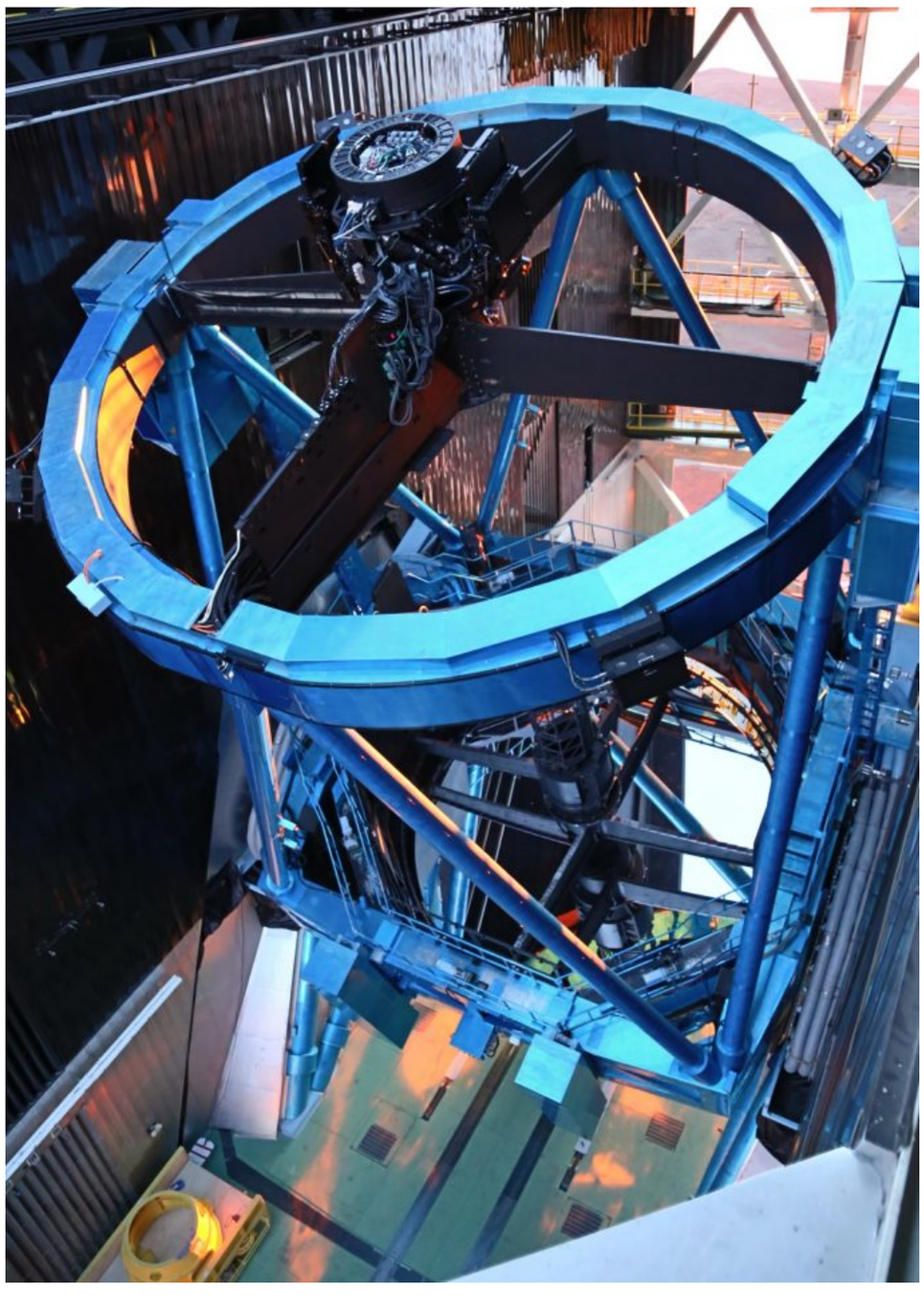
FAPESP-JSPS workshop Feb. 20th, 2019

Systematic Study of Protoclusters based on Wide-field Imaging



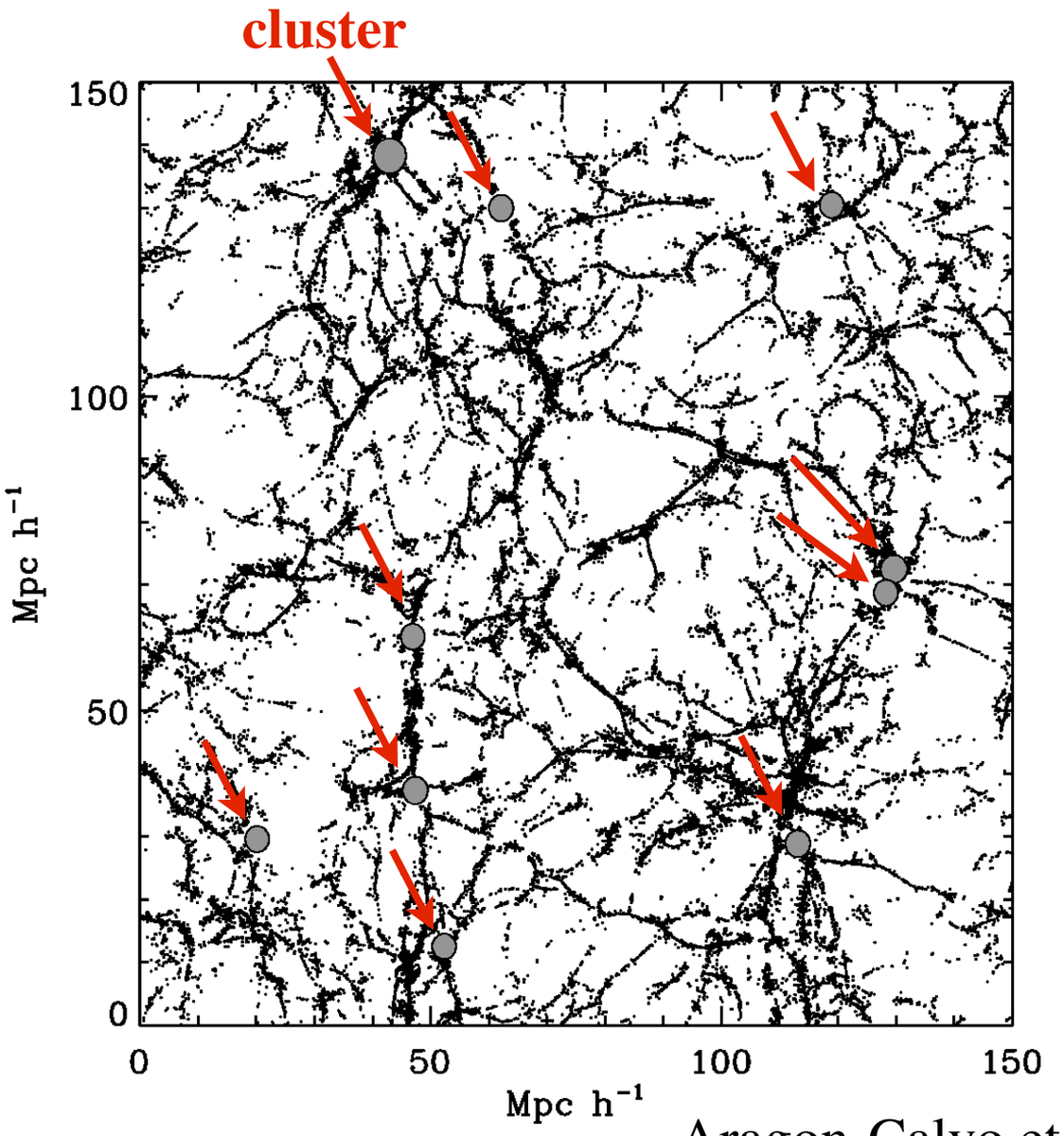
Toshikawa, et al. (2018, PASJ, 70, S12)
Uchiyama, et al. (2018, PASJ, 70, S31)

Jun Toshikawa (ICRR, Univ. of Tokyo)
Hisakazu Uchiyama, Nobunari Kashikawa,
Masami Ouchi, Roderik Overzier, et al.

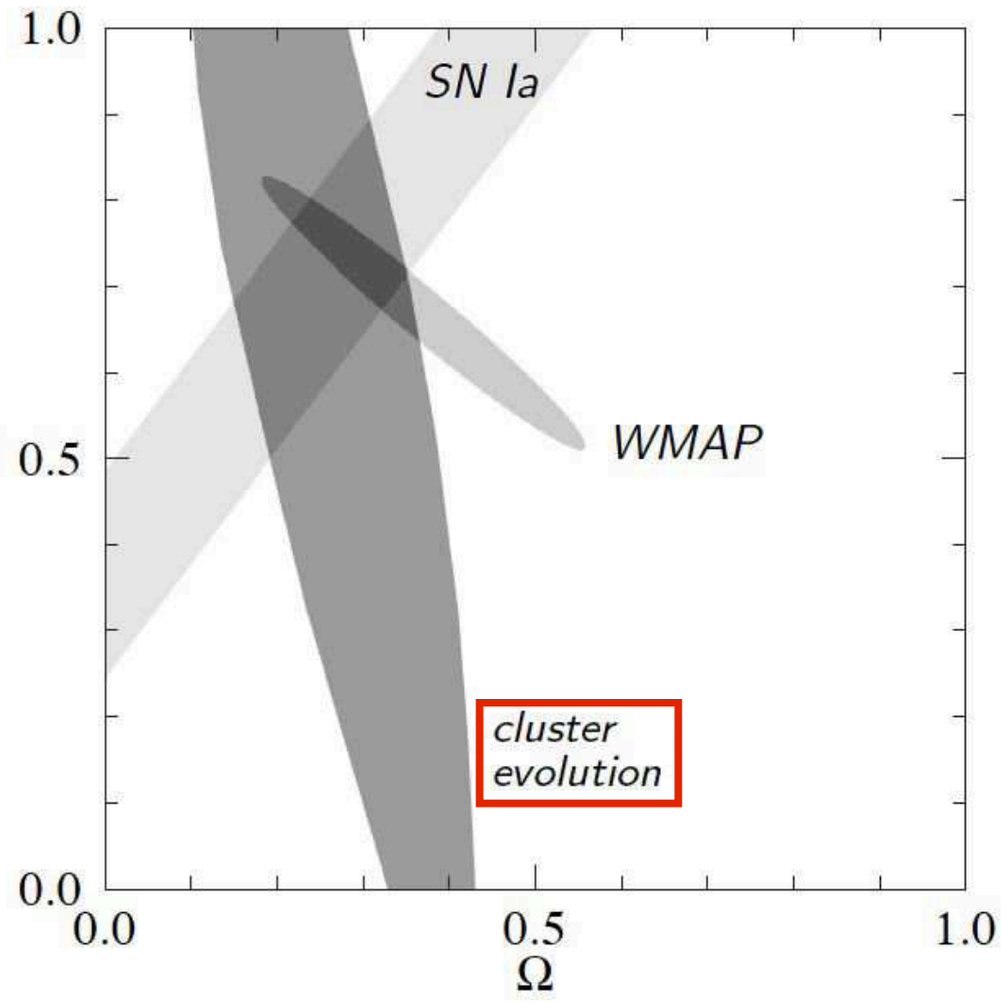
Importance of galaxy clusters

1. The relation of structure formation of the universe

Galaxy clusters form in the densest peaks of dark matter.
They can be used to estimate cosmological parameters.



