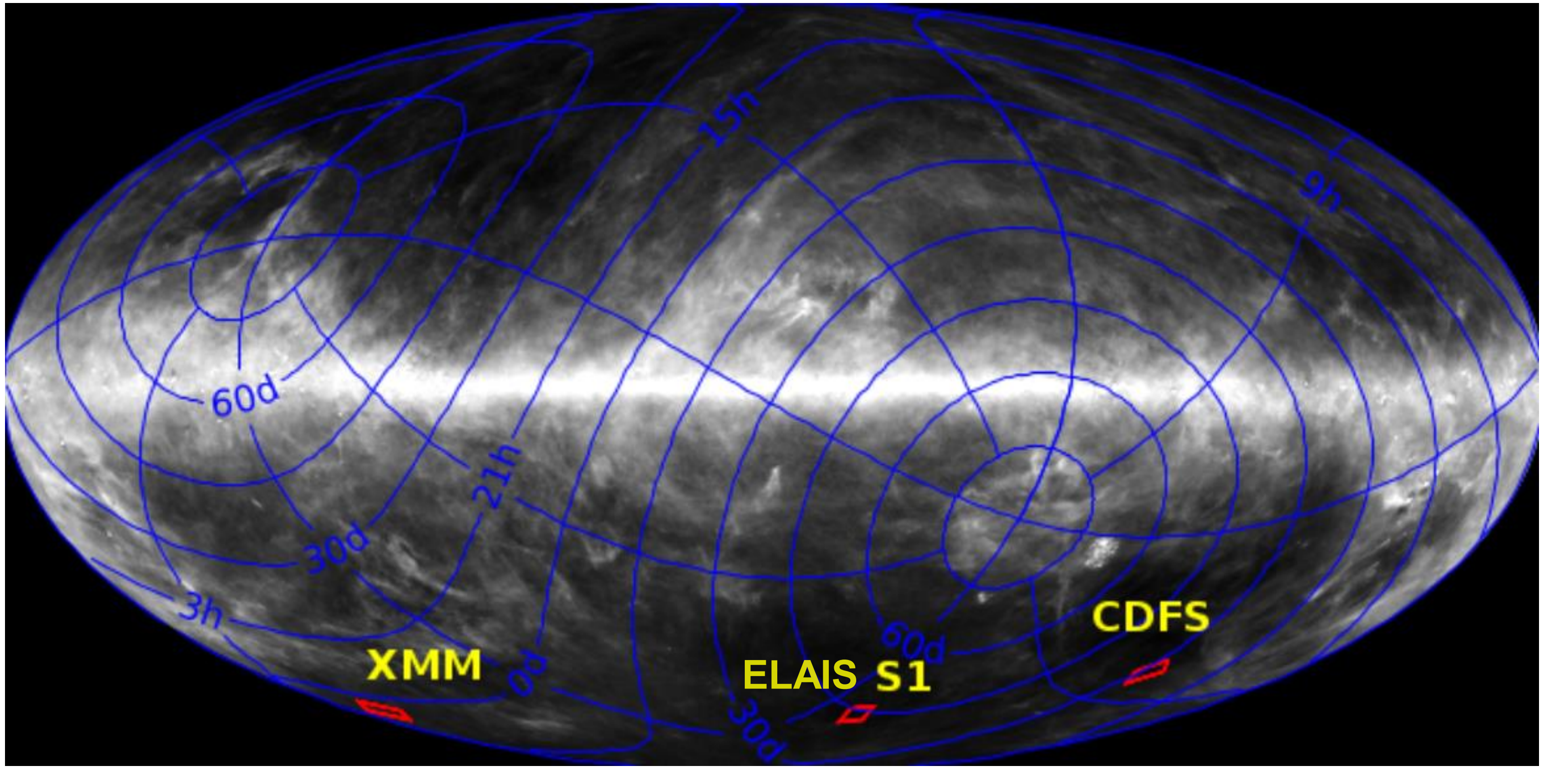
Study	Magnitude Cuts	Colour Cut [3.6]-[4.5] >	Search Radius	Overdensity Threshold	Purity
Papovich (2008)	[4.5] < 21.4	-0.1	1.4’	3σ	38 ± 9%
*Wylezalek et al. (2013)	[4.5] < 22.9	-0.1	1’	2σ	27 ± 5%
Rettura et al. (2014)	[4.5] < 21.46 19.5 < [4.5] 20.45 < I	-0.1	1’	5.2σ	57 ± 25%
*Martinache et al. (2018)	[4.5] < 22.9	-0.1	1’	3σ (4σ)	46 ± 6% (67 ± 11%)

* Targeted searches so likely to have higher values for purity

Producing our own protocluster sample in LSST's DDFs

The Deep Drilling Fields

- The Vera C. Rubin observatory will dedicate ~20% of its observing time to a set of DDFs
- These are the CDFS, ELAIS S1 and XMMLSS fields which cover ~ 30 deg^2
- LSST will reach a depth of 26.2 - 28.7 (AB), with high temporal sampling
- Deep Spitzer data from Lacy et al. (2021), reaching 5σ depth of ~ 2 μJy

