Subaru Users' Meeting 21, Jan., 2016

A Systematic Survey of Protoclusters at z~3-6 in the CFHTLS Deep Fields

(submitted to ApJ)

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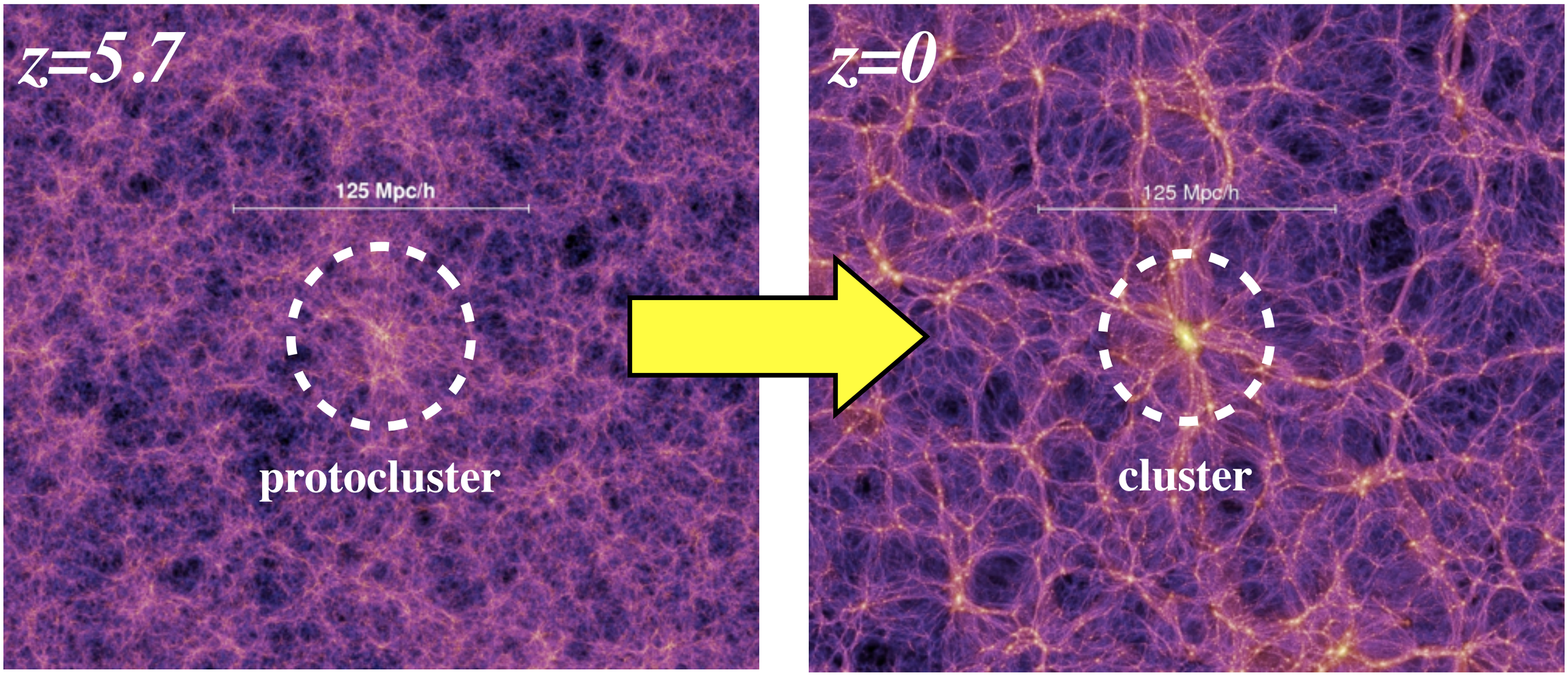
Outline

- Introduction
- Our Research : *Search for protoclusters at z~3-6*
  - ✓ Protocluster candidates
  - ✓ Follow-up spectroscopy
  - ✓ Discussion
    - 3D structure and Galaxy properties
- Future work : *Subaru/HSC strategic survey*
- Summary

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.



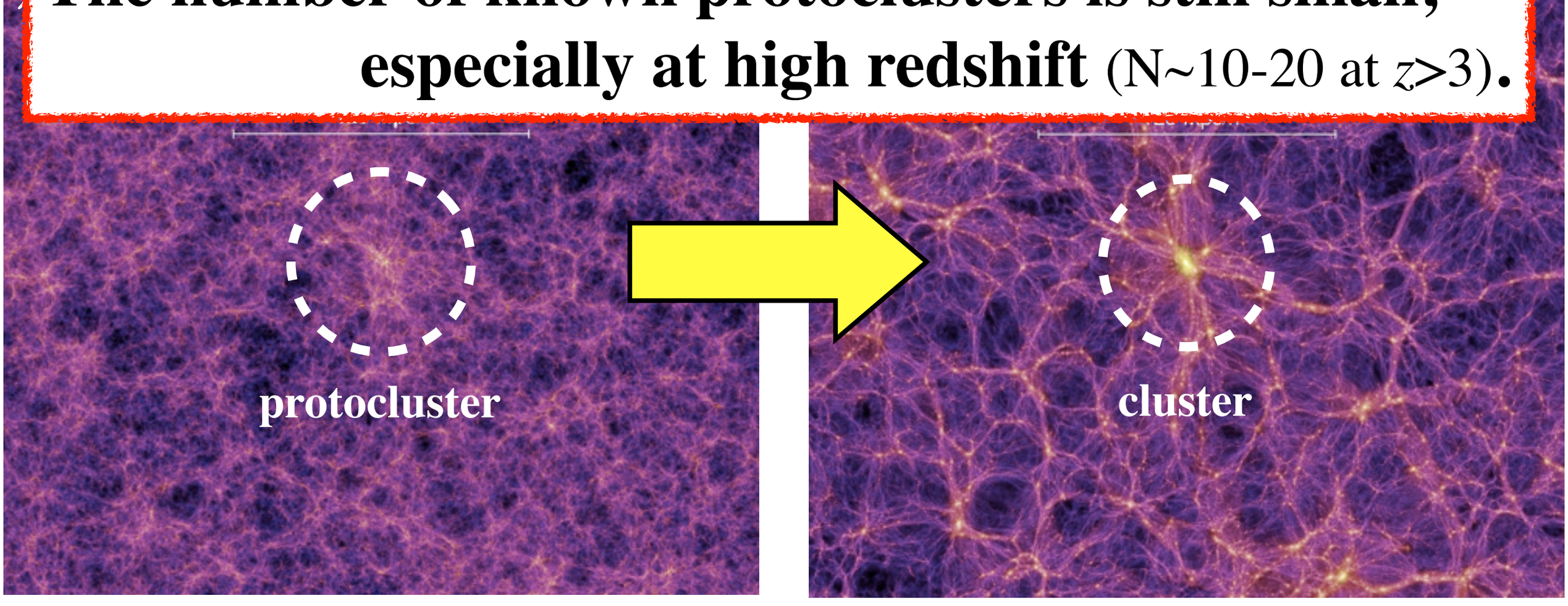
Springel et al. (2005)

Importance of protoclusters

When and how are galaxy clusters formed?

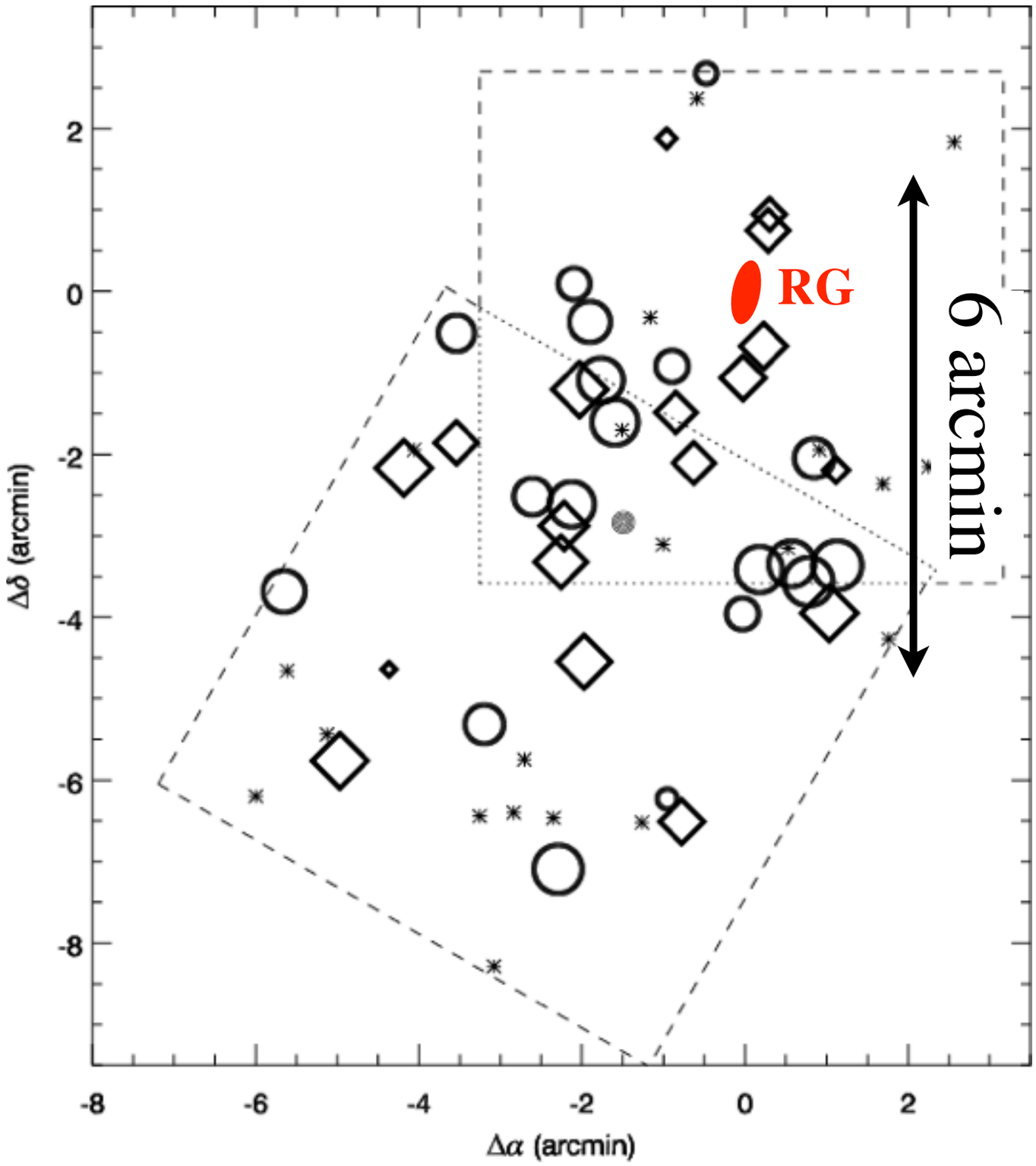
Protoclusters in the early universe would reveal
the primordial condition of clusters at their birth.

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



Springel et al. (2005)

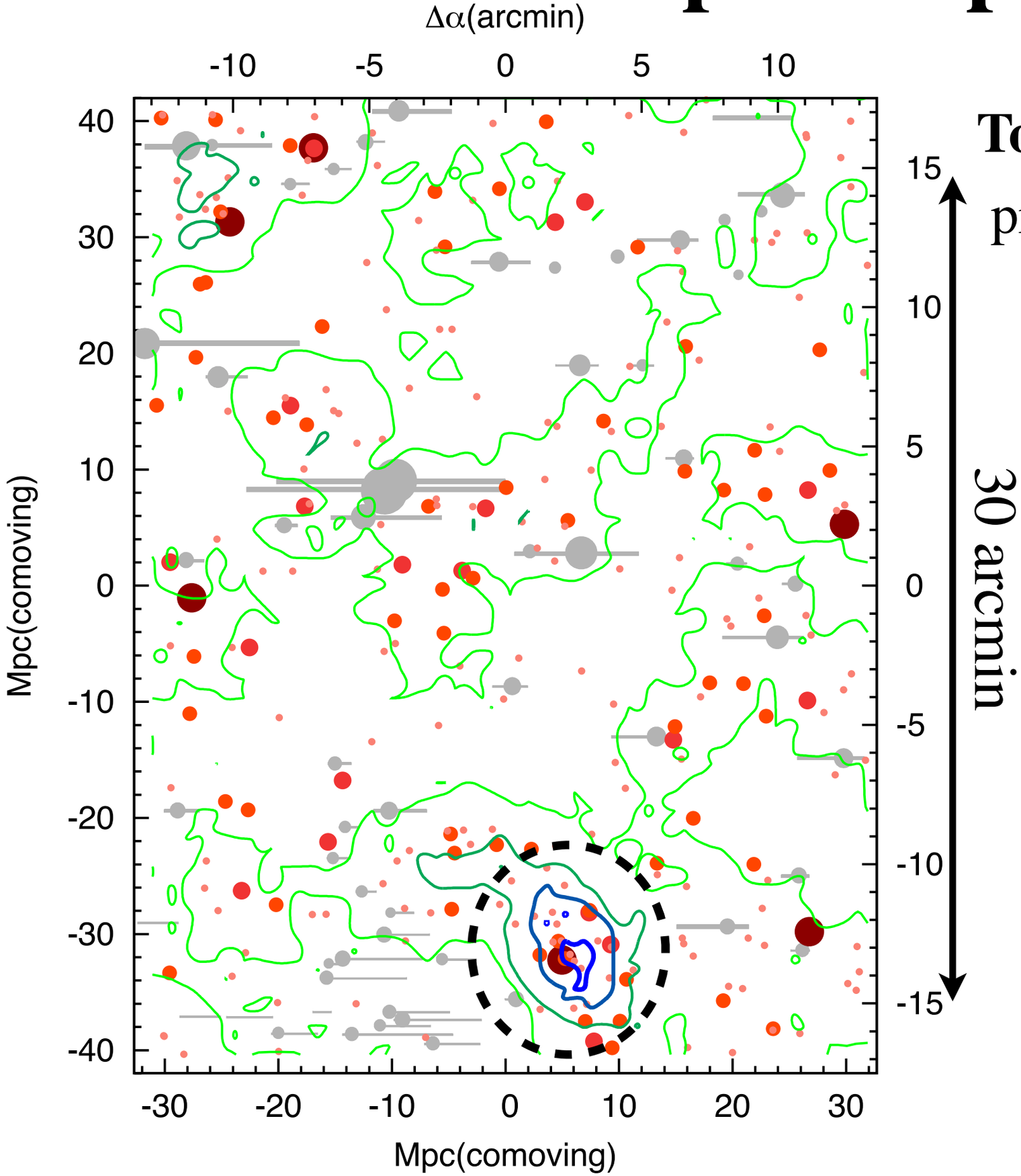
Some examples of protoclusters



Venemans et al. (2007)

protocluster at z=4.11
in **radio galaxy** (RG) field
(TN J1338-1942)

Some examples of protoclusters



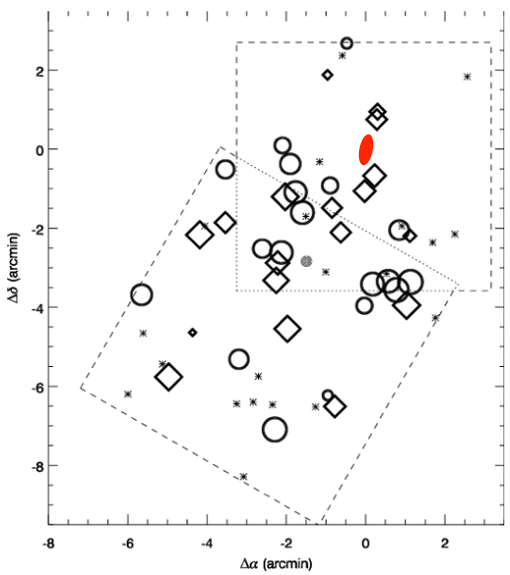
Toshikawa et al. (2012)

protocluster at z=6.01

in **blank** field

(Subaru Deep Field: SDF)