Aragon-Calvo et al. (2010)

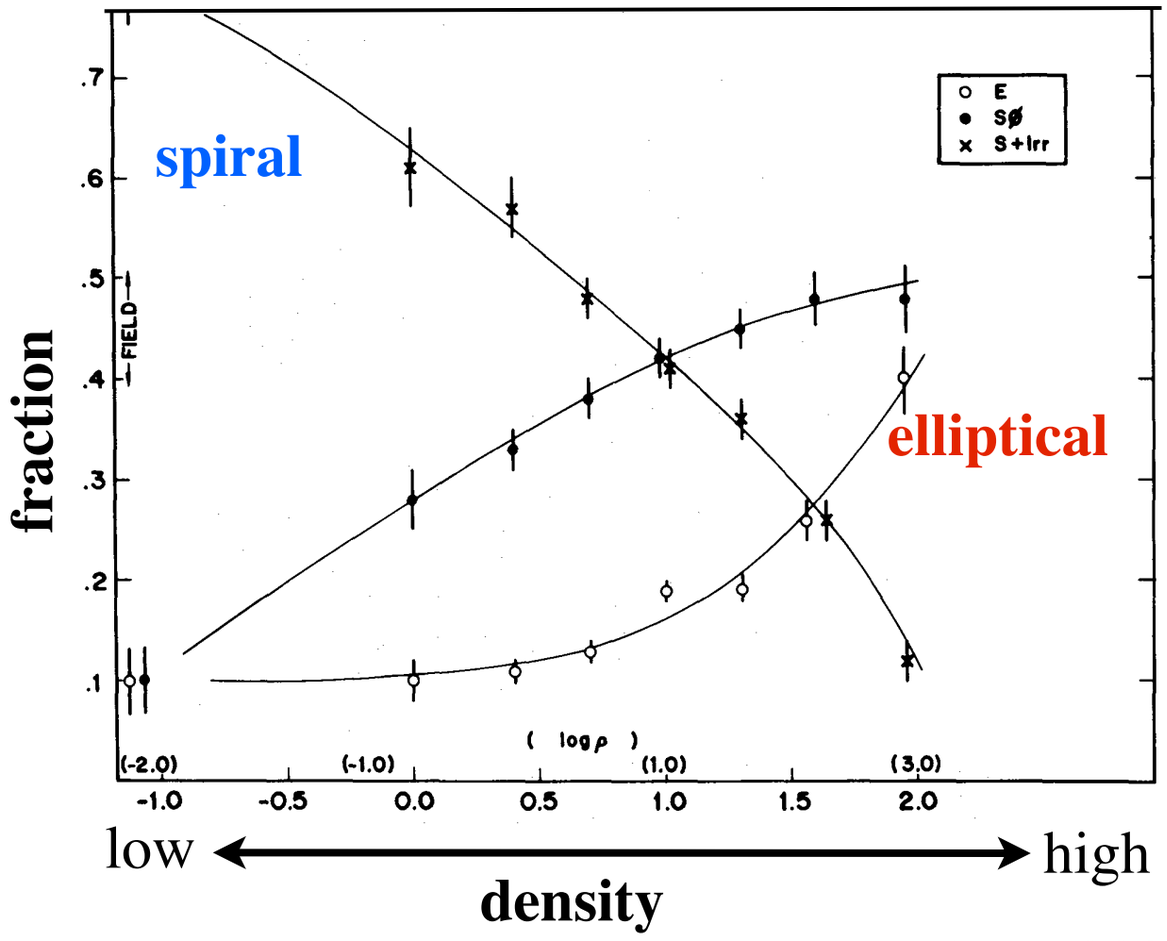


Voit, G. M. (2005)

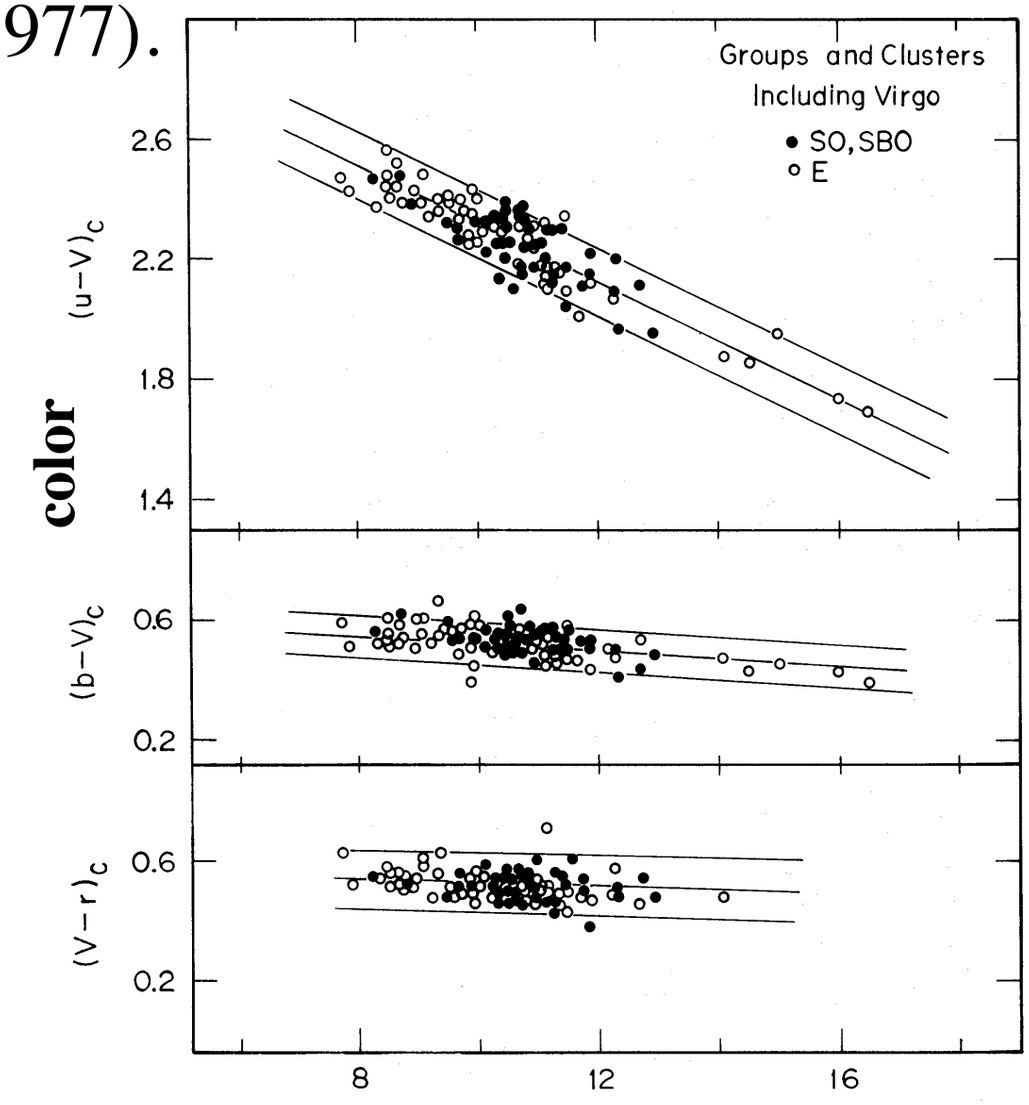
Importance of galaxy clusters

2. Environmental effects on galaxy evolution

From observations, it is proved that galaxy clusters have distinct properties:
morphology-density relation (Dressler 1980),
red sequence (Visvanathan & Sandage 1977).



Dressler (1980)

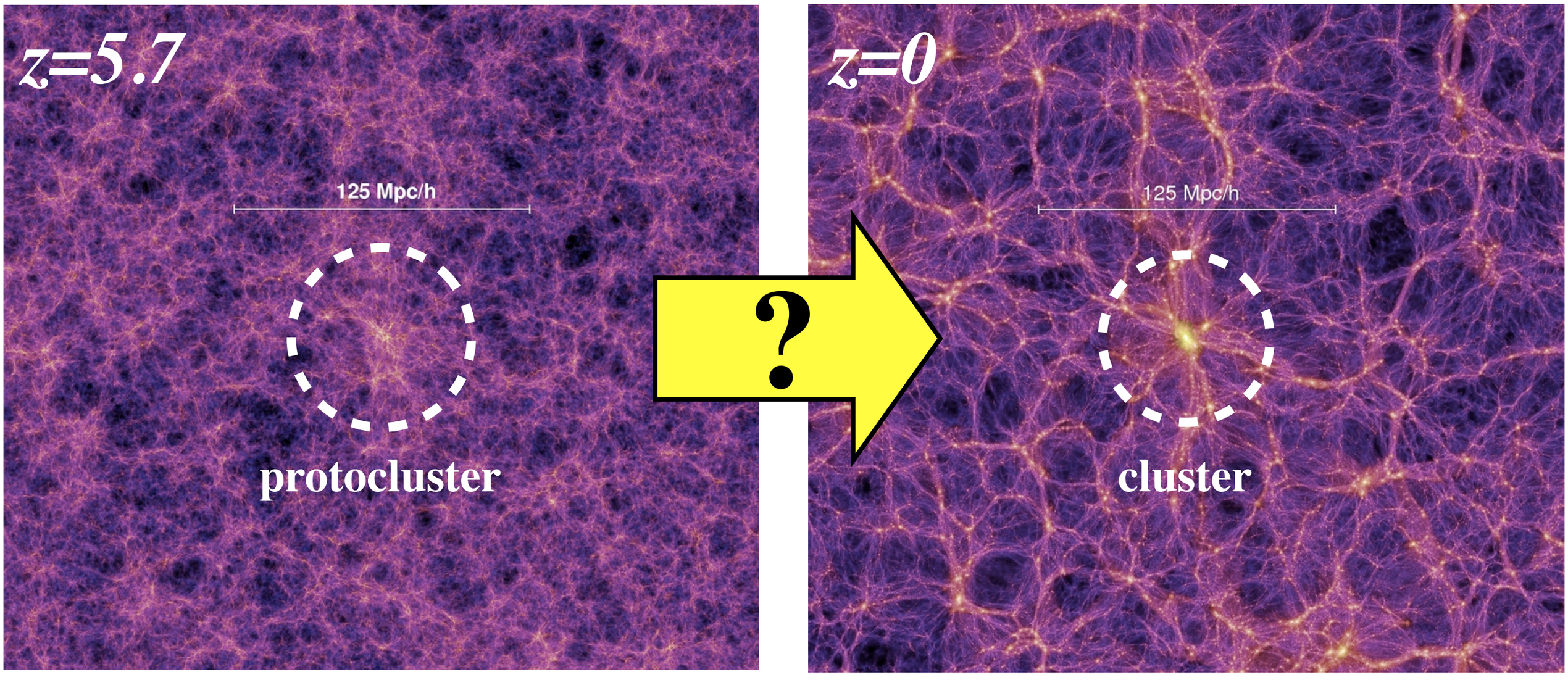


Visvanathan & Sandage (1977)

Importance of protoclusters

When and how are galaxy clusters formed?

Protoclusters in the early universe would reveal
the primordial condition of clusters at their birth.



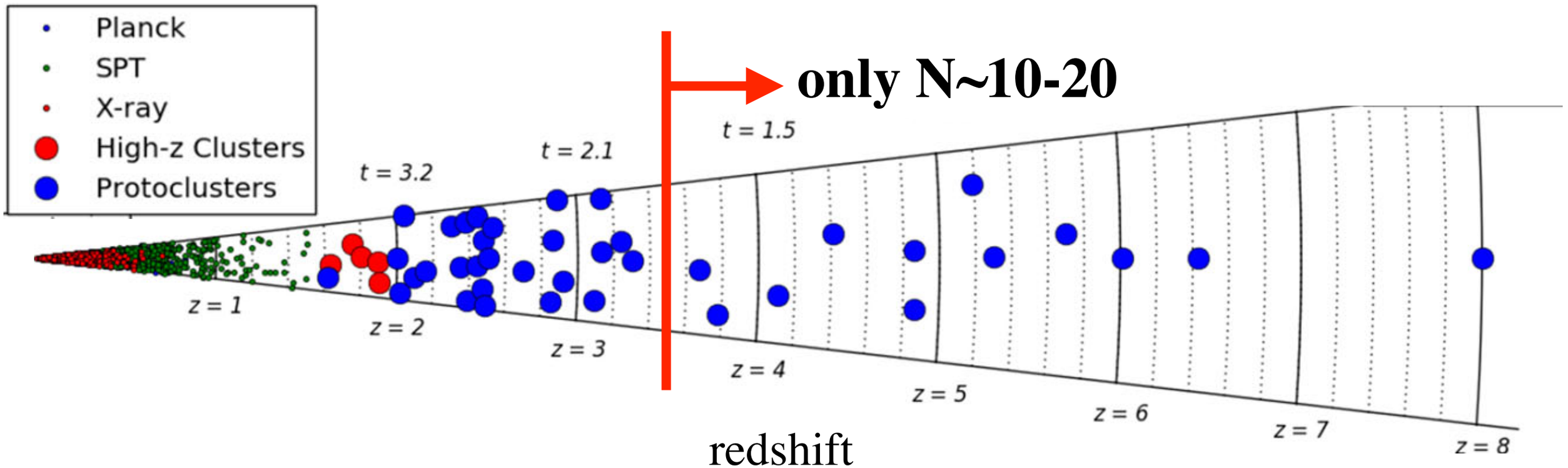
Springel et al. (2005)

Importance of protoclusters

When and how are galaxy clusters formed?

Protoclusters in the early universe would reveal
the primordial condition of clusters at their birth.