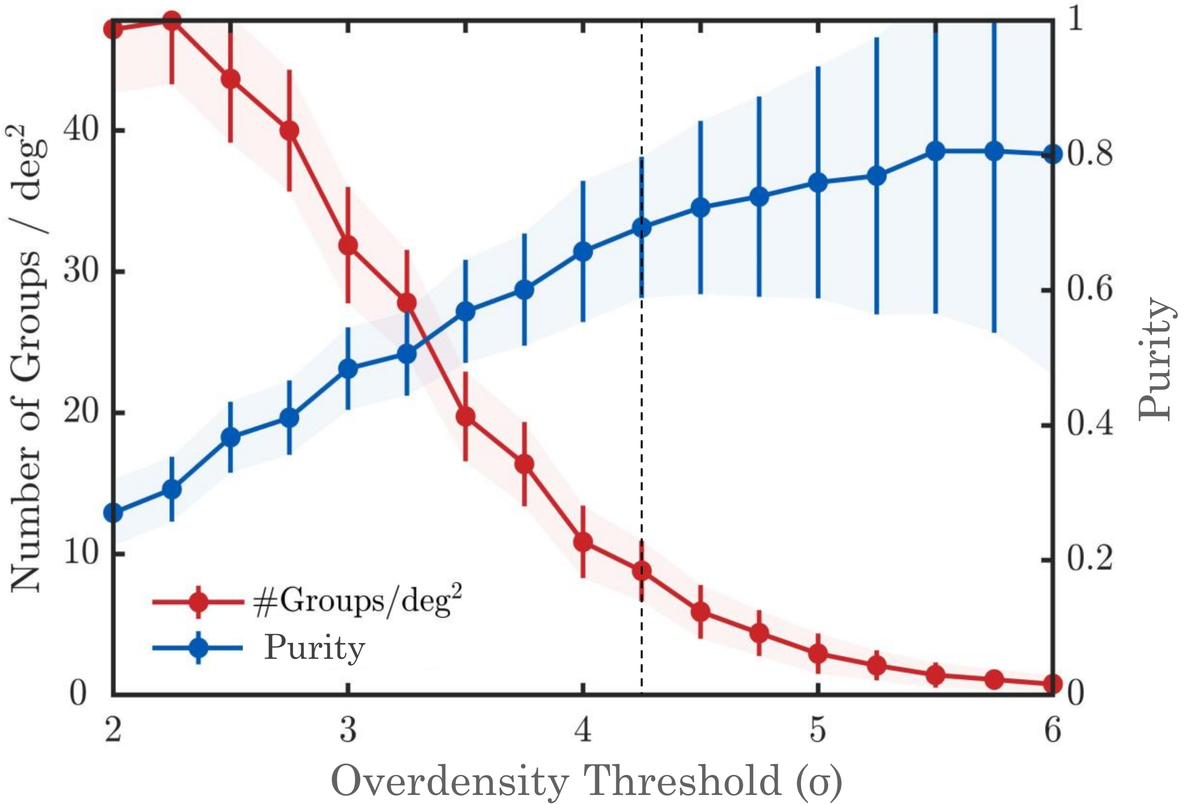


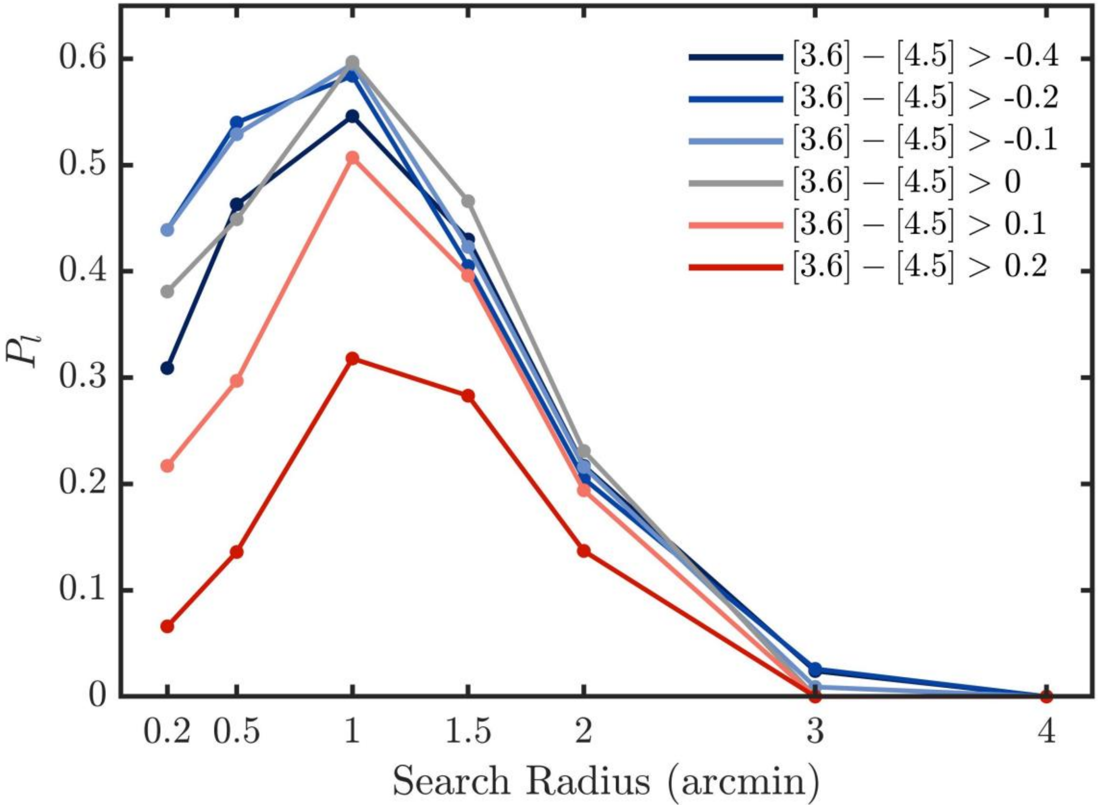
Producing our own protocluster sample in LSST's DDFs

Optimisation

- We optimise on the lower bound of the purity (the lower error bar)
- This is to take into account the number of selected groups

- We find an optimal value of colour cut at [3.6] – [4.5] > -0.05
- We find an optimal value of search radius of 1 arcminute