Wide-field imaging



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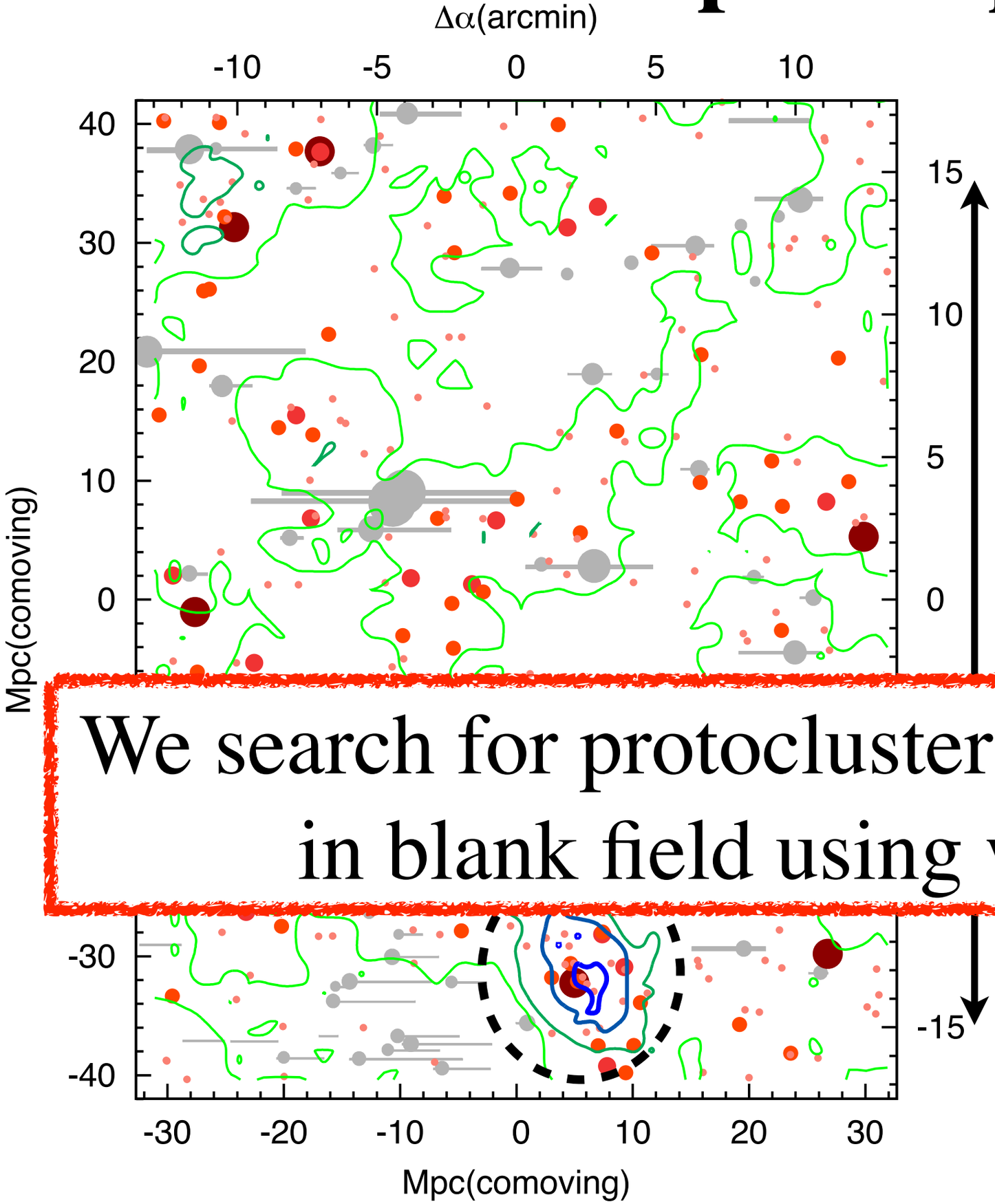

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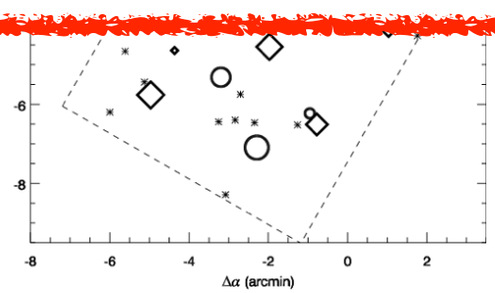
(Subaru Deep Field: SDF)

Wide-field imaging

We search for protoclusters at z~3-6

in blank field using wide-field imaging.



Our Research

Search for protoclusters at z~3-6

- Protocluster candidates
- Follow-up spectroscopy
- Discussion:
  protocluster structure and galaxy properties

Photometric data

CFHT Legacy Survey Deep fields (CFHTLS D1 - D4)

- **wide field**

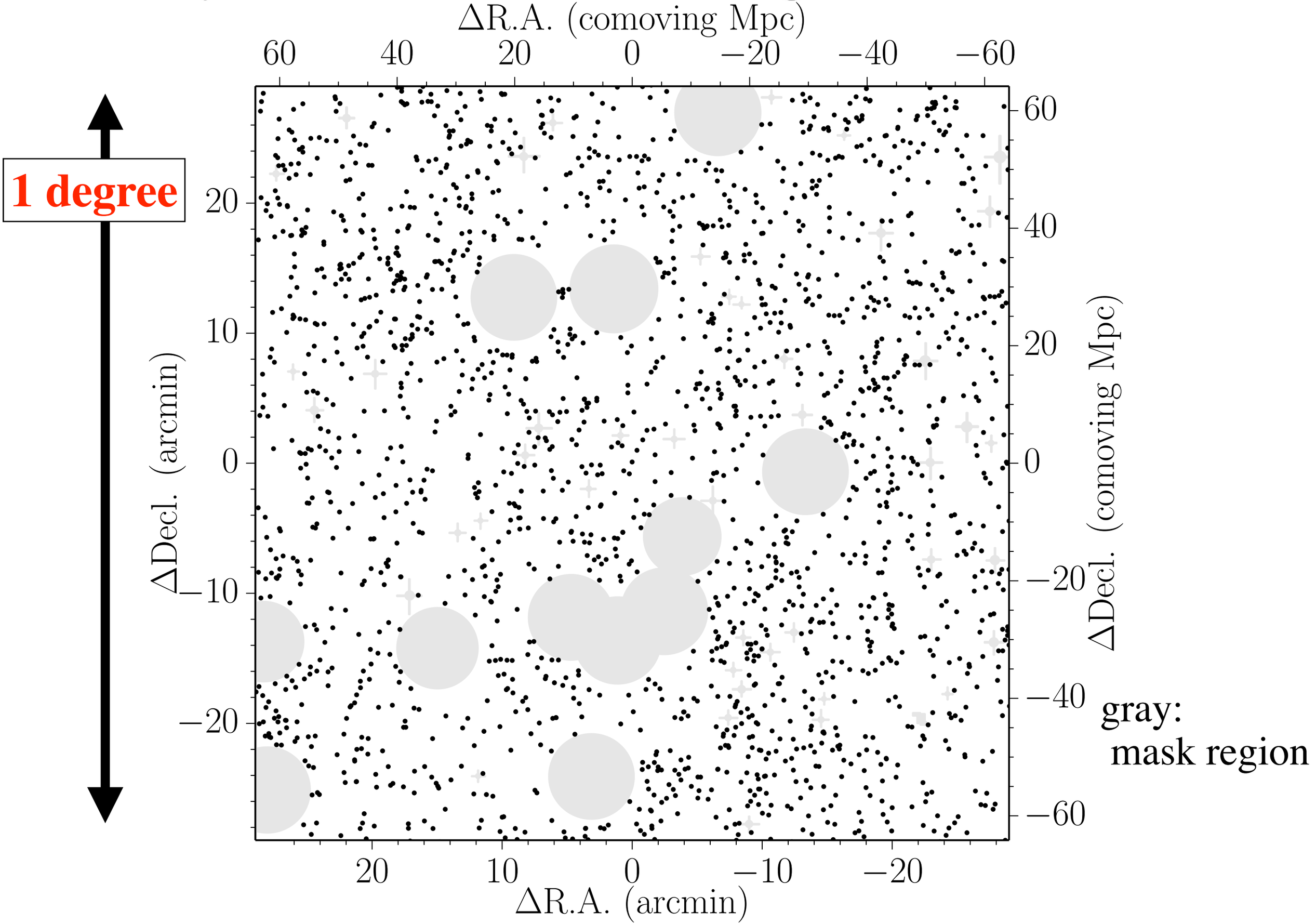
  four separated fields, each field ~1 degree^2 (~4 degree^2 in total)

- **deep multi-band photometry**

  3σ limiting magnitude: ~27.2 (*i*-band), ~26.2 (*z*-band)

select z~3-6 LBGs (u-, g-, r-, and i-dropout)

Sky distribution of z~5 galaxies in D4



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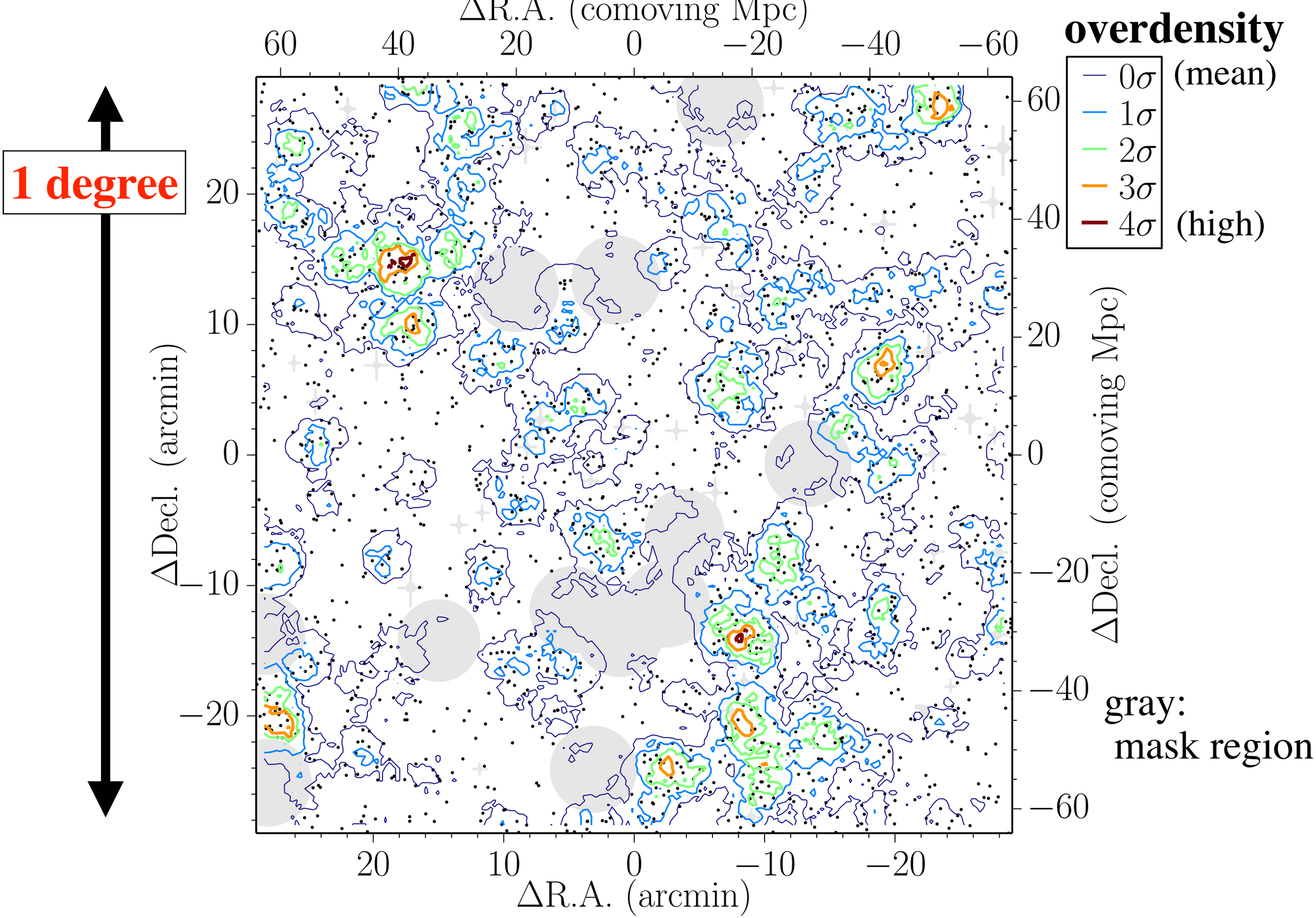