Problem: Protoclusters are very rare…



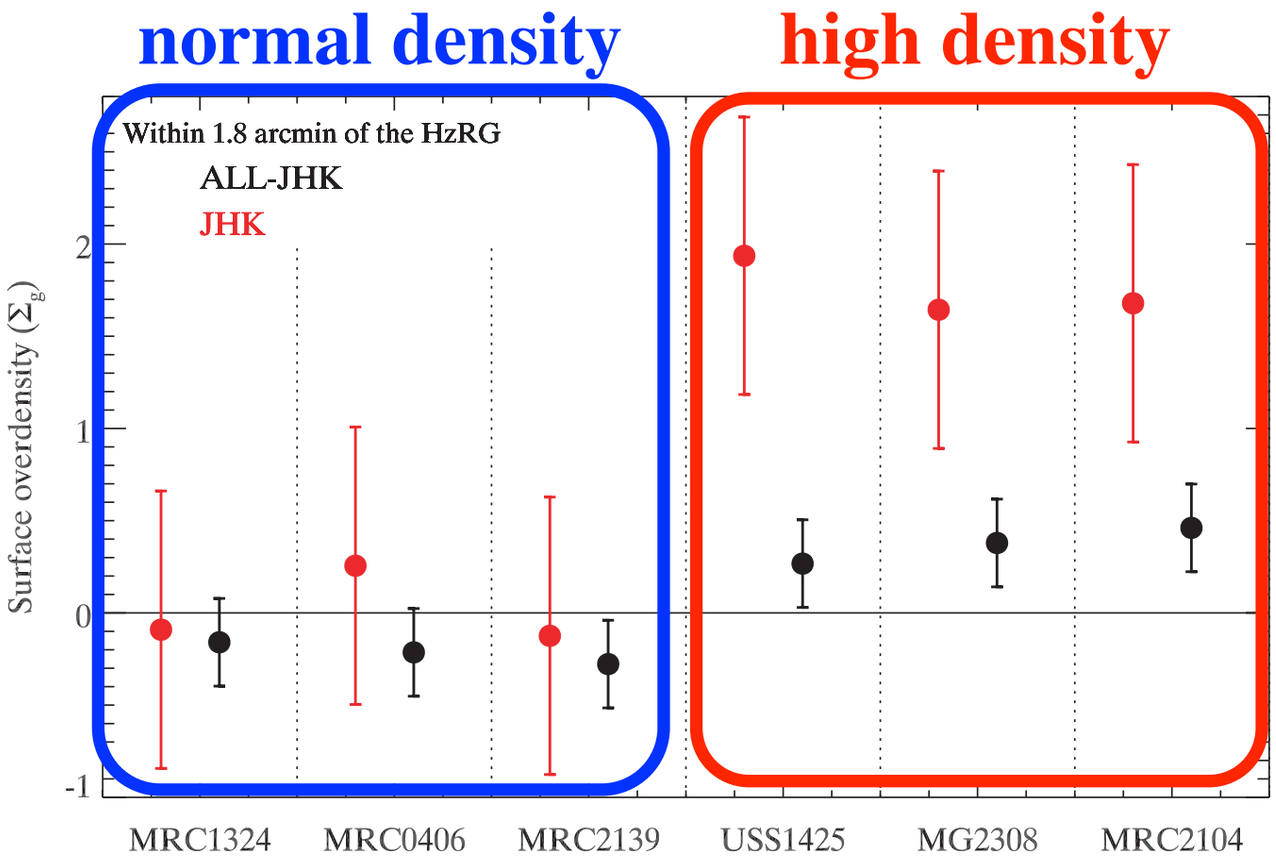
Overzier et al. (2016)

Where are protoclusters?

Most of previous works are searching for protoclusters
around QSOs and radio galaxies.

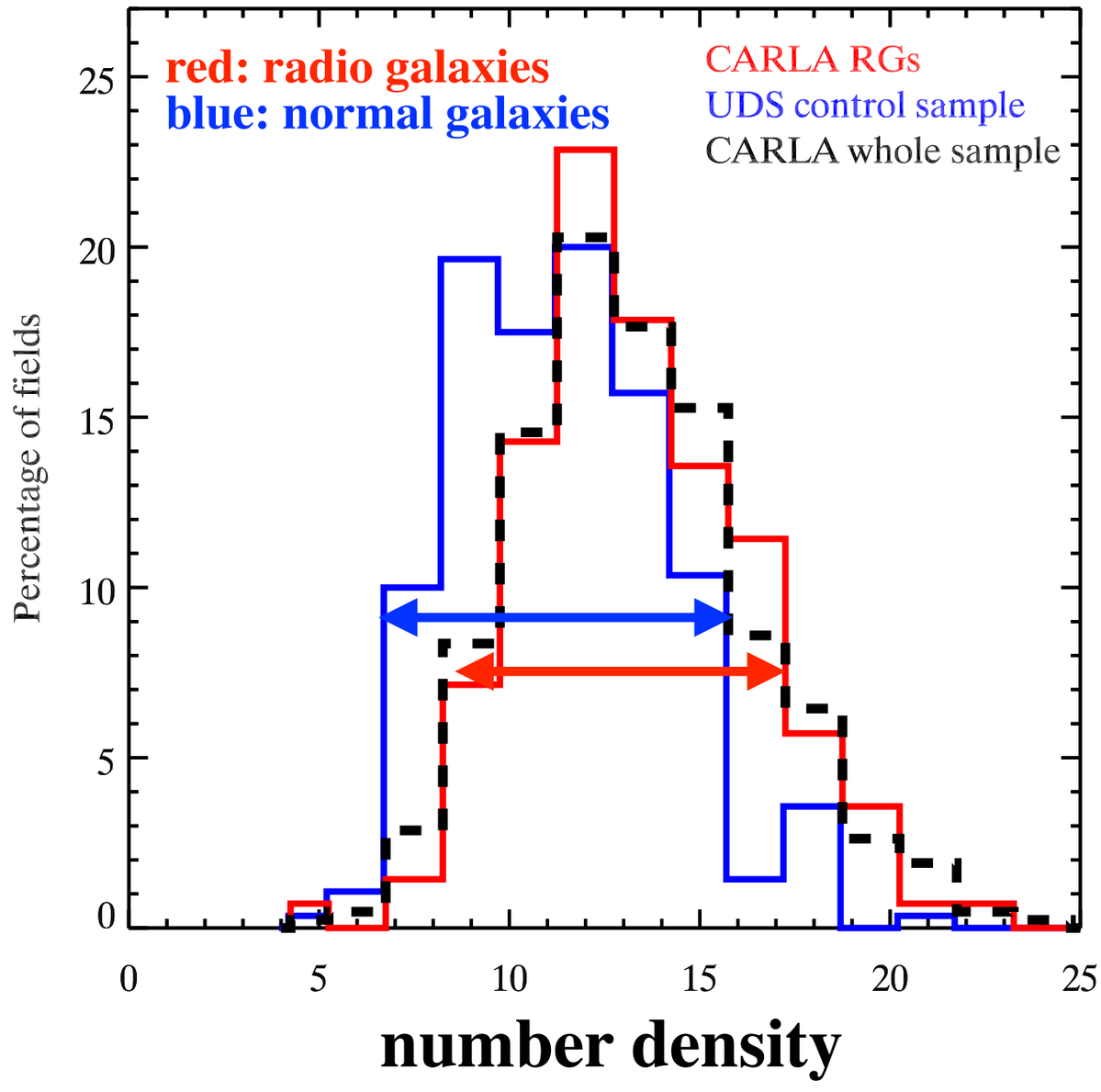
Are these galaxies really good probes of protoclusters?

around six radio galaxies at z~2.4



Hatch et al. (2011)

Hatch et al. (2014)



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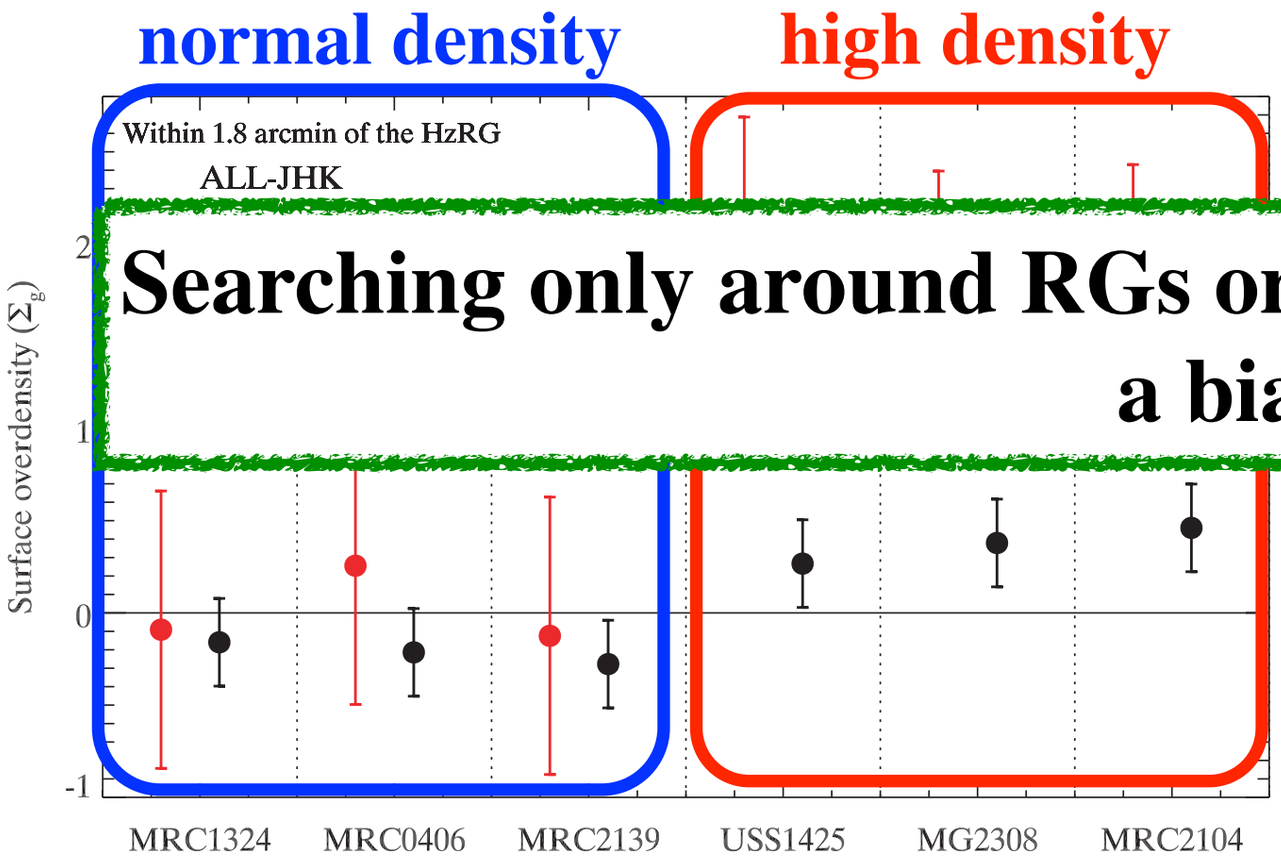

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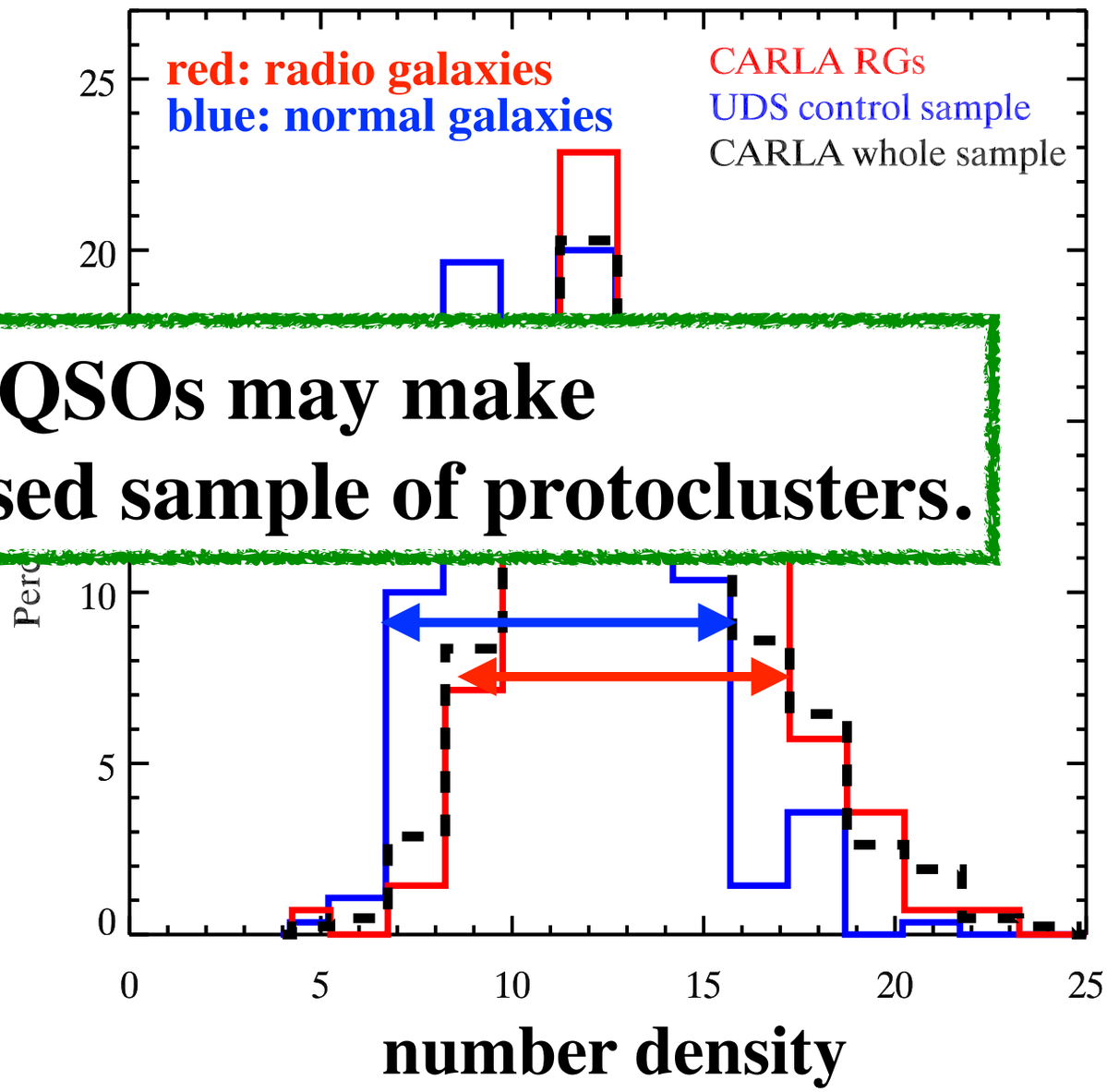