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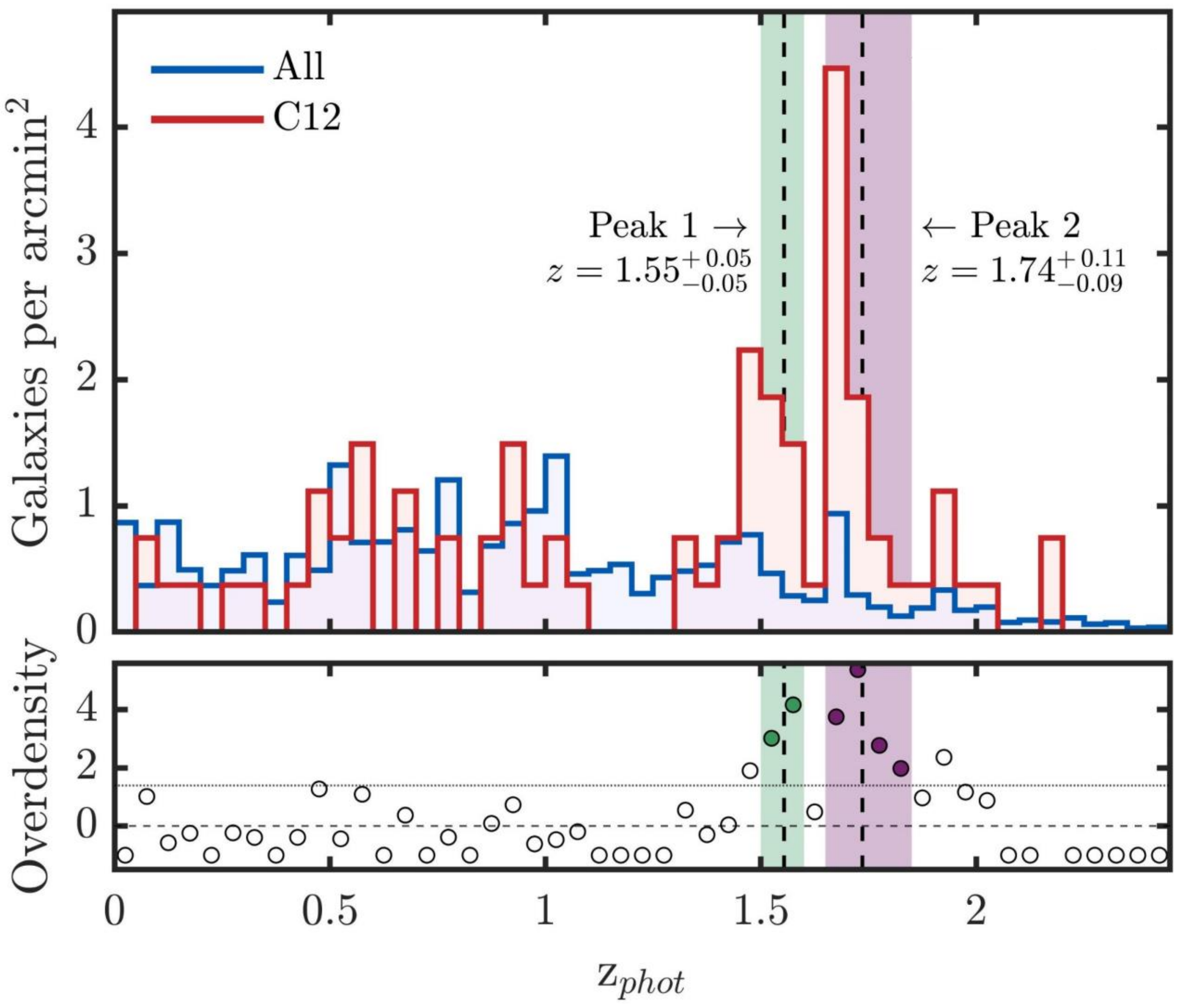
This work	[4.5] < 22.75	-0.05	1′	4.25σ	70 ± 11%

* Targeted searches so likely to have higher values for purity

Producing our own protocluster sample in LSST's DDFs

The Sample

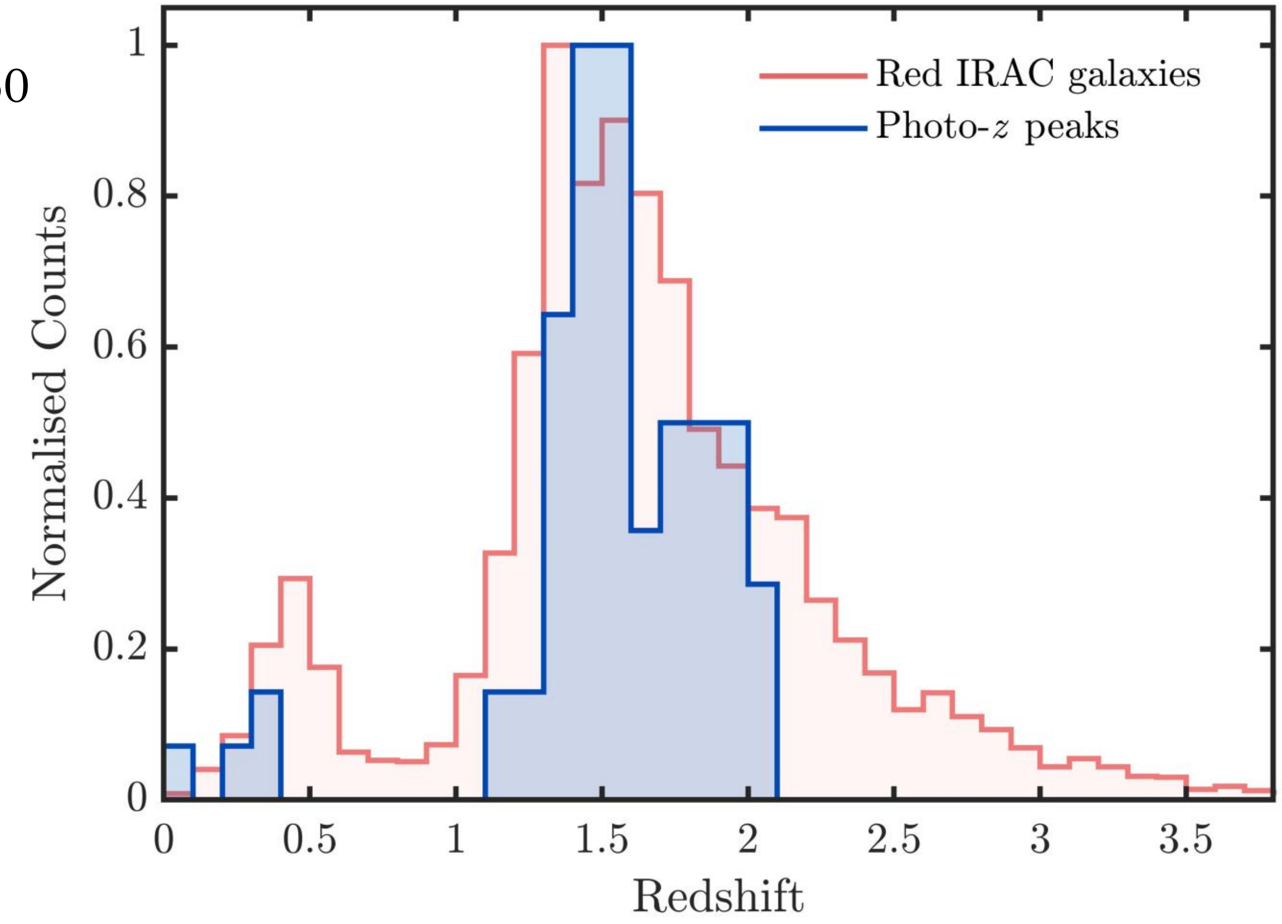
- We detect 189 candidate protoclusters across the three fields
- Limited information available with Spitzer
- We can use photo-z catalogues to estimate their redshifts
- Search for photo-z peaks in the redshift distribution for galaxies within our candidates