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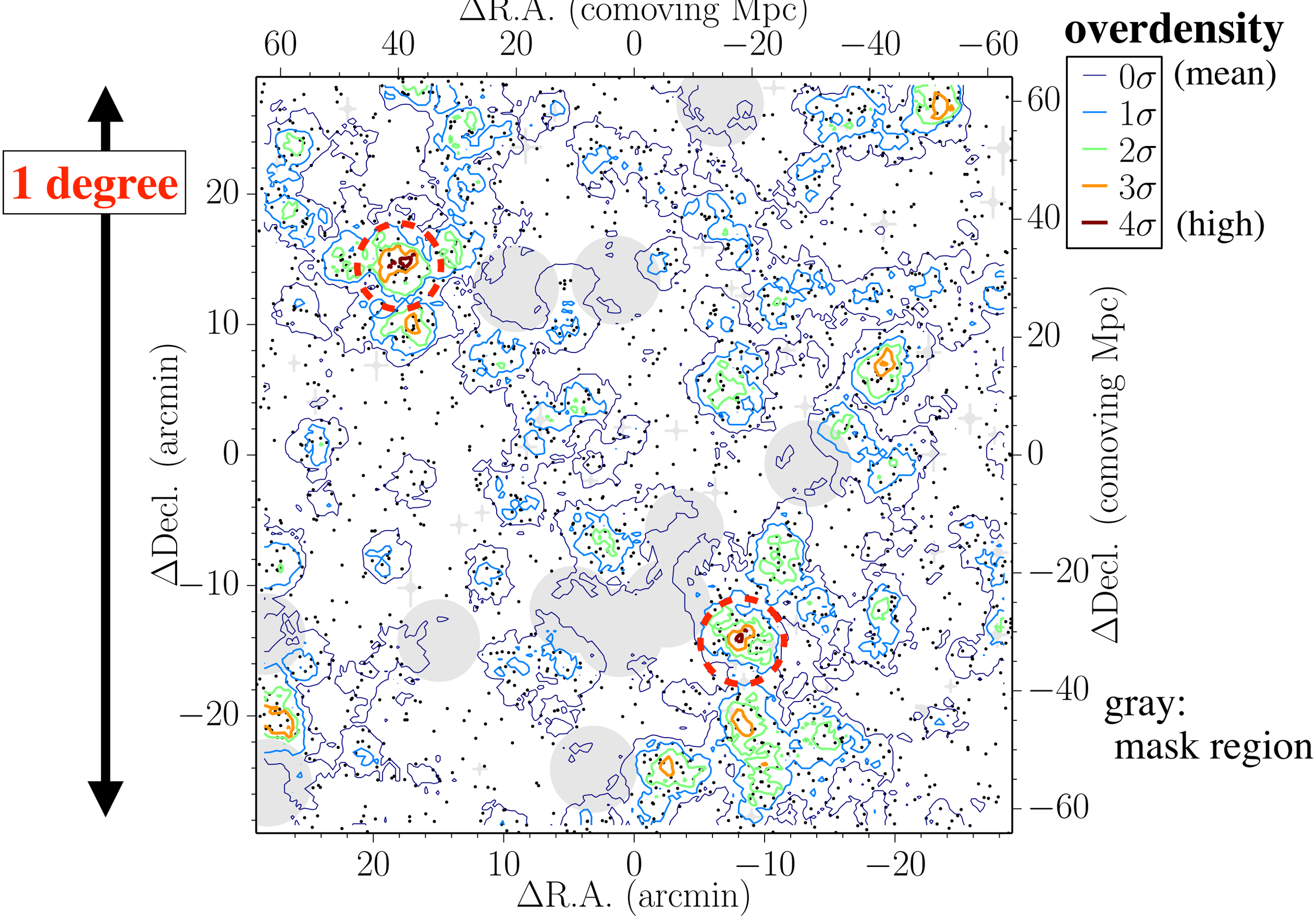
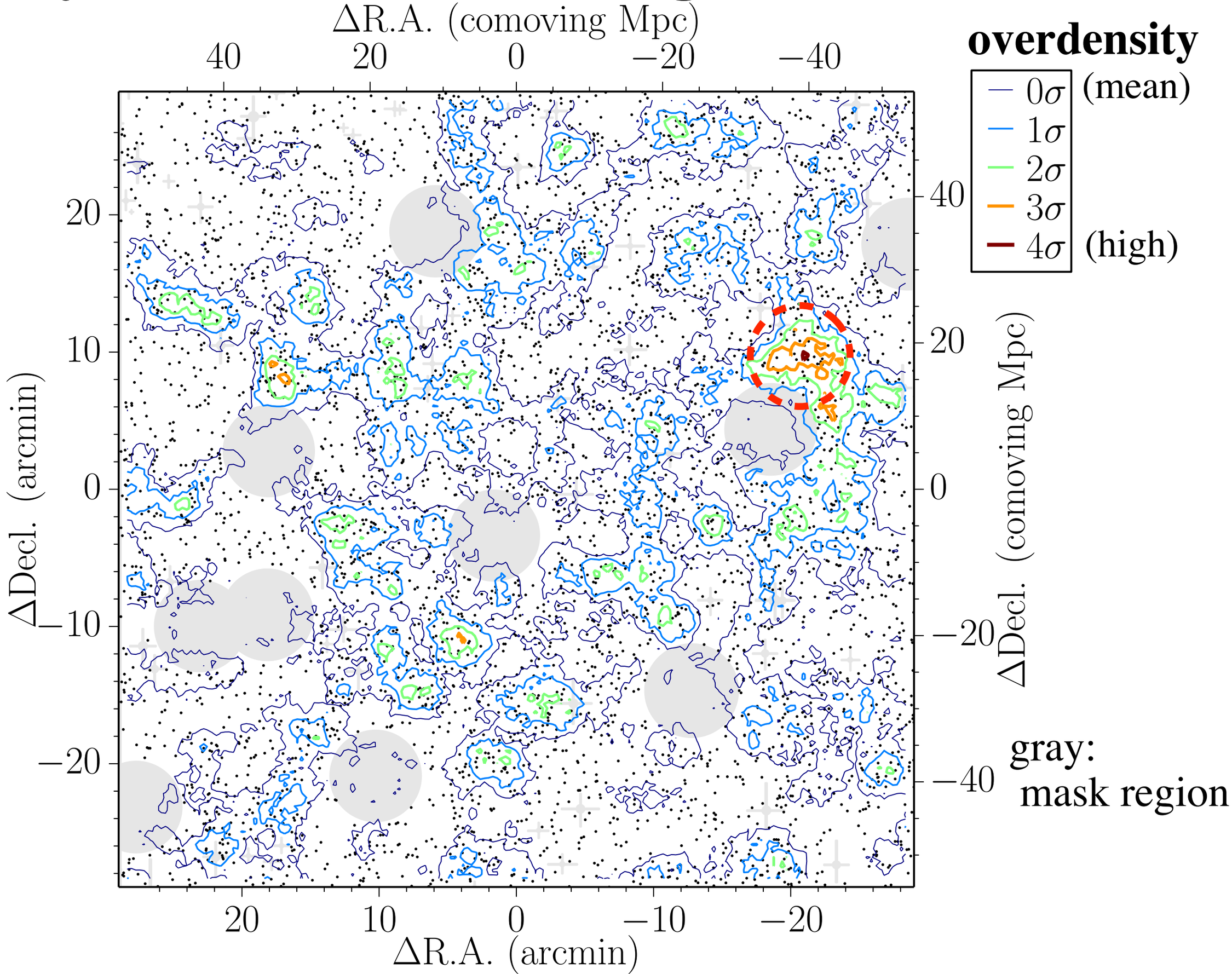
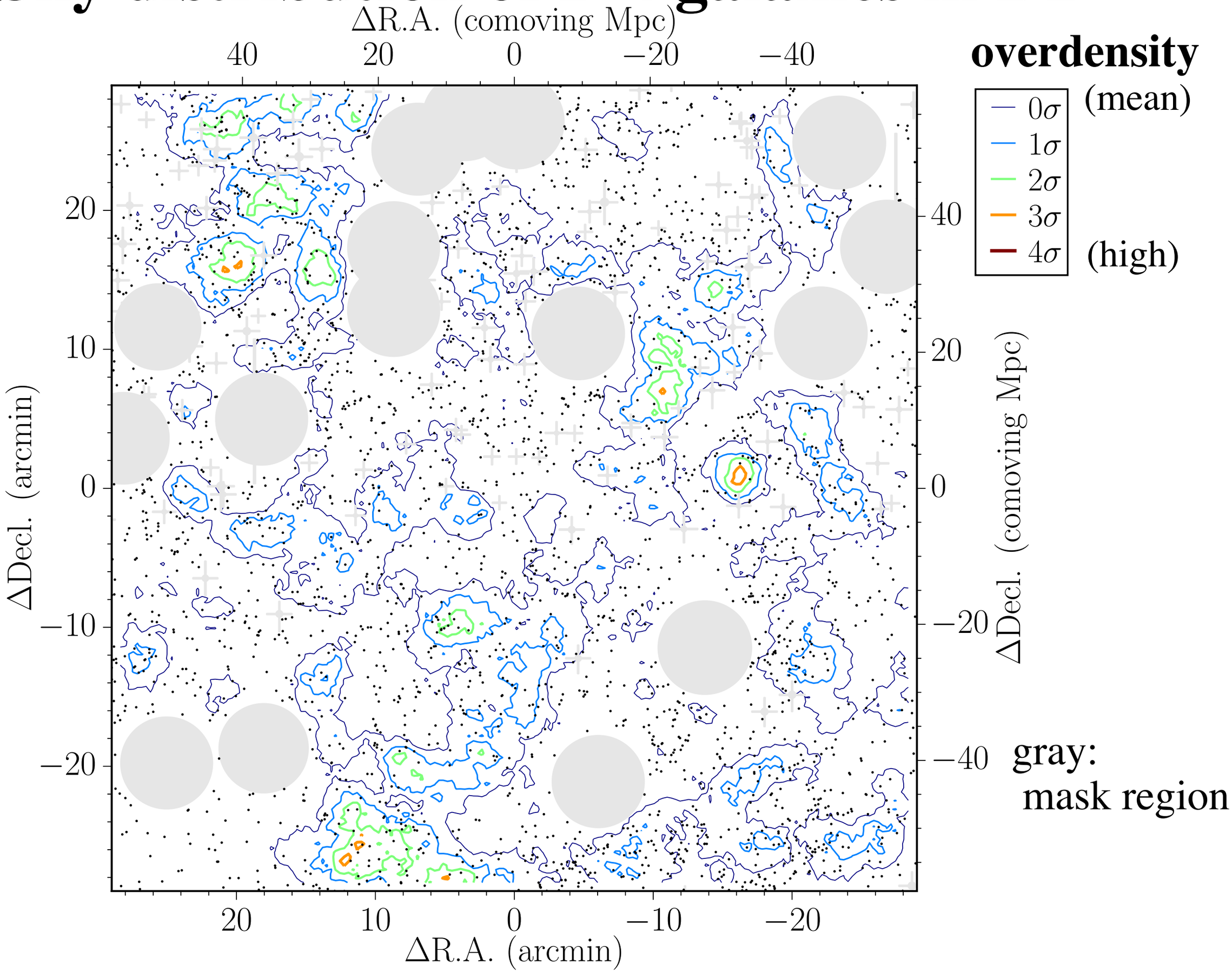


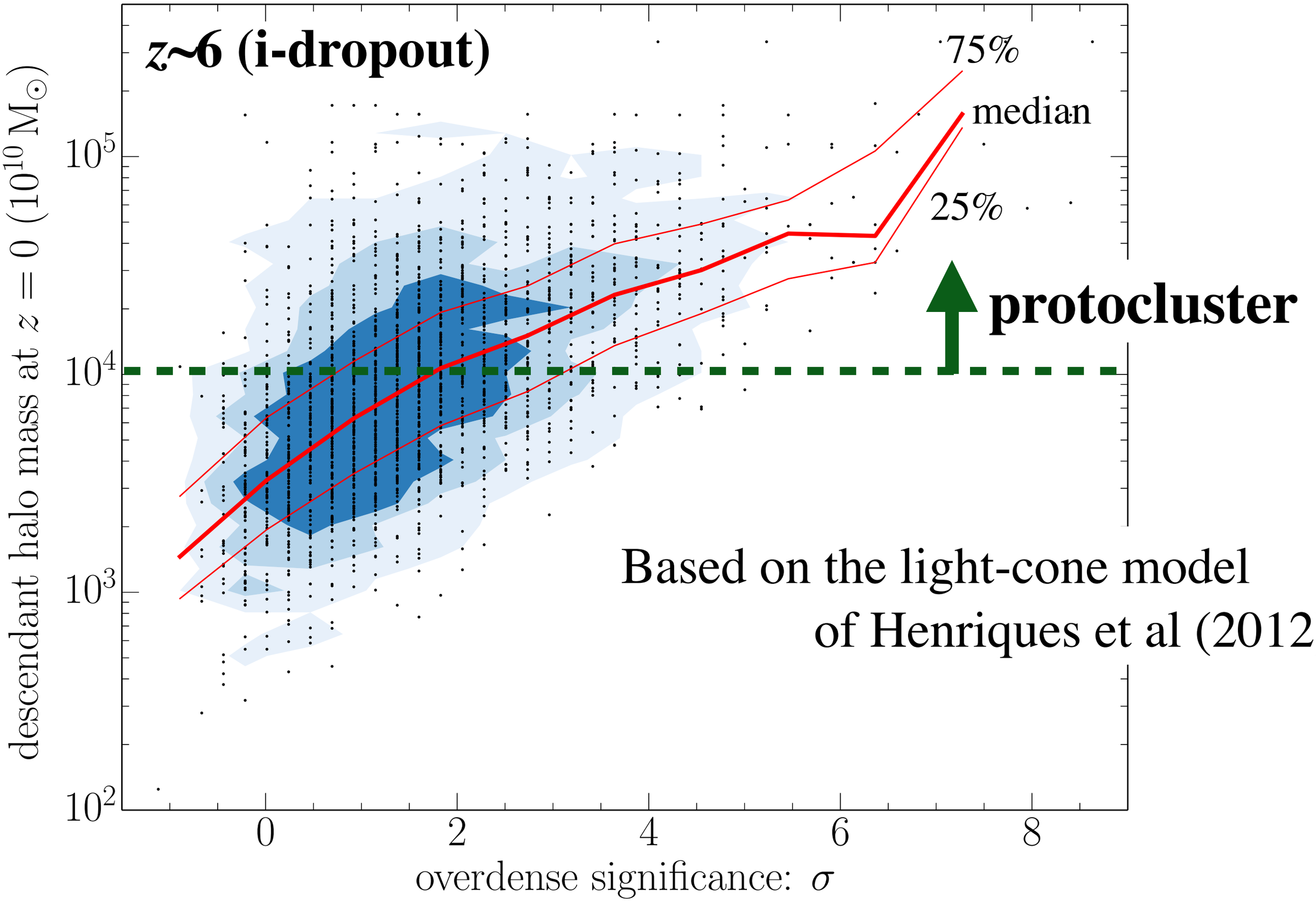
Sky distribution of z~3 galaxies in D1



Sky distribution of z~4 galaxies in D2



What overdense regions are protoclusters?



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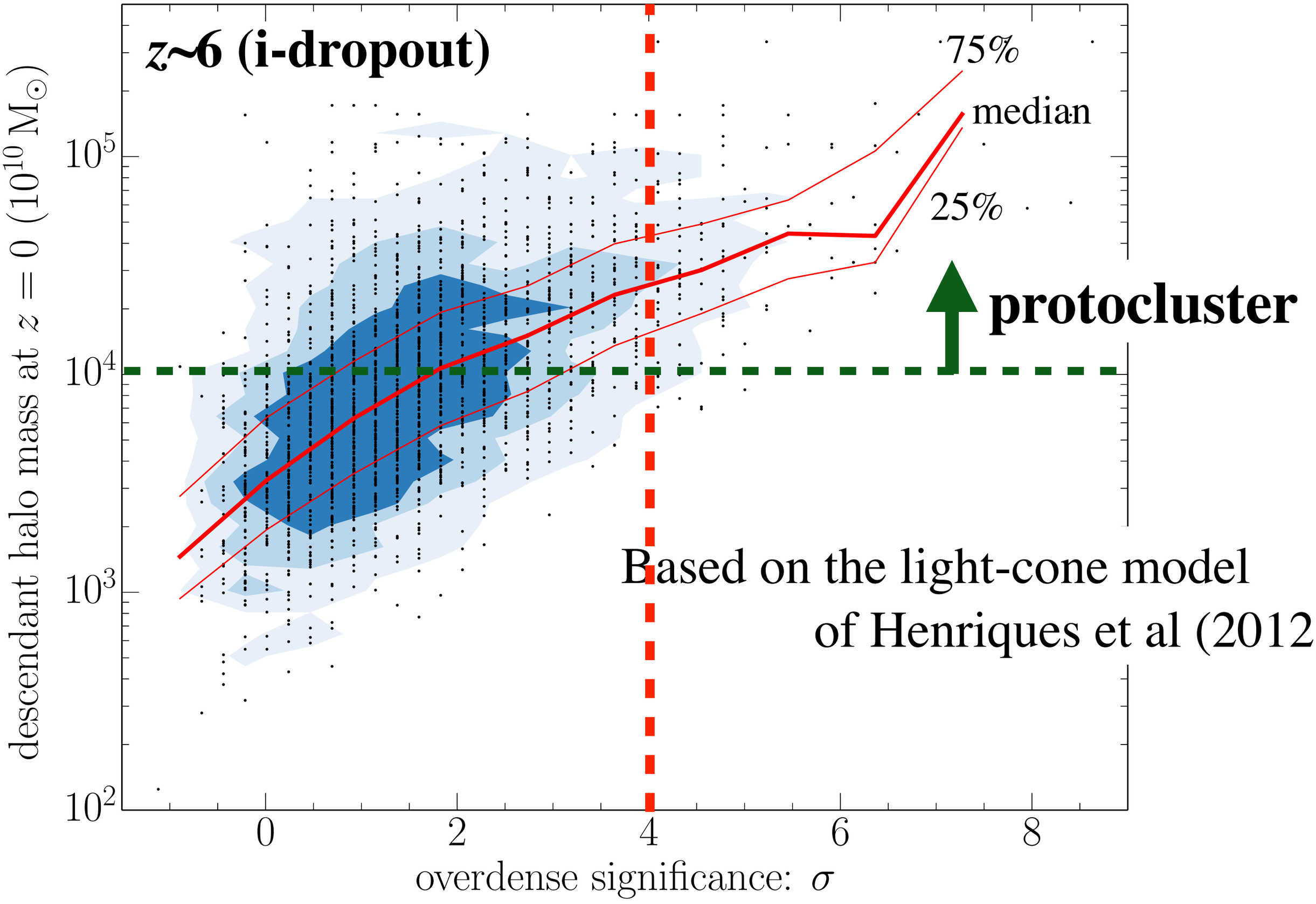