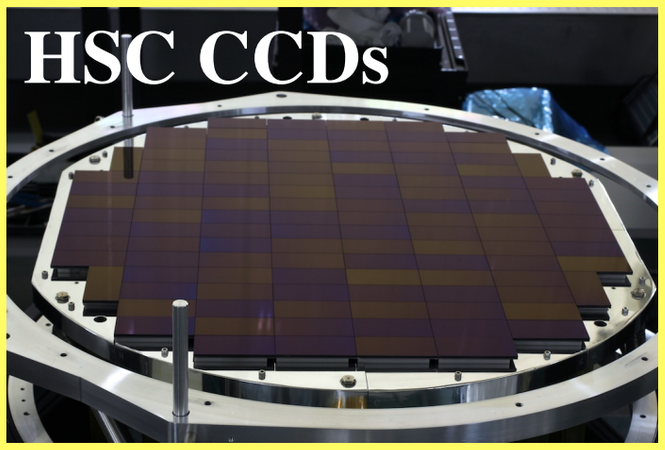
Searching only around RGs or QSOs may make a biased sample of protoclusters.

Wide-field Survey

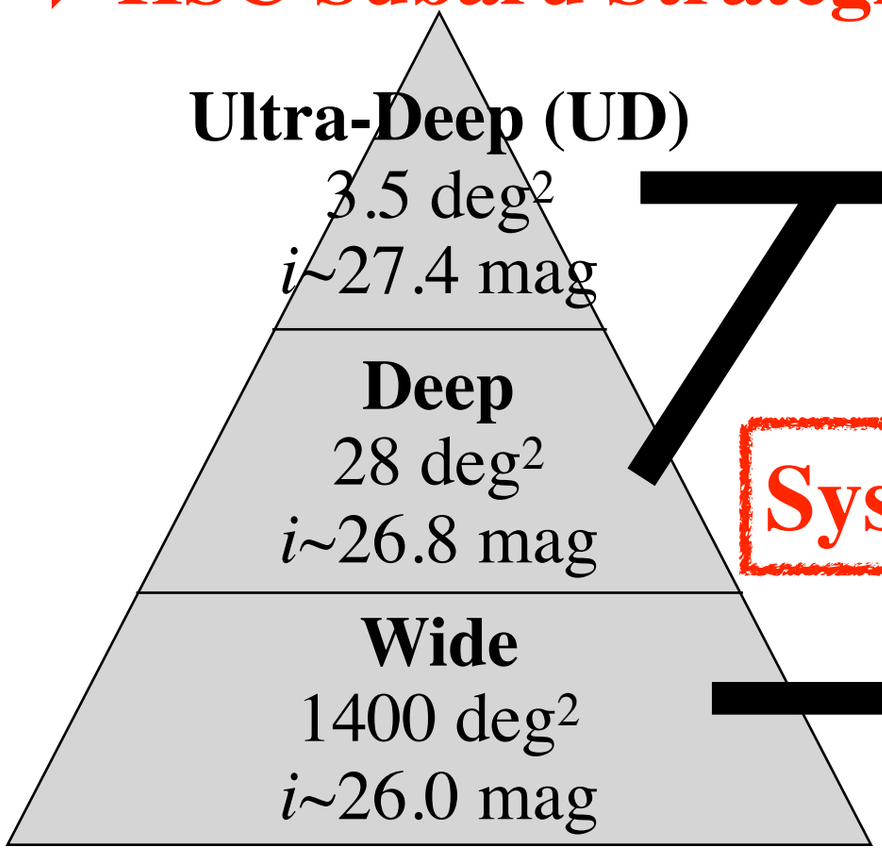
We perform an unbiased search of protoclusters
by using wide-field imaging of HSC survey.

Hyper Suprime Camera (HSC)
on Subaru telescope

- **1.7 deg² FoV (104 CCDs)**
- 5 broad-bands (*g*, *r*, *i*, *z*, *y*)
  and many narrow-bands



HSC Subaru Strategic Program (HSC SSP) (**300 nights** in 2014-2019)

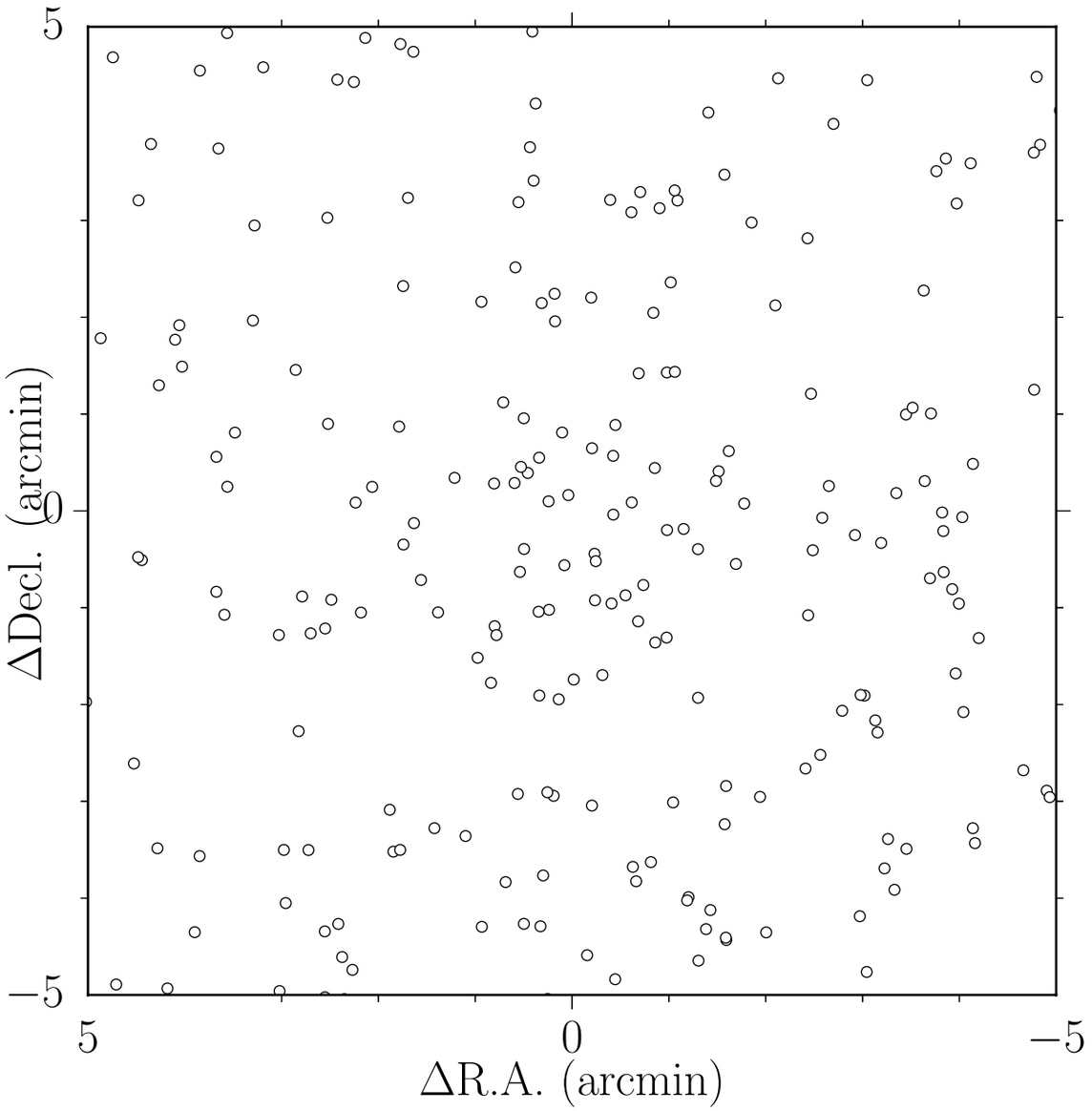


~10-20 protoclusters will be found
at each redshift from *z*~2 to *z*~6
redshift evolution of protoclusters

Systematic Study of Protoclusters at *z*~2-6

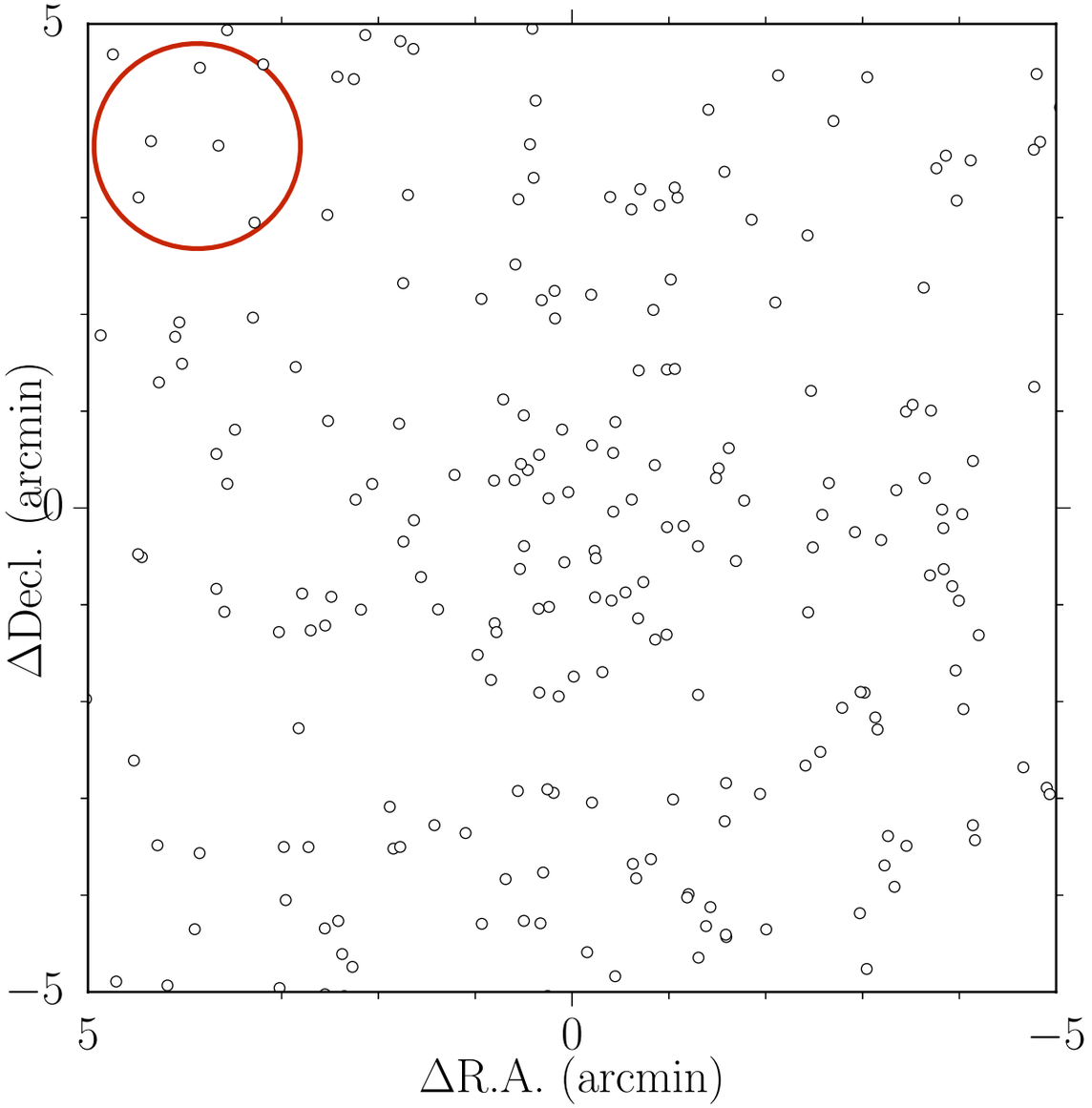
~1000 protoclusters will be found at z~4
statistics of protoclusters