Producing our own protocluster sample in LSST's DDFs

Photometric Redshifts

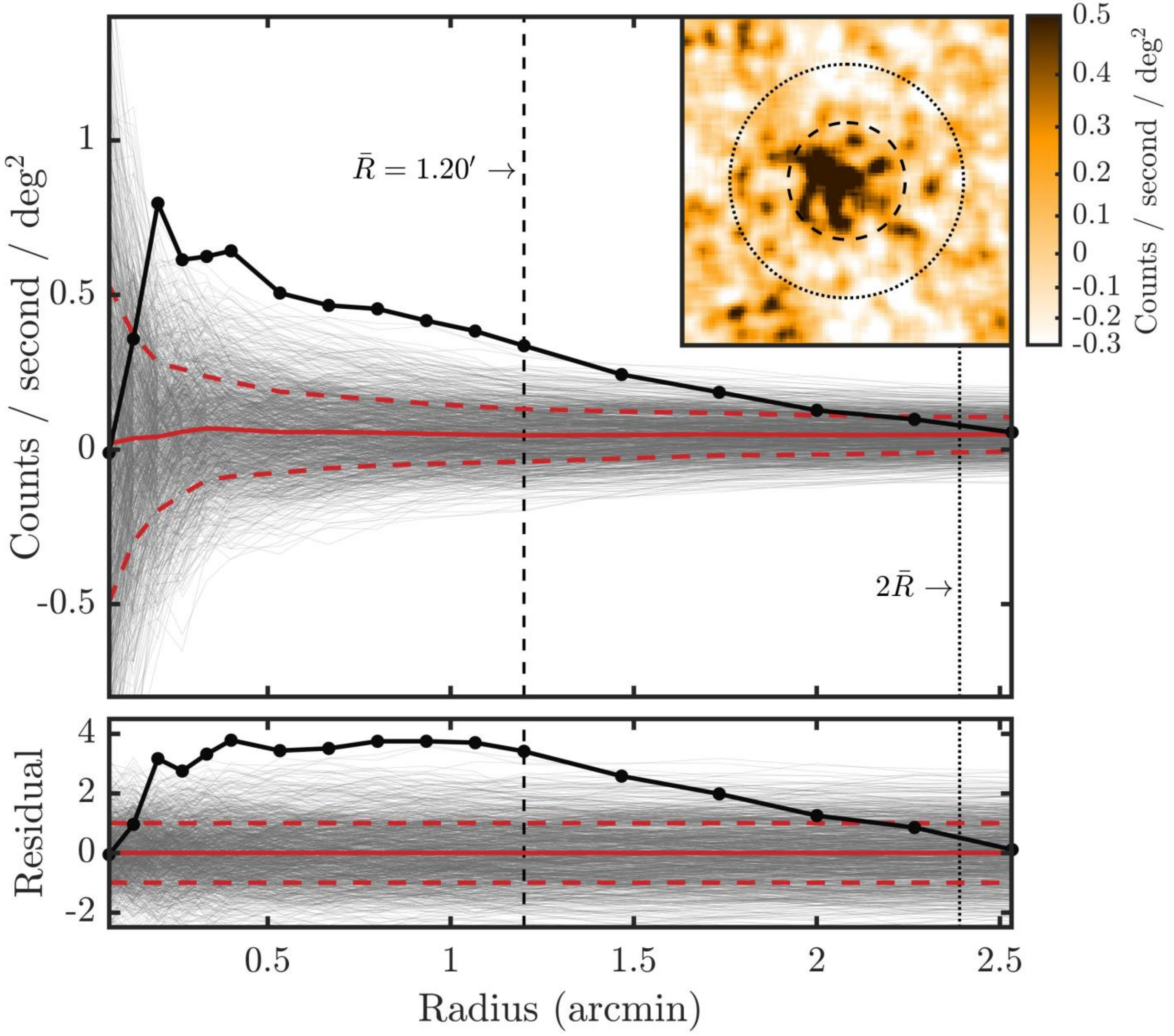
- Due to large uncertainties in photo-z catalogues we can only detect peaks for 50 candidates
- Does not confirm nor deny presence of protoclusters
- This can give us an idea on the redshift distribution of our sample
- Possibly suggests redshift limitation for Spitzer/IRAC method at z~2