Protocluster candidates

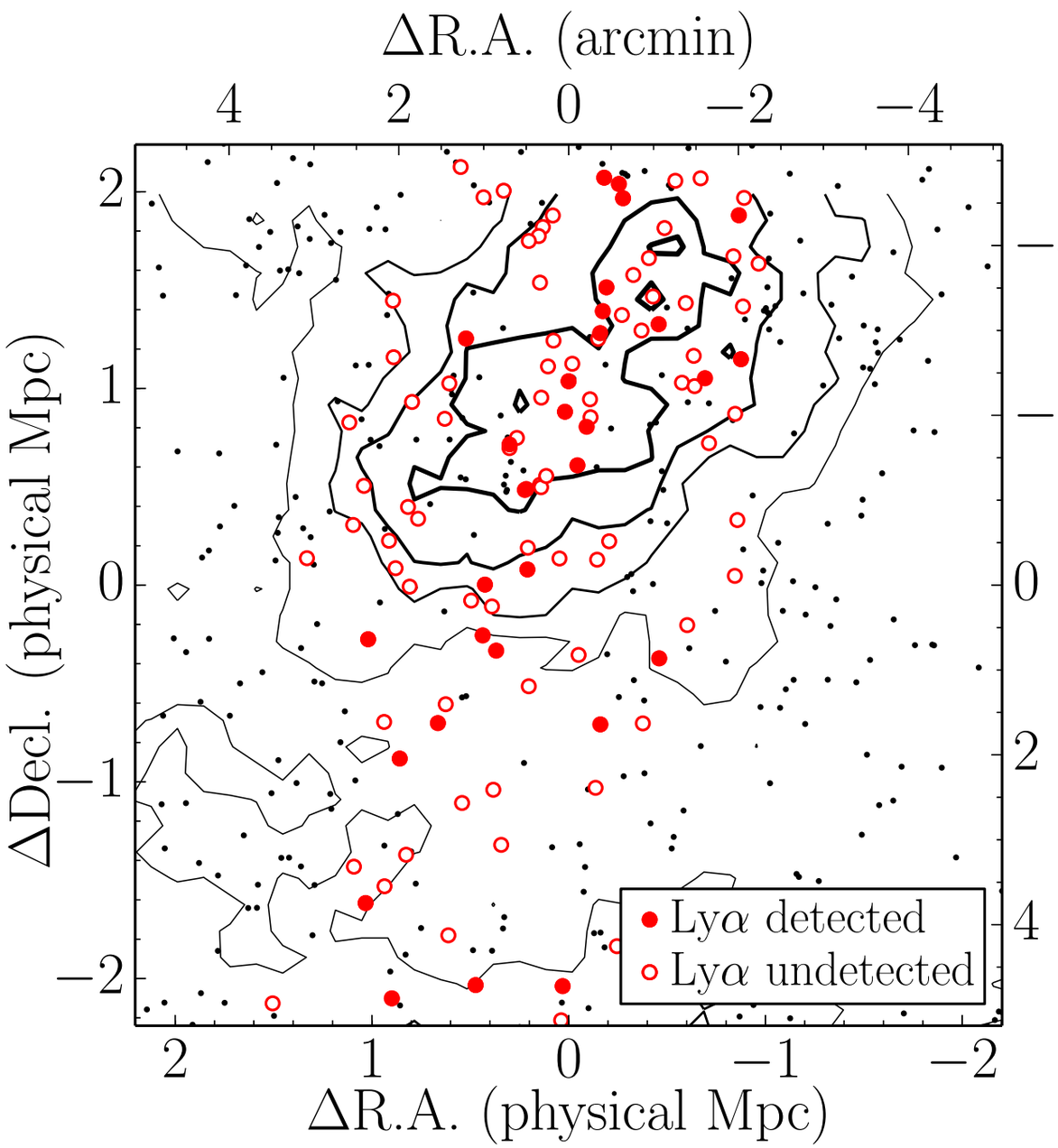
Criterion of protocluster candidate: >4σ overdenisty

(~85% of candidates are expected to be real protoclusters.)

- **Number of protocluster candidates** (CFHTLS: 4 × 1deg^2)

	z~3.1	z~3.8	z~4.8	z~5.9	
total	5	5	6	5	**21**
model prediction	2.9	3.0	5.2	6.4	
follow-up spec.	2	2	2	2	**8**

Protocluster confirmation

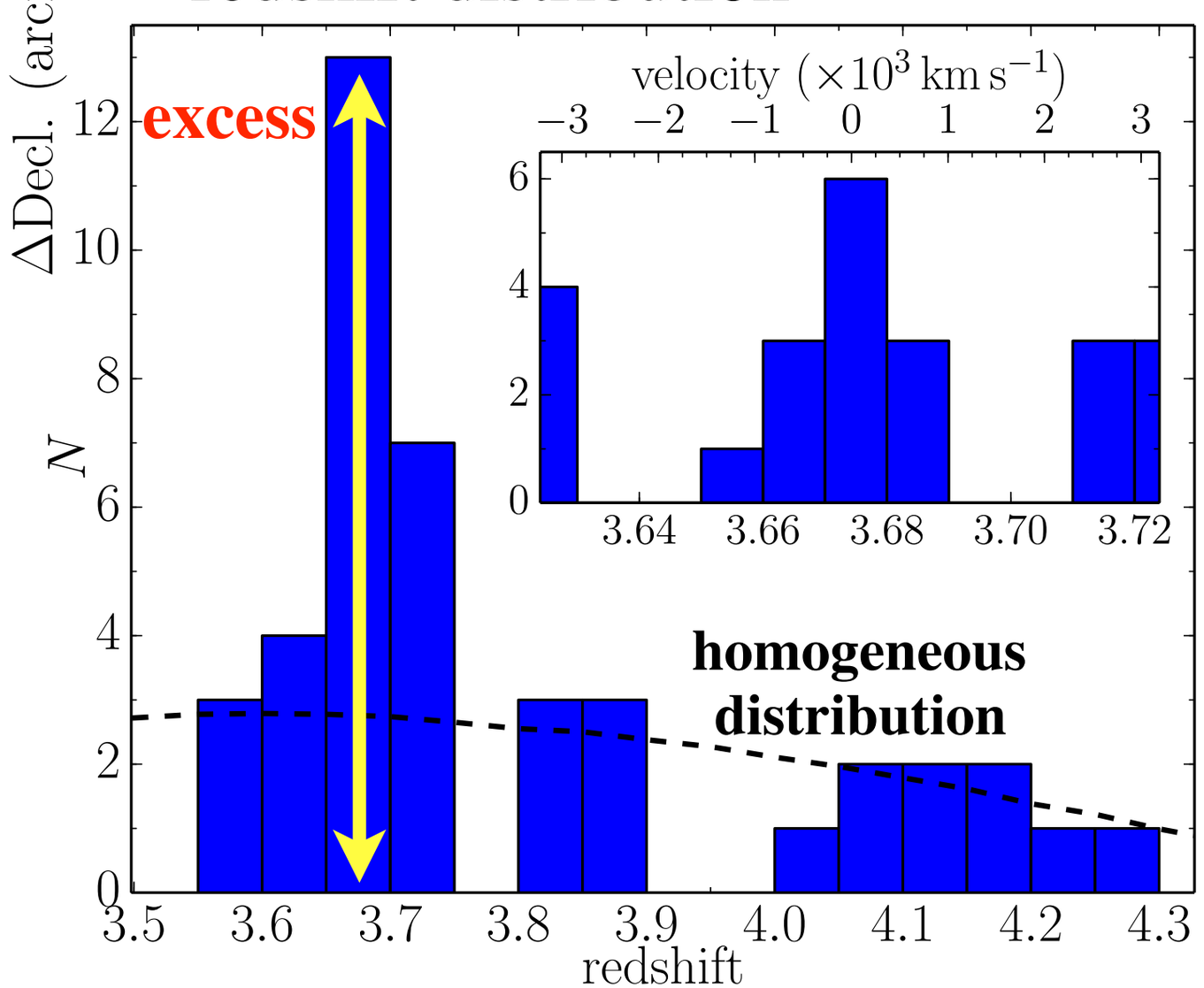


- sky distribution

Clustering at z=3.67 (Δz=0.016)

→ real protocluster

- redshift distribution



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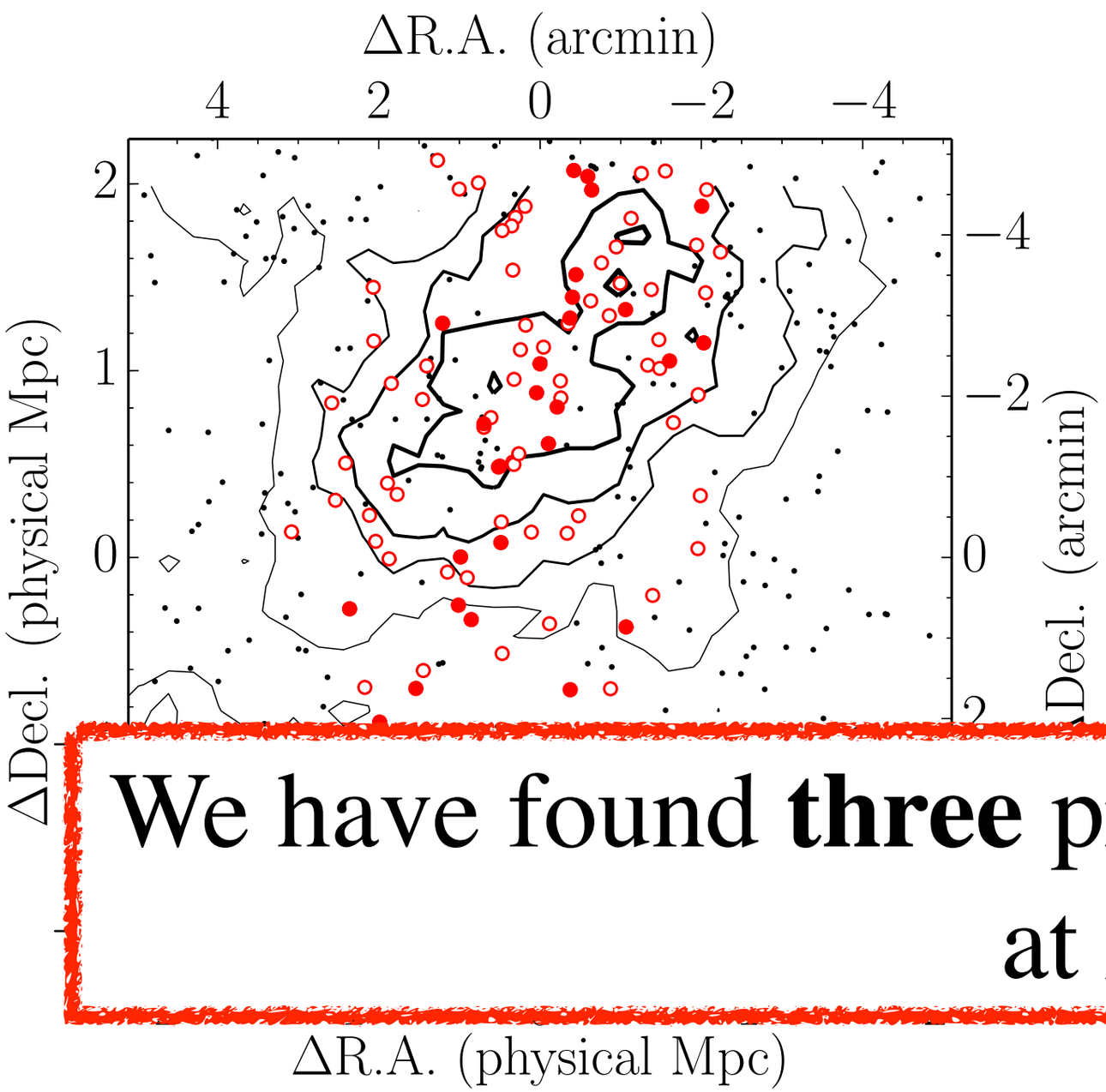

