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A Systematic Search of Protoclusters at z~4 Based on the >100deg² Area

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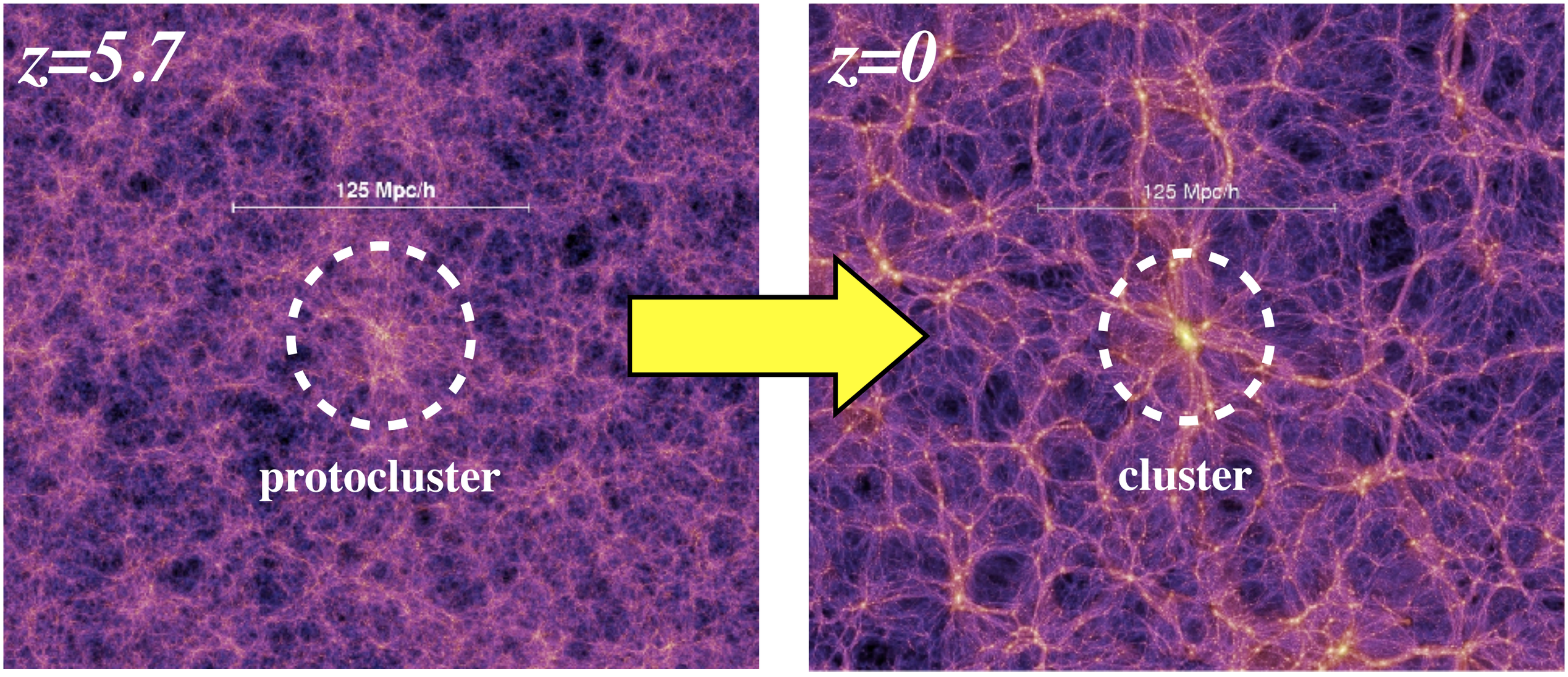
Hisakazu Uchiyama, Nobunari Kashikawa, Masami Ouchi,
Yoshiaki Ono, Yuichi Harikane, and the HSC project 96

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.



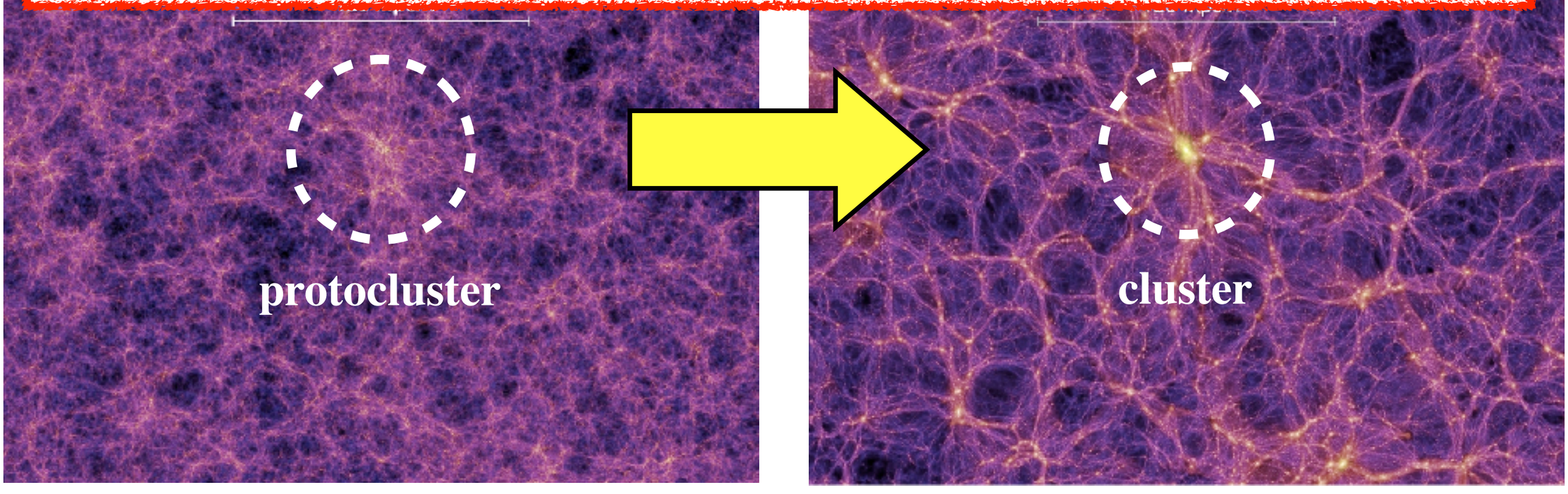
Springel et al. (2005)

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.

The number of known protoclusters is still small, especially at high redshift (N~10-20 at z>3)**.**