Producing our own protocluster sample in LSST's DDFs

X-ray Stacking

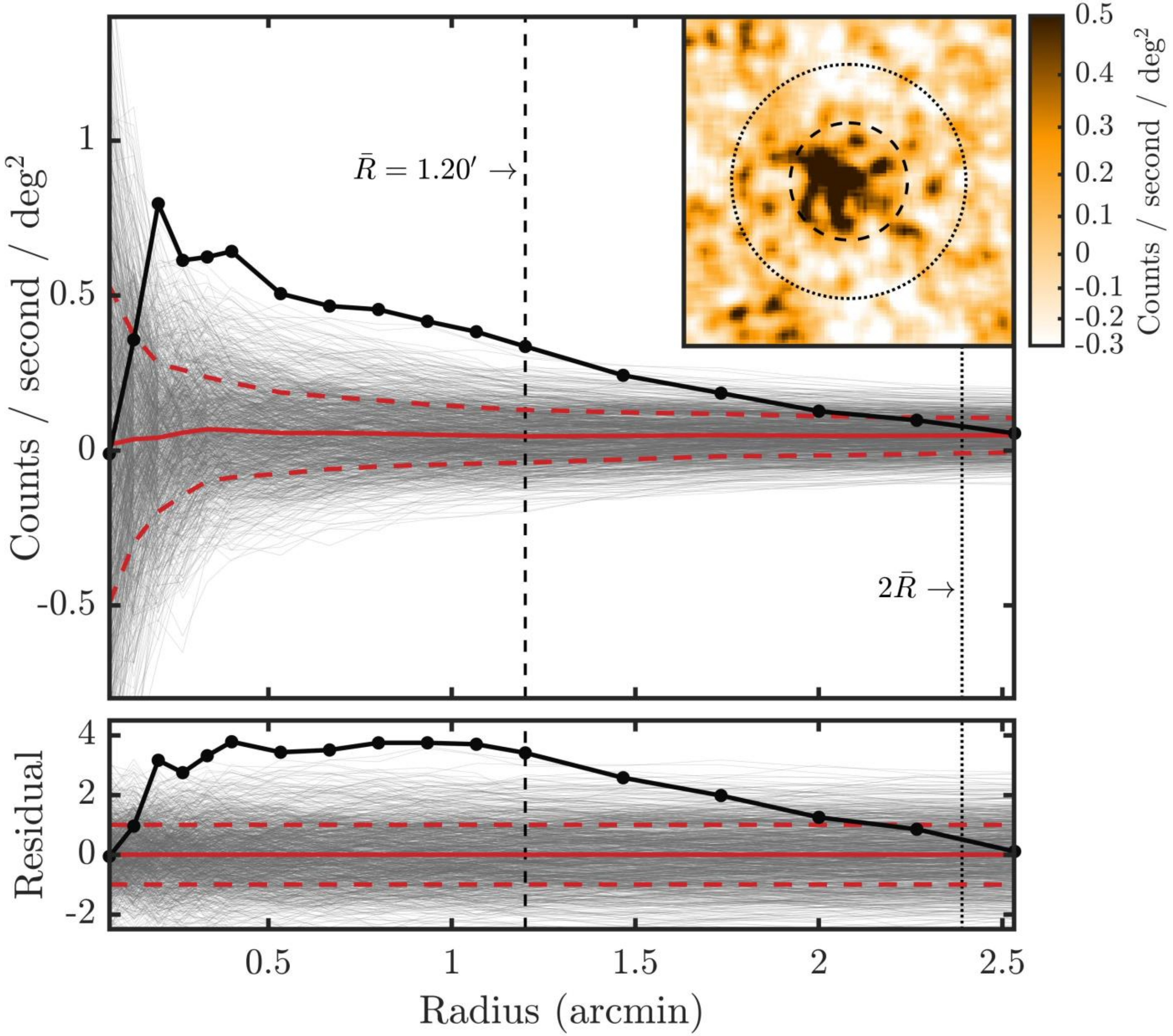
- X-ray data from XMM-SERVS covering 13.1 deg^2 across the DDFs (Ni et al. 2021, Chen et al. 2018)
- We expect collapsed structures to emit X-rays due to thermal Bremsstrahlung
- Protoclusters are systems in the process of collapsing and so are not thought to have strong X-ray signals
- By stacking X-ray images of our candidate protoclusters, we can determine what sort of systems our sample is made up of



Producing our own protocluster sample in LSST's DDFs

X-ray Stacking

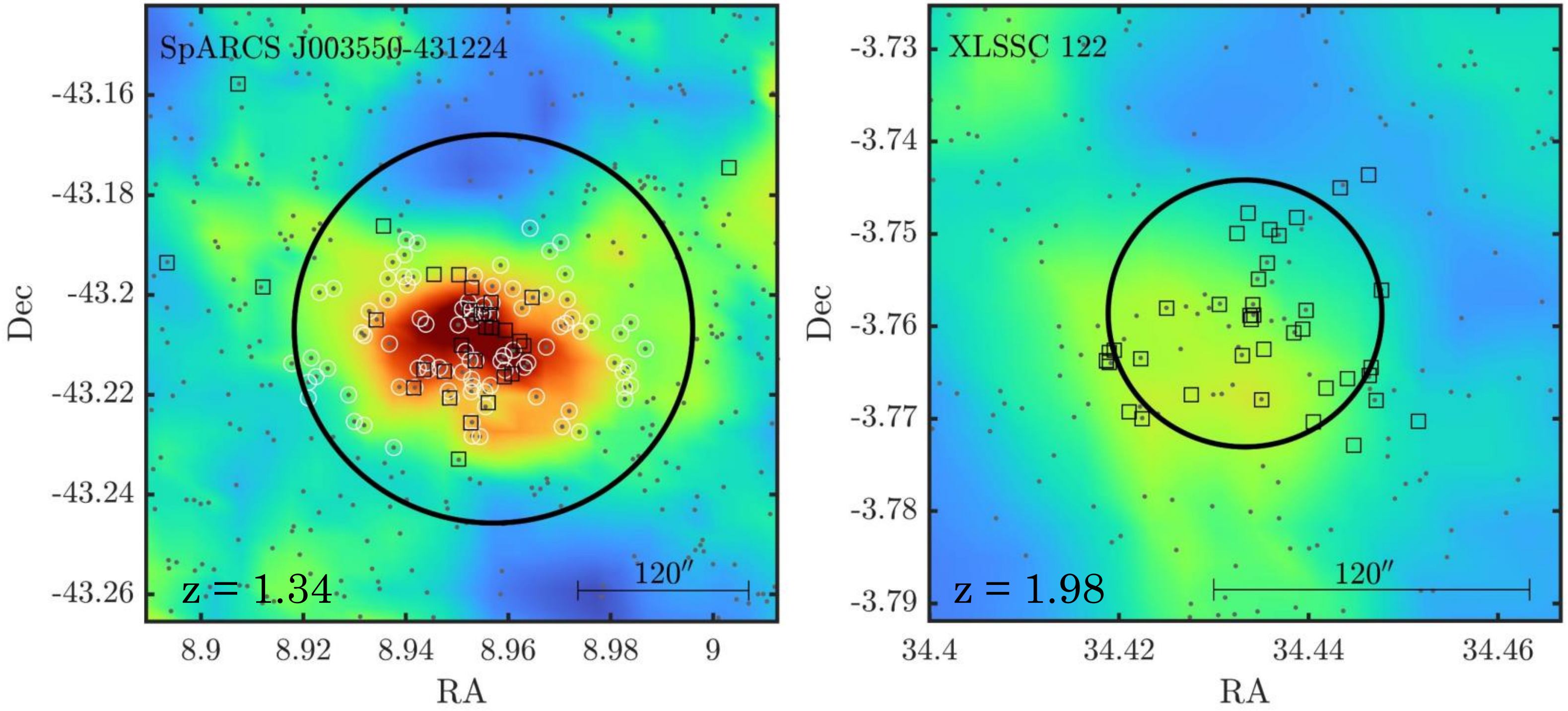
- We compare the X-ray signal from regions around the clusters in our sample to random regions across the fields
- We do this radially to increase the strength of the signal
- Within the mean effective radius of our protoclusters, we have an almost 4σ detection