Search for Protoclusters



1. select high-redshift galaxies
by Lyman break technique

Search for Protoclusters



1. select high-redshift galaxies
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2. count galaxies within an aperture
   aperture size corresponds to
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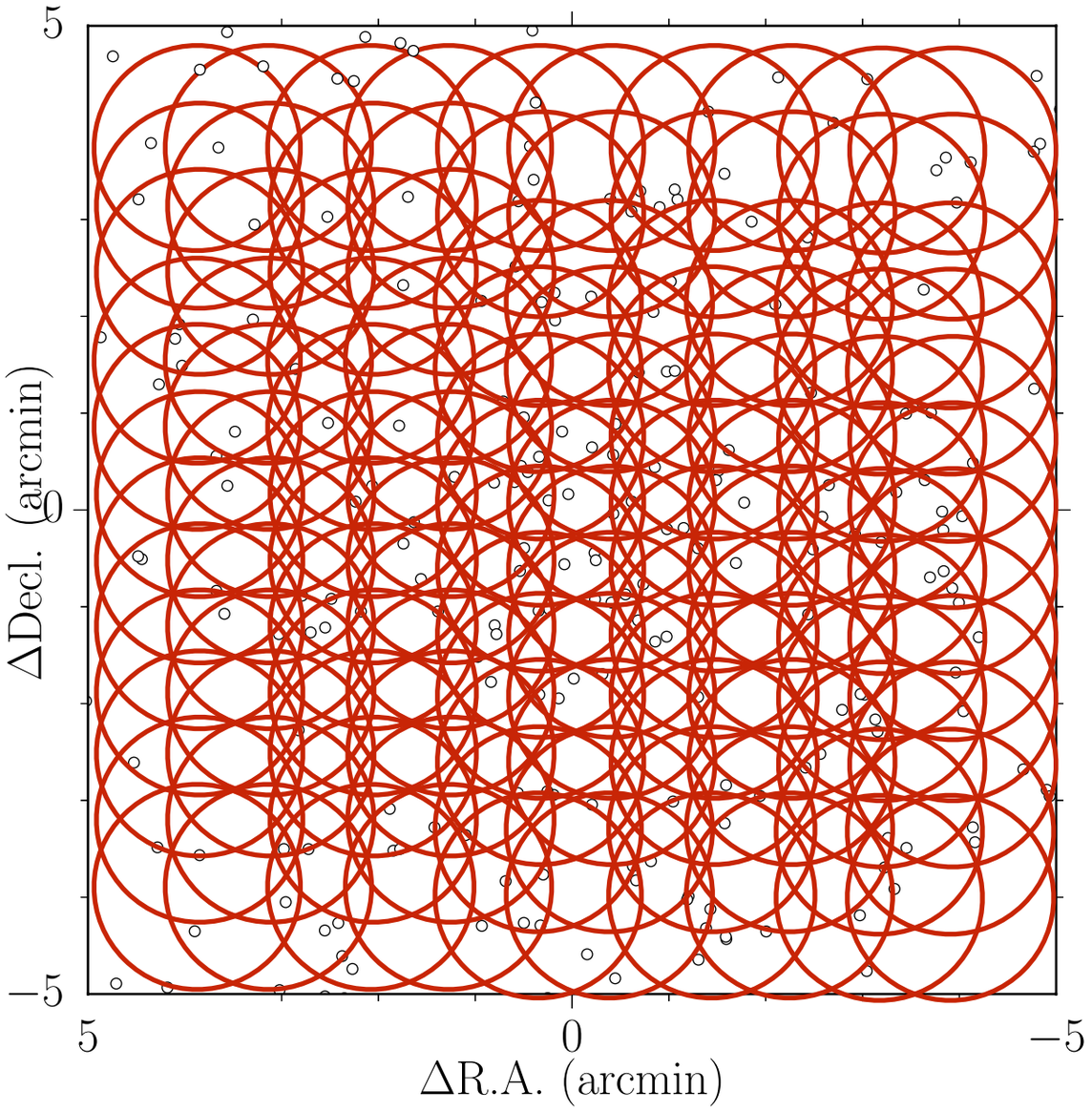
Search for Protoclusters



1. select high-redshift galaxies
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2. count galaxies within an aperture
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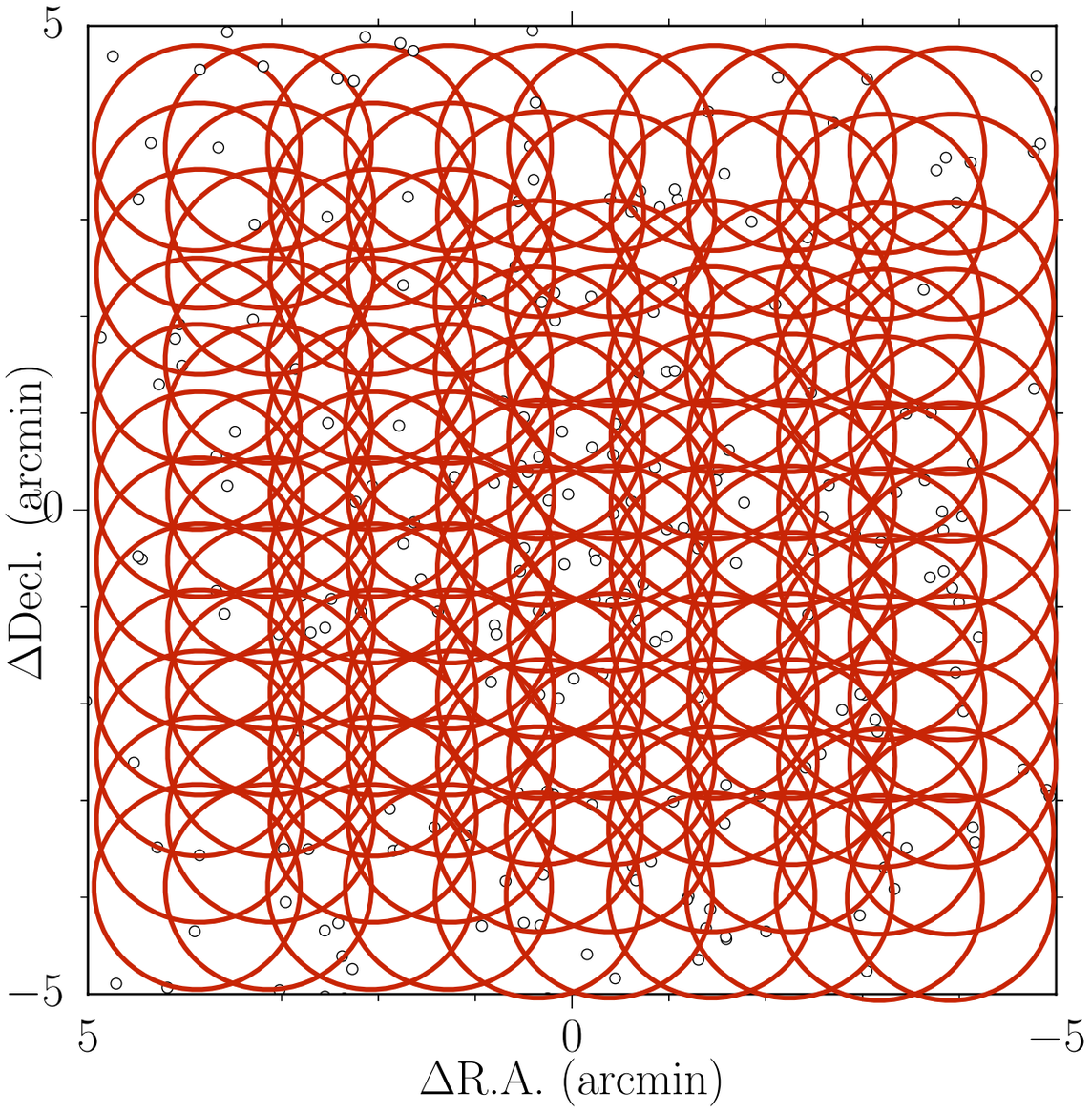
3. distribute apertures over whole area

Search for Protoclusters



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4. calculate the average and dispersion
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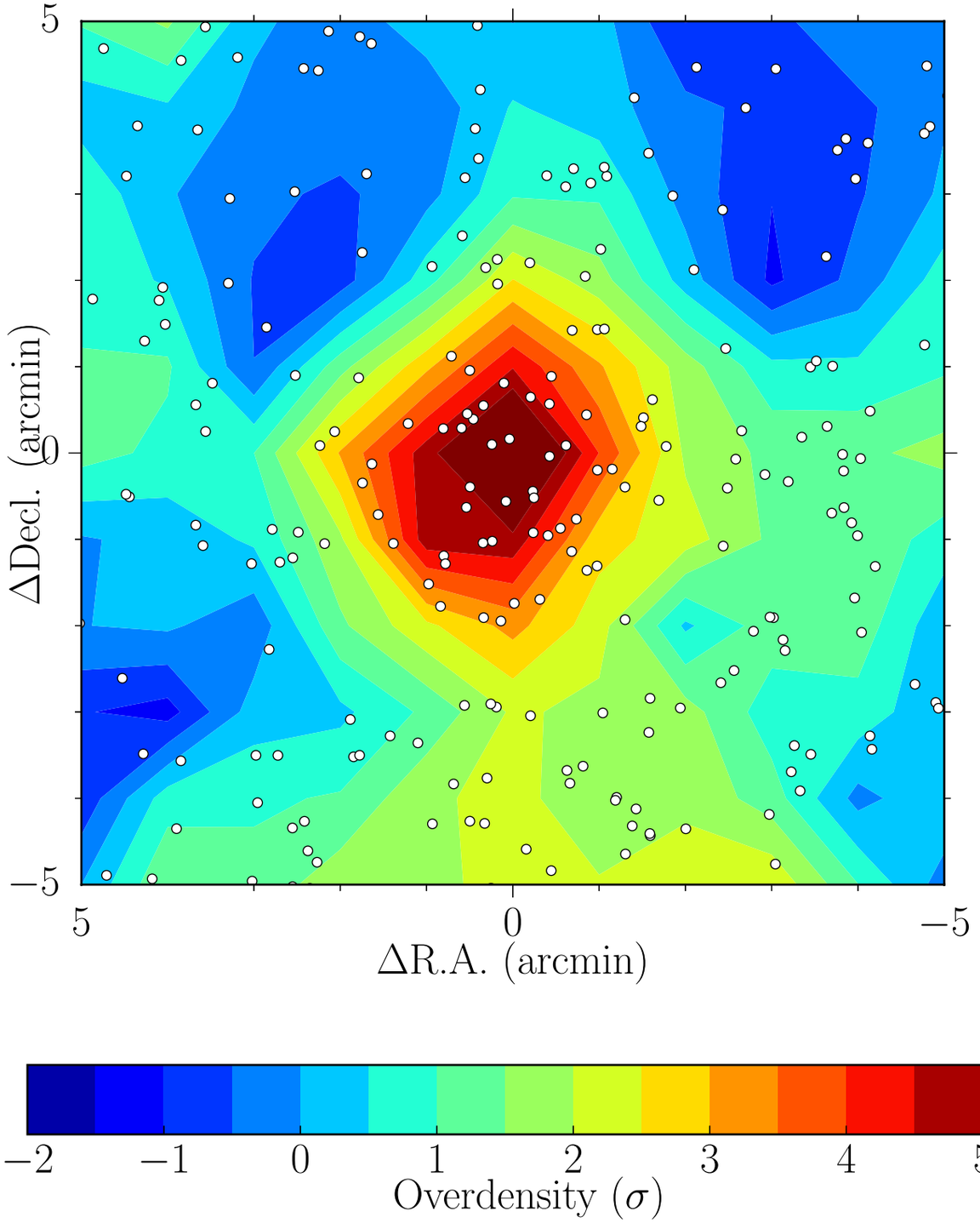
Search for Protoclusters