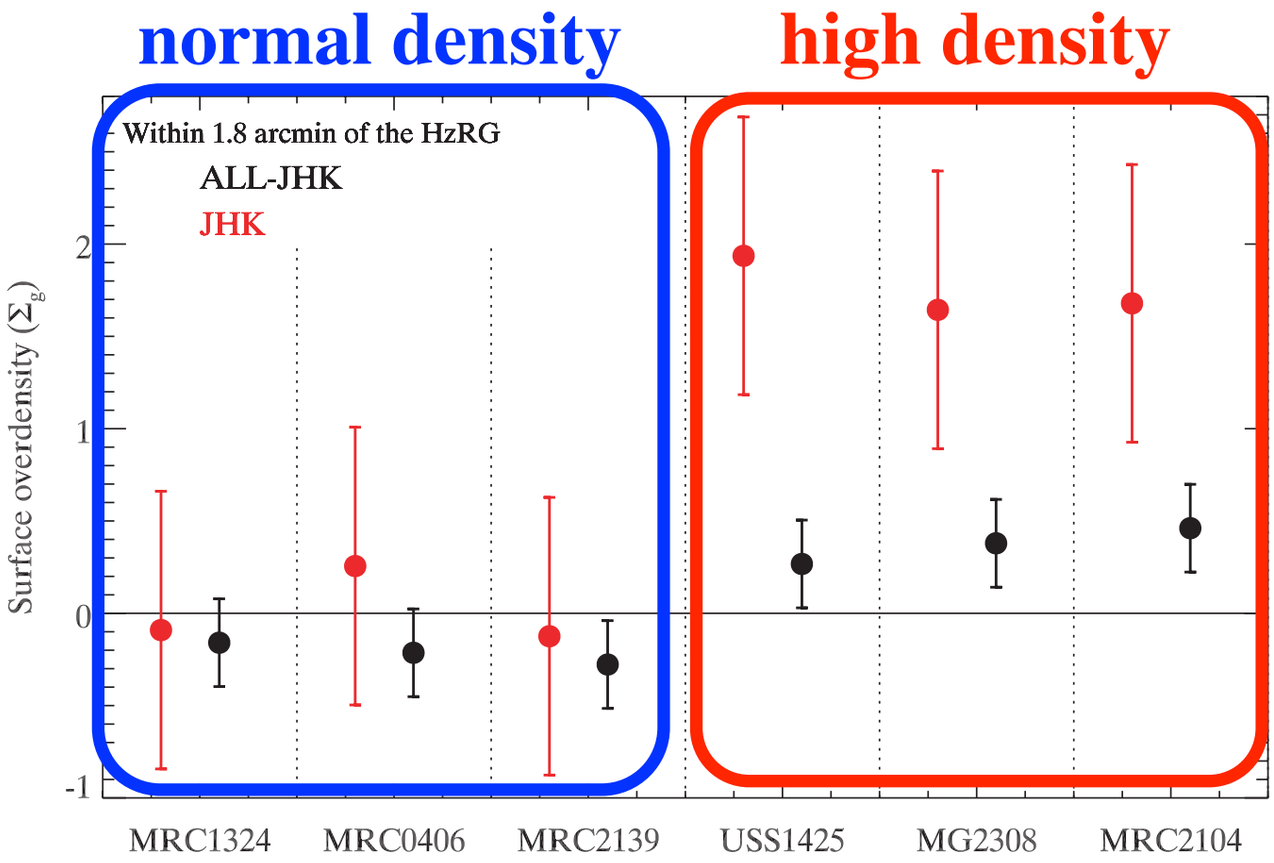
Springel et al. (2005)

Where are protoclusters?

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

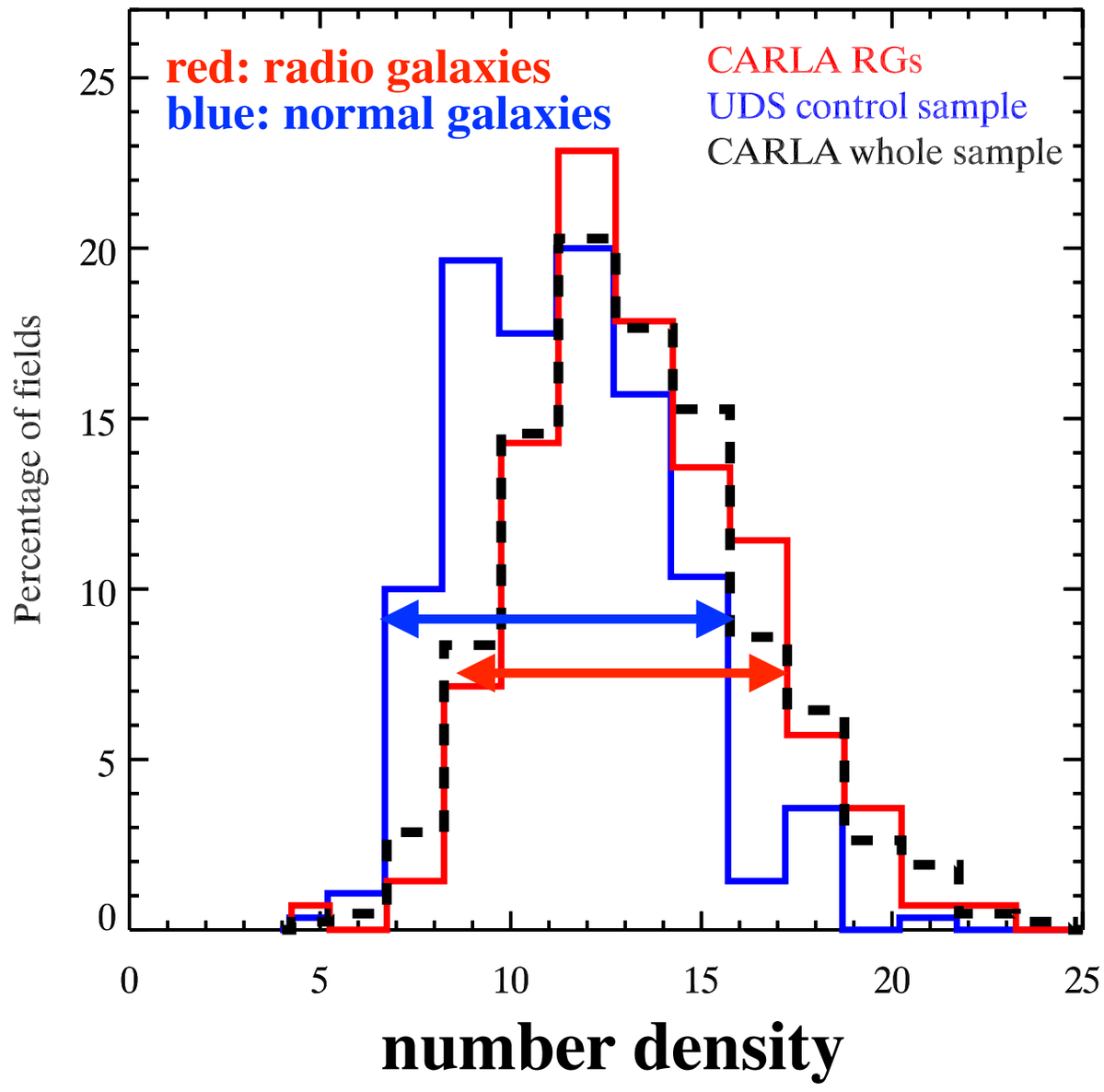
Are these galaxies really good probes of protoclusters?

around six radio galaxies at z~2.4



Hatch et al. (2011)

Hatch et al. (2014)