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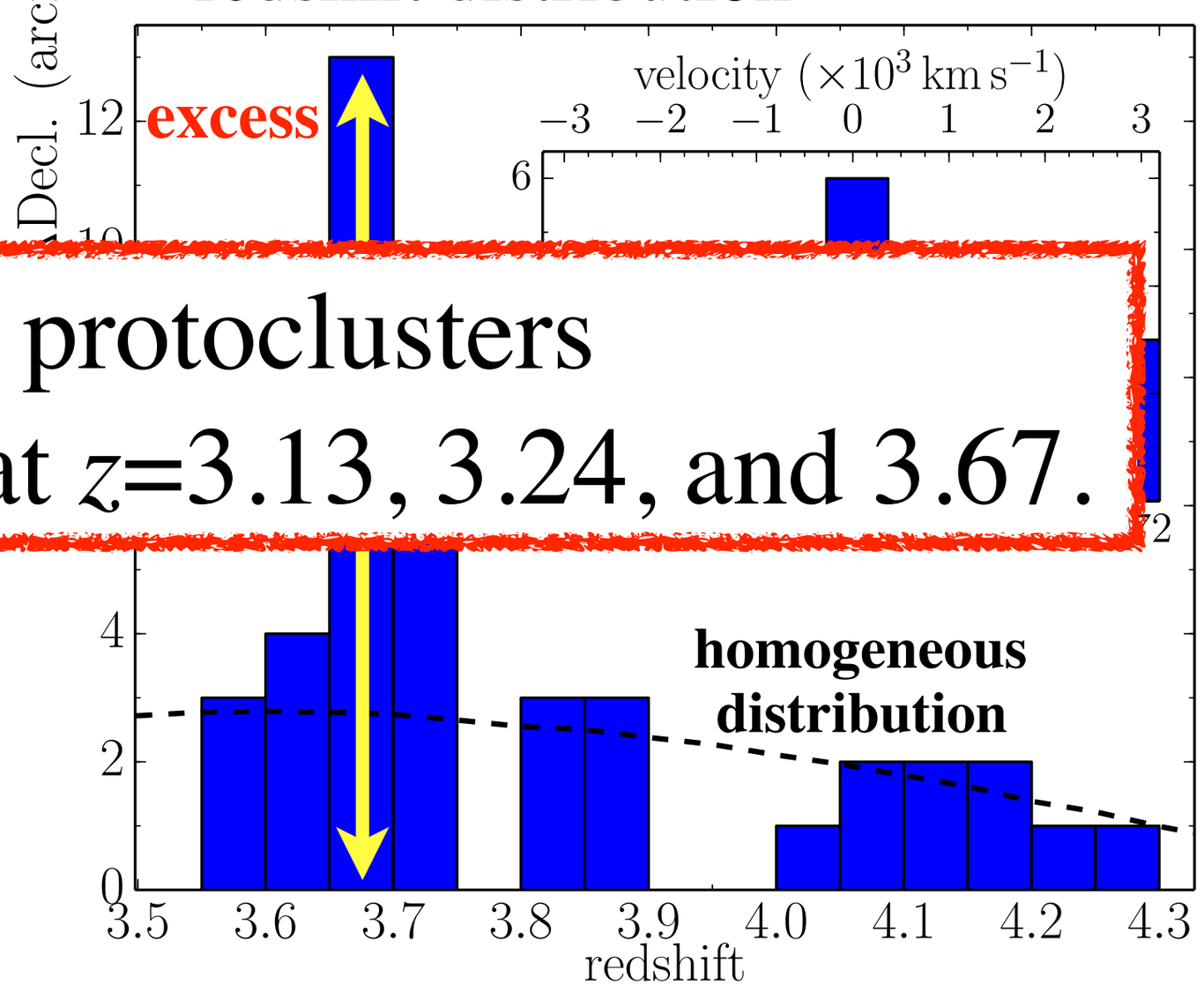
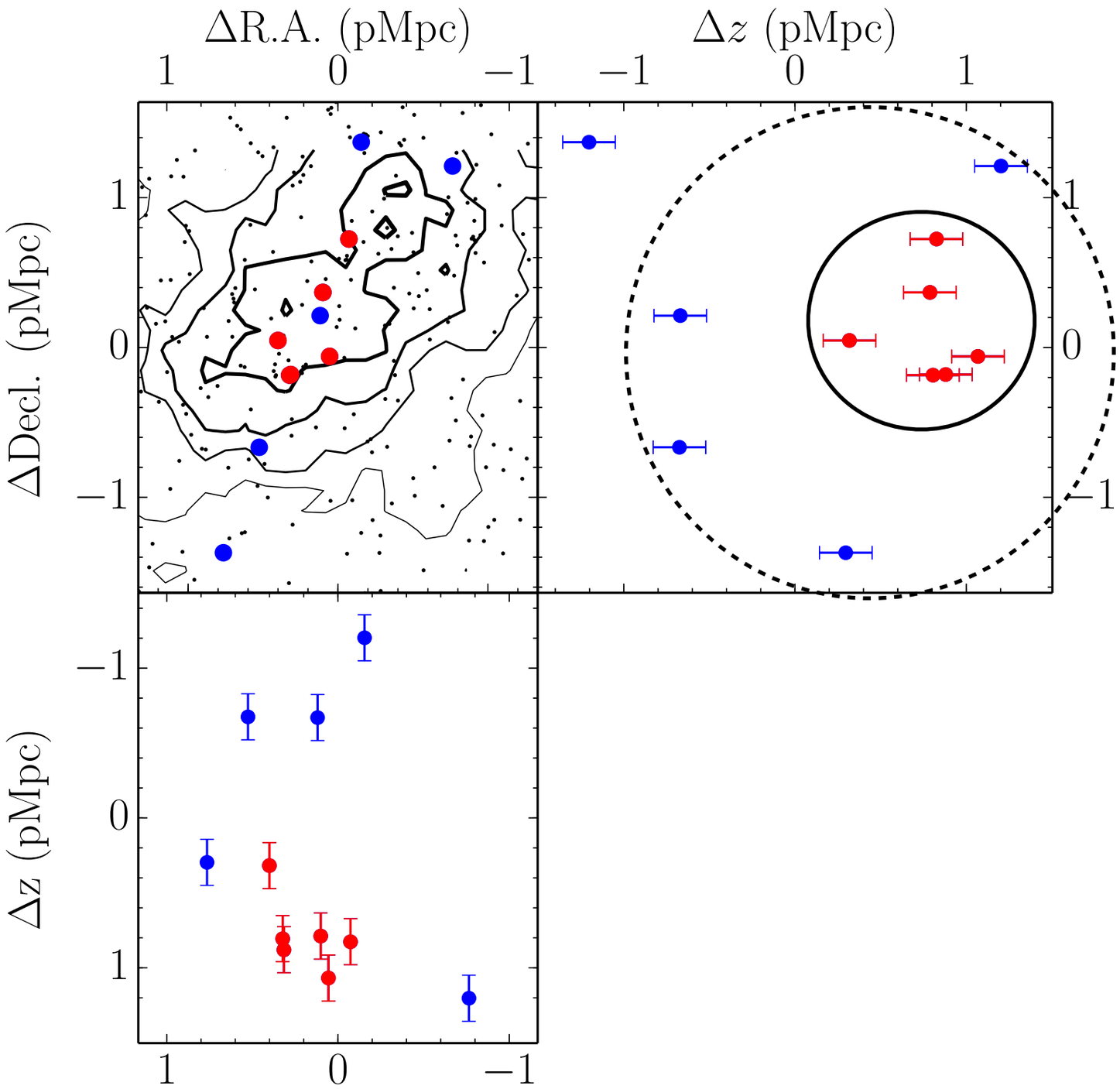


We have found **three** protoclusters at z=3.13, 3.24, and 3.67.

Protocluster structure

at z=3.67



Protocluster structure

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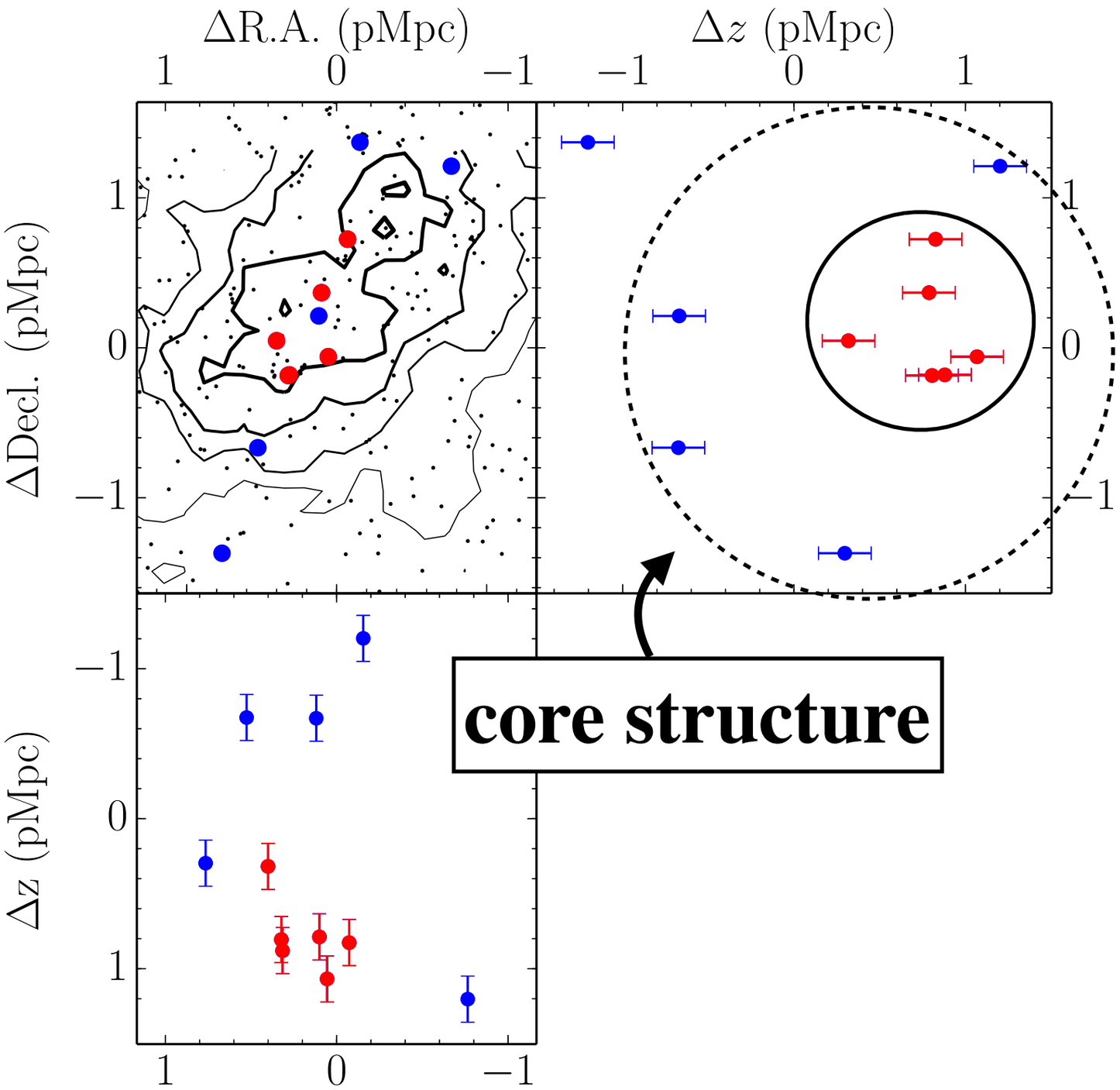

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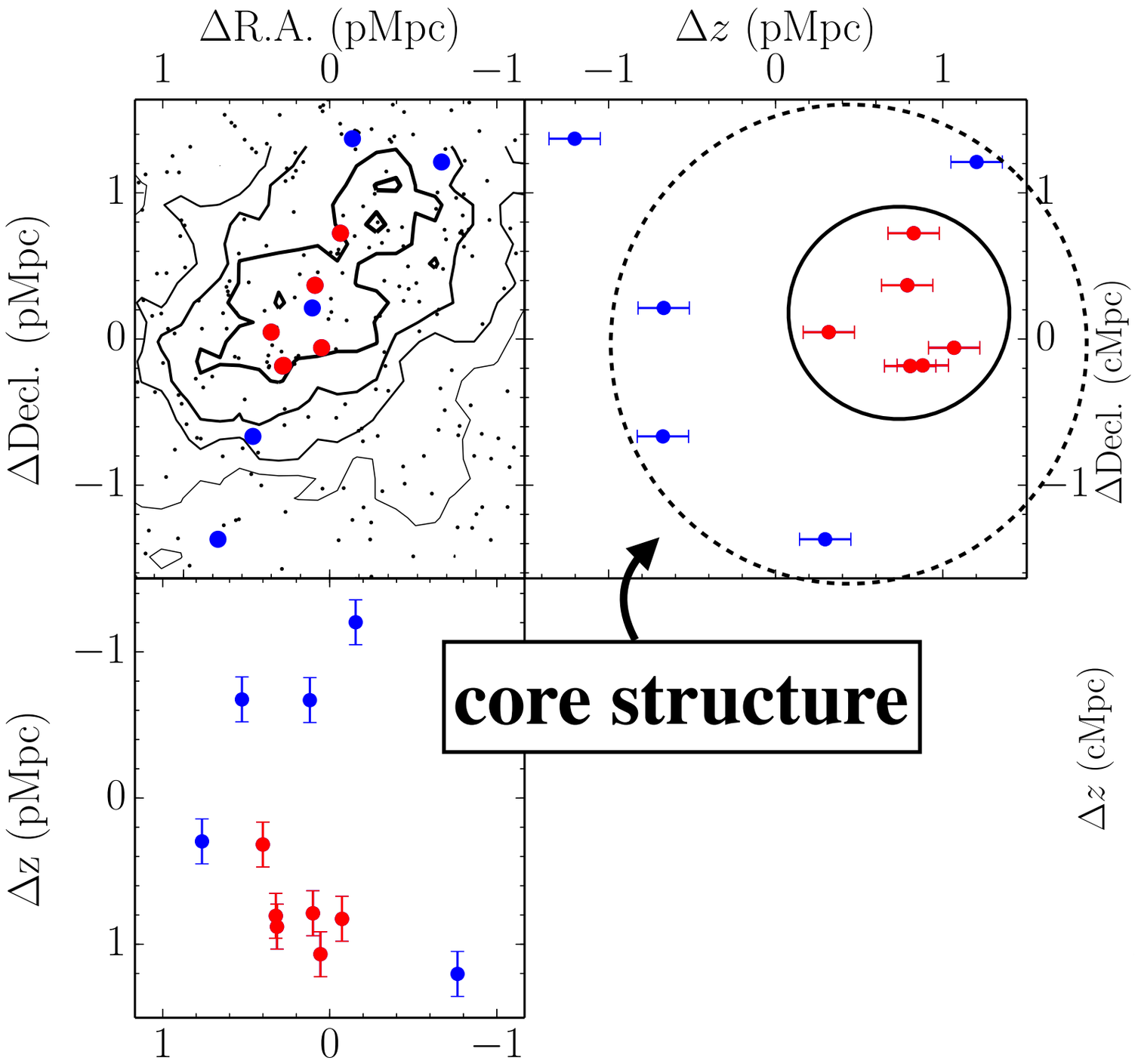
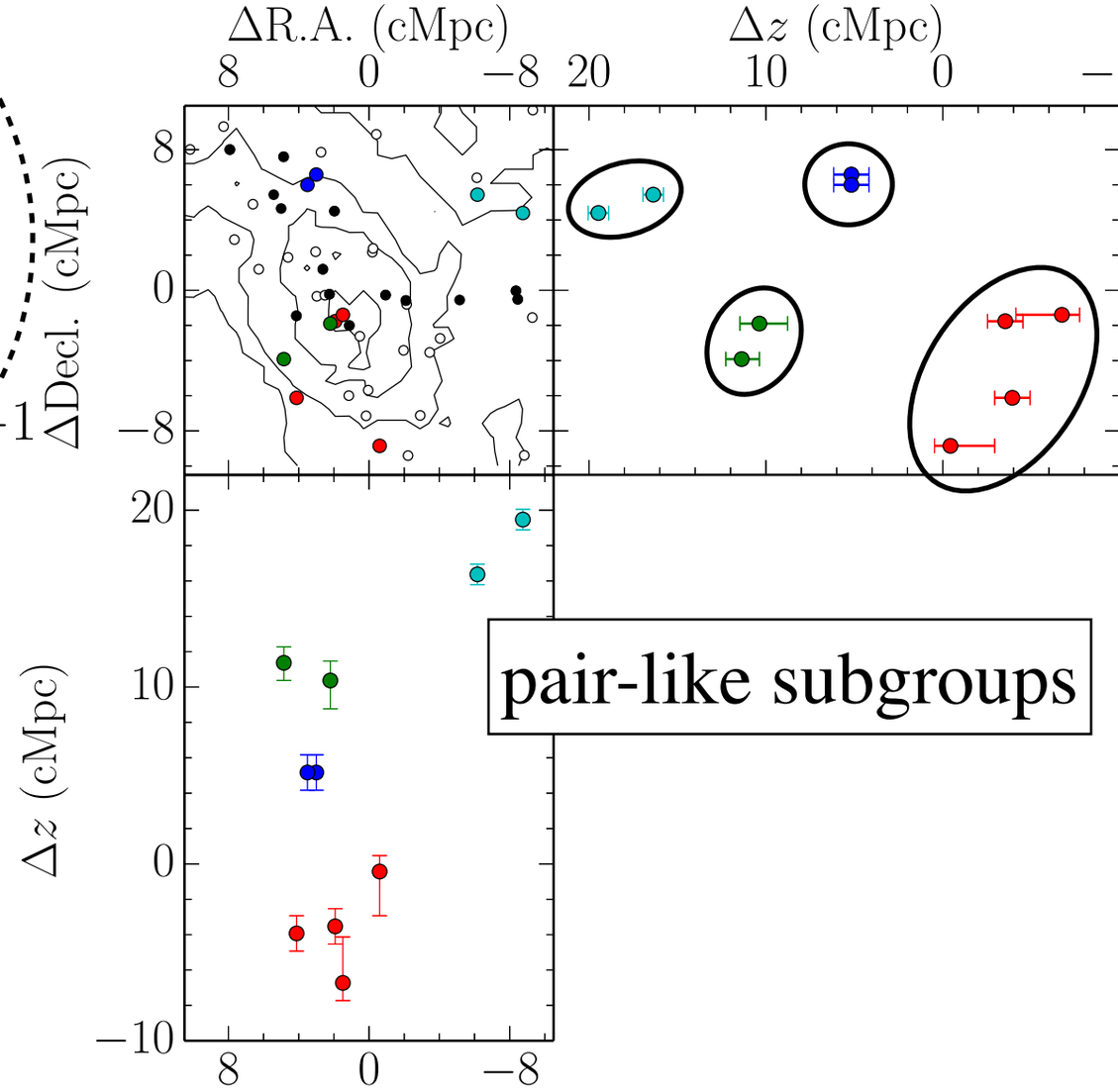


cf. at z=6.01

(Toshikawa et al. 2014)