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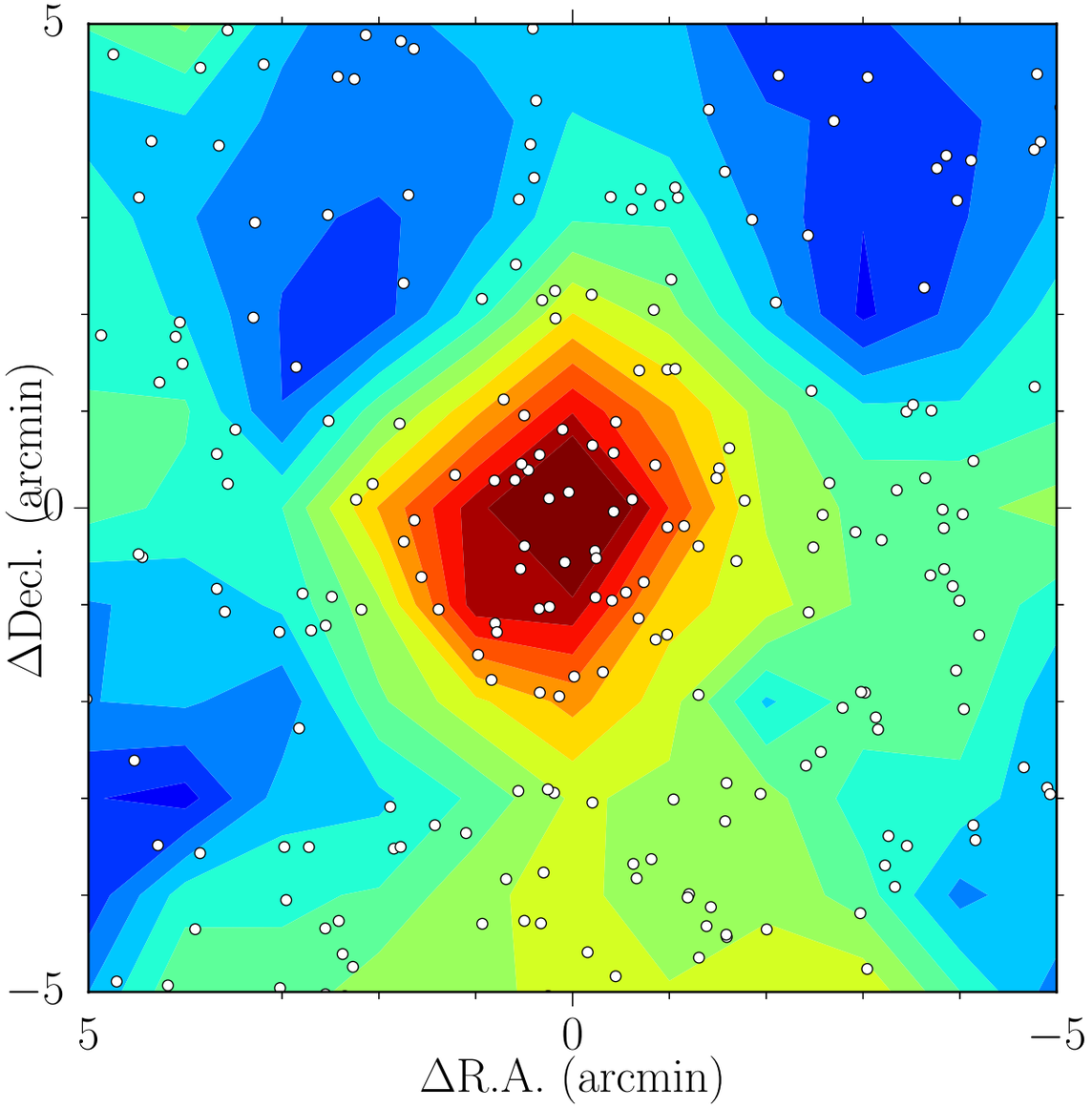
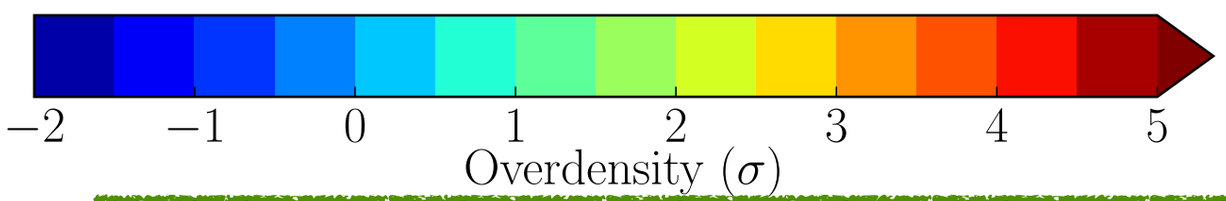
Search for Protoclusters





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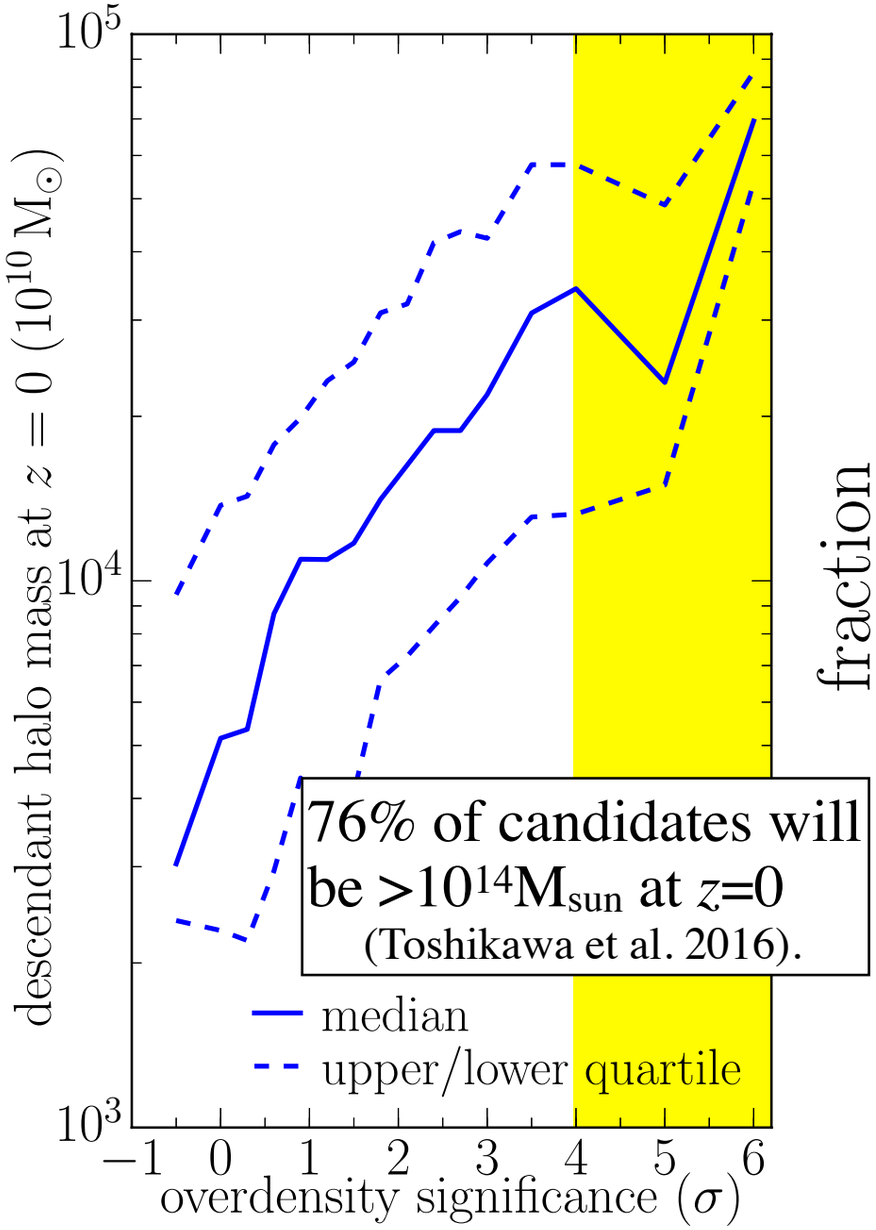
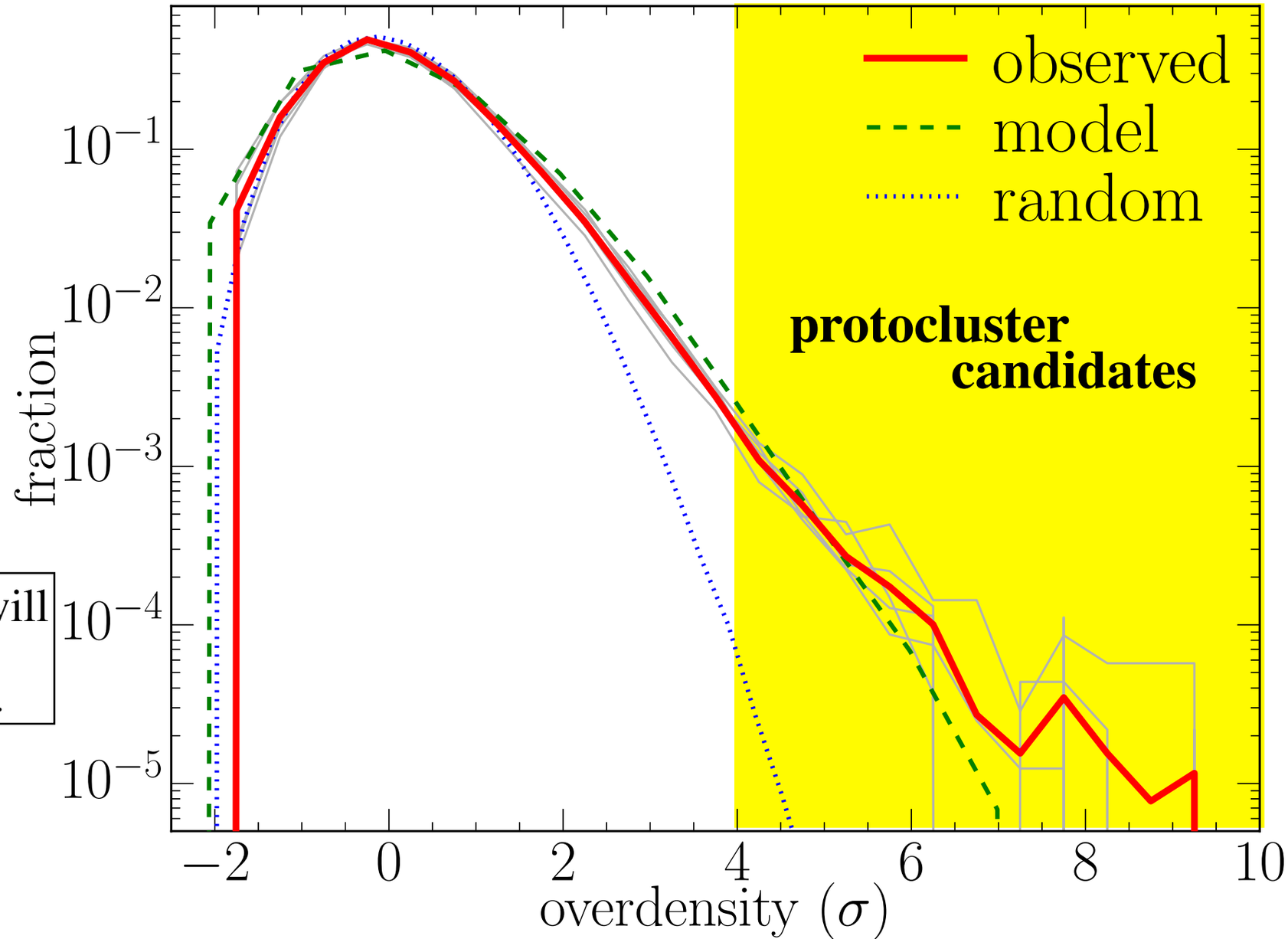
Based on the initial data of the HSC survey,
we have searched protoclusters at z~4 **in 121deg² area**.