Uniqueness of our research

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

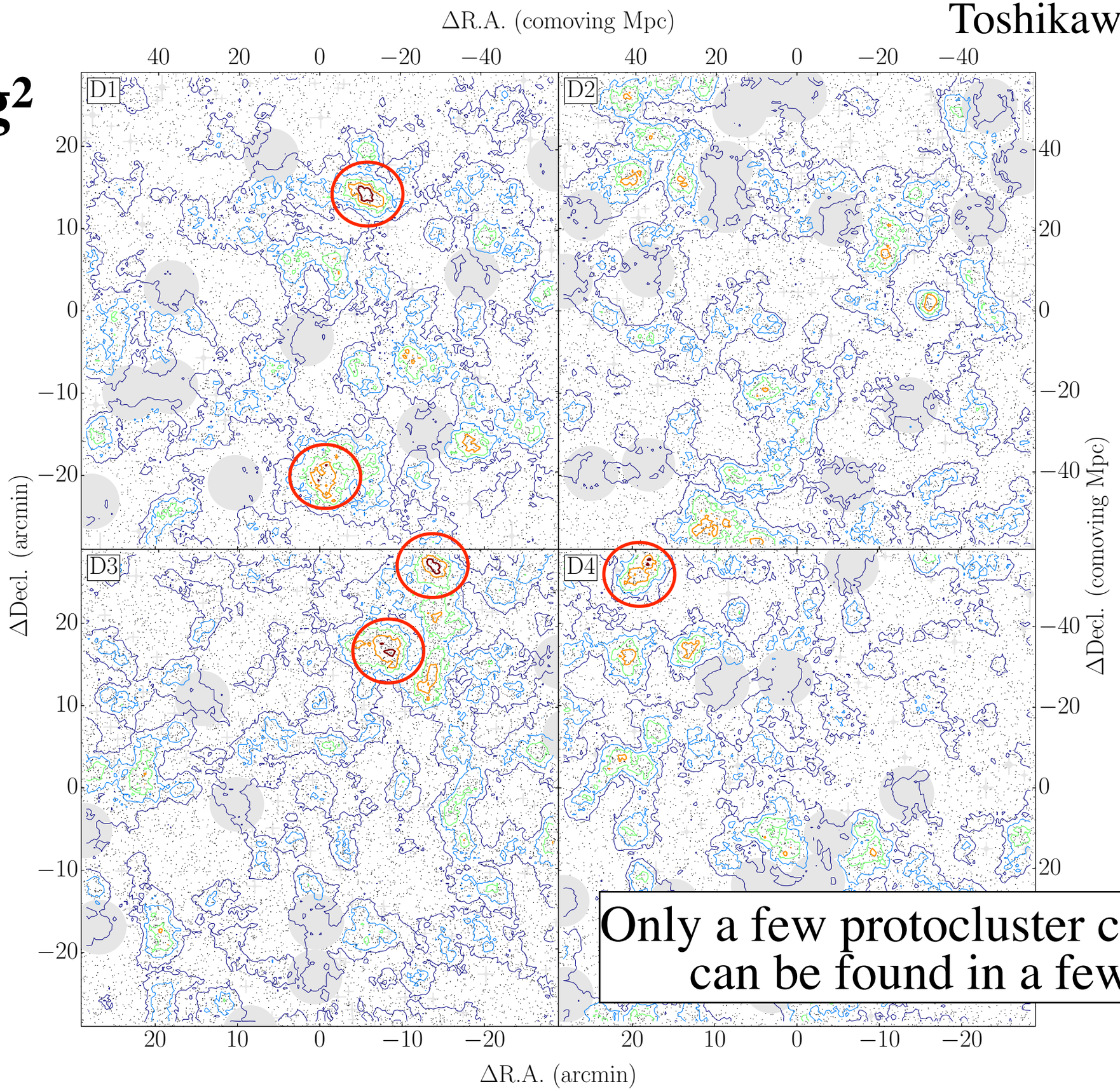
We will perform an unbiased search of protoclusters by using wide-field imaging of HSC survey.

Based on a systematic sample of protoclusters,
we can investigate galaxy evolution in high-dense environments
and the formation of clusters/large-scale structure.

Previous work in CFHTLS Deep

Toshikawa et al. (2016)

~4deg²



Only a few protocluster candidates can be found in a few deg² area.

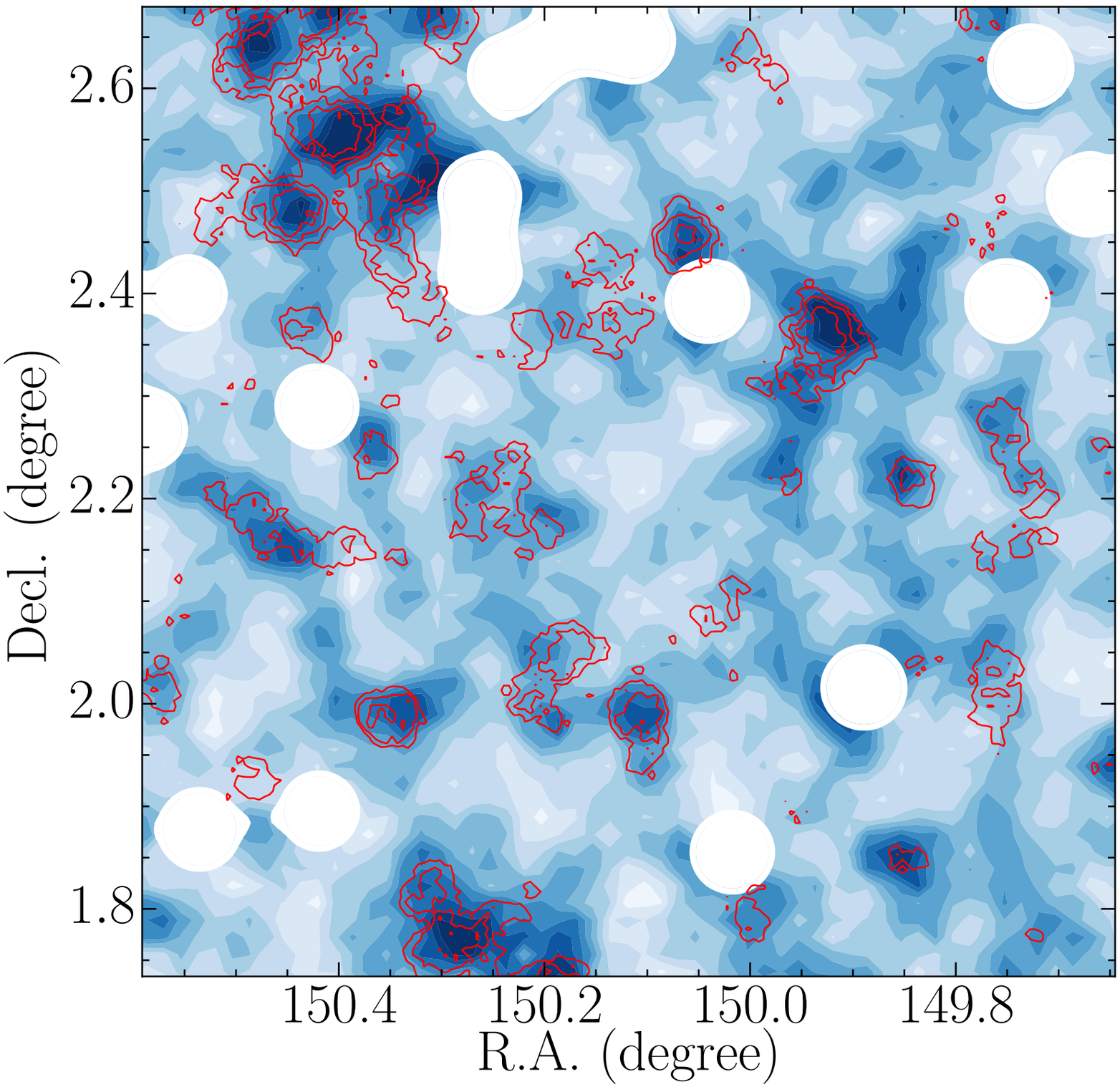
Data, Overdensity estimate

- based on the S16A data release
- select LBGs at z~4 in HSC-WIDE (S_{eff}=121deg^2)
- estimate local surface number density
(by the same method as in Toshikawa et al. 2016)

use LBGs down to i=25.0mag,
count LBGs within an aperture of r=1.8arcmin (0.75pMpc),
overdensity is defined as $(N-N_{ave})/\sigma$

Consistency check

Two datasets are available in the COSMOS (HSC-UD & CFHTLS D2).
We apply the same analysis (LBG selection & overdensity estimate).