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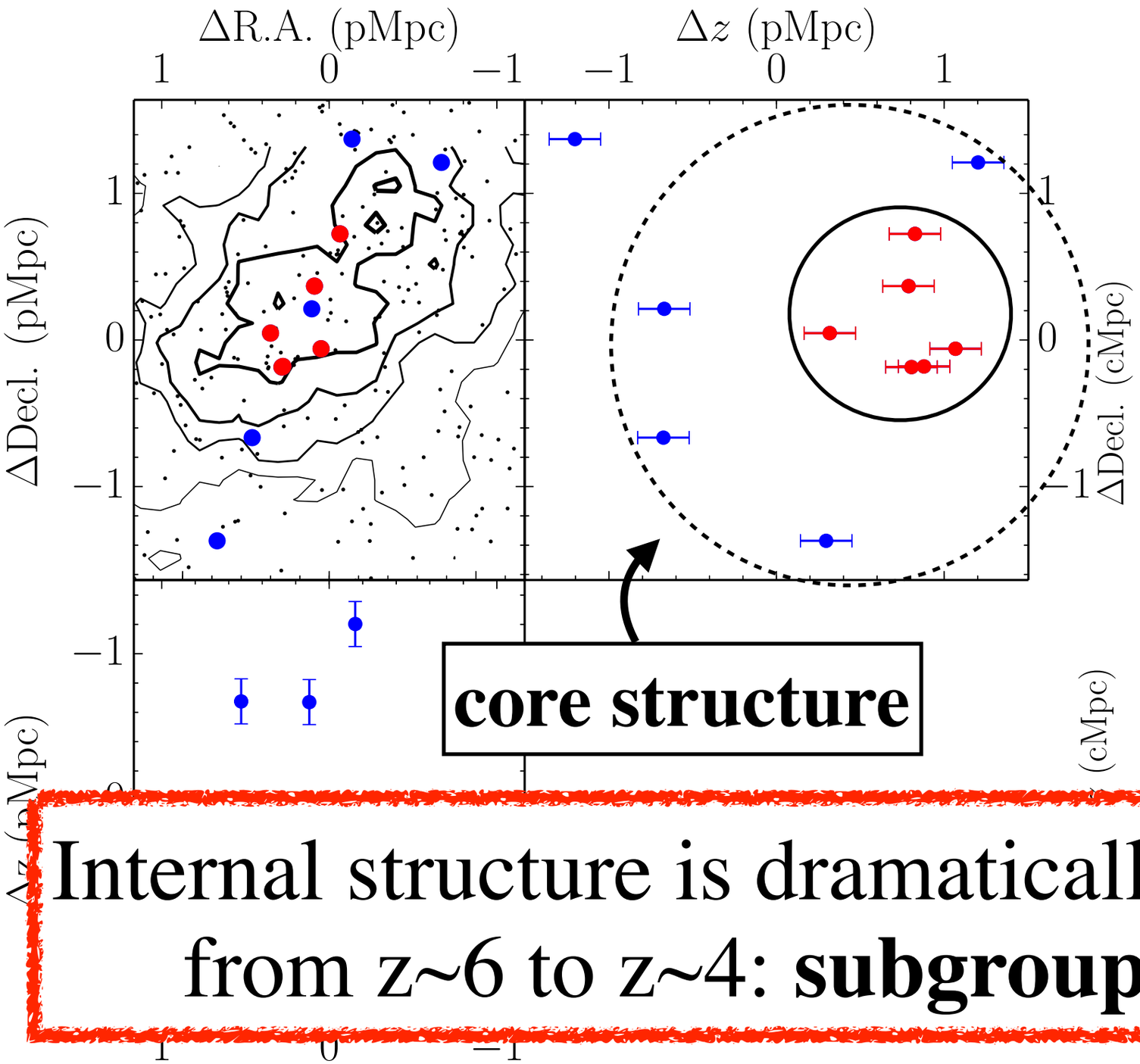

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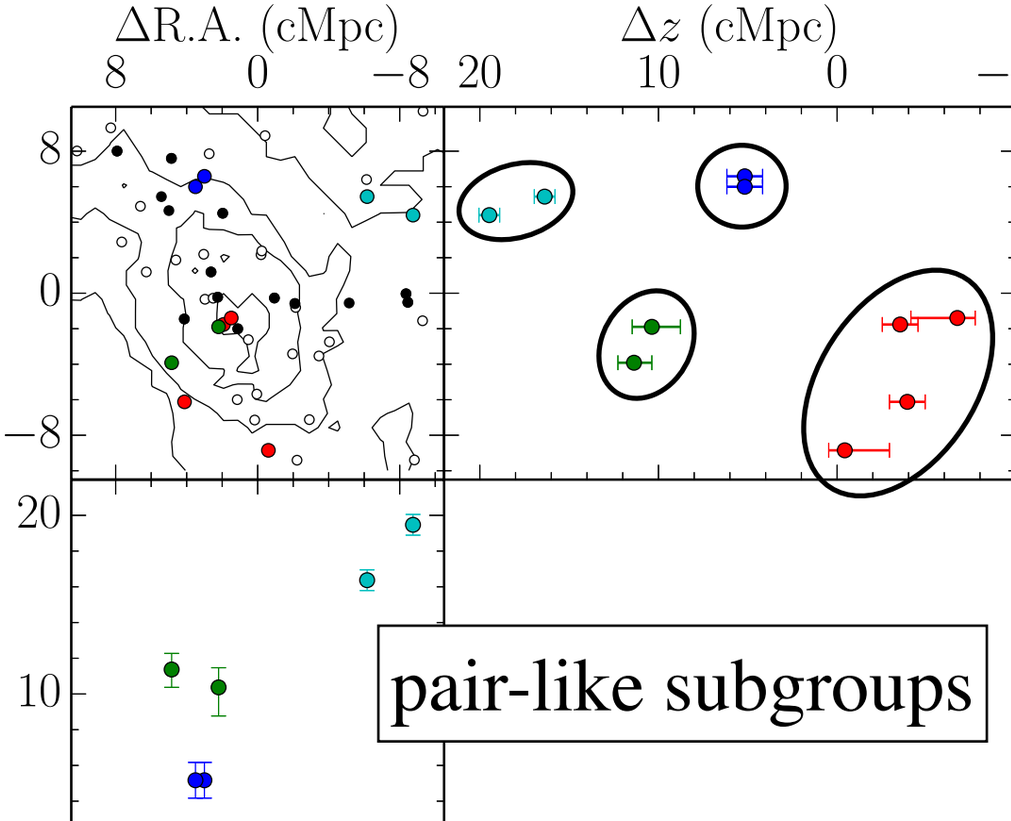
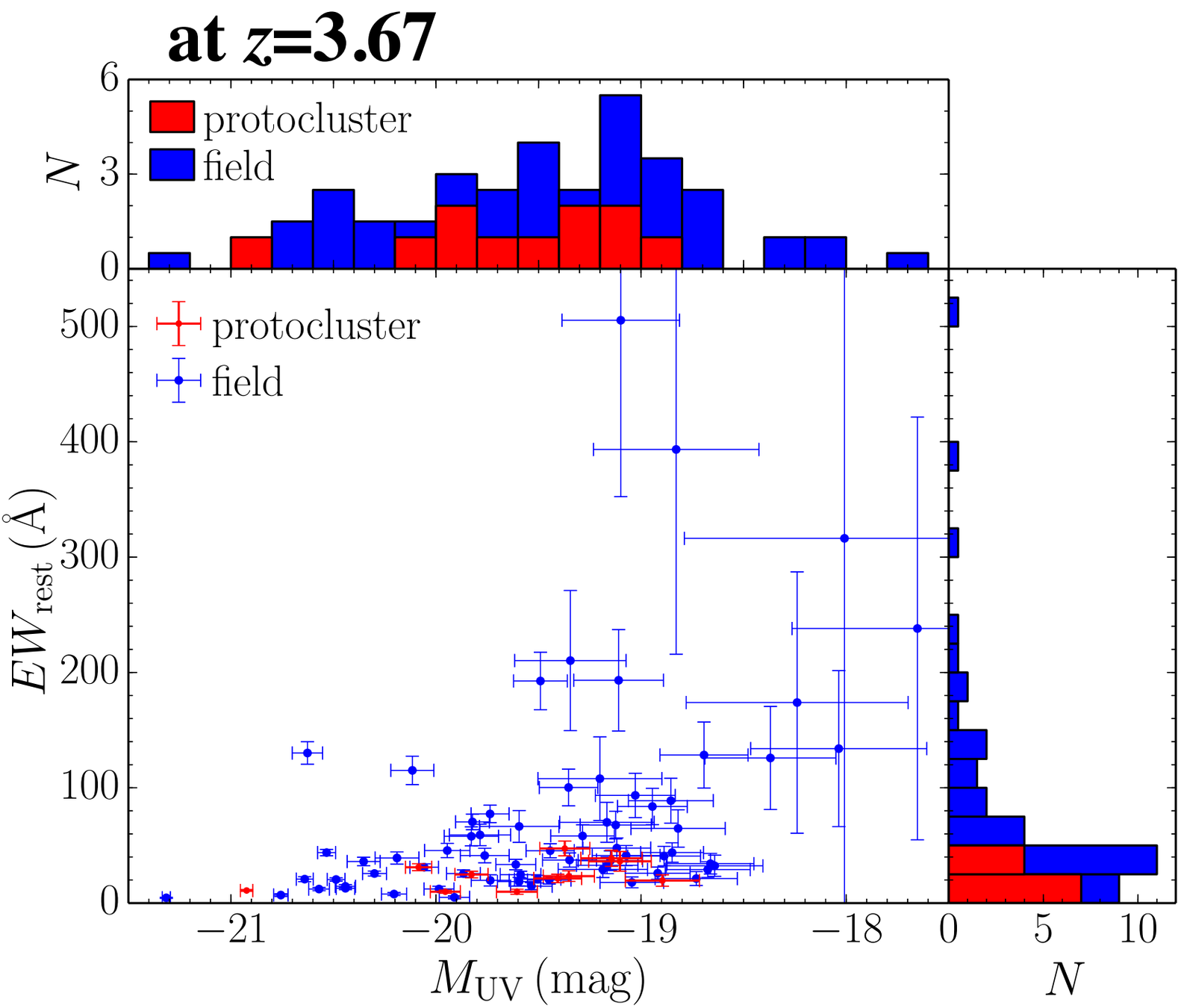


Internal structure is dramatically changed
from z~6 to z~4: **subgroups to core structure**.

Galaxy properties



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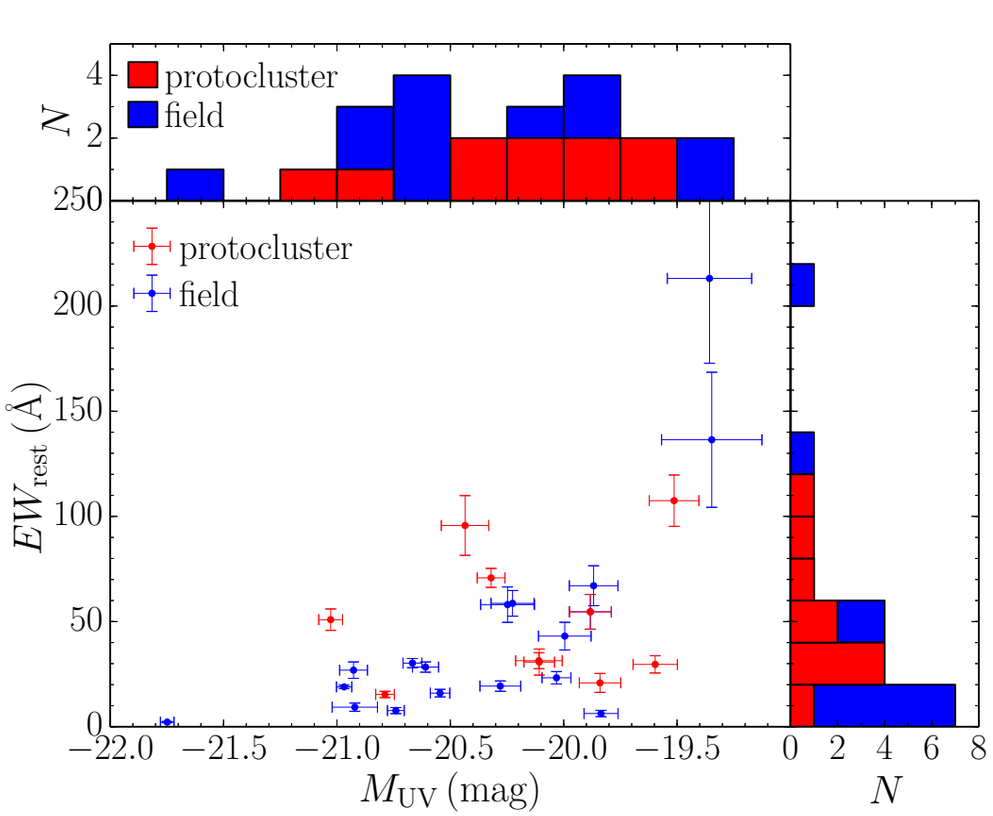