Search for Protoclusters at z~4 in Wide layer

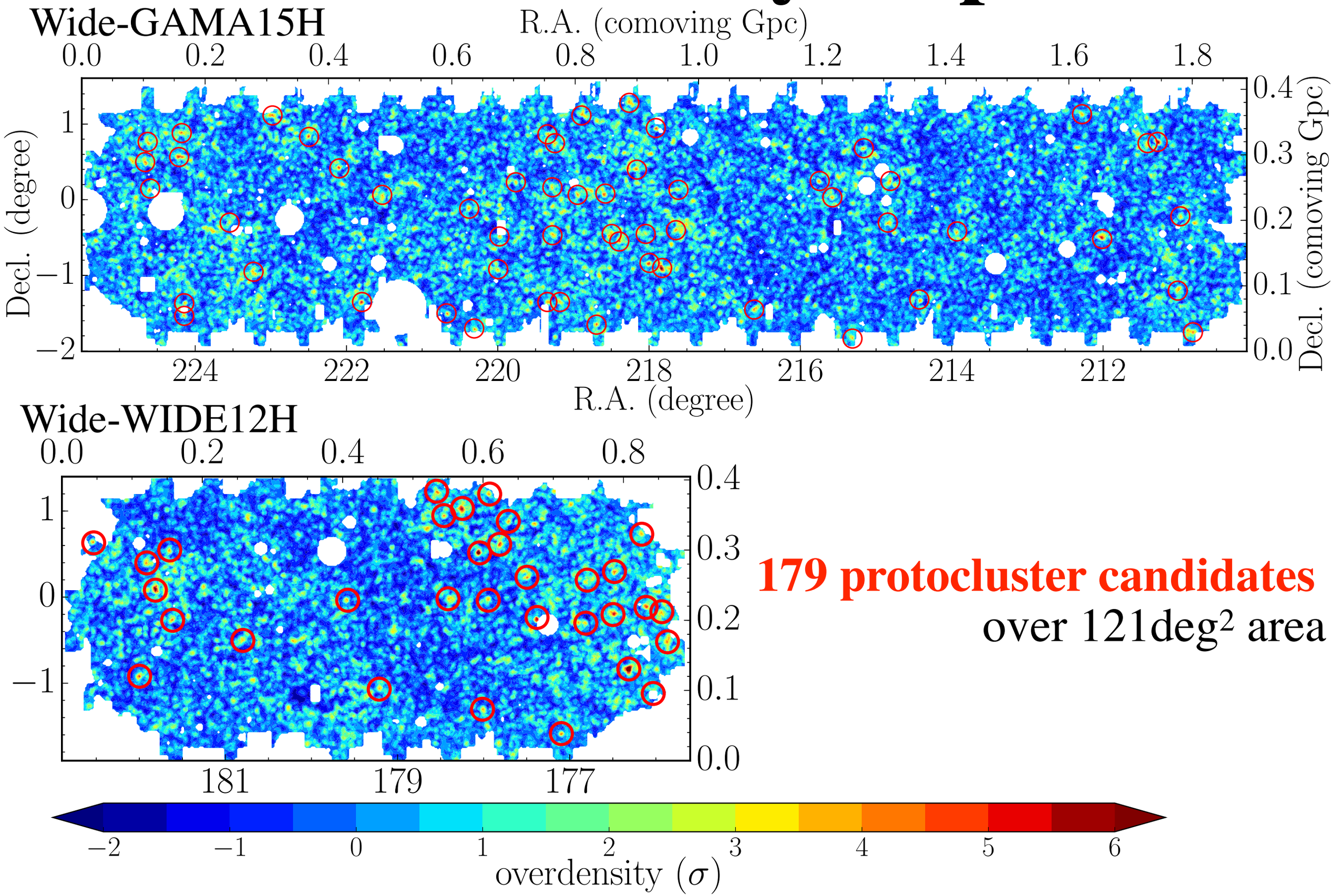
The same analysis applies to a theoretical model
→ the relation between overdensity and descendant halo mass at z=0.

Protocluster candidates are defined as regions with **>4σ at the peak**.





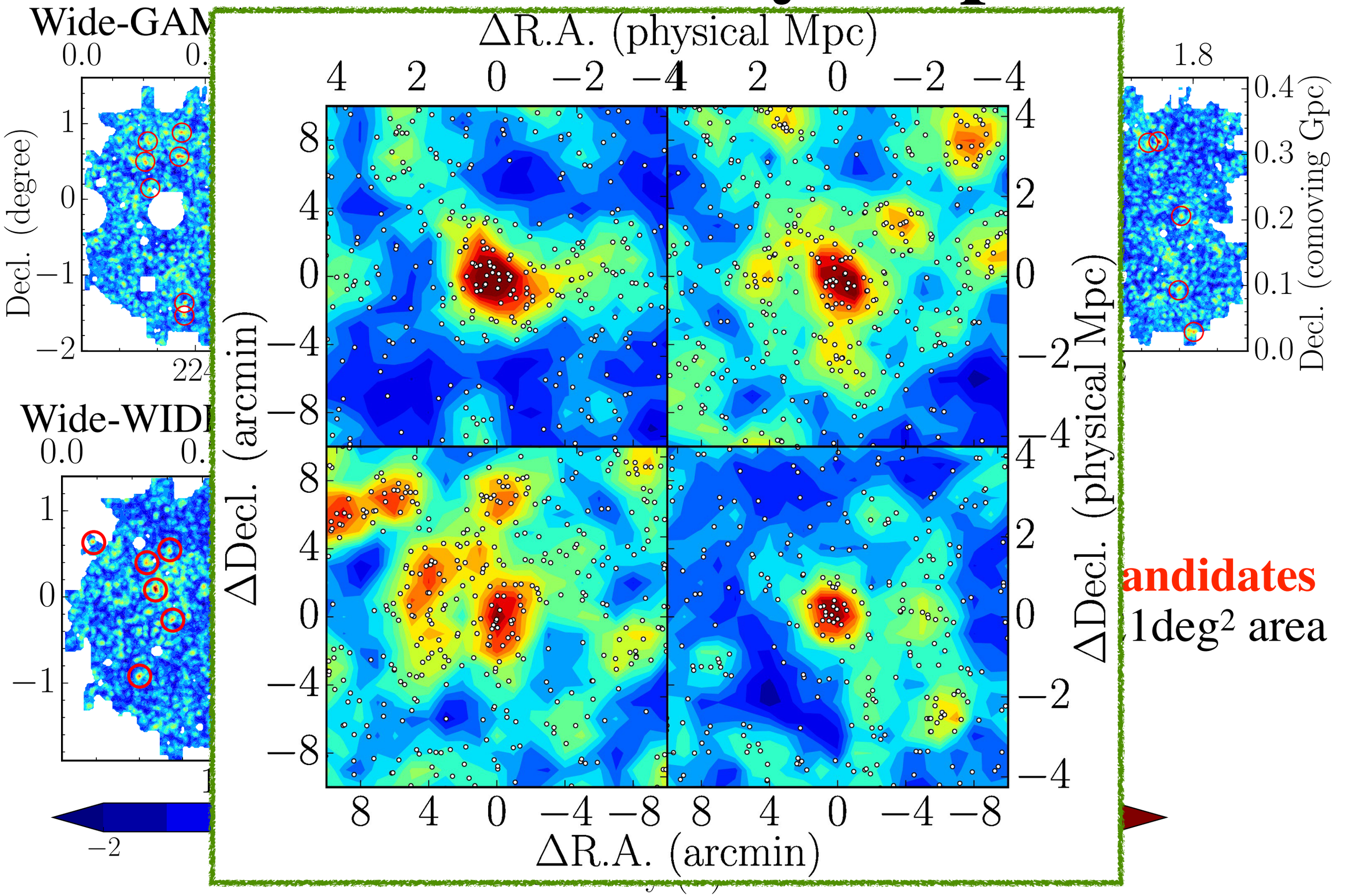
Overdensity map



179 protocluster candidates

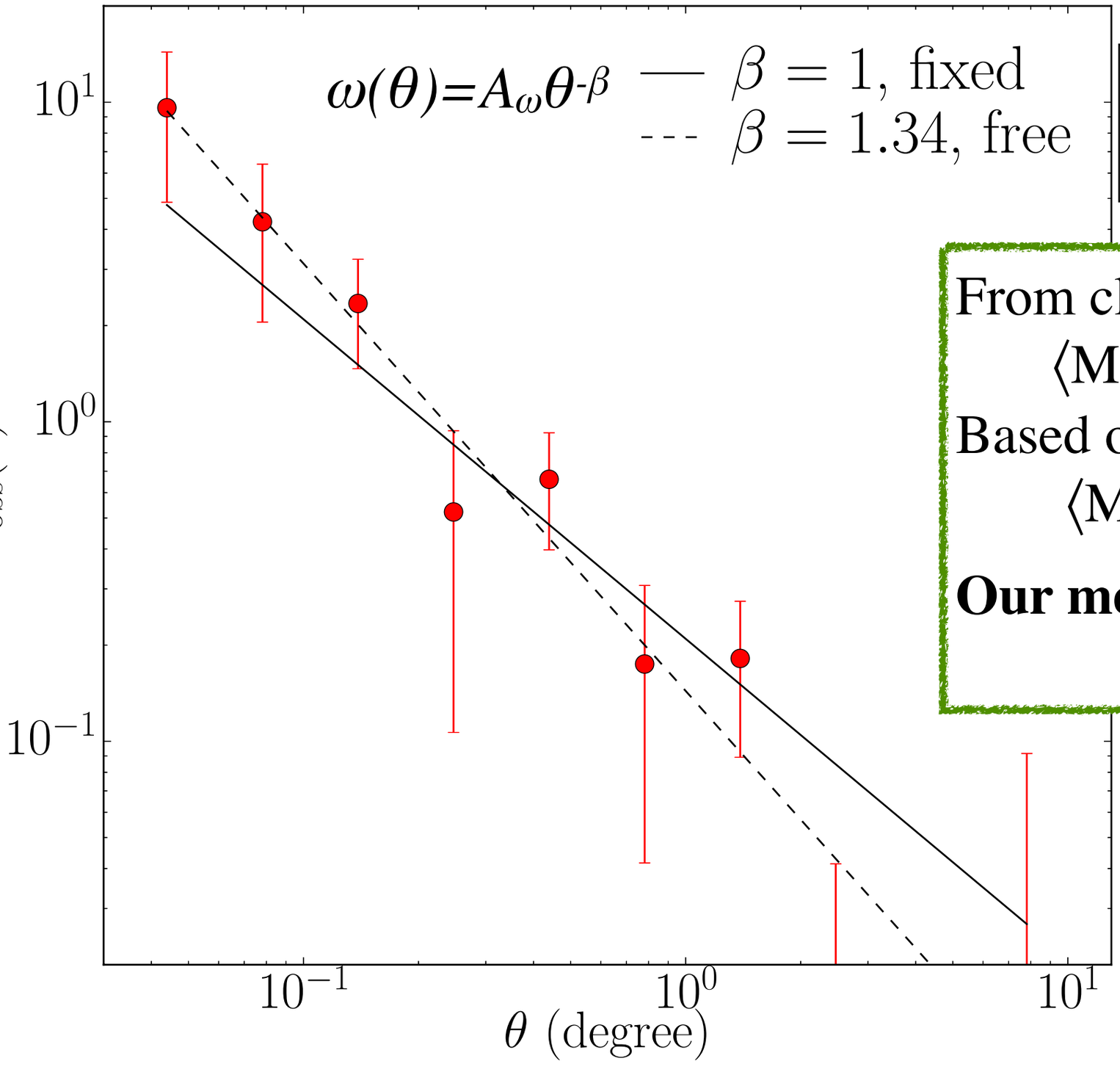
over 121deg² area

Overdensity map



Clustering of protoclusters

We have estimated angular correlation function at z~4 for the first time.



$r_0 = 35.7\ (+4.6/-5.5)\ h^{-1}$ Mpc
$n = 4.6 \times 10^{-7}\ h^3\ \mathrm{Mpc}^{-3}$

From clustering analysis,

$\langle M_h \rangle = 2.3\times10^{13}\ h^{-1}M_{sun}$ at z~4

Based on EPS model,

$\langle M_h \rangle \sim 4\times10^{14}\ h^{-1}M_{sun}$ at z=0

Our method can certainly identify progenitors of local clusters.

Clustering of protoclusters

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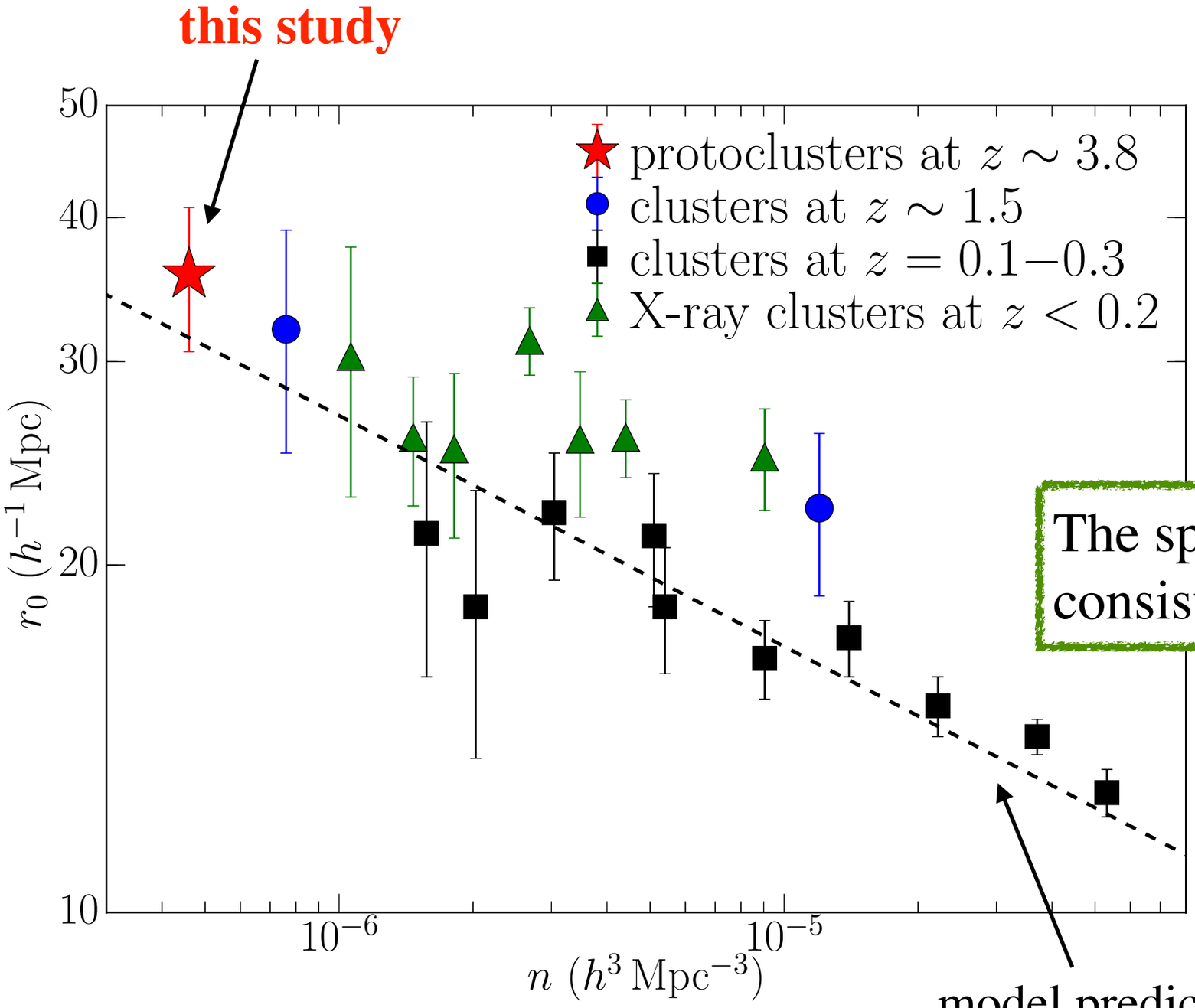