Producing our own protocluster sample in LSST's DDFs

Known clusters

- There are four spectroscopically confirmed (proto)clusters in the DDFs
- We successfully detect three of them
- We believe the reason we do not detect the other is because it is much more compact



Black squares: spectroscopically confirmed members
Black circle: R_200

Grey dots: red IRAC field galaxies
White circles: galaxies selected by our method

How is our protocluster sample biased?

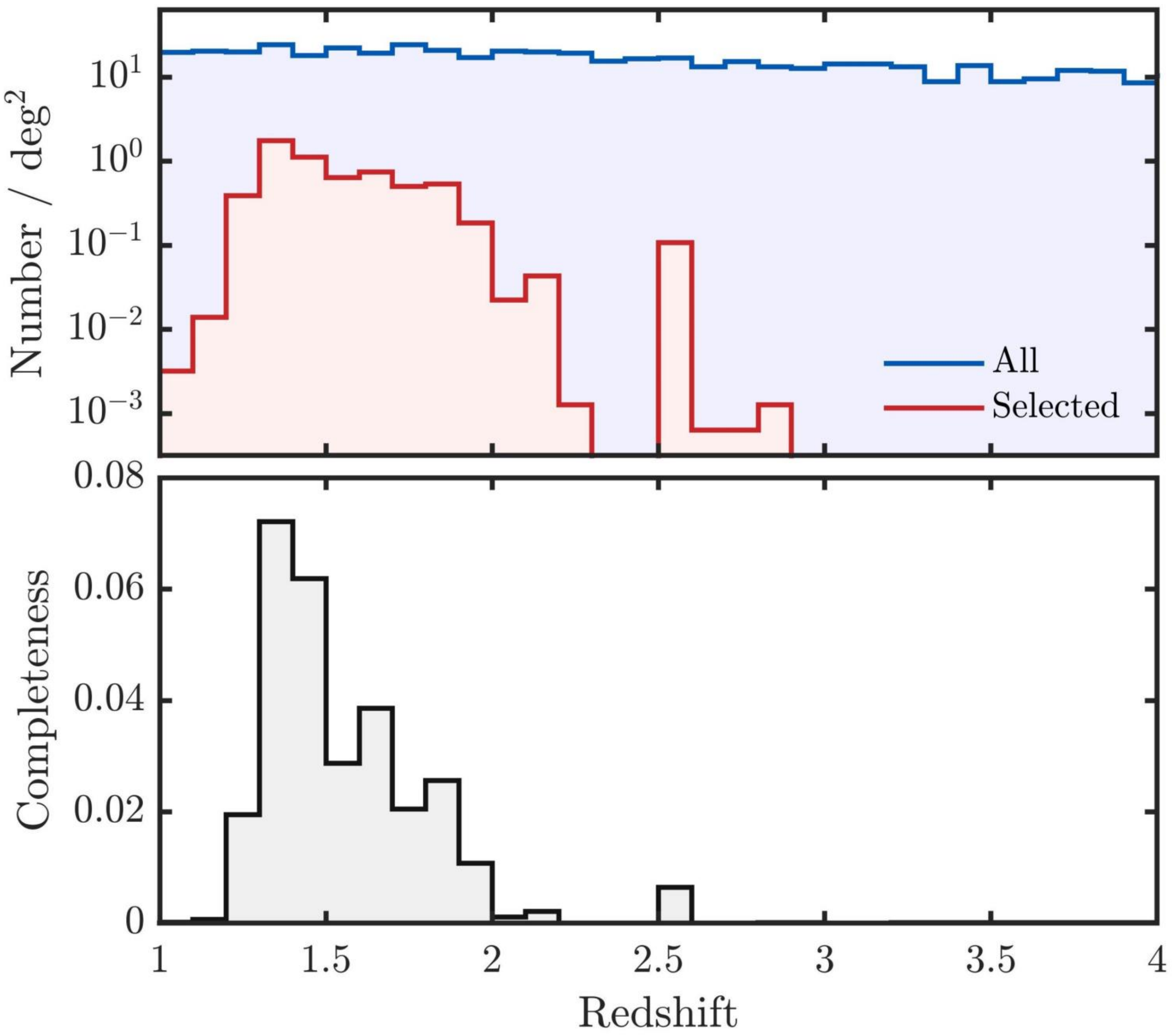
Completeness

- Using the lightcone, we can compare properties of the sample of protoclusters we find with those we do not