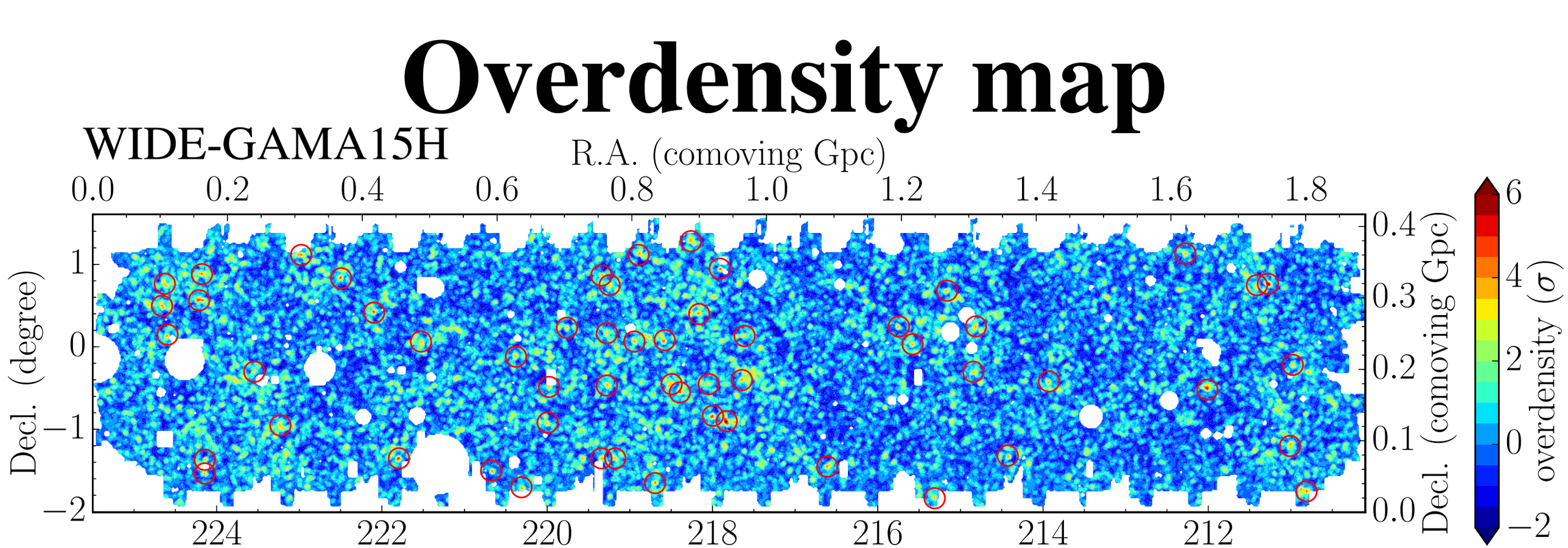


overdensity contour maps

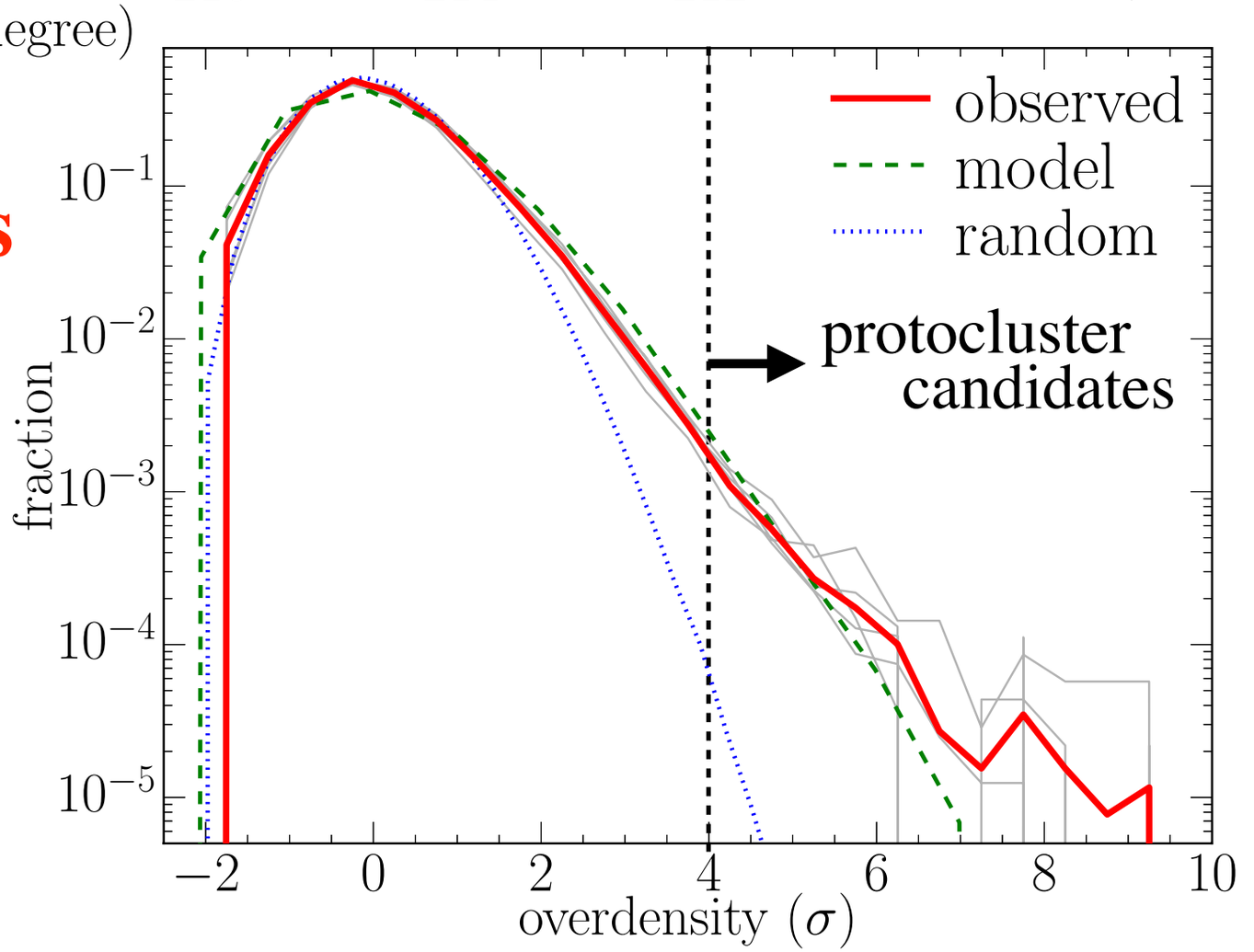
blue color scale: HSC dataset

red lines: CFHTLS dataset

Overdensity map

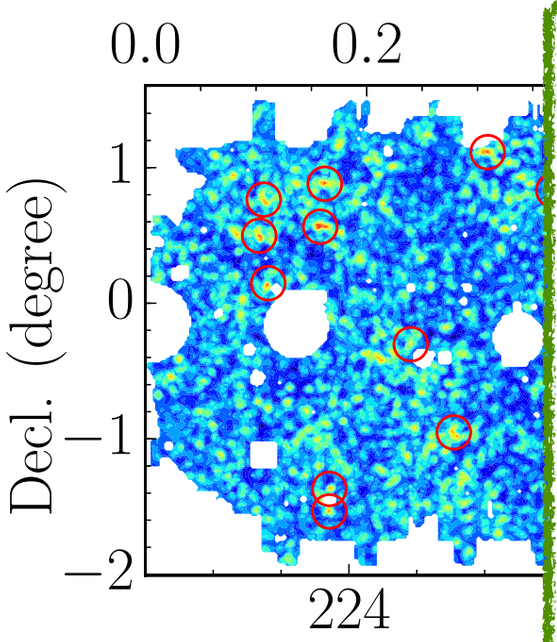


179 protocluster candidates are identified from the S16A HSC dataset (S_{eff}=121deg^2).



Overdensity map

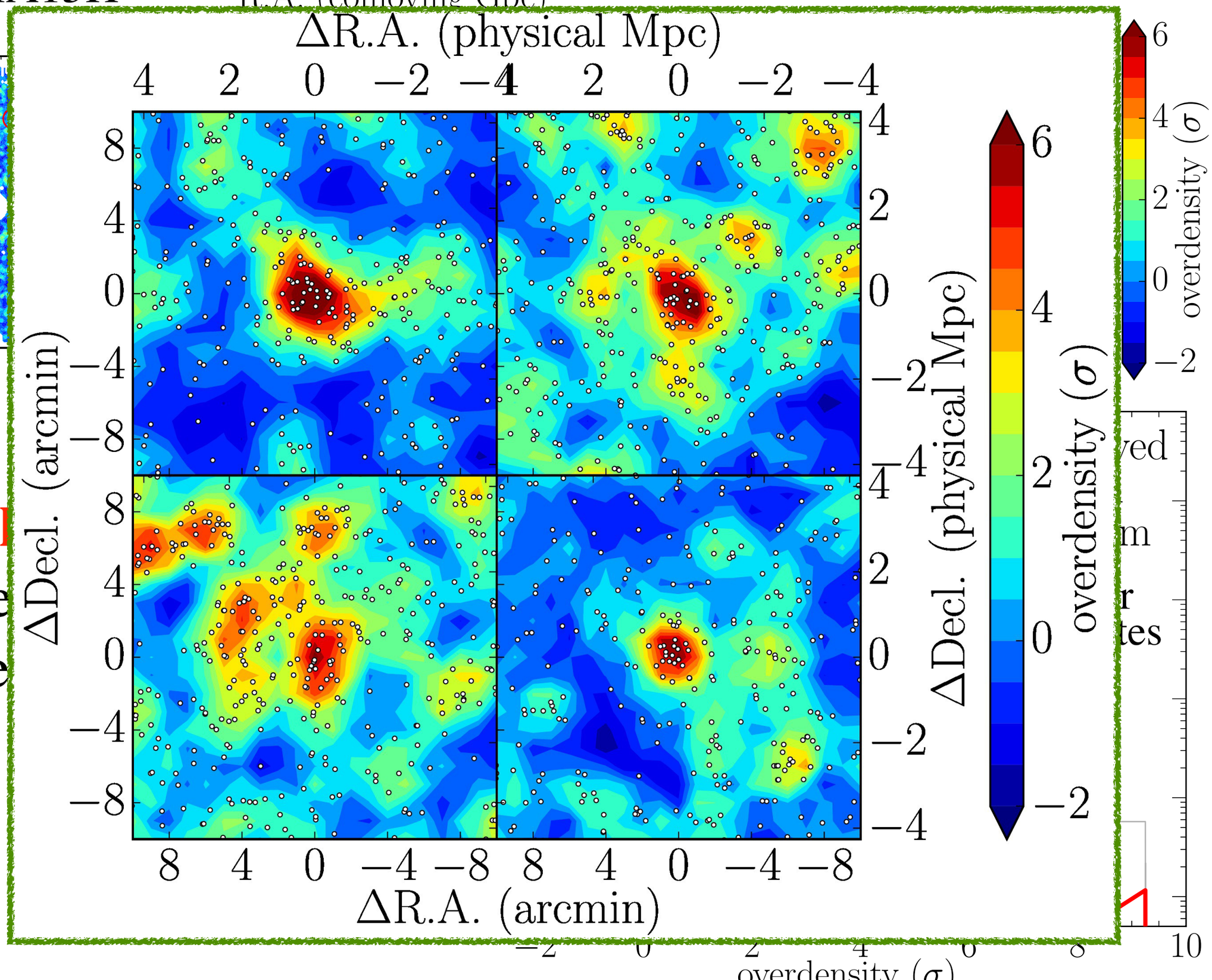
WIDE-GAMA15H



179 protocl

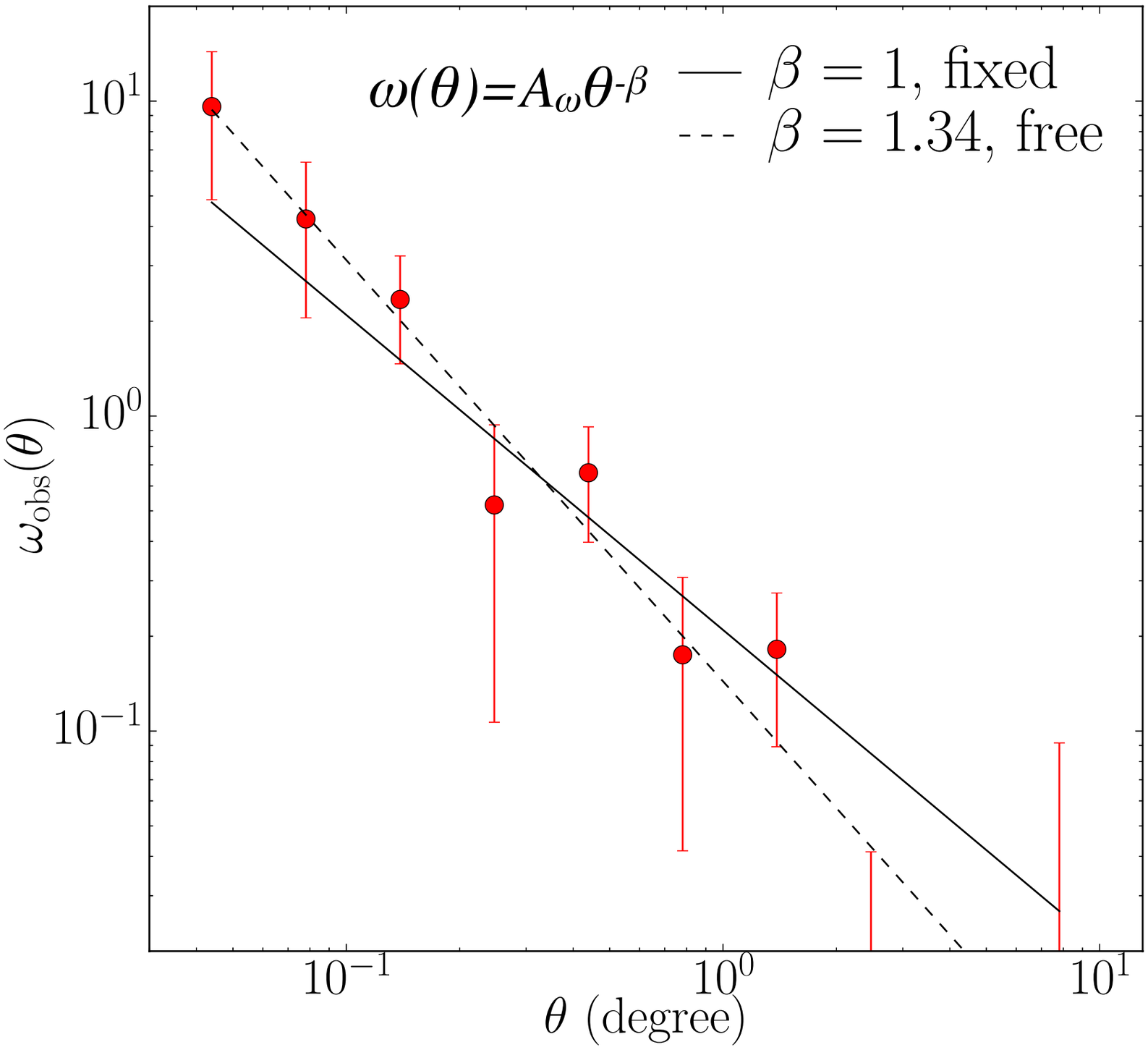
are identifie

HSC datase



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

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

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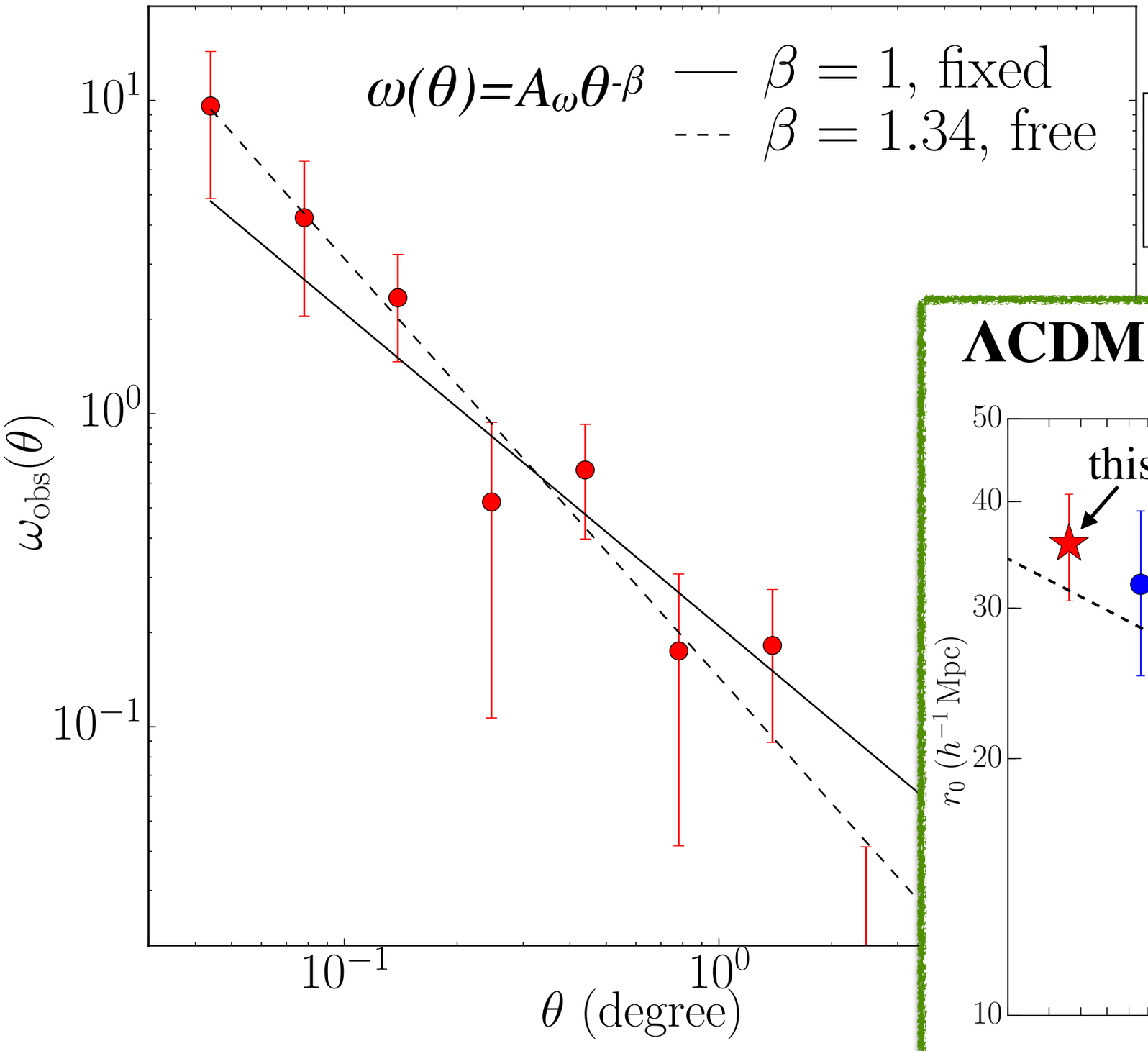

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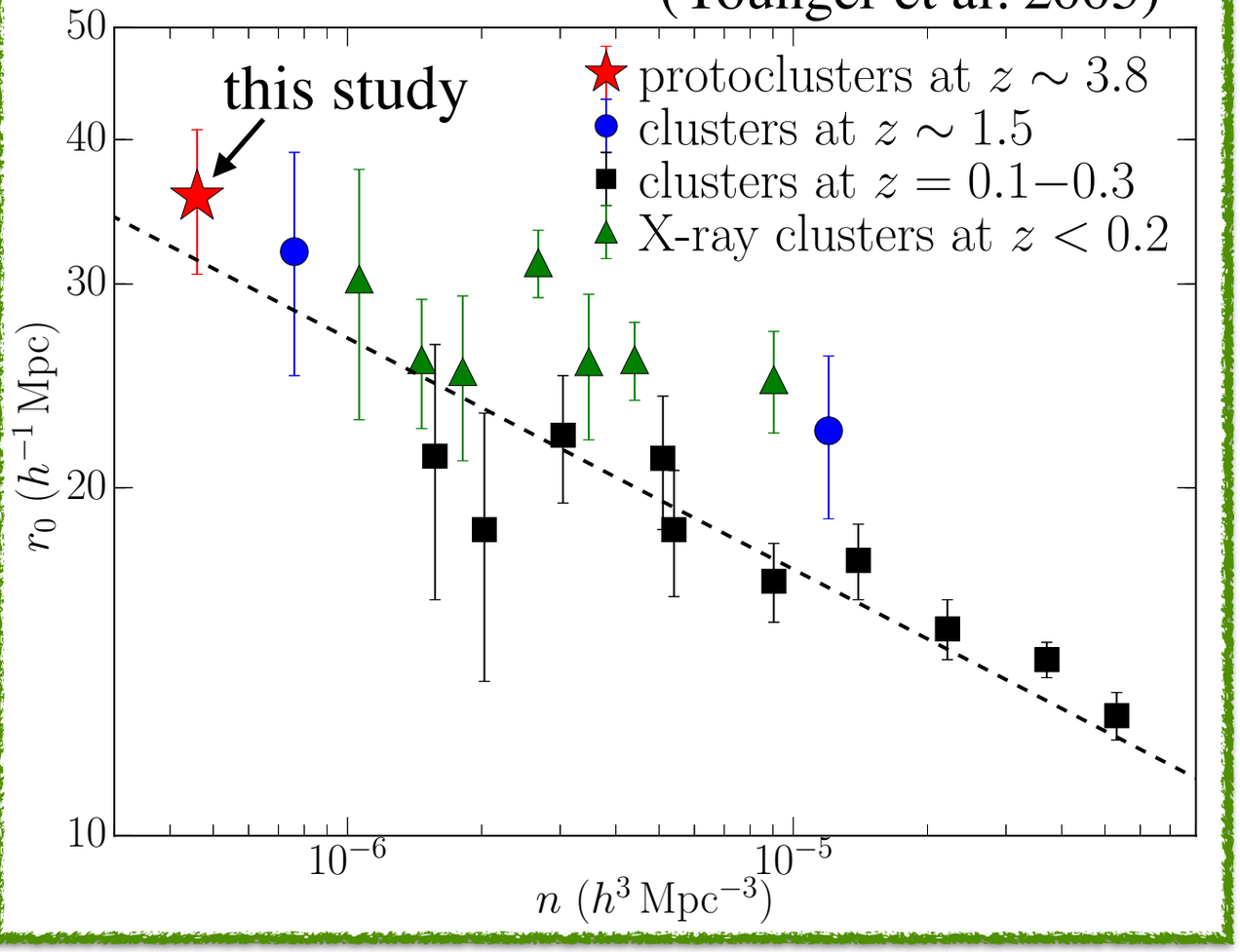
ΛCDM prediction: $r_0 \propto n^{-1/5}$

(Younger et al. 2005)



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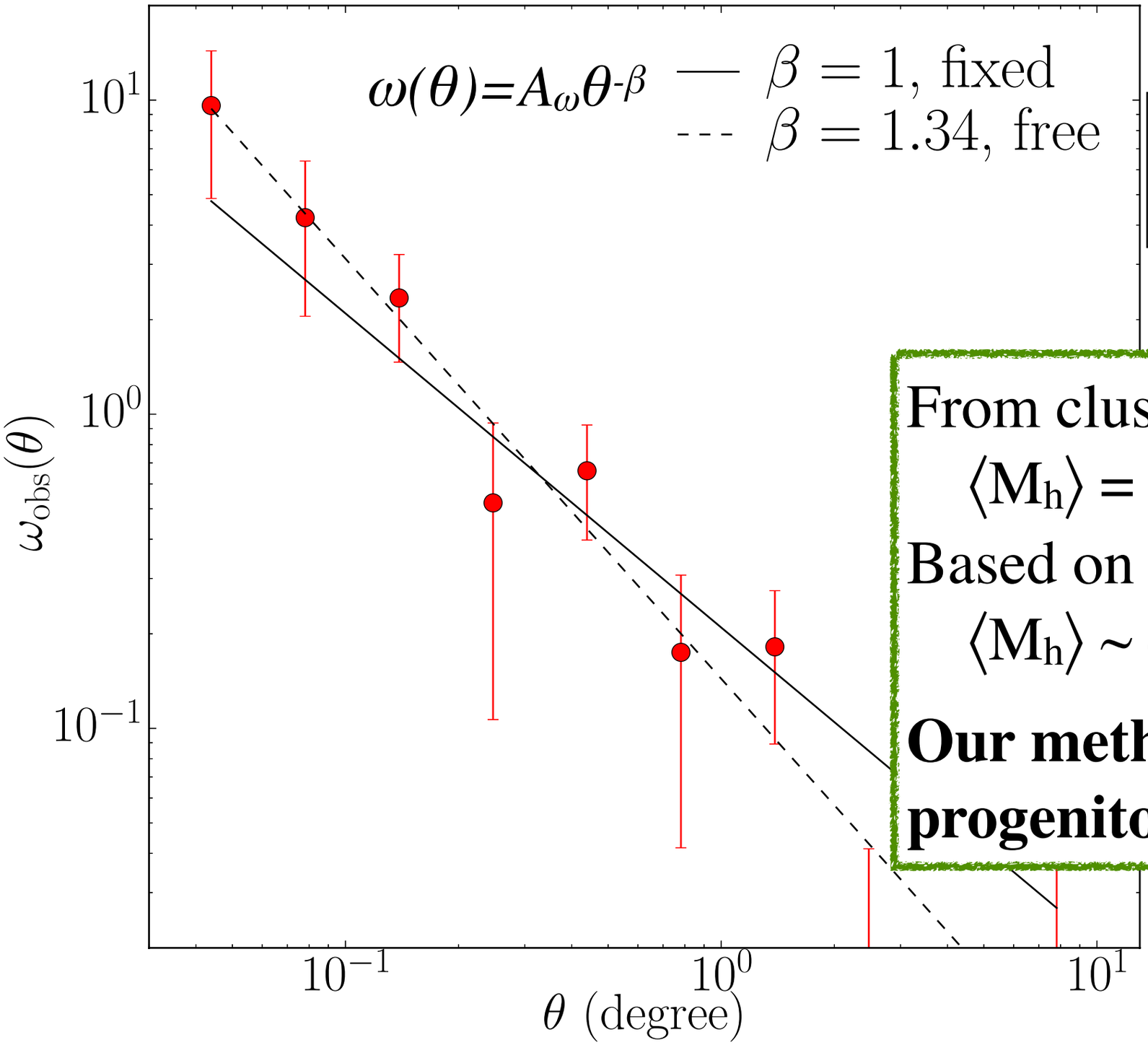


$r_0 = 35.7$ (+4.6/-5.5) h^{-1} Mpc
$n = 4.6 \times 10^{-7}$ h^3 Mpc^{-3}

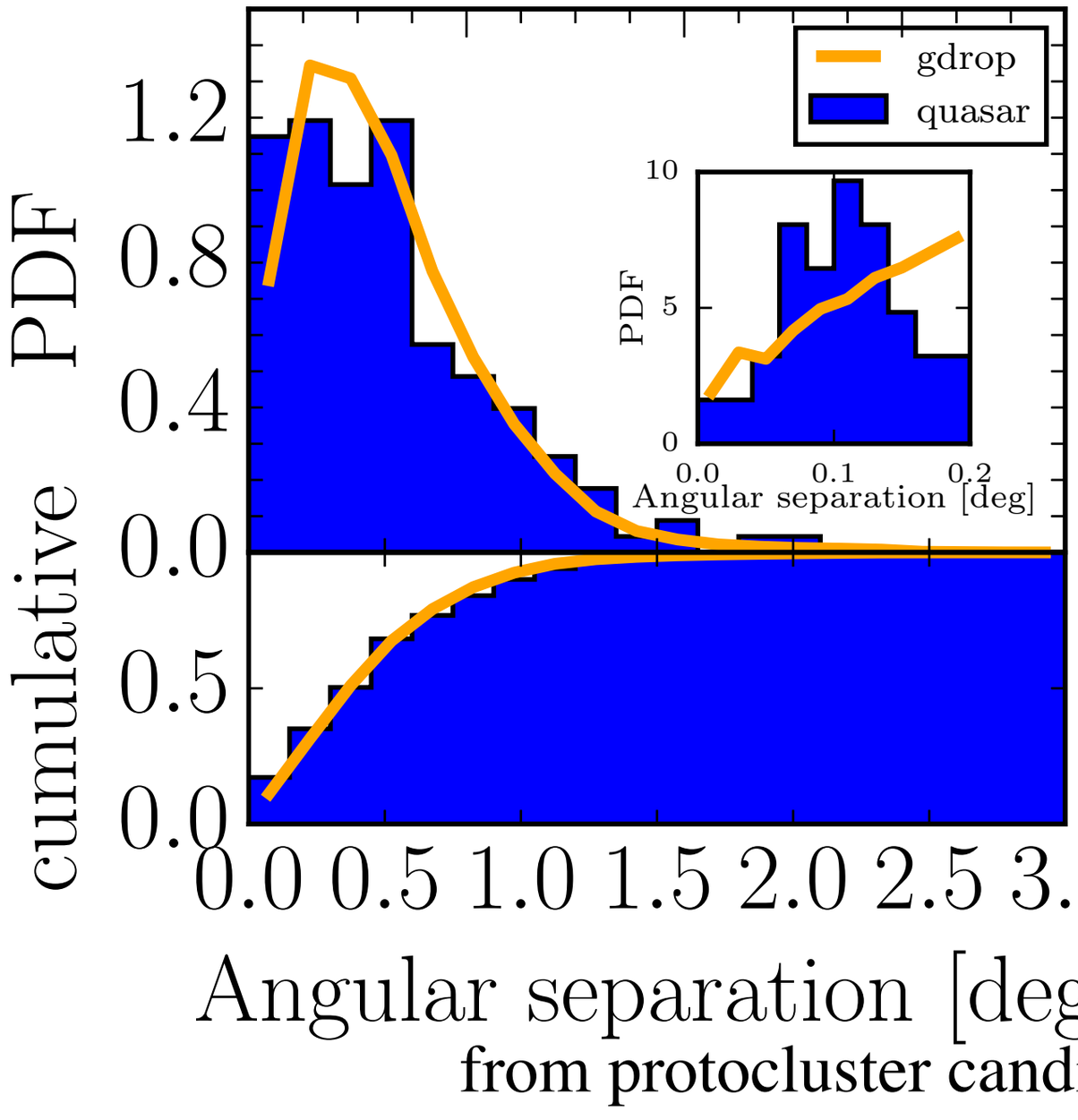
From clustering analysis,
$\langle M_h \rangle = 2.3\times10^{13}$ $h^{-1}M_{sun}$ at z~4
Based on EPS model,
$\langle M_h \rangle \sim 4\times10^{14}$ $h^{-1}M_{sun}$ at z=0

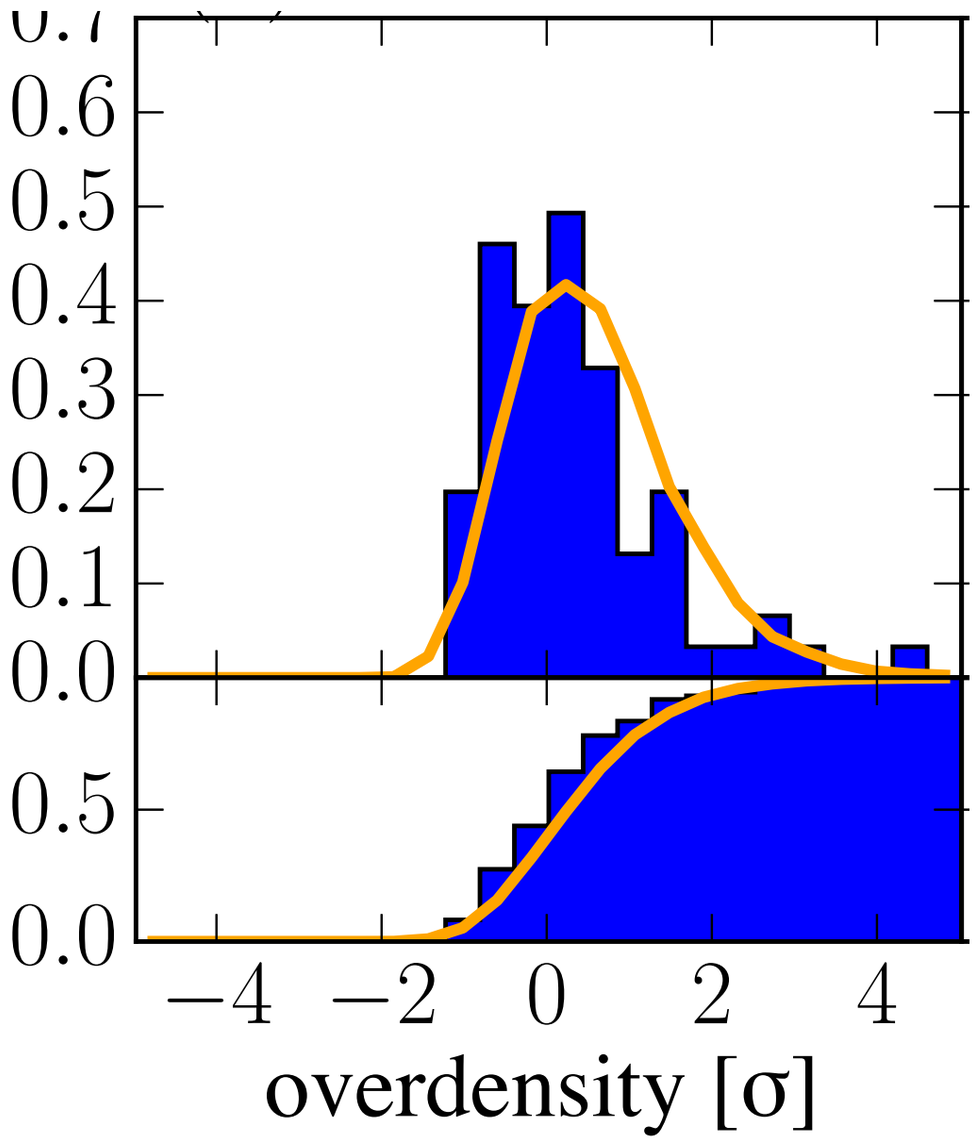
Our method can certainly identify progenitors of local clusters.

Relation between protoclusters and QSOs

led by Hisakazu Uchiyama

Based on the HSC protocluster candidates at z~4





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

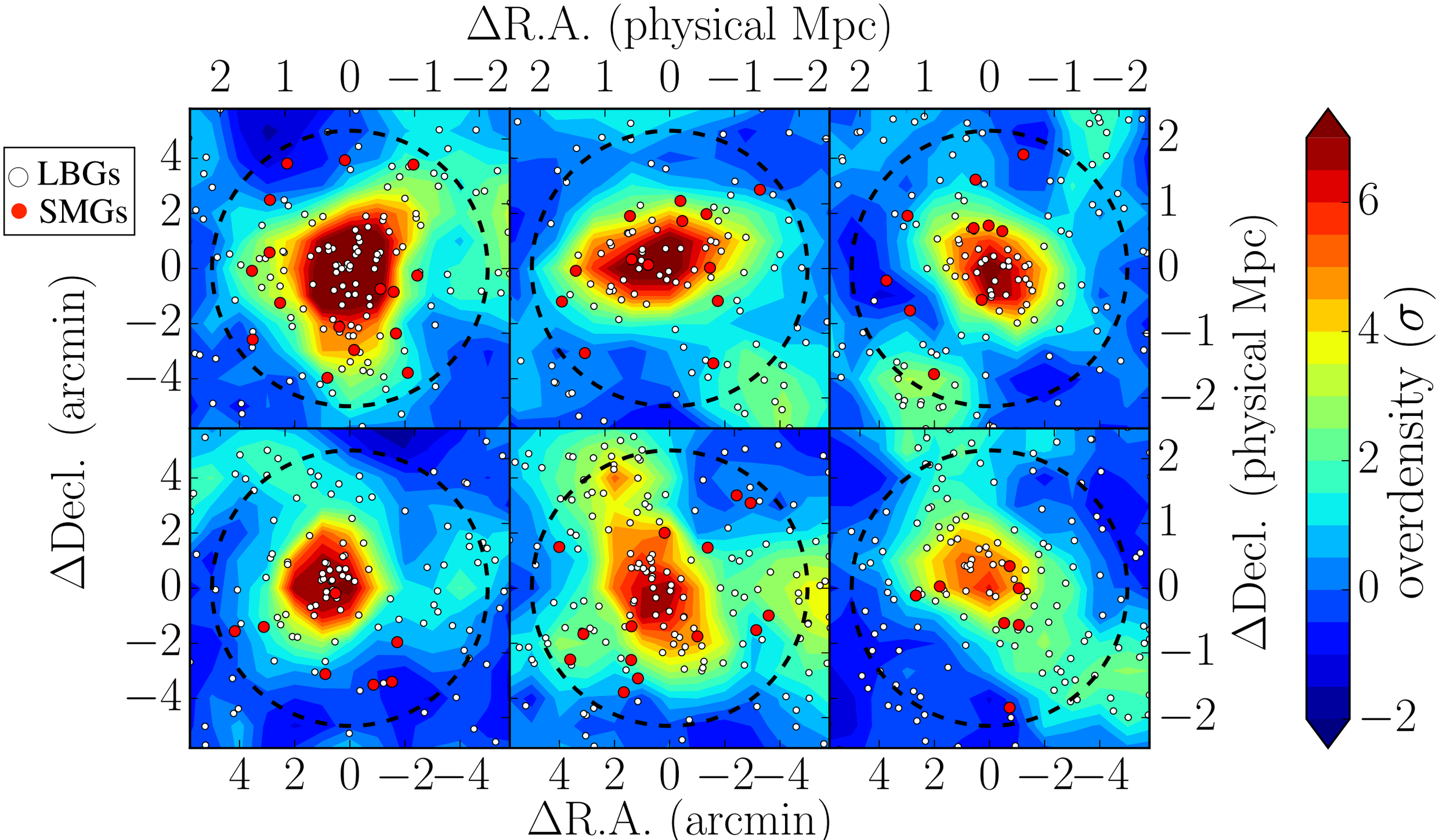
→ **QSOs do not tend to reside in high dense environments.**

Ongoing/future work

- sub-mm follow-up imaging (HSC project 196, PI: Y. Matsuda)

JCMT/SCUBA2 (850μm) imaging was conducted.

We will investigate the distribution/properties of SMGs in protoclusters.



Summary

- 179 protocluster candidates at z~4 are identified in the HSC-WIDE.
- 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 reside in overdense regions.
- Follow-up observations are ongoing.
  (spectroscopy, multi-wavelength imaging).

We will extend this protocluster search to z~3-6 in order to understand cluster formation history.