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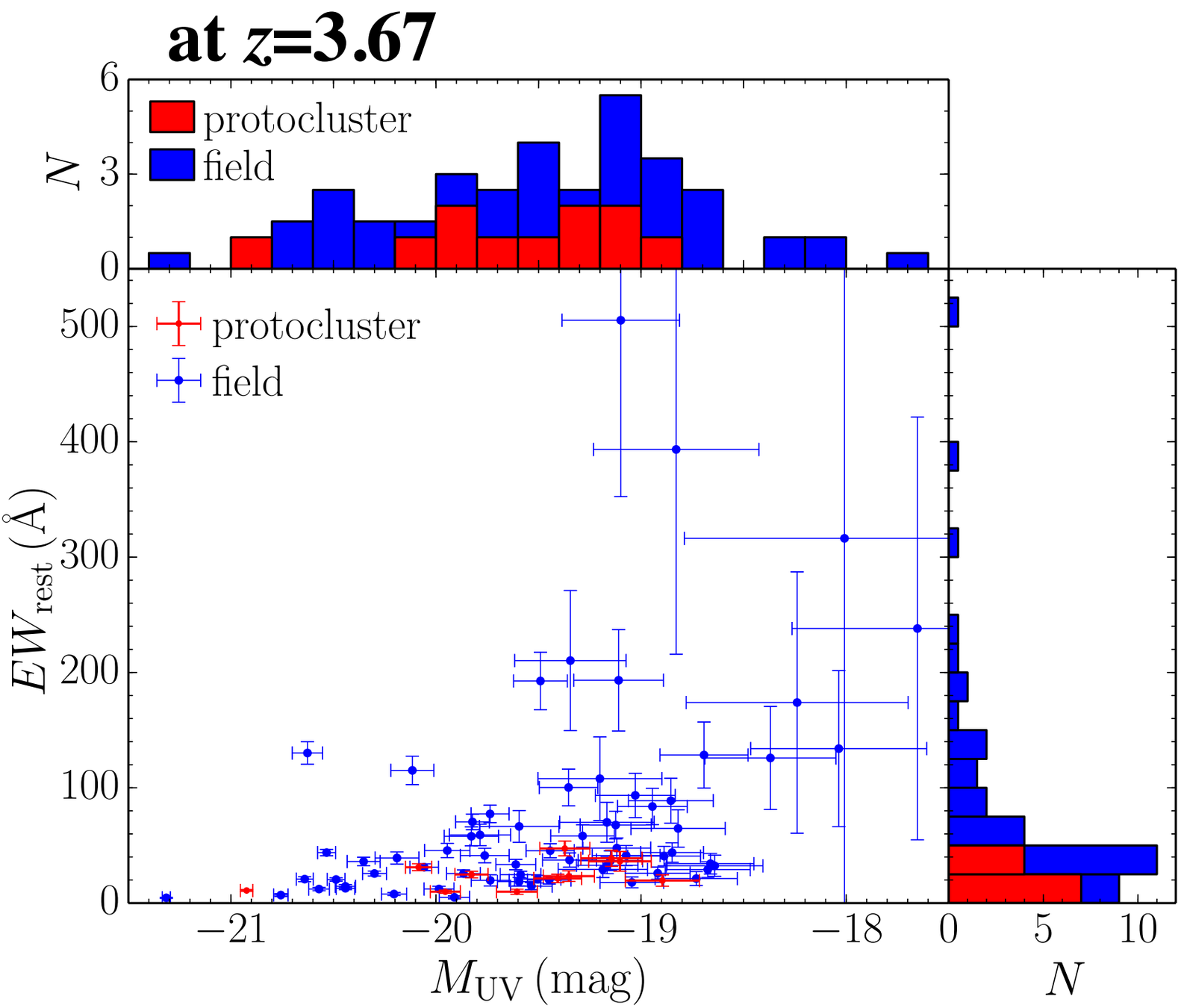

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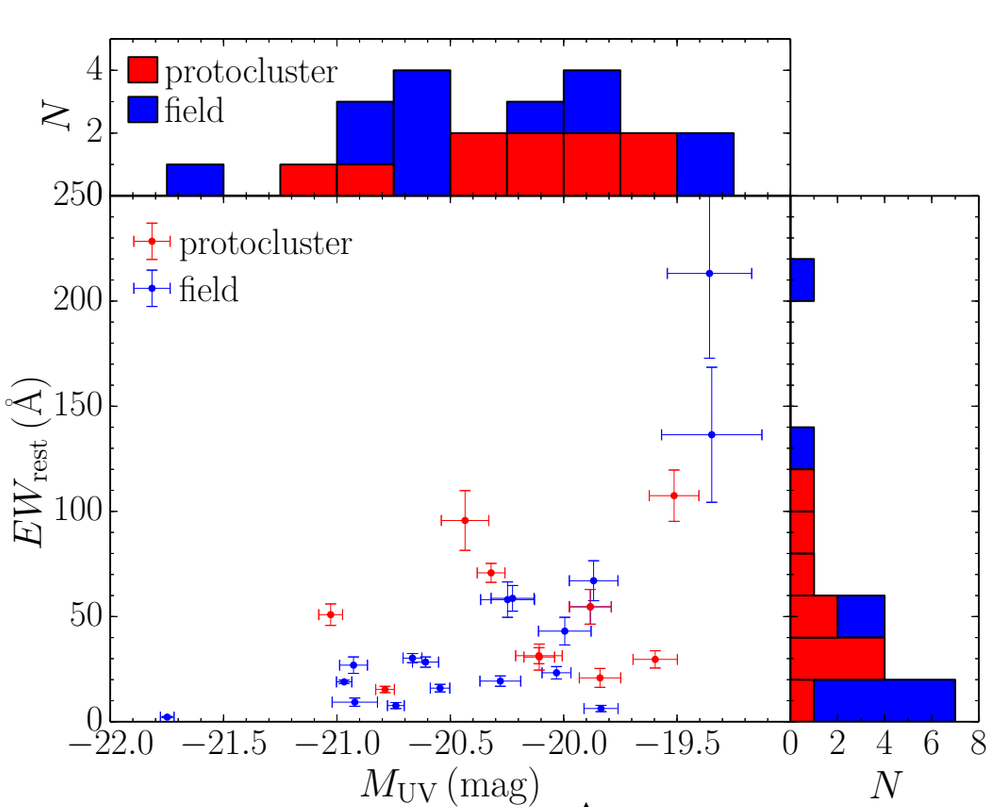


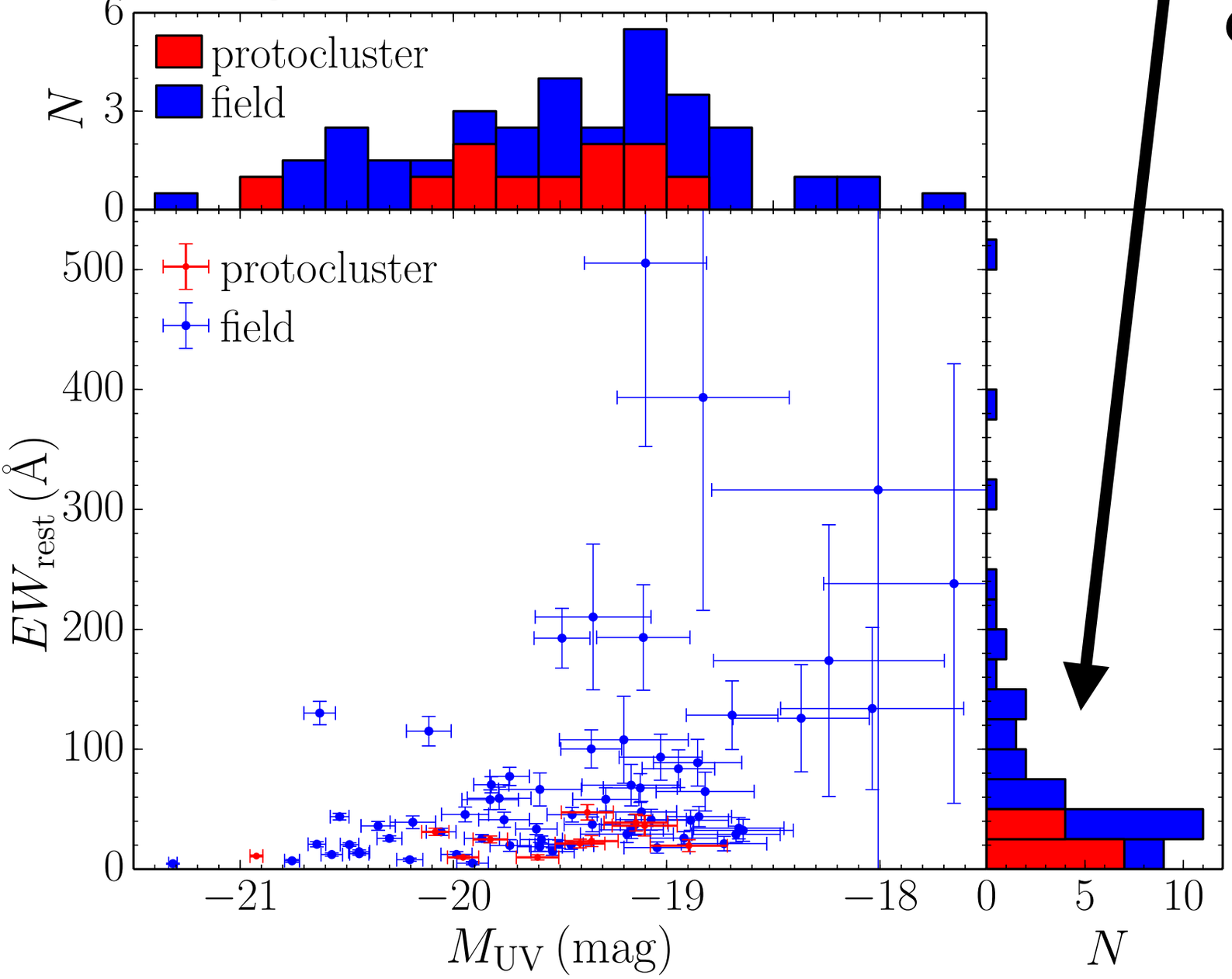
no difference

Galaxy properties

smaller Lya EW in protocluster

dust? or HI gas?

at z=3.67



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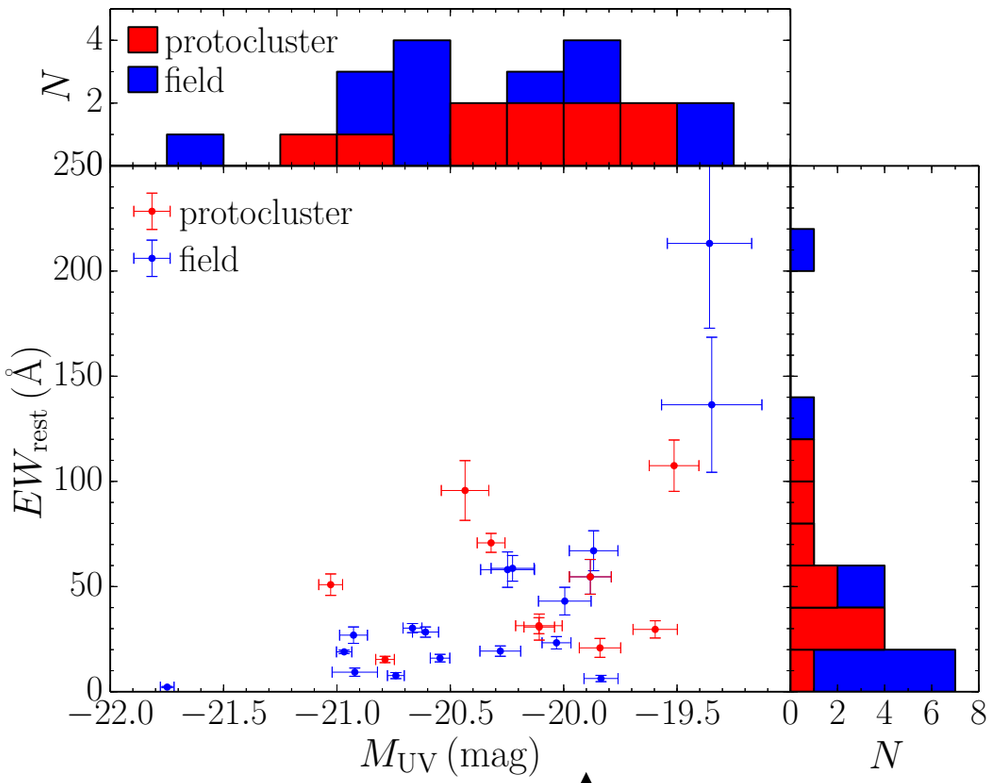

no difference

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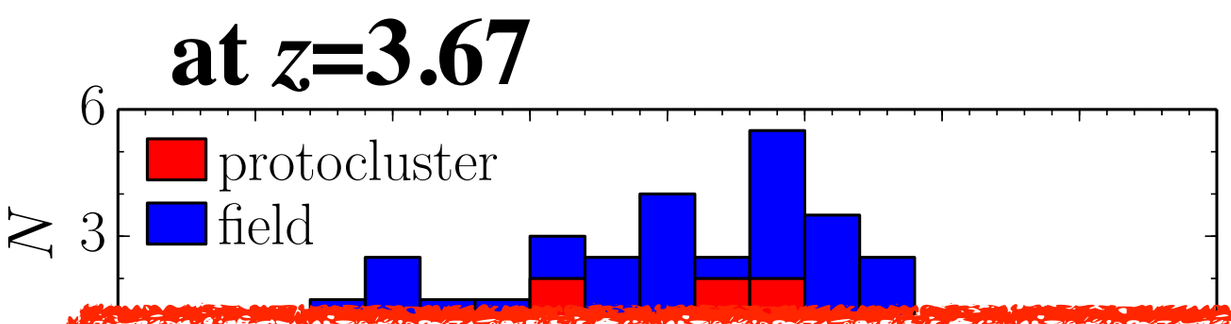
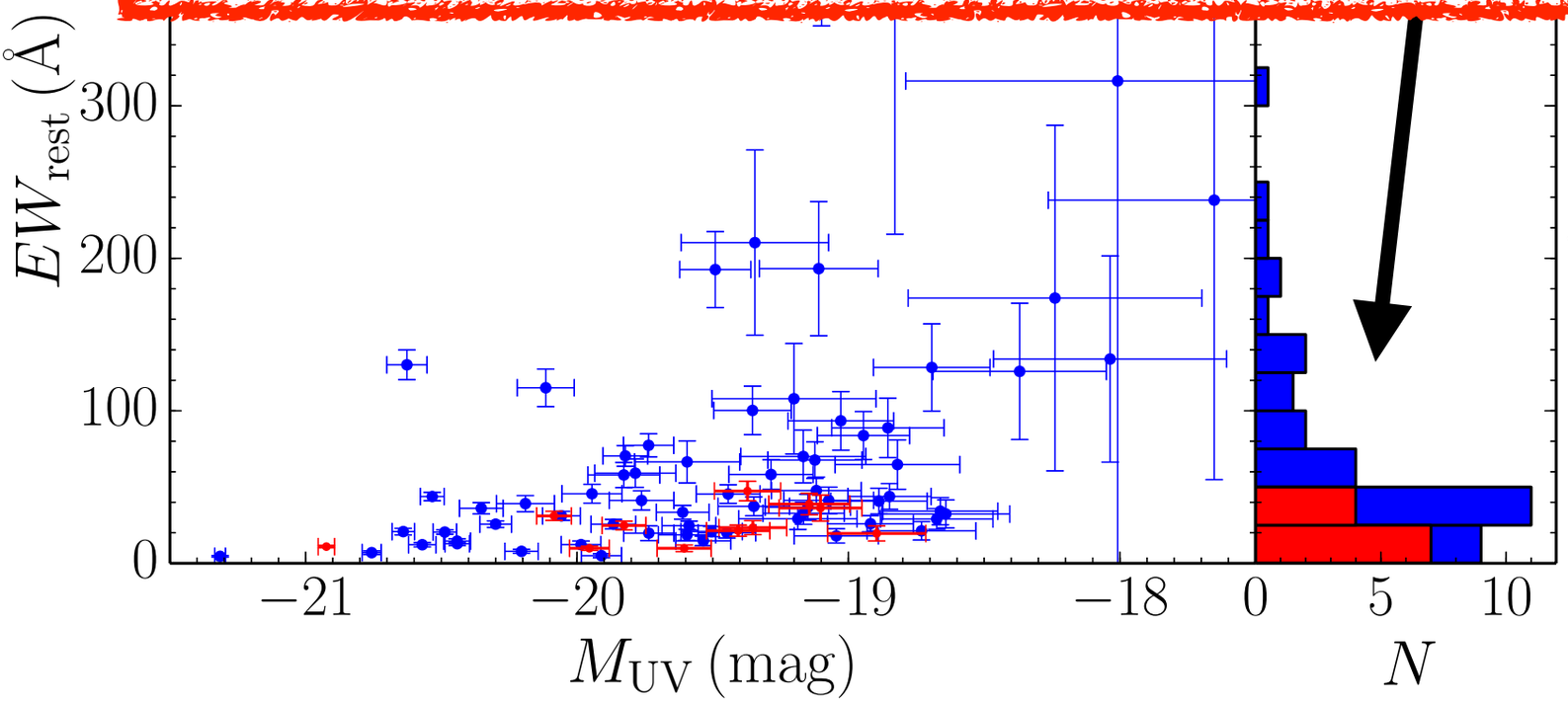
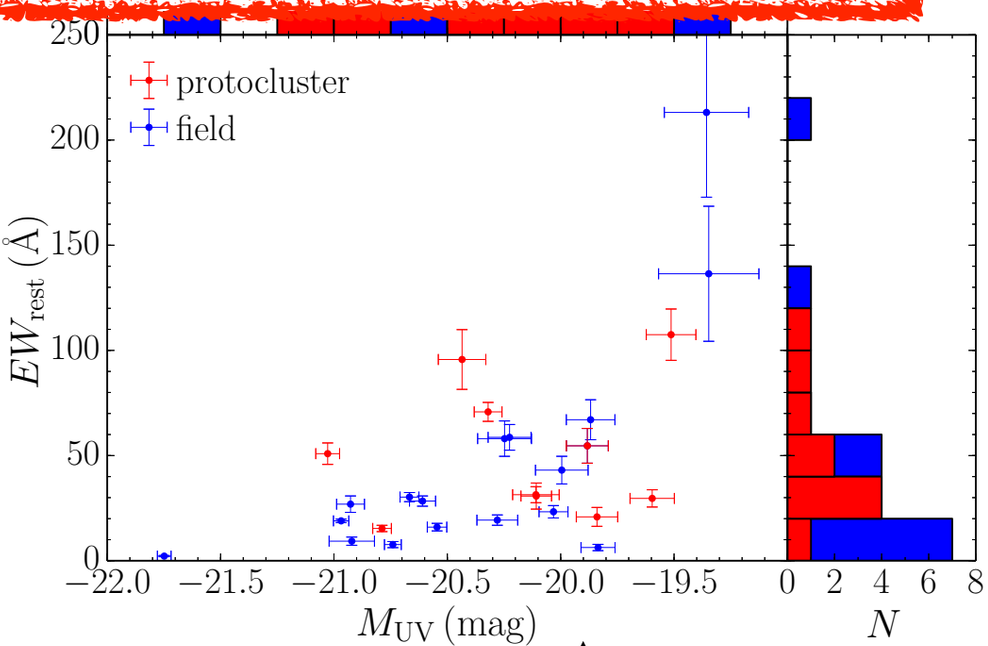