- In the range 1 < z < 5, we have ~1,800 protoclusters

- On average, we detect just 19 of them (1% complete)

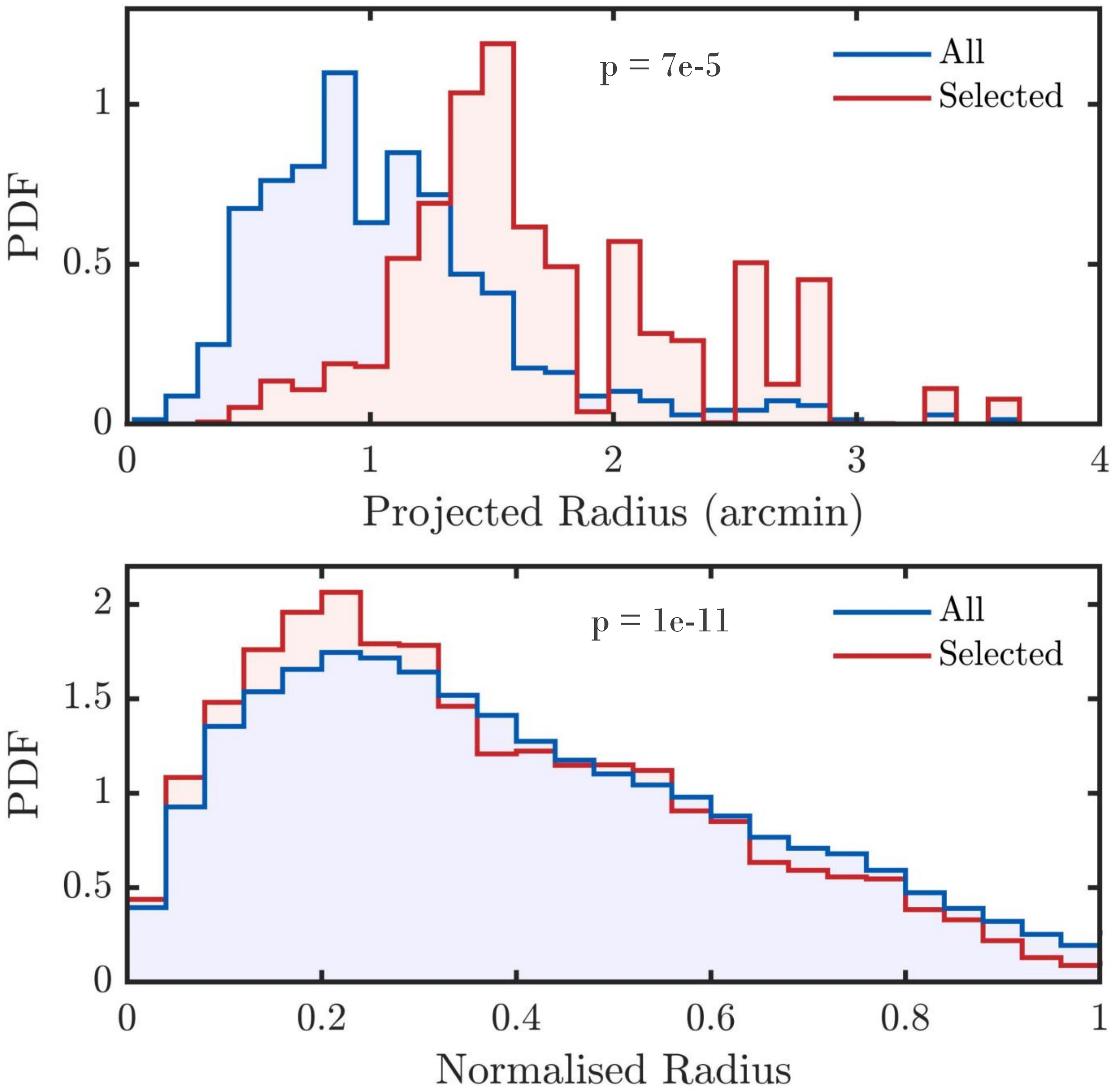
- The vast majority we do detect are between 1.2 < z < 2 (4% complete)



How is our protocluster sample biased?

Size and Concentration

- Limiting the comparison to $1.2 < z < 2$ protocluster, we can make comparisons
- We select protoclusters with larger projected sizes
- The ones we detect are also more centrally concentrated, with the radial distribution of galaxies skewed towards the centre