$r_0 = 35.7\ (+4.6/-5.5)\ h^{-1}$ Mpc

$n = 4.6 \times 10^{-7}\ h^3$ Mpc^{-3}

The spatial distribution (r_0 - n) is consistent with the ΛCDM prediction.

Relation between protoclusters and QSOs

Protocluster

HSC-SSP Wide S16A DR

~121 deg^2

>4σ g-dropout overdense reg.

179 protocluster z=3.3-4.2

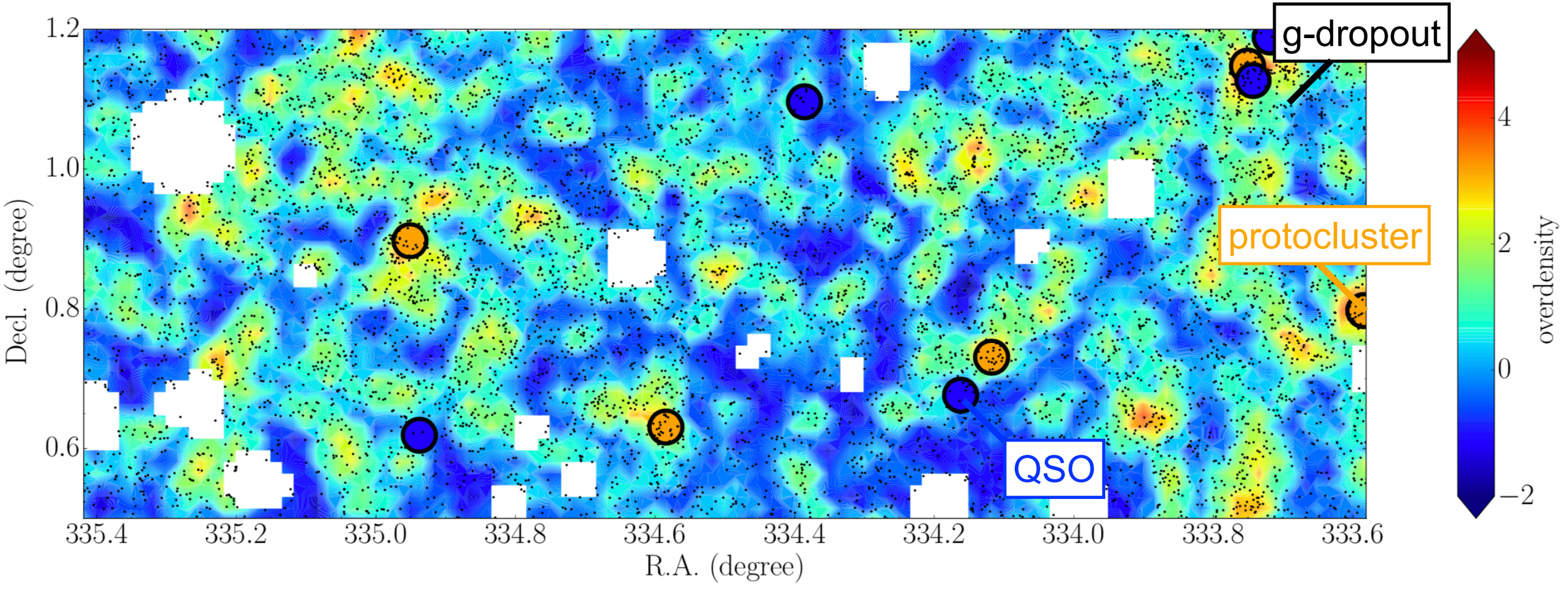
?

QSO

SDSS DR12 QSO (DR12Q)

~121 deg^2

151 QSOs at z=3.3-4.2



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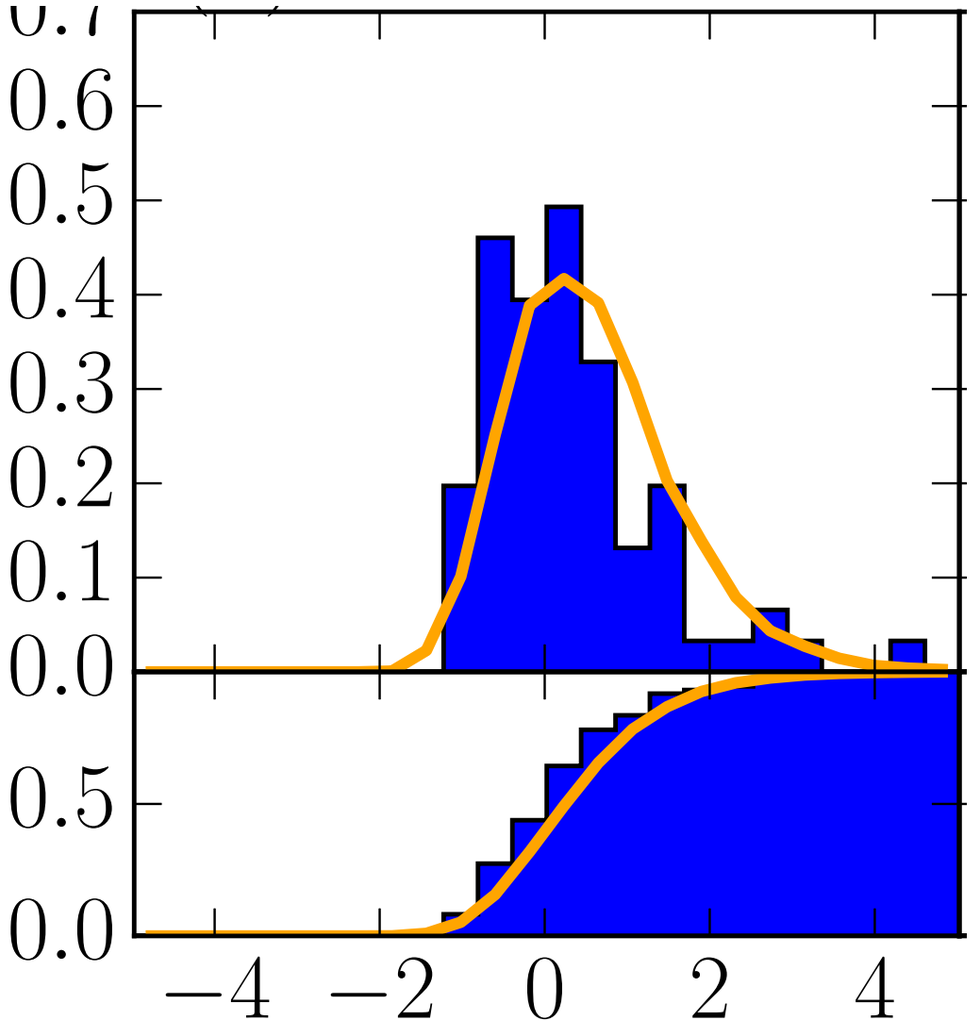

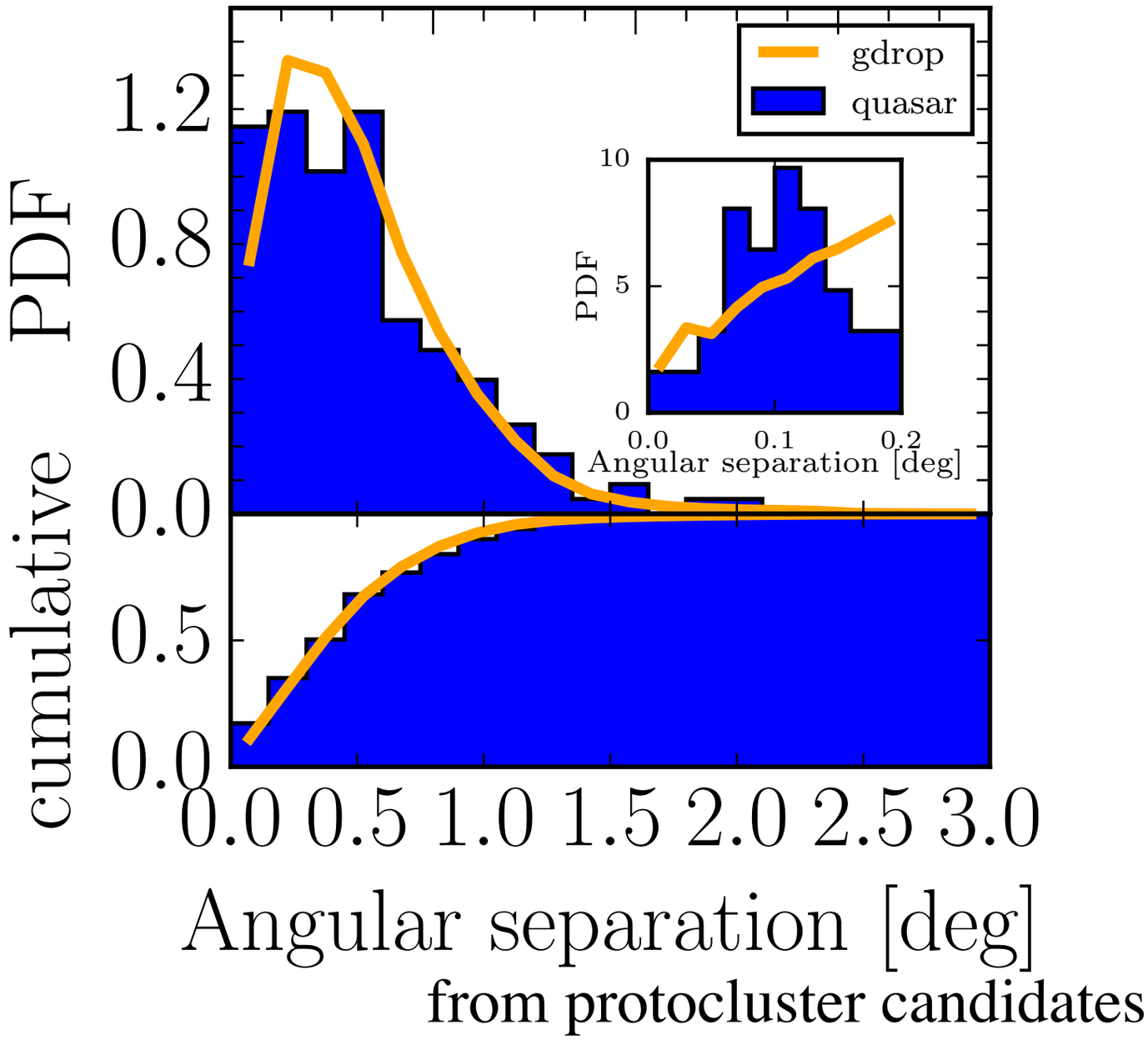

from protocluster candidates

There is no significant difference between QSOs and g-dropout galaxies.

→ **QSOs do not tend to reside in high dense environments.**

Summary

- We have searched protoclusters in the 121deg^2 area of the HSC-WIDE.
- 179 protocluster candidates at z~4 are identified.
- Clustering analysis was applied for the first time.
- The spatial distribution (r_0-n) is consistent with the prediction of ΛCDM.
- The dark matter halo mass is found to be $2\times10^{13}M_{sun}$.
- QSOs do not tend to be located in high dense environments.

This study will expand into
wide redshift range to trace redshift evolution.