smaller Lya EW in protocluster

dust? or HI gas?

The difference between protocluster and field appeared at z~4.





no difference

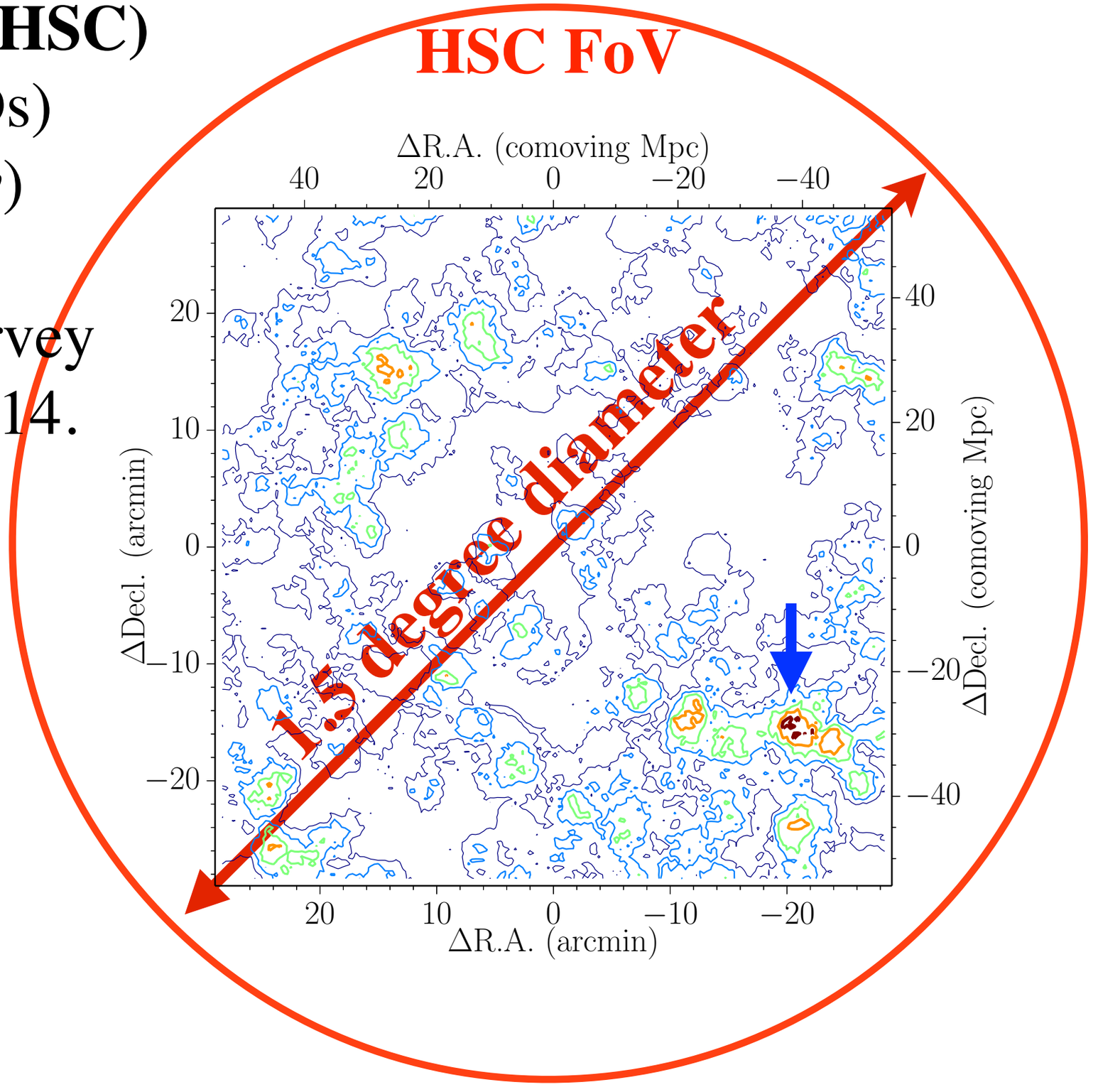
Future work

Subaru/HSC strategic survey

Ongoing survey with HSC

Hyper Suprime Camera (HSC)

- ~1.7 deg^2 FoV (104 CCDs)
- 5 broad-bands (g, r, i, z, y)
- many narrow-bands
- Subaru/HSC strategic survey started from April, 2014.



Ongoing survey with HSC

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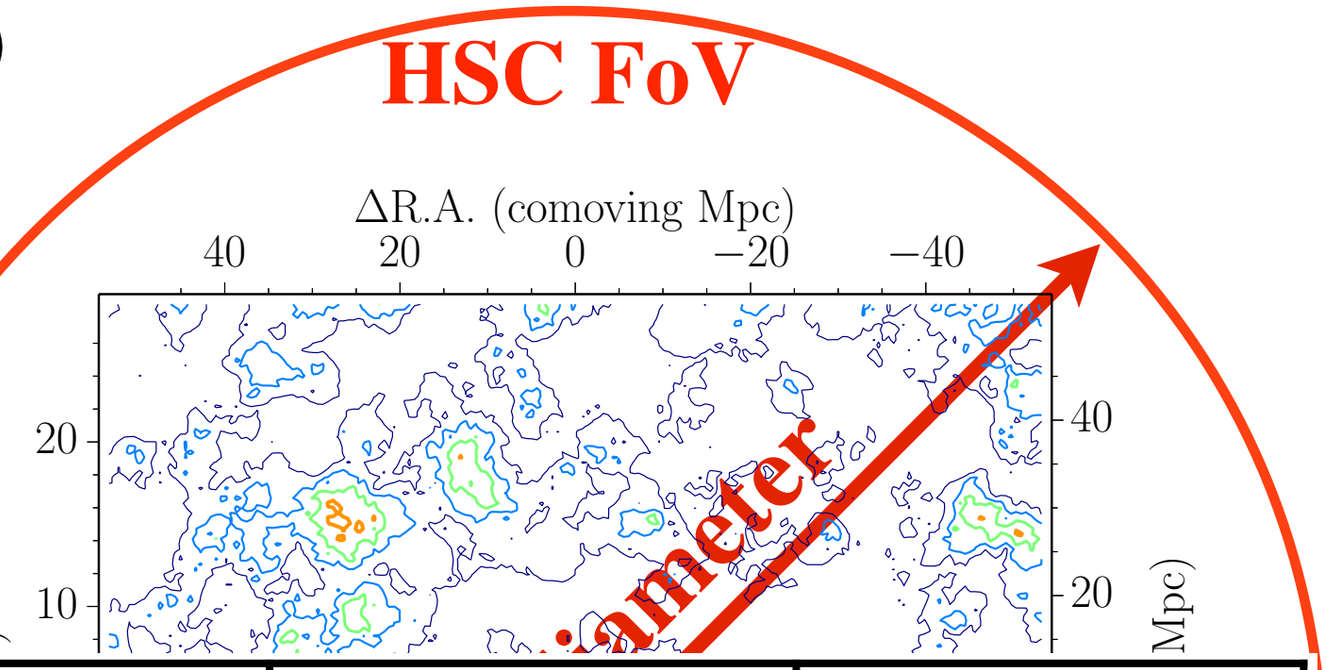
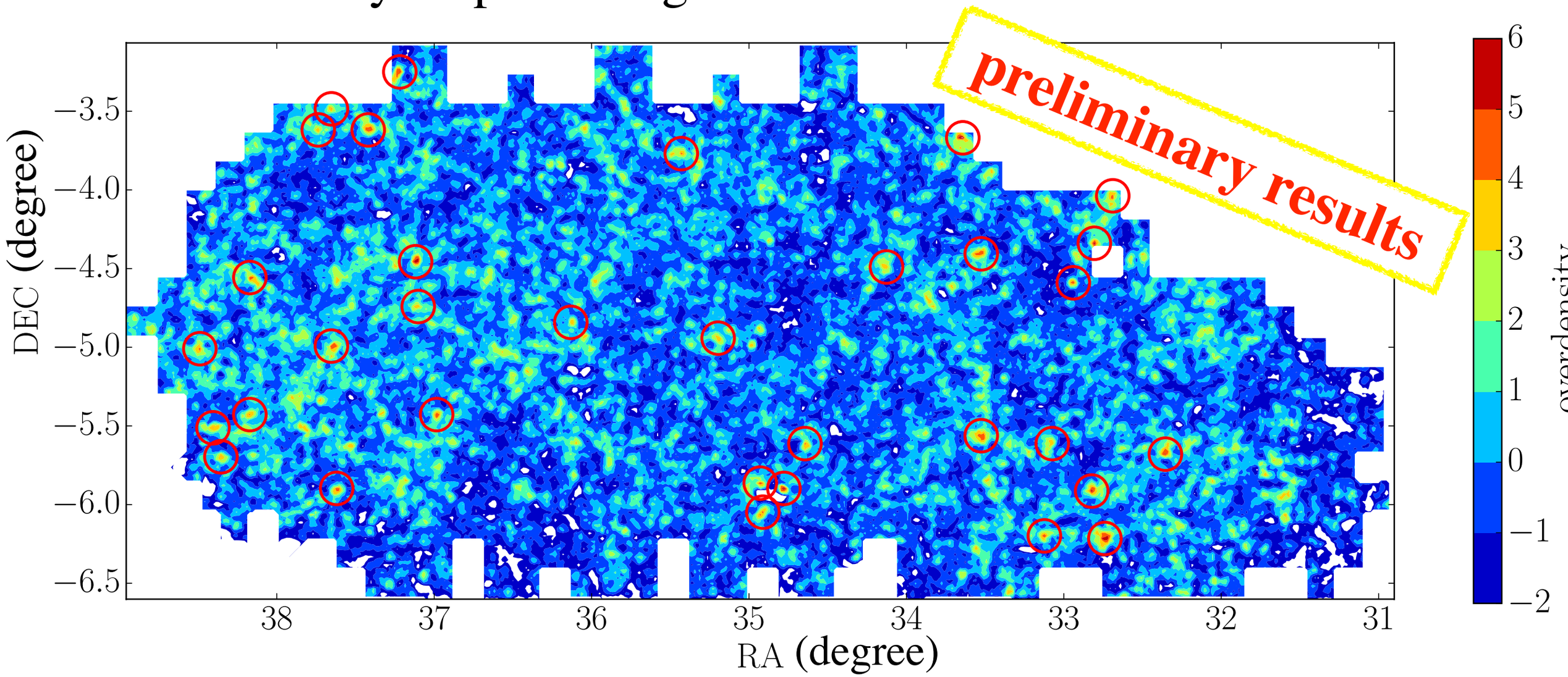


layer	area (deg^2)	filters	depth (mag)
Wide	1400 (700 deg^2 × 2 fields)	*grizy*	*z*~25.1
Deep	27 (7 deg^2 × 4 fields)	*grizy* + 3NB	*z*~26.3
Ultradeep	3.5 (1.8 deg^2 × 2 fields)	*grizy* + 3NB	*z*~26.8

>10 protoclusters at z~6 and ~1000 at z~4 will be found by the HSC strategic survey.

Ongoing survey with HSC

- number density map of z~4 galaxies in WIDE-XMM field



Many overdense regions with >4σ significance are found.

We will investigate:

galaxy properties in overdense regions → **galaxy evolution**

distribution of overdense regions → **structure formation**

Summary

- 21 protocluster candidates are identified
  from z~6 to z~3 in the CFHTLS Deep Fields.
- We carried out follow-up spectroscopy for eight of them.
- **New three protoclusters were confirmed.**
- The internal structure of protoclusters would be changed
  from z~6 to z~4: from pair-like substructure to core structure.
- **The difference of galaxies properties**
  between protocluster and field galaxies appeared at z~4.
- More protoclusters will be discovered by HSC survey.

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Thanks!

Protocluster confirmation

We have discovered three protoclusters at z>3 in blank fields.

- **Summary of follow-up observation**

Name	N_{obs}	N_{det}	Protocluster?	N_{member}	redshift
z~6 D1	8	3	unclear	—	—
z~6 D3	8	2	unclear		
z~5 D1	15	6	unclear		
z~5 D4	12	3	unclear	—	—
z~4 D1	123	36	No	—	—
z~4 D4	144	42	Yes	11	3.67
z~3 D1	95	30	Yes	5	3.13
z~3 D4	57	16	Yes	5	3.24

due to small number of redshift identification