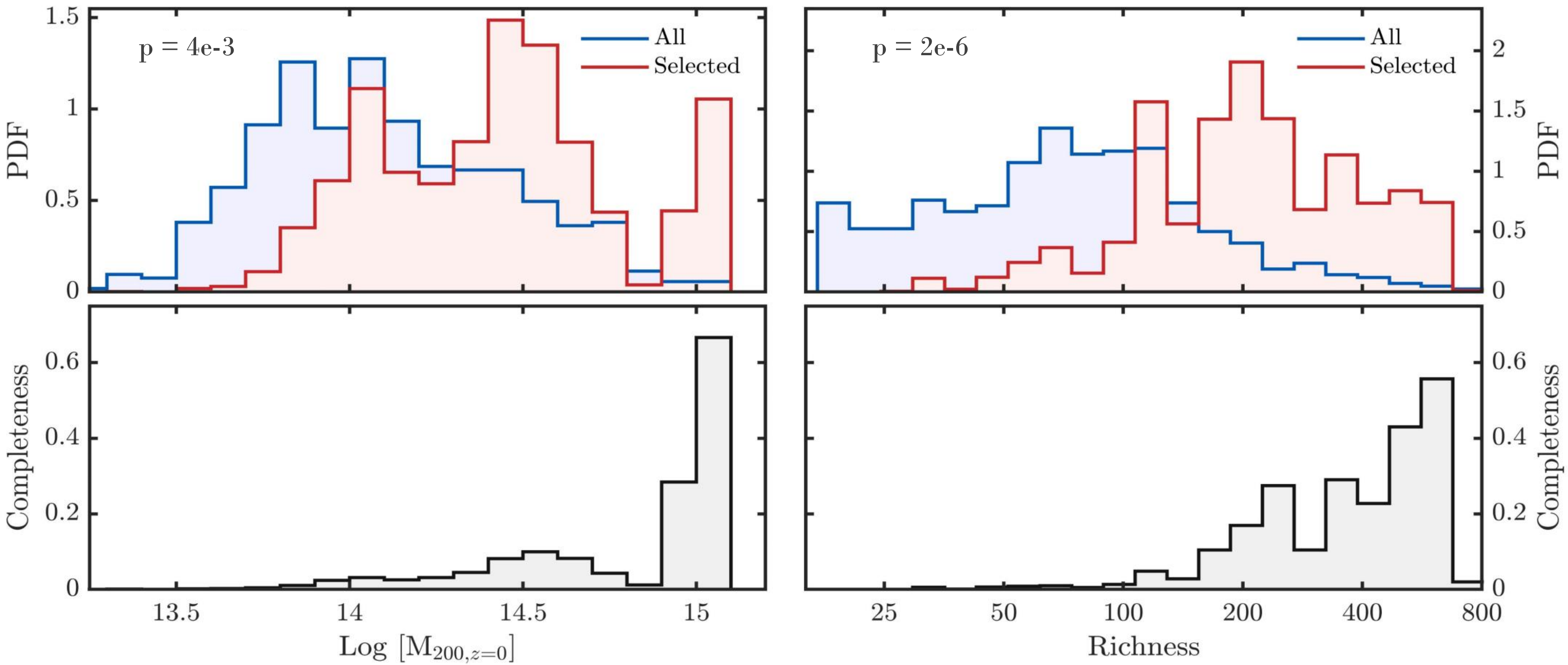


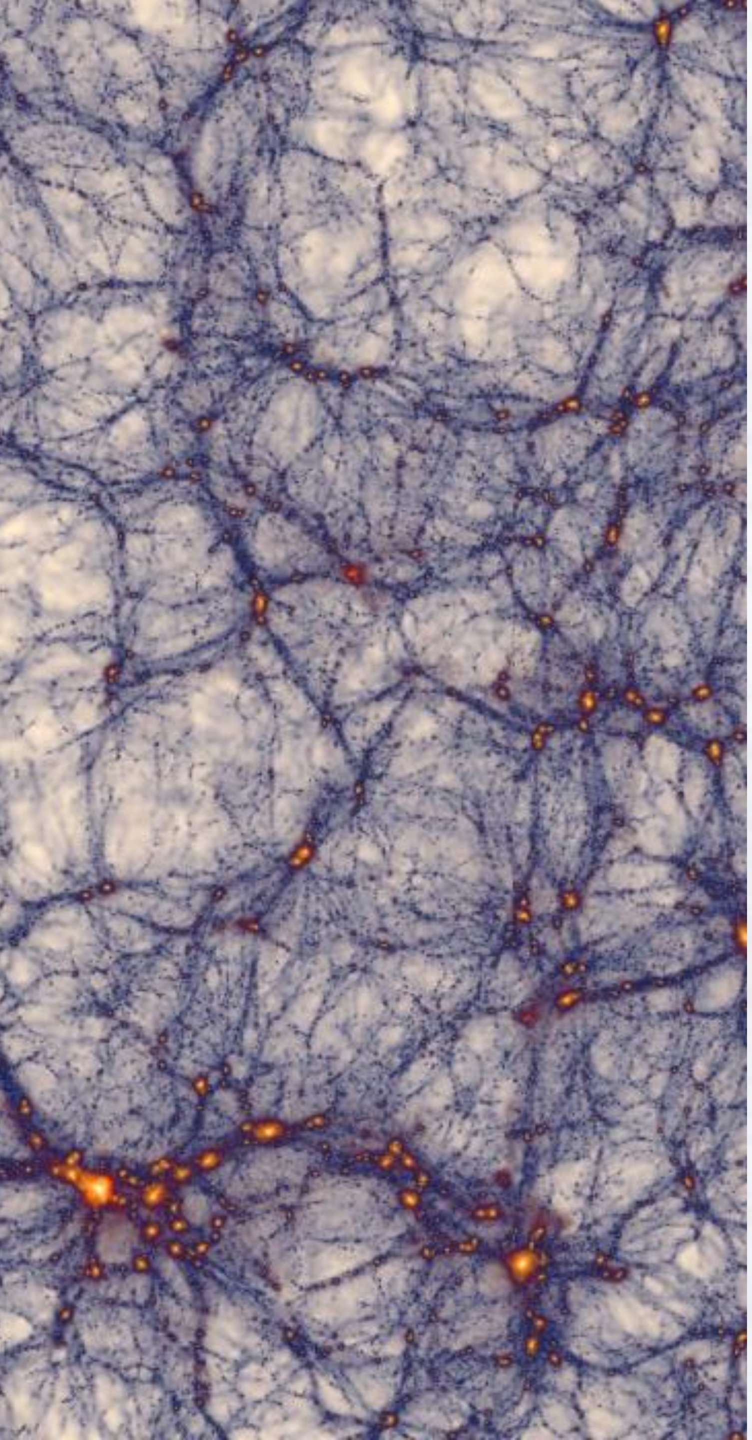
How is our protocluster sample biased?

Mass and Richness

- We tend to select the protocluster which form more massive halos by z=0
- Reaching a completeness of 67% for halos > 10^{15} solar masses

- We also select the richest protoclusters
- Reaching a completeness of 40% for protoclusters with more than 500 members





Conclusions

- Using a lightcone we have shown how to optimise the Spitzer/IRAC method to improve purity
- We have a sample of 189 candidate protoclusters
  - We expect 70% to be genuine
  - This is backed up by a 4σ X-ray signal and 50 photo-z estimates
- We understand the biases of our sample
  - Biased to richest, most massive, largest, most centrally concentrated protoclusters in the field
- Ready to use when LSST starts